GEOLOGY

and Economic Minerals of Canada

PART A

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Available in Canada through

Authorized Bookstore Agents
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or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada, K1A 0S9

Catalogue No. M43-1-1976-1-7
ISBN 0-660-00553-0

Canada: $8.00
Other Countries: $9.60

Price subject to change without notice

Ottawa 1976
Reprinted 1981

QE
185
E3d
no.1
1976
pt.A

GEOLOGICAL SURVEY
OF CANADA

ECONOMIC GEOLOGY
REPORT No. 1

GEOLOGY AND ECONOMIC MINERALS OF CANADA

Part A (Chapters I - VII)

R. J. W. Douglas,
Scientific Editor

DEPARTMENT OF
ENERGY, MINES AND RESOURCES
CANADA

For the convenience of readers, this work is published in three volumes. Part A comprises Chapter I to VII; Part B, chapters VIII to XIII; and Part C, a folio of charts and a map related to both Part A and Part B.

COVER Malak

ENDLEAVES

Spheroidal andesite, eastern Hudson Bay (F. C. Taylor, 125219)

PREFACE

This is the fifth edition of *Geology and Economic Minerals of Canada,* a general review of our present knowledge of the geology of Canada. It has been possible for the first time to treat many different aspects of the geology in considerable detail on a nation-wide basis, and to attempt a tectonic synthesis of the four major geological regions — the Canadian Shield, and the bordering Phanerozoic platforms and orogens of southeastern, western, and arctic Canada. The accompanying folio contains a geotectonic correlation chart for each of those regions and eight maps at 1:5 million scale dealing with the geology, tectonics, mineral deposits, glacial features, physiography, isotopic ages, and magnetic and gravity anomalies. In the text, factual data are concisely summarized and economic and scientific interpretation and conclusions are clearly separated.

Each of the five editions represents a report of progress, but still the need and challenge to acquire more information remain. Geological knowledge is fundamental to the evaluation of the nation's potential mineral resources and to the search for mineral deposits, both important factors in Canada's general economic growth and in the development of our vast northland. Familiarity with geological structure is essential to engineering construction, groundwater supply, management of urban and rural land resources — both renewable and non-renewable — and for the conservation of man's environment. This book is a storehouse of cultural knowledge on the physical make-up of Canada, and will serve as a reference text for all scientists.

Y. O. FORTIER,

Director, Geological Survey of Canada

OTTAWA, August 14, 1968

COVER Malak

ENDLEAVES

Front: Spheroidal andesite, eastern Hudson Bay (F. C. Taylor, 125219)

Back: Inco's reduction works at Copper Cliff, Ontario (George Hunter)

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1

Introduction

R.J.W. Douglas

Since the fourth edition of *Geology and Economic Minerals of Canada* was published in 1957 our knowledge of the geology of Canada has increased greatly. Heretofore, geological information was meagre for many parts of the country, although detailed but isolated information was available for the mineral producing areas and more accessible regions. A large part of the new knowledge has been gained in the course of systematic geological mapping; by 1957 nearly 75 per cent of Canada was still unmapped geologically whereas in 1968 only 15 per cent remained unmapped at reconnaissance scales. The important element of continuity has been established by the initial mapping, so that it is now possible to assess and present a broad range of data in both geological and tectonic terms of reference. Of the total geological research in Canada, however, only a part has been directed towards the regional type of investigation; continuing studies have been made of many matters of economic and scientific interest, not only by the Geological Survey of Canada but also by provincial organizations, the mining and petroleum industries, consultants, and the universities (*see* Appendix).

The increased knowledge has resulted from a larger number of geologists active in geological studies, general improvements in accessibility, greater use of helicopters and other aircraft, and expansion in the exploration and production programs of the petroleum and mining industries. Federal and provincial organizations, whose prime function is to publish, have acquired much of this additional knowledge, but also industry has been freer in permitting staff to publish data of scientific value and data no longer considered to have competitive economic value. Moreover, money is available to university professors to engage in geological investigations and they too are contributing even more than ever before to the literature. Grants are made by the Geological Survey of Canada on the advice and recommendation of the National Advisory Committee on Research in the Geological Sciences and also by the National Research Council. Whole new fields of endeavour and extensions to the old established fields of geology have been developed in relatively recent times, and more and more other scientists, particularly physicists and chemists, are bringing their own techniques and ideas to bear on geological problems. As a consequence, it is no longer practicable to summarize all the facts pertaining to the geology of Canada, or to attempt to portray them on a single map. Instead, we must be selective in preparing a text, and in presenting certain facets in visual form on several maps.

The objective of this edition is to provide both the geologist and non-geologist with a brief and handy reference to new and important facts, concepts, and interpretations of the geology and mineral resources of Canada. For the Canadian geologist, it is hoped that the book will serve as a ready source of information on regions not particularly familiar to him and stimulate the development of new ideas involving tectonics and metallogenesis. For geologists from other countries and for students the book is intended to serve as a reference, the starting point for an understanding of the geology of Canada and an introduction to its literature.

DEVELOPMENT OF RESOURCES

Canada's economic growth is dependent to a very large degree on the discovery of new mineral deposits and continual renewal of reserves. Mineral production represents more than 7 per cent of the Gross National Product, and more than 40 per cent of the total primary

production. It is the largest component of our export trade, accounting for 30 per cent of the total. The value of the total mineral production in 1968 was $4,735,000,000; of this amount metals represented 53 per cent, fuels 28 per cent, non-metallic minerals 10 per cent, and structural materials 9 per cent. About 60 per cent of the output was exported, the greater part to the United States. In the last decade gains have been made in almost all sectors of the industry. Prominent among these advances have been increases in the production of iron ore, potash, natural gas, and sulphur. The increase in iron ore production has resulted from the revolutionary advances made in beneficiation processes and steel-making technology, and from the construction of the St. Lawrence Seaway which permits ore from Quebec and Labrador to be shipped into the interior. The potash deposits deep beneath the plains of southern Saskatchewan have been reached by the novel engineering technique of freezing the bedrock aquifers that were penetrated during the sinking of the shafts. The crude oil and natural gas industries have experienced rapid growth, natural gas now ranking sixth in the mineral industry, and at the same time production of sulphur as a byproduct has increased to the extent that Canada is the world's second largest producer.

Exploration and development of the mineral resources of Canada are carried out principally by private industry, the exceptions being Eldorado Mining and Refining Company, Société québécoise d'exploitation minière, and Panarctic Oils Ltd. Federal and provincial government agencies do not engage directly in prospecting or exploration, although some valuable mineral deposits have been developed as a result of their investigations. Within the bounds of the provinces, mineral rights are vested in the provincial governments except for the lands granted some years ago when land titles included both surface and mineral rights. The provincial governments enact legislation to regulate exploration, development, and conservation of mineral and other natural resources. Federal departments formulate and administer regulations governing the mineral industry in Yukon and Northwest Territories,

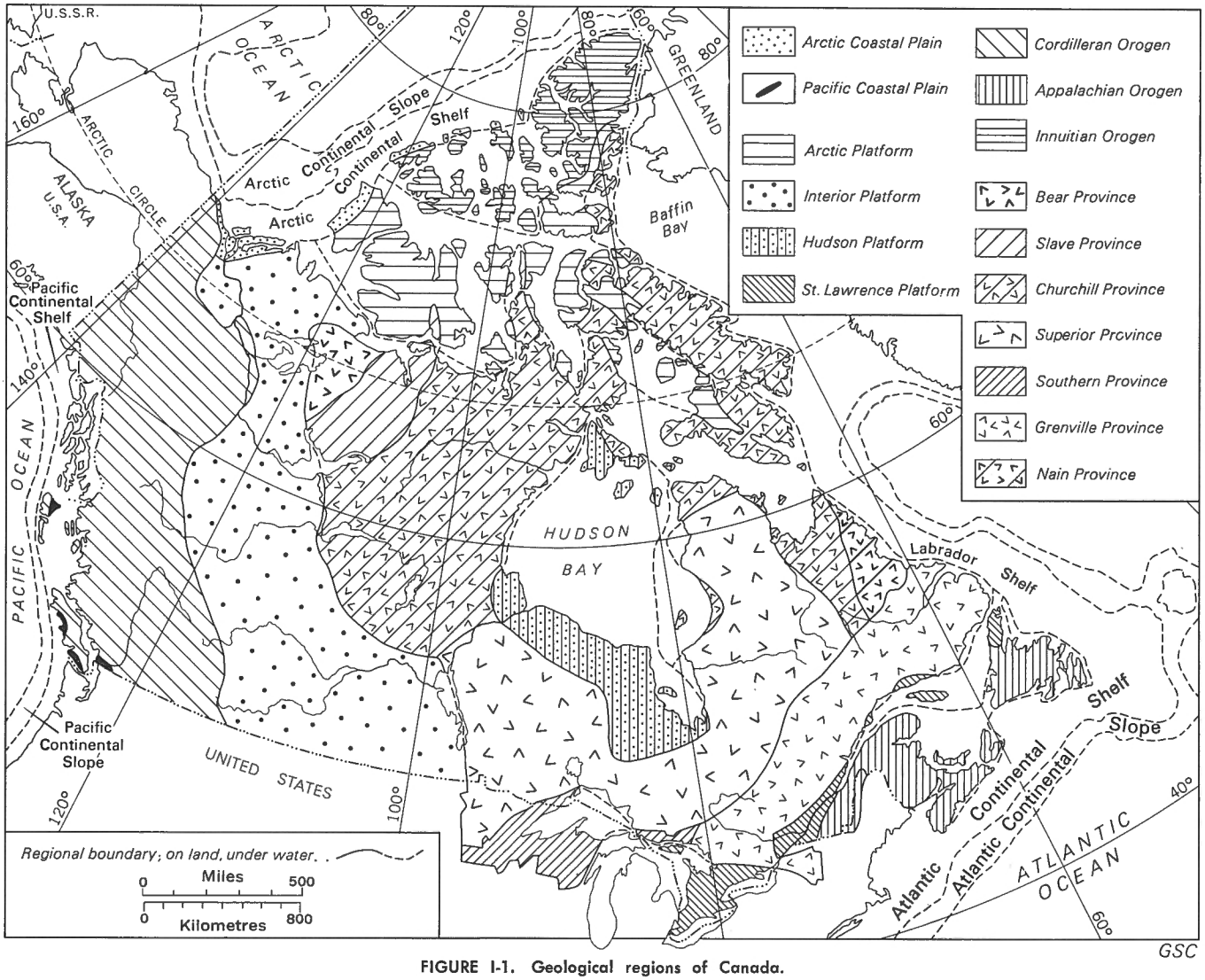

FIGURE I-1. Geological regions of Canada.

offshore, and in certain lands within the provinces such as Indian lands.

The Department of Energy, Mines and Resources is the principal federal government department dealing with the scientific and technical aspects of the nation's mineral, water, and energy resources (*see* Appendix). Three branches are concerned with geology — the Geological Survey of Canada, Marine Sciences, and the Earth Physics Branches; other branches are concerned with hydrogeology, mineral development, and other matters. The Earth Physics Branch contributes mainly in the fields of seismology and gravity; the Marine Sciences Branch investigates the sediments of the ocean floor; the Geological Survey of Canada conducts investigations designed to add to the understanding of the geology of Canada, to contribute to the advancement of knowledge in the earth sciences, and to provide data needed for the discovery and exploitation of the nation's mineral deposits.

GEOLOGICAL AND GEOGRAPHIC SUBDIVISIONS

Canada (Fig. I-1)[1] has a land area of 3,852,000 square miles of which 292,000 square miles is covered by freshwater lakes (Table I-1); about 2,964,000 square miles is mainland, and 596,000 square miles is islands, situated mainly in the Arctic. In common with other maritime nations, Canada exercises sovereign rights over adjacent regions under the sea for the purpose of exploring them and exploiting their natural resources. Within the confines of the extremities of the land areas of Canada is some 858,000 square miles of enclosed marine waters. The submarine area of the continental shelves bordering the Atlantic, Arctic, and Pacific coasts is about 523,000 square miles, and of the continental slopes is 563,000 square miles. The area, then, within the limits of the continental slope surrounding Canada totals about 5,526,000 square miles, or 2.9 per cent of the surface of the globe.

Geologically, the central part of Canada contains the Precambrian rocks of the Canadian Shield, the outcropping part of the North American craton. The several structural provinces comprising the Shield are composed of rocks laid down during the different Precambrian eras, and rocks, mainly crystalline, that were produced or affected by the orogenies near the close of the Archean eon and of the Proterozoic eras. These provinces are Superior, Slave, Bear, Churchill, Nain, Grenville, and Southern Provinces. The craton is bordered by three geosynclines composed mainly of Phanerozoic and late Precambrian rocks. They have been deformed at various times, and at present constitute the Appalachian, Innuitian, and Cordilleran Orogens. Between the Canadian Shield and the orogens

[1] All figures, tables, and plates are given in terms of consecutive arabic numbers preceded by a roman numeral which refers to the chapter. The exception is in Chapter XI — Biochronology, where the customary usage of plate and figures by paleontologists is used.

TABLE I-1 *Area of principal geological and geographic elements of Canada*

	Square Miles
Land areas	3,852,000
Land	3,560,000
Freshwater lakes	292,000
Mainland	2,964,000
Islands	596,000
Enclosed marine waters	858,000
Queen Elizabeth Islands	84,000
Southern arctic islands	217,000
Foxe Basin	83,000
Hudson Strait	64,000
Hudson and James Bays	320,000
Gulf of St. Lawrence	90,000
Continental Shelves	523,000
Atlantic	225,000
Labrador	125,000
Arctic	134,000
Pacific	39,000
Continental Slopes	563,000
Atlantic	124,000
Labrador	56,000
Baffin	219,000
Arctic	148,000
Pacific	16,000
Canadian Shield Provinces	2,146,000
Superior	586,000
Slave	87,000
Bear	47,000
Churchill	
western mainland	554,000
eastern mainland and islands[1]	449,000
Southern[2]	89,000
Nain	43,000
Grenville[2]	291,000
Orogens	1,046,000
Appalachian[1]	191,000
Innuitian[1]	230,000
Cordilleran[2]	625,000
Platforms	1,601,000
St. Lawrence[1]	110,000
Arctic[1]	408,000
Interior	701,000
Hudson[1]	382,000
Coastal Plains	27,500
Arctic	25,000
Pacific	2,500

[1] Includes areas under marine waters
[2] Includes contiguous parts in U.S.A.

are the St. Lawrence, Arctic, and Interior Platforms, which are the parts of the craton that subsided slightly in the past and are now covered by thin veneers of Phanerozoic sedimentary rocks. In the central part of the Canadian Shield, and underlying most of Hudson Bay, is the Hudson Platform. Bordering the oceans are the Atlantic, Arctic, and Pacific Continental Shelves which are composed mainly of little deformed Mesozoic and Cenozoic strata. The Arctic shelf has a broad, nearly co-extensive Coastal Plain; the Pacific Coastal Plain is small. The continental shelf and slope together constitute a depositional geological province, the outer margin of which marks the edge of the continental crust and the transition to oceanic crust.

SCOPE OF THE BOOK

Aspects of the geology and mineral deposits of Canada are treated either by major geological regions — the Canadian Shield, Southeastern Canada, Western Canada, and the Arctic Archipelago — or by individual subjects covering the whole of the country — physiography, mineral resources, biochronology, Pleistocene geology, and groundwater. The accompanying folio includes a new series of maps at 1:5 million scale showing the geology, tectonics, glacial features, physiography, mineral deposits, magnetic anomalies, and gravity. A geotectonic correlation chart is also presented for each of the four major geological regions, an innovation that reduces to visual form the sequence of rocks and tectonic events that ultimately produced the geology of each local sector as we know it today.

On the Geological Map of Canada (1250A) the four principal geological parameters — age, facies, structure, and degree of metamorphism — are used to typify and unify the geology of major sectors of the country and to show the fundamental geological features of the Precambrian geosynclinal belts of the Canadian Shield and the bordering Phanerozoic geosynclines in a consistent way (Douglas, 1969). Rocks are categorized by age according to two standards—depositional and orogenic. Although orogenic ages are, in large part, customarily considered to be determined by radiometric methods, the geological age designation of the orogeny is assigned only those rocks demonstrably igneous, intrusive, or metasomatized. Metamorphism does not change the geological age of sedimentary, volcanic, and basic igneous rocks unless they have been so reconstituted that their original nature can no longer be determined. The same principle is applied to granites and other plutonic rocks; they are considered to be metamorphosed or remetamorphosed unless it can be shown that they have been reintruded, remelted, or metasomatically replaced.

On the Tectonic Map of Canada (1251A) the geology is portrayed in relation to the age of the last major orogeny that the rocks have undergone. The rocks are categorized according to both their tectonic position within the geosynclines and craton and to the stages of geosynclinal evolution. In the course of preparation of the map considerable progress has been made in time classification of Precambrian rocks and in establishing structural provinces and subprovinces in the Canadian Shield (Stockwell, 1964). Much of this progress has been due to the steadily increasing numbers of isotopic age determinations available. Approximately 1,500 age determinations of rocks and minerals have been made in the laboratories of the Geological Survey of Canada; most are by K-Ar methods on biotite, muscovite, hornblende, and the whole rock. About the same number have been made on rocks from Canada at Canadian universities and at several universities and other organizations in the United States. Selected data, categorized according to method, material, geological environment, and laboratory, are shown on the Isotopic Age Map of Canada (1256A).

Mineral deposits, produced or being produced, are set forth on Map 1252A, Mineral Deposits of Canada. The metallic and non-metallic deposits are classified according to type and geological environment; only those with cumulative production of more than 36,000 tons are shown. The fuels are classified according to commodity; if designated a field, petroleum and natural gas deposits are shown regardless of size, and the age of their producing horizons is indicated. The bulk of the developed mineral deposits are in the southern part of the country close to the main population centres. This is partly a function of the geology, but in large part is related to the high costs of exploration, development, and marketing of mineral products from the less accessible regions of Canada where only those deposits of exceptional quality, grade, and size can now be produced economically (Lang and Douglas, 1959).

For the past 20 years aerosurveys of the total intensity of the earth's magnetic field have been carried out, in large part jointly by federal and provincial departments. The results are being published at a scale of one inch to one mile. These surveys are flown with a half-mile spacing of flight-lines and a mean terrain clearance of 1,000 feet. The sensitivities of the magnetometers used vary from 3 to 5 gammas. Some of these data, together with information from private companies, reduced to 1:5 million scale, are on the Magnetic Anomaly Map of Canada (1255A). To the end of 1967, aeromagnetic maps for about 1,250,000 square miles, one third of Canada, have been published. The large-scale maps, mainly of the Canadian Shield, are used by industry in exploration for mineral deposits and by the geologists of the Survey during their geological investigations or in the subsequent interpretation of their data. On the small-scale compilation many of the details are suppressed, but aspects of the larger features of the surface geology and structures deep in the crust are evident.

The intensity of the earth's gravity field has been systematically determined for a large part of Canada by the Gravity Division of the Earth Physics Branch, and the anomalies are shown on the Bouger Gravity Anomaly Map of Canada (1257A). Spacing varies from a grid of one determination per 6 to 7 miles in remote regions to more closely spaced determinations in the more accessible areas

or where the values are anomalous. Most of the larger gravity features are now known but not all have been related to geological features.

In some chapters certain subjects are treated on a Canada-wide basis. In Chapter II, Physiographic Subdivisions of Canada, the distinctive features of each major division are described, and for the first time formal physiographic subdivisions of the Canadian Shield are defined. The limits of the units are outlined on Map 1254A. This map is also useful for geographic reference as it has the maximum number of place names and physical features. The importance of mineral production to the economy is described in Chapter III, The Canadian Mineral Industry, together with data on Canada's position relative to other mineral producing countries of the world, and some other economic comparisons. The composition of the typical and most useful faunas used in correlating and establishing the age of the Phanerozoic rocks of Canada are given in Chapter XI, Biochronology: The Standard of Phanerozoic Time. Some of these accounts also include comments on the paleogeographic significance of the faunal realms and evolutionary trends. In recent years much knowledge has been obtained on the Pleistocene of Canada not only of the relationships and extent of the northernmost continental ice sheets and glacier complexes, but also, particularly in the more southerly regions, of more precise stratigraphy, correlation of events by radiocarbon dating, and the details of the history of deglaciation from the Wisconsin maximum to the present-day glaciers and ice fields. These data are presented in Chapter XII, Quaternary Geology, and portrayed on Glacial Map of Canada (1253A). A brief account of the hydrogeological regions of Canada is given in Chapter XIII, Groundwater, together with descriptions of some of the types of current investigations of the groundwater resources of Canada, whose appraisal, on a national scale, has just recently commenced.

Chapters IV to X deal with the geology and economic geology of the four major regions — the Canadian Shield, Southeastern Canada, Western Canada, and the Arctic Archipelago. In the geological chapters, the approach is basically tectonic, an ordering of the data temporally and regionally. For the Canadian Shield, the Precambrian rocks are described according to the main structural provinces and their tectonic evolution by era. For the parts of Canada composed mainly of Phanerozoic rocks, the geology of the adjacent platformal and geosynclinal regions are brought together. To this are added the as yet rather meagre data on the geology of the bordering continental shelves and coastal plains. The tectonic history for each period is summarized in general terms that can be appraised without familiarity with the rock units themselves or recourse to stratigraphic nomenclature. They are interpretive and speculative to some extent. The main body of the texts of the four geological chapters is descriptive and essentially factual, but of necessity selective. Structures and facies are shown in their present geographic positions as regional palinspastic bases cannot yet be prepared. On the geotectonic correlation chart for each of the four major geological regions of Canada all correlations are in time, three degrees of certainty being indicated. The time standard to which the correlation is made is not indicated, however. The sectors are of unequal size. They vary in geographic extent to embrace an area appropriate to the particular sequence of rock units and events. They are generalizations, as it is not practicable to show all possible geological relationships for each sector.

In the economic geology chapters — treating the Canadian Shield, Southeastern Canada, and Western Canada — the mineral deposits are grouped and described in sections on each commodity whether metal, mineral, or fuel. Generalizations are expressed in the introductory statements to the degree that seems warranted without engaging in undue speculation, and serve also to place the deposits in their natural setting or geological habitat. Descriptions themselves are intended to be factual and are limited to geological, mineralogical, and genetic features and to the factors controlling formation of the deposits. Read in conjunction with the chapters on geology it is hoped that other ideas concerning mineral associations will be suggested, particularly to exploration geologists.

ACKNOWLEDGMENTS

Acknowledgment of data used is not generally in accordance with the custom followed in the preparation of scientific papers because it is not practical to cite all sources of factual data and concepts or to list all available publications. The authors are indebted to all those who have contributed to knowledge of the geology of Canada whether or not their work is listed in the references. We are especially indebted to colleagues who have generously contributed unpublished data and interpretations, participated in discussions, and engaged in critical reading of the manuscripts. The partial reference system is intended primarily to facilitate the interested reader's transition from this book to the geological literature where he can get additional information and references, and only secondarily to extend credit to individual contributors. Personal communications and data from unpublished theses are acknowledged simply by use of the individual's name. Bibliographic lists of all reports and maps by provincial and federal organizations are available on request (*see* Appendix), and are also available from some of the publishing geological societies.

REFERENCES

Douglas, R. J. W.
1969: Orogeny, basement and the Geological Map of Canada; *Geol. Assoc. Can.*

Lang, A. H., and Douglas, R. J. W.
1959: Minerals and fuels, *in* The Canadian Northwest: its potentialities; *Royal Soc. Can.*

Stockwell, C. H.
1964: Fourth report on structural provinces, orogenies, and time-classification of rocks of the Canadian Precambrian Shield; *Geol. Surv. Can.*, Paper 64-17, Pt. II, pp. 1–21.

APPENDIX

SOURCES OF GEOLOGICAL INFORMATION

Federal Departments

Department of Energy, Mines and Resources

Geological Survey of Canada
Director,
601 Booth Street,
Ottawa 4, Ontario.

Institute of Sedimentary and Petroleum Geology,
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British Columbia Office,
326 Howe Street,
Vancouver 1, British Columbia.

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Yellowknife, Northwest Territories.

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615 Booth Street,
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Mines Branch
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Inland Waters Branch
Director,
No. 8 Temporary Building,
Ottawa 3, Ontario.

Policy and Planning Branch
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Department of Indian Affairs and Northern Development

Northern Administration Branch
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Scientific Organizations

Alberta Society of Petroleum Geologists,
524 Lougheed Building,
Calgary, Alberta.

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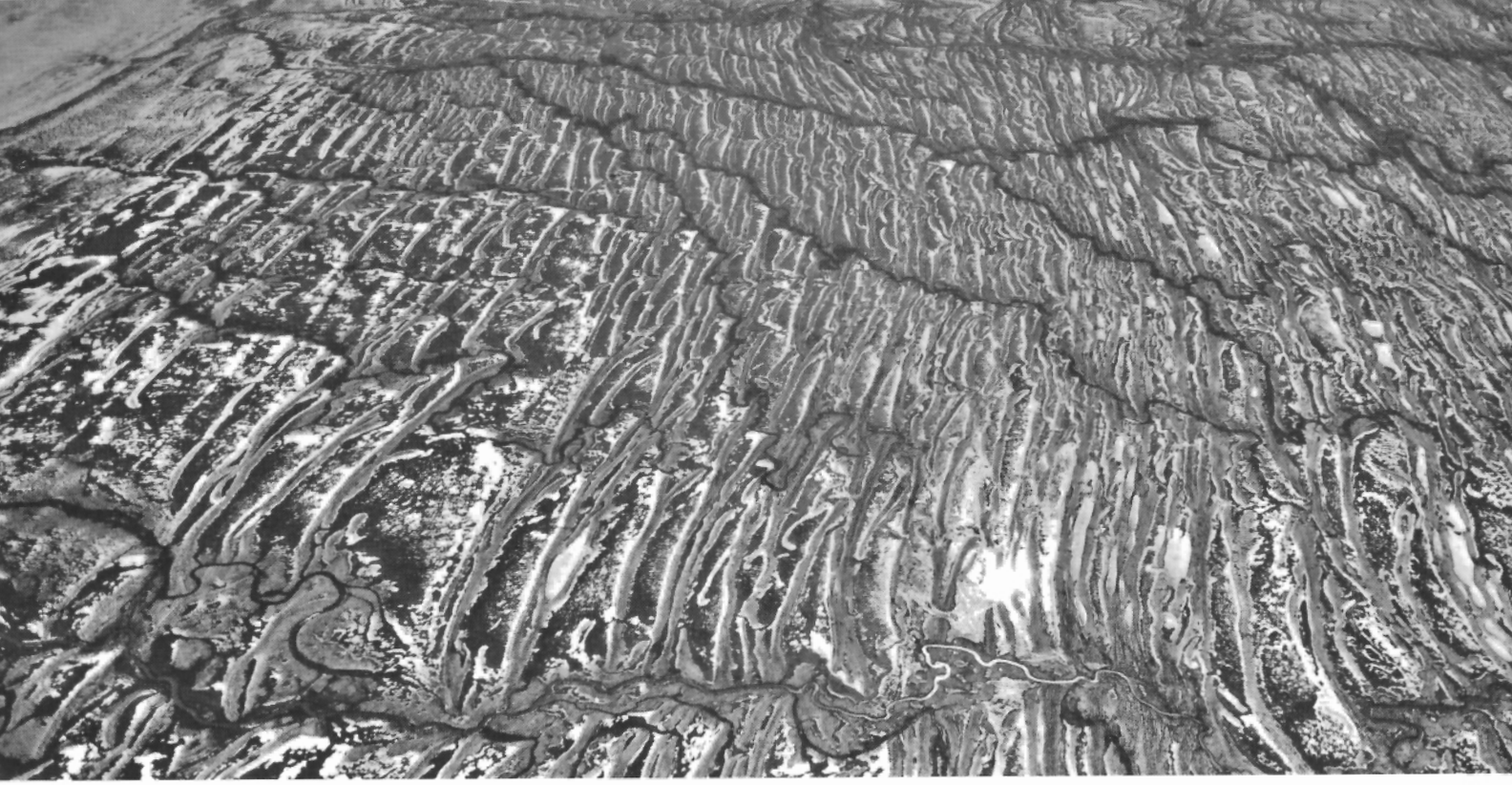


INTRODUCTION

Physiographically and geologically Canada is composed of two great parts: a core of old, massive, Precambrian crystalline rocks forming the Shield, and a surrounding crescent of younger, mainly stratified, rocks forming the Borderlands. In simple terms, the surface of the Precambrian core resembles that of an inverted dinner plate with its flat, slightly depressed centre and an outward shelving rim terminated by a steep edge. The younger rocks of the Borderlands surround the northern, western, and southern parts of the plate as segments of two concentric rings. The inner ring comprises a chain of lowlands, plains, and plateaux of generally flat lying sedimentary rocks overlying the gently shelving rim; the outer ring is formed of discontinuous areas of mountains and plateaux in which the younger rocks are deformed. On the northeast rim of the plate the Borderlands are absent; there the edge of the Shield is tilted upward and drops abruptly into the sea.

Part of the boundary between Canada and adjoining territories of the United States is natural, marked by lakes, rivers, or divides; much is, however, drawn at parallels or meridians. Canada has immensely long and irregular coastlines that embrace great bays, inlets, and channels within the general confines of her headlands and islands. Parts of these coastal waters are shallow and cover the continental shelves along the Atlantic, Pacific, and Arctic coasts.

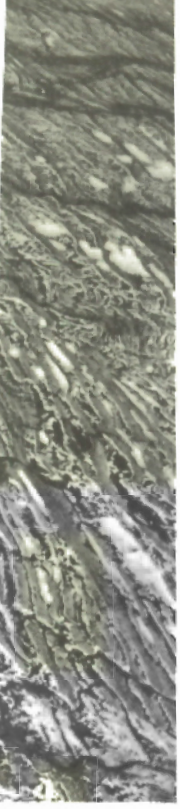
Physiographically the Shield and Borderlands are divided into regions or provinces each comprising many smaller units. In the Borderlands physiographic boundaries are to a great extent indicated by distinctive changes in the topography and geology. For the Shield no such single controlling factor is evident, although the ages of orogeny form a basis for geological subdivision (Stockwell, 1965). Despite this, there are features that enable a physiographic division of the Shield into major and minor units to be made.

THE SHIELD

General Features

Viewed from some prominent summit the landscape presents an even, monotonous skyline interrupted by rounded or flat-topped monadnocks and ranges of hills. The smooth horizon is evidence of an old, almost all-subduing erosion surface; this is the most outstanding characteristic of the Shield and gives a similarity to the terrain whether it is seen in Labrador or the Northwest Territories. Only in scattered areas such as the Davis and Labrador Highlands, around Wager Bay, and Mealy Mountains is the relief mountainous, but even in these places remnants of an old erosion surface form the summits. Over the greater part of the Shield local relief is 200 to 300 feet. The greatest relief of more than 5,000 feet is found in the Davis and Labrador Highlands.

Many long periods of erosion have had a great influence in levelling the broad expanses of the Shield and reducing them to a nearly featureless surface even though parts are geologically distinct. Such features as



Raised beaches on Hudson Bay Lowland.

II

Physiographic Subdivisions of Canada

H.S. Bostock

the East Arm Hills are no higher than the crystalline uplands on either side of them. The eastern edge of Kaniapiskau Plateau is a marked scarp that overlooks the sinuous ridges of the Labrador Hills, although some of their summits stand as high as the plateau surface.

Drainage

The surface of the Shield varies in detail, but as a result of glaciation a great proportion of it is taken up by water as lakes, ponds, and swamps. Although the percentage of area covered by water has not been accurately measured, it is known to exceed 25 per cent in many large regions; in some parts, such as the Thelon Plain or areas of Pleistocene lakes and marine submergence, the percentage is relatively small.

The drainage pattern varies widely and as yet no preglacial system has been deciphered even for the main streams. With a few exceptions such as Leaf River, the main streams flow in the direction of general slope of the land surface. The details of the tributary drainage, however, are disrupted by the local effects of glaciation including the tilting of the land surface, the grouping of the bedrock, and the deposition of surficial materials. Stream channels commonly follow elements of bedrock structure such as persistent fracture zones, major joint patterns, or the traces of soft strata; in places they are diverted across former divides dammed by glacial debris.

In many areas glacial movement transverse to bedrock topography and scattered deposition of glacial drift have formed a mosaic of ponds interspersed with small ridges and hummocks amongst which streams flow along tortuous courses. In contrast to this heterogeneous drainage, where drift deposits are scarce the streams show a trellis drainage pattern, developed to various degrees, in which the main lines follow long straight lineaments, major fracture zones, or the dominant joint systems in the massive rocks. Differences in the resistance to erosion of the strata or gneisses may also impress a drainage pattern guided by the sinuous twists of the folds with S-shaped lakes or concentric or radiating valleys. In other localities depositional features of glaciation may have been the overruling influence, imposing a strong parallelism upon the drainage in drumlin fields, the swells and troughs of drumlinoid features, or the irregularly parallel, congruent system of ridges and hollows of ribbed moraines. Indeed, in no other region of the world has glaciation more clearly placed its stamp upon the drainage pattern.

A comparison of the drainage patterns on each side of the boundary between the Shield and the Borderlands commonly reveals decided differences despite the over-all masking effect of glaciation. On the Shield the drainage generally shows a multitude of lakes and streams, their pattern controlled by the Precambrian bedrock; whereas on the adjacent Borderlands lakes are less numerous and often display bulbous outlines, and the Paleozoic bedrock imposes different stream patterns.

Old Peneplains

The general surface of the Precambrian rocks of the Shield dips at low angles under the bordering Paleozoic strata of the Arctic and Interior Plains, the southwest part of the St. Lawrence region, and particularly around

Hudson Bay Lowland and Foxe Plain. In some areas drilling has shown that the surface is undulating but in general it shelves gradually to great depth beneath the rocks of the Borderlands. Where the character of the Precambrian surface is well exhibited along the border its hills and valleys continue beneath the overlying Paleozoic strata. The strata fill hollows on the Precambrian surface, encroach on the ridges, partly mantle them, and leave only the summits projecting as inliers along the continuations of the ridges. The present surface of the Shield, at least in many areas near its borders, appears to be an exhumed pre-Paleozoic erosion surface.

Outliers of Paleozoic strata are widely scattered in the Shield (some lying far within its borders) generally in depressions or grabens. Some are in valleys such as that of Lake Timiskaming (Hume, 1925) where the Paleozoic strata were deposited on a relief of more than 200 feet, or in deep basins such as that of Manicouagan Lake (Rose, 1955) where several outliers are preserved at 1,200 feet or more below the surrounding Precambrian upland surface without evidence of tectonic movement to bring them to their present position. From the distribution of the Paleozoic outliers it appears that the Shield was peneplaned and the valley system cut in the bedrock before the Paleozoic. It seems that the Precambrian surface has been little changed since the removal of the Paleozoic cover, and that glaciation has only superficially modified its character (Ambrose, 1964).

Although the surface of the Shield seen today is mainly an exhumed surface once buried under Paleozoic strata many areas of Proterozoic sedimentary rocks show similar relationships to the surface of the crystalline Archean rocks beneath them (Ambrose, 1964). The surface of the Shield has had an ancient and complex history indeed. First there was the development and partial dissection of a peneplain on the Archean rocks in pre-Proterozoic time, then the burial and exhumation of this surface once or perhaps twice during the

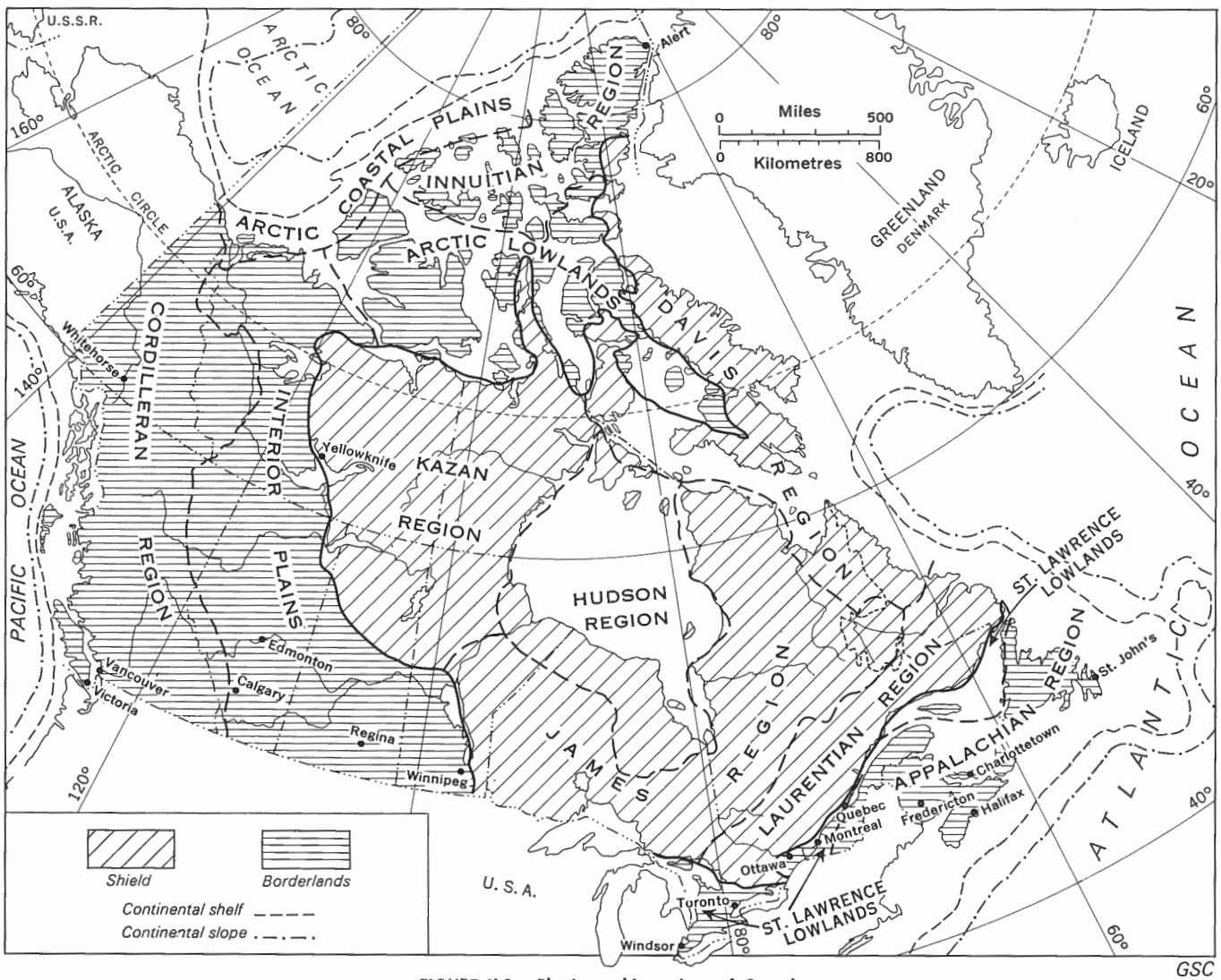


FIGURE II-1. Physiographic regions of Canada.

Proterozoic, followed by the exhuming of these several surfaces from beneath the cover of Paleozoic strata, and finally the scouring of the surface during the surges of Pleistocene glaciation.

Subdivisions of the Shield

Despite the general uniformity of its terrain, geological structure and evidence of orogenies show that the Shield is composed of different parts that were once probably as distinct physiographically as the Cordilleran Region and Interior Plains are today. The ancient boundaries are still geologically evident and in places are physiographically distinct. Accordingly, some geological boundaries transect terrain that forms a single physiographic unit.

Four types of terrain in the Shield are relatively easy to distinguish as physiographic units and coincide with particular geological characteristics: (1) plains, formed on areas of unmetamorphosed rocks more or less flat lying, such as the sandstone and conglomerate terrains of the Thelon, Athabasca, and Cobalt Plains or the terrain of flat-lying gabbro sills of Nipigon Plain; (2) hills, composed of low-grade metamorphic rocks, generally tilted or gently folded sediments or sills, such as the Bathurst, East Arm, Penokean, and Labrador Hills; (3) mountains, composed of particularly resistant massive rocks, such as the anorthosites of the Mealy Mountains which stand well above the surrounding terrain; (4) highlands, formed of broad uplifted areas of deeply incised massive crystalline rocks, such as the Labrador Highlands or the glacier-capped Davis Highlands. Other units are distinguished by less obvious characteristics, and in some places the boundaries are arbitrarily drawn to divide uniform but unwieldy units.

Kazan Region

This region consists of great areas of massive rocks that form broad sloping uplands, plateaux, and lowlands — a rather expressionless terrane. Included in its northwestern part are hills formed of down-faulted and folded stratified rocks, and in its southern and central parts there are some sandy plains of flat-lying strata.

The largest unit of the region is *Kazan Upland,* which covers a wide expanse of rolling lake-spattered country, typical in general aspect of so much of the Shield. North of the Athabasca Plain the highest points are 1,500 to 1,900 feet in elevation with relief rarely more than 200 or 300 feet. The upland slopes gently and drains to Hudson Bay except along its western border where it drains into the Mackenzie River system. Towards Hudson Bay, but about 150 miles from the coast, the relief increases to 600 feet and the higher summits become separated and conspicuous. As much as 100 miles from the sea the upland was covered by the postglacial marine overlap that reached as high as 675 feet above present sea level (Lee, 1959). The area of overlap forms a coastal plain of little relief mantled largely by reworked drift deposits that obscure nearly all the bedrock.

Athabasca Plain forms a large embayment into the western part of Kazan Upland. The plain consists of nearly flat lying sandstones and has a rolling hummocky, lake-spotted, forested surface that rises from 900 feet elevation on the west to 2,000 feet on the east and has a local relief of 200 to 300 feet.

Thelon Plain lies in the central part of the region and includes areas of nearly flat lying sandstones and volcanic rocks that are characteristically expressed on the surface by sandy flats sparsely covered by vegetation.

Southwest of Thelon Plain, *East Arm Hills* are formed of down-faulted and folded, differentially eroded sediments and gabbro sills. On the north side the resistant sills dip southerly forming broad cuestas as much as 900 feet above Great Slave Lake, the surface of which is about 500 feet in elevation. Most intervening valleys are flooded by arms of Great Slave and other lakes. On the south side the hills are narrow and lower, ending abruptly at the long, straight, high, fault scarp bordering Kazan Upland.

In *Back Lowland,* east of Bathurst Hills near Thelon Plain, some upland areas are more than 1,000 feet in elevation. The lowland surface, however, is generally lower than that of Kazan Upland and Wager Plateau which border it on the south and east, particularly between Back and Ellice Rivers. Much is typical of the treeless Shield, but near the coast the surface is mantled by mud and silt of the postglacial marine overlap. Eskers are a typical feature of the inland areas.

The surface of *Wager Plateau* rises gradually from Chesterfield Inlet and Wager Bay to 2,000 feet elevation where it is deeply dissected. From Wager Bay northward the surface declines and loses its identity in low patches alternating with rugged areas of 400 to 700 feet elevation.

Boothia Plateau is underlain by crystalline gneiss forming a narrow north-trending prong of the Shield partly covered by outliers of Paleozoic strata. In the south its surface merges with Wager Plateau 2,500 feet above sea level; northward the surface declines as that of the adjacent lowlands rise.

Bathurst Hills (Bird and Bird, 1961) are composed of down-faulted, folded sediments and sills that lie within and extend south from Bathurst Inlet between higher upland areas of massive rocks. The softer strata have been eroded and in many places lie submerged beneath bays and channels, leaving the harder members, generally the sills, as long cuestas more than 1,000 feet in elevation. Marine silts and reworked deposits from the marine overlap mantle some of the lower parts. Southwestern Bathurst Hills form a prong of ridges termed the Peacock Hills. Some are rugged and reach more than 2,000 feet elevation standing as much as 600 feet above nearby lakes.

Bear–Slave Upland consists mainly of massive rocks though some stratified rocks lie in the northeastern part. Generally the peneplain surface is typical of the treeless,

bare-rock parts of the Shield. Numerous lakes fill the hollows, and rounded rocky hills, exhibiting a relief of a few hundred feet, are characteristic. Many monadnocks exceed 1,000 feet in relief, their summits reaching above 1,600 feet elevation.

The main part of the *Coronation Hills* area is low, extending along Rae and Richardson Rivers eastward into Coronation Gulf. The hills are formed of gently northward dipping sediments intruded by sills and dykes, the latter showing as islands in the Gulf. The hills and ridges rise more than 800 feet above sea level. In the southwest the ridges become more closely spaced until they merge to form the broad, relatively smooth topped uplands of the Coppermine Hills with altitudes of 2,000 feet. Southwest of Dismal Lakes massive rocks protrude through the sediments to form large rounded hills.

Davis Region

Davis Region (Dunbar and Greenaway, 1956) extends from Ellesmere Island south and southeastward to northern Labrador. It is relatively narrow at each end but widens in the middle where crystalline Precambrian rocks surround flat-lying Paleozoic strata of Foxe Plain, a part of Hudson Region. The general aspect is one of a broad, gently warped, old erosion surface, shallowly etched by erosion along joint systems and zones of weakness. Surficial deposits are few except locally near Foxe Plain. Along the eastern coast relief is generally high. The region is divided into a northern or insular part and a southern or mainland part.

Davis Highlands (Ives and Andrews, 1963) are an elevated belt of deeply dissected crystalline rocks (Pl. II-1) that extend along the northeastern flank of Baffin and Bylot Islands and thence north over eastern Devon Island and Ellesmere Island as far as Bache Peninsula. Along this distance of some 1,200 miles the highlands are mountainous with remnants of an old erosion surface forming the summits or marked by a general accordance of peaks 5,000 feet or more above sea level. The old surface slopes gently westward in the north and southwestward in the south. Long arms of the sea penetrate the land as sounds or fiords, and on Baffin Island some cut through the highland into Baffin Upland. The highest parts are commonly crowned by ice caps; the largest is Penny Ice Cap along the border with Baffin Upland, at an elevation of 6,000 to 7,000 feet.

Baffin Coastal Lowland borders the Davis Highlands on eastern Baffin Island, extending from Henry Kater Peninsula to Eglinton Fiord. Its greatest width is about 25 miles, but generally it occurs as isolated, narrow strips at the ends of the peninsulas or islands.

Baffin Upland is also dominated by the high upland surface present on Davis Highlands. The old erosion surface slopes generally southwestward from 3,000 feet elevation near the highland and Barnes Ice Cap to near sea level around Foxe Plain. The border between Davis

PLATE II-1. Fiords and glaciers, Davis Highlands, Baffin Island.

Highlands and Baffin Upland is drawn where the dissection is shallower, the old erosion surface becomes dominant, and the drainage begins to flow southwestward.

Hall Upland on Hall Peninsula is separated from Baffin Upland by Cumberland Sound; the surfaces of these two uplands are similar. Hall Upland reaches 3,800 feet elevation on the northeast side and slopes southwestward into Frobisher Bay. South of the bay *Frobisher Upland* rises abruptly from the sea to 3,000 feet, then slopes southward into Hudson Strait. A similar but lower and more irregular terrain extends westward to Foxe Peninsula. The southwest part, with maximum elevations of about 1,200 feet, is included in the Frobisher Upland. The massive rocks that underlie all these uplands apparently continue beneath the sea and project as isolated areas of the Frobisher Upland in the rugged plateaux of Salisbury and Nottingham Islands.

The mainland part of *Melville Plateau* is largely a featureless smooth upland 1,500 to 2,000 feet above sea level, but with some rugged areas along its west border. On Southampton Island the upland surface is lower at the northwestern and eastern ends, but near the centre much reaches 2,000 feet elevation.

Labrador Highlands and *George Plateau* together resemble the highlands and uplands of Baffin Island. They exhibit parts of an old erosion surface that is cut on massive rocks and slopes inland. The highlands are deeply incised by valleys and fiords along the sea coast; they include several ranges such as Torngat Mountains, the highest and most rugged area of the eastern mainland of Canada. These ranges commonly reach 3,500 feet above sea level and occasionally 5,000 feet. The old erosion surface occurs as undulating, generally westerly sloping remnants around which glaciation has sculptured cirques, rugged peaks, and deep U-shaped valleys and fiords where the cliffs drop precipitously into the sea. In the north some deep valleys traverse the highlands and connect with others in George Plateau, whose streams drain into Ungava Bay. Inland, the old surface becomes more continuous and somewhat less undulating. It forms the main features of George Plateau sloping towards Ungava Bay and Whale Lowland. The highest parts of the plateau are generally between 1,000 and 2,000 feet elevation, but are somewhat higher near Labrador Highlands. Much is covered by areas of drumlinized drift, particularly the lower parts.

Whale Lowland is a broad, irregular, drift-covered area drained by Whale River. Scattered hilltops range from 2,000 feet elevation in the south to 800 feet in the north. Its boundaries, determined largely by the limits of drift cover, are arbitrary.

Hudson Region

Hudson Region includes Hudson Bay Lowland, Hudson Bay itself, Southampton Plain, the Belcher Islands, and Richmond Hills. It is composed of the partly submerged blanket of unmetamorphosed, mainly flat lying Paleozoic and Proterozoic strata that form the main central depression on the surface of the Shield.

Hudson Bay Lowland is a low, swampy, marshy plain with subdued glacial features and a belt of raised beaches that border the bay *(Frontispiece).* Paleozoic strata mantle the massive or stratified Precambrian rocks, and slope gently northeastward and eastward into Hudson and James Bays. Elevations of 200 to 400 feet are reached along the edge of the Severn and Abitibi Uplands; part of its south border is marked by an escarpment overlooking Abitibi Upland. A most conspicuous feature is Sutton Ridge, an inlier of Precambrian strata that rises to 600 feet elevation, about 500 feet above the surrounding surface.

Southampton Plain (Dunbar and Greenaway, 1956), formed on flat Paleozoic strata, is rather irregular but well drained. It is generally less than 300 feet in elevation and is bordered by two higher outliers of Precambrian rocks of Melville Plateau: that on Southampton Island reaching 500 feet and the other at the north end of Coats Island, 700 feet.

Belcher Islands, ranges of hills projecting through the waters of Hudson Bay, are formed from the resistant strata of a thick section of Proterozoic sedimentary and volcanic rocks elaborately folded into long curved hairpin-shaped structures. The higher summits reach about 400 feet above the sea and are truncated by an old erosion surface. *Richmond Hills,* including the Nastapoka Islands and other islands to the north, are mainly a group of east-facing cuestas of Proterozoic sedimentary and volcanic rocks.

Within the main area of *Hudson Bay* the average depth of water is 100 metres, but in the north-central region it reaches 230 metres. The general bathymetric configuration of Hudson Bay is saucer-shaped, particularly in the peripheral areas. Long ridges and valleys disrupt the pattern, however, and in some places, the more continuous, sinuous trends resemble a submerged river system. Echogram soundings clearly show steep-walled valleys as much as 30 metres high that extend beyond present estuaries. The floor of one valley, which is 80 miles west of the Ottawa Islands and trends northerly, lies 330 metres below sea level, almost 200 metres below the level of the adjacent sea floor. It appears to owe its configuration to subaerial erosion along a structural trend.

Other linear trends comprise topographic highs, the most prominent of which is the northerly trending ridge parallel to and 75 miles west of the deep trough mentioned above. The highest part of this arcuate ridge, the Central Shoals, lies at a depth of about 30 metres and may be bedrock controlled. Other smaller ridges are apparent and are thought to be submerged interfluvial areas. In northeastern Hudson Bay adjacent to Digges Islands, a steep-walled, linear trough about 490 metres deep is

thought to have resulted from subaerial erosion and glaciation along a fault.

James Region

The greater part of James Region exhibits the characteristic features of the Shield that are apparent in the major uplands and plateaux of Kazan Region but are less apparent in Davis Region. It is divided into a number of units mainly on arbitrary grounds, but also includes small distinct units such as Nipigon Plain and the Labrador Hills. The physiography of northern Quebec and Labrador has been described by Hare (1959) from a study of airphotographs. His map has been used extensively in preparing this report, but his boundaries have been simplified and some names added.

Severn and *Abitibi Uplands* are similar; both are underlain by crystalline Archean rocks and both have broad rolling surfaces that rise gently from Hudson Bay Lowland in the north reaching about 1,500 feet in their higher parts near the southwest and southern borders. Most of the uplands lie between 900 and 1,200 feet elevation. Large areas in southwest Severn Upland and northern Abitibi Upland are mantled by glacial lake deposits.

Nipigon Plain is formed on nearly flat lying Proterozoic gabbro sills and sediments surrounding Lake Nipigon. It lies at an elevation of 900 feet and is deeply dissected so that remnants of the resistant sills stand as scattered hills. *Port Arthur Hills* are also formed of Proterozoic sills and sediments tilted to the south forming cuestas and ridges some of which extend as promontories into Lake Superior. They reach summits of 1,500 feet and in places rise 800 feet above the lake and adjacent valleys. Michipicoten Island is formed of stratified rocks and forms a link with the *Penokean Hills,* which are composed of folded sediments. Most summits of the latter are 800 to 1,000 feet in elevation, but two points reach at least 1,500 feet, giving a maximum relief of about 900 feet. *Cobalt Plain* is composed of flat-lying clastic sediments with ridges and hills formed by gabbro sills or inliers of Archean crystalline rocks.

The surface of *Eastmain Lowland* joins those of Abitibi Upland and Larch Plateau. It is generally lower than either of these units, however, and large areas are covered by the Pleistocene marine overlap, particularly near the border of James Bay. Lakes are few and muskeg prevails. As a whole the plain has a gently westward sloping surface, broken here and there by hills. In the highest part northwest of Lake Mistassini, lakes are 1,200 feet above sea level.

Larch Plateau has an undulating surface with elevations of 500 to 1,500 feet (Stevenson, 1965). Bedrock is widely exposed and drift is thin over most of its surface. Areas on the west side were covered by the postglacial marine overlap, however, and much of the low-lying southeast part is cloaked with drumlinized till. In the south drainage is westward to Hudson Bay, but farther north a large area is drained to Ungava Bay by Leaf and Larch Rivers. Leaf River starts within 30 miles of Hudson Bay at an elevation of about 500 feet; as it flows northeastward the hills in the heart of the plateau rise from 600 to more than 1,000 feet.

Povungnituk Hills include the Cape Smith and Povungnituk Ranges. Their rocks are largely Proterozoic volcanic rocks and gabbro sills similar to those of Richmond and Labrador Hills. The folded strata form a series of east–west ridges and valleys with a relatively high relief in the western part but of more subdued character in the east where the summit surface of the hills virtually merges with the Larch and Sugluk Plateaux.

Sugluk Plateau at the northern tip of Ungava Peninsula is separated from Larch Plateau by Povungnituk Hills. In places along the north coast the plateau drops precipitously as much as 1,700 feet into the sea. To the west it slopes gently and was covered by the postglacial marine overlap. Inland its slightly undulating surface reaches elevations of 1,900 feet.

The general aspect of *Lake Plateau* is that of a rolling plain with numerous lakes (Hare, 1959); isolated hills of bedrock (some of rugged character) stand about 500 feet above the general surface. In the northwest the elevations are between 1,500 and 3,000 feet. The southern part is generally higher with less relief and ranges from 2,500 to 3,000 feet, whereas to the northeast the elevations are generally lower, between 1,400 and 2,100 feet.

Kaniapiskau Plateau forms the core of Lake Plateau and is composed of rugged hills of massive rocks in which fracture systems are conspicuously etched. Parts reach elevations of more than 3,000 feet. Its eastern border forms an escarpment overlooking Labrador Hills but elsewhere its surface merges with that of Lake Plateau.

The *Mistassini Hills* consist of subparallel hills, ridges, and valleys; the valleys are partly filled with the waters of Lake Mistassini. Summits are more than 3,500 feet in elevation in the Otish Mountains, and stand 2,500 feet above Lake Mistassini. Most ridges are north-facing cuestas formed of sedimentary rocks and gabbro sills and generally have a subdued aspect, particularly around the lake.

Labrador Hills cover the main part of the belt of folded Precambrian sedimentary and volcanic rocks along the east side of Larch and Kaniapiskau Plateaux. It is a belt of sinuous ridges and valleys formed by downwarped folded and faulted strata. The summit elevations range from 2,400 feet in the south and central parts to 1,200 feet in the northern part. In the northern end the

relief is subdued but towards Koksoak River it is bolder and as much as 300 feet. Farther northward again the belt of hills becomes narrow and merges with the adjacent plateau areas. There the valleys are generally floored with drift, tills, drumlins, and sand.

Laurentian Region

This region comprises uplands and highlands that rise abruptly above the St. Lawrence Lowlands along its southeast border. The strong relief at the border is partly caused by fault scarps, in contrast to the western and northern margins of the Shield where the peneplain surfaces dip gently under the overlapping Paleozoic strata of the Interior Plains and Arctic Lowlands.

Laurentian Highlands rise abruptly above the St. Lawrence Lowlands, or the water of the St. Lawrence River and Gulf. The southeastern edge is deeply, and in places widely, incised by several large rivers that gather volume in the high undulating interior and drop rapidly into the river or the gulf. As a result, the southeastern border has a mountainous appearance, the relief commonly at 1,000 to 2,000 feet. In many parts of the interior the surface is also mountainous, but the evenness of summit levels is commonly apparent. This old erosion surface has a relief of 1,000 to 1,500 feet, somewhat higher than that of the adjacent Abitibi Upland to the north. Much of the upland surface lies at about 2,000 feet elevation but here and there broad areas have summits at 3,000 feet, and in a few parts at 4,000 feet. Laurentian Highlands extend south of Ottawa River and include the spur of hills formed of Precambrian rocks that cross St. Lawrence River to form the Thousand Islands and join with Adirondack Mountains of the United States.

Mecatina Plateau is a large area of varied terrain — a rough undulating region with deeply dissected margins. Its surface rises rapidly from the coast to elevations of 700 to 1,200 feet and thence slopes gently to about 1,800 feet along its inland borders. Much of the western and inland parts is drift covered.

Northwest of Mecatina Plateau and bordering on James and Davis Regions is an area of broken terrain composed of upland and plateau units with intervening lower areas. *Hamilton Upland* is a composite unit of three bold, rugged areas of hills, each as much as 2,500 feet in elevation, that stand 500 to 1,000 feet above the surrounding lake and drift-covered plateau surface. Southeast of the upland, drift-covered areas form *Hamilton Plateau*. *Melville Plain,* which contains Lake Melville lying practically at sea level, is an irregular lowland, mainly about 500 feet in elevation; a few hills reach 1,000 feet. It is much dissected by river valleys entering from the west. *Mealy Mountains* rise abruptly above the south side of the Melville Plain and reach their highest elevation of 3,700 feet in the east. An old erosion surface truncates their summits and slopes downward to the west. Cirques are reported in the highest part (Hare, 1959).

THE BORDERLANDS

The Borderlands, which contain a great variety of physiographic provinces, are divided into easily recognized subdivisions, many with long established names. They include the Innuitian Region, Arctic Coastal Plain, and Arctic Lowlands in the north; the Interior Plains and Cordilleran Region of western Canada; and the St. Lawrence Lowlands and Appalachian Region in the east.

Innuitian Region

This is a region of varied topography — on the average more rugged than that of the surrounding provinces — developed from the thick assemblages of deformed sedimentary rocks and minor intrusions. The region is roughly triangular, covers an area of about 210,000 square miles, and forms part of the outer ring of the Borderlands between the Shield and the Arctic Ocean. According to E. F. Roots it is characterized by two curving belts of relatively rugged terrain separated by extensive and discontinuous tracts of more subdued topography. The landscape shows the effects of several interrupted or superimposed physiographic cycles, but most of the landforms are in an intermediate or comparatively youthful stage of development and reflect directly the rock composition, geological structure, and recent vertical movements of the Innuitian system.

The northernmost mountain belt comprises the *Grantland* and *Axel Heiberg Mountains,* which include the British Empire and United States Ranges of northwest Ellesmere Island and the mountainous central and western Axel Heiberg Island. They consist mainly of long ridges of folded Mesozoic and Paleozoic strata, with minor igneous intrusions. The local relief is as much as 4,000 feet, and the highest summits reach 8,200 feet above sea level. In central Axel Heiberg Island and northwestern Ellesmere Island the mountains are nearly buried by ice sheets through which the peaks project as rows of nunataks. On their northwestern flank the mountains pass rather abruptly into a narrow seaward-sloping plateau; on the east and southeast sides they pass with decreasing ruggedness into the elevated dissected edge of the Eureka Upland. At the south end of Axel Heiberg Island, however, the ridged terrain is apparently continuous with that of the inner mountain belt of Eureka Upland. The ranges and ridges are transected by numerous parallel-sided, steep-walled cross valleys, some straight and angular, and some smoothly curving. In northwest Ellesmere Island these make impressive fiords and trough-like valleys with glaciers at the head.

The inner belt of rugged topography extends the length of the Innuitian Region from northeast Ellesmere to the west end of Parry Islands, and is developed throughout on subparallel, gently curving folds in Paleozoic carbonates, shales, and sandstones of the Franklinian Geosyncline. The topography is on the whole less rugged than

that of the outer mountain belt; it is most mountainous in northeast Ellesmere Island where *Victoria and Albert Mountains* reach elevations above 6,500 feet and carry an extensive ice sheet and numerous glaciers. Well-developed valley and ridge topography, with ridge tops 3,500 to 4,000 feet in altitude and a local relief up to 2,500 feet, trends south to southwest across Ellesmere Island and then swings abruptly westward continuing, with interruptions, to Melville Island. The tops of the ridges become progressively broader, and the flat or undulating summit surfaces become the dominant feature of the landscape as the ridged upland passes into the little dissected Parry Plateau.

Eureka Upland comprises an elongated area of relatively subdued topography in central and western Ellesmere Island and eastern Axel Heiberg Island, and lies between the two major mountain belts of the Innuitian Region. In large part it has a rolling and ridged surface controlled by underlying folded strata, but with altitudes generally less than 3,000 feet. There are extensive areas of low dissected plateaux and gently rolling low uplands developed on soft late Mesozoic and Tertiary sandstone and shale. The uplands are cut by trench-like depressions, curving, sinuous, or branching in plan, forming great dendritic drainage systems with floors that extend gradually beneath the sea to depths of more than 300 metres in Nansen Sound and Norwegian Bay.

The terrain of *Parry Plateau* is strongly ridged on Bathurst Island. The ridges are broad, flat topped and straight sided, average less than 800 feet above sea level, and separate wide flat-floored longitudinal valleys transected by rugged, ravine-like cross valleys. Farther west on Melville Island where the plateau surface dominates the landscape, the average elevation increases to more than 1,000 feet. A few hills at 2,500 feet elevation in the western part of the island carry four small ice caps, and cliff-walled fiord-like bays and straits cut deeply into the uplifted plateau surfaces.

In the western Queen Elizabeth Islands, Parry Plateau is bounded on the north by *Sverdrup Lowland,* a region of low relief developed on a structural basin of generally soft, poorly consolidated, and little deformed Mesozoic rocks. For the most part the land surface is a rolling, scarped lowland less than 500 feet above sea level. Locally areas of low upland and dissected plateau reach 1,200 feet elevation and elsewhere extensive areas of plain lie only a few feet above sea level. Among the distinctive landforms are dissected domes and ring structures developed on gypsum anhydrite piercement diapirs and igneous intrusions. About half the total area of Sverdrup Lowland is covered by water; the sea floor is nearly flat and lies at depths of 200 to 500 metres over large areas, with a relatively abrupt rise to the island shores. This suggests an extensive period of erosion controlled by a wave-base level below that of the present seas.

Arctic Coastal Plain and Continental Shelf

Arctic Coastal Plain includes the coastal terrain along the shores of the Arctic Ocean from Meighen Island to Alaska. The plain borders and lies seaward of the Innuitian Region, Arctic Lowlands, Interior Plains, and Cordilleran Region. Although there is a general similarity of landscape throughout the province, each section has distinctive physiographic characteristics.

The *Island Coastal Plain,* the section extending from Meighen Island to Banks Island, is underlain by the Beaufort Formation of unconsolidated Tertiary or early Pleistocene sands and gravels. On Meighen Island this formation has been uplifted 600 feet and eroded to form a hilly terrain that carries an ice cap whose summit is more than 800 feet above sea level. On Ellef Ringnes, Borden, Brock, and Prince Patrick Islands the coastal plain is low, remarkably flat, and uniform, with a network of consequent streams (incised at most a few feet) draining seaward. The inland boundary of the coastal plain, as much as 100 feet above sea level, is marked in places by a low ridge or scarp facing seaward or inland. There are scattered remnants of the coastal plain surface in Sverdrup Lowland. On Banks Island the coastal plain is characterized by low rolling hills and well-organized drainage, with alluvial plains and low westward-sloping terraces bordering the master stream valleys that bear witness to several stages of erosion and uplift. Inland at an altitude of about 300 feet the plain merges with the Victoria Plain.

On the mainland the Arctic Coastal Plain is represented by Mackenzie Delta and Yukon Coastal Plain. *Mackenzie Delta* has a compound character and includes not only the delta of the present river but remnants of earlier deltas and complex fluviatile-marine features such as Cape Bathurst (Mackay, 1958). The delta plain is remarkable for its multitude of lakes and channels, and the older parts for the scores of pingoes, some of large size, which form the most outstanding features of the landscape.

Immediately west of the mouth of Mackenzie River, *Yukon Coastal Plain,* which lies considerably higher than the Mackenzie Delta, appears to be largely an erosion surface cut in bedrock mantled with a thin veneer of recent sediments. Towards the west, the plain decreases in elevation and is drift or lake covered along the coast to near Herschel Island. West of the island to the Alaskan border, the plain is formed of coalesced deltas and alluvial fans built by streams flowing from the British Mountains and of coastal lagoons.

Arctic Coastal Plain extends beneath sea level to merge with *Arctic Continental Shelf.* Offshore from Meighen, Ellef Ringnes, Borden, and Prince Patrick Islands the sea floor is shallow and slopes both seaward and towards the channels which separate the islands where the slope is steeper, more irregular, and reaches depths of about 300 metres. It is evident that the exposed part, or Arctic Coastal Plain, is but a part of an emerged sur-

face of deposition which, in the main, antedates the formation of the deep channels between the islands. Below about 300 metres the drowned headlands that extend seaward from each island group merge with the continental shelf proper. The continental shelf is a nearly plane surface (sloping seaward at about 12 feet per mile) whose inner part is smoothly continuous with the flat channel floors at a depth of 450 metres and whose outer edge, 80 to 120 miles from the headlands of the outermost islands, breaks sharply and cleanly at a depth of 750 metres to fall away as a relatively steep continental slope which descends smoothly to the Arctic Ocean basin. North of the mainland the continental shelf is shallower, and the general slope of Yukon Coastal Plain continues unchanged beneath sea level, reaching a depth of only 100 metres at a distance of 50 or more miles from shore. There the shelf breaks away rapidly to an irregular, relatively dissected continental slope that drops steeply to oceanic depths beneath Beaufort Sea.

Arctic Lowlands

The Arctic Lowlands are formed on the flat-lying or nearly flat Paleozoic and late Proterozoic sedimentary rocks, lying between the Shield and the Innuitian Region. They include Lancaster Plateau, Foxe Plain, Boothia Plain, Victoria Lowland, and Shaler Mountains.

In the northeast the surface of *Lancaster Plateau* slopes gently southward from about 2,500 feet on southern Ellesmere Island, across central Devon Island to average elevations of 1,000 to 2,000 feet on Somerset Island and Brodeur Peninsula of northwestern Baffin Island. Its general uniformity is continuous without apparent deflection across the wide channels of Jones and Lancaster Sounds and Prince Regent Inlet. Farther south the surface descends still lower until on both sides of the Gulf of Boothia it forms the surface of *Boothia Plain* reaching sea level and apparently dips beneath it at Committee Bay.

Foxe Plain is low, smooth, and underlain by Paleozoic strata. It forms a very shallow basin-like area on the old surface of the Precambrian rocks which is partly covered by very shallow seas. On Baffin Island the plain is divisible into three parts, the Great Plain of the Koukdjuak, Soper Highland north of Koukdjuak River, and Putnam Highland to the south. The last reaches 600 feet elevation. Conspicuous features of the Great Plain of the Koukdjuak are a broad belt of emerged beaches stretching north-south on the easterly part and numerous, circular lakes on the central part of the plain.

West of the narrow finger of crystalline rocks of the Shield forming Boothia Plateau, the east side of the *Victoria Lowland* appears to have the same tilted surface as that forming Lancaster Plateau and Boothia Plain, the general elevations decreasing to the southwest and south across Prince of Wales Island, the southwest coast of which is very low. Little is known of the water depths in M'Clintock Channel, but it may be that the channel floor is a part of the lowland surface below present sea level, for to the west the surface rises again to form the low east coast of Victoria Island ultimately reaching 2,500 feet elevation in the central part of Shaler Mountains in the interior of the island. *Shaler Mountains* are composed of later Proterozoic stratified rocks intruded by gabbro sills which form cuestas and are capped by flat-lying volcanic rocks. Farther west, the elevation of the general surface of Victoria Lowland decreases gently, and in central Banks Island it merges with Arctic Coastal Plain. On eastern Banks Island and throughout much of Victoria and Prince of Wales Islands, the smooth undulating ancient erosion surface of the lowland is covered by a variety of glacial deposits, with extensive areas of drumlinoid ridges that impart a characteristic grain to the minor topography. Belts of very thick, rough moraines form irregular hills on southwestern Victoria Island and on both sides of Prince of Wales Strait comprising the most rugged topography within the Victoria Lowland.

Interior Plains

Interior Plains are underlain by flat-lying later Proterozoic, Paleozoic, Mesozoic, and Tertiary strata, occupying the region between the Shield on the east and the mountains of the Cordilleran Region on the west. They join with the St. Lawrence Lowlands of eastern Canada through the United States of America and are separated from the Arctic Lowlands by Amundsen Gulf. The southern part is semi-arid grass land; the central part is tree-covered; the northern part is tundra. The region is divided into several units, those in the north being smaller and more varied than those in the south.

Horton and *Anderson Plains* form the Arctic slope where drainage is directly to the Arctic Ocean. Anderson Plain is covered by a sheet of glacial drift and outwash, the main feature which distinguishes it from the somewhat higher Horton Plain where bedrock is generally exposed. Horton Plain is underlain by nearly flat lying Paleozoic and late Proterozoic sediments and its surface reaches elevations of 1,200 to 2,000 feet, the higher parts being in the south. Much of the western part of the plain is rocky, but in the eastern part rolling areas of drift occur. With few exceptions the lakes are small and scattered. Throughout, as the streams gather size, they become entrenched 200 to 400 feet below the surface. In the north some late Proterozoic strata are slightly folded and faulted giving rise to a rolling surface of low scarps and scattered mesas. Melville Hills, which include Mount Hooker, 1,600 feet in elevation, form the divide between Horton River and the sea. Anderson Plain (Douglas, *et al.*, 1963; Mackay, 1958) is characteristically undulating and rises inland. Large parts of its higher levels are rocky, but extensive areas of outwash from an ice front that lay near its southeast border cover much of the surface and several entrenched run-off channels wind across the plain. On the north along the coast it includes the low, flat, lake-dotted

Capes Bathurst and Parry but inland it rises abruptly along an escarpment 600 to 1,000 feet in elevation. As elevations gradually increase southward the main stream valleys and lake-floored run-off channels lie at elevations of 500 to 700 feet whereas the surrounding surface is about 800 to 1,000 feet.

Peel Plain (Douglas, *et al.*, 1963) lies southwest of Mackenzie River. The southwest part is a broad, shallow hollow about 400 feet in elevation, some parts with innumerable small lakes and others without any. On the northeast the surface rises to Grandview Hills which reach 1,500 feet elevation at their eastern end. Arctic Red River is entrenched across Peel Plain, and Ontaratue River rising on its surface also follows a deeply incised course to Mackenzie River. The southwestern part of the plain is underlain by Mesozoic sediments whereas Paleozoic strata form the hills in the north and east.

Peel Plateau rises in steps between Peel Plain and Mackenzie Mountains. The surface of the first step truncates the upturned edges of the Paleozoic and Mesozoic strata and is, therefore, an erosion surface. Above, a second step or terrace rises in parts of the plateau and on top of this a group of undulating, rounded plateaux of nearly horizontal strata form a third step. These plateaux are separated from Mackenzie Mountains by a broad, shallow but poorly defined valley. In the southwest some areas of the plateau appear unglaciated but most of its surface is covered by thin drift deposits with small scattered lakes lying in the hollows. Remnants of one or more large, entrenched, meltwater channels wind across the plateau from the east to Snake and Peel Rivers.

Colville Hills (Douglas, *et al.*, 1963) embrace several ridges of Paleozoic strata that stand above the general level of the surrounding plains. The hills and ridges enclose hollows with several large lakes in a net-like pattern whose meshes are 10 miles or more across. The lower ground within the meshes lies at 800 to 1,000 feet elevation, whereas the rather sinuous ridges have summits up to 2,200 feet.

Great Bear Plain (Douglas, *et al.*, 1963) is largely composed of Mesozoic strata. Its rolling surface is generally below 1,000 feet elevation, but a number of small subcircular plateaux and hills such as the Scented Grass and Grizzly Bear Hills, rise above this, reaching elevations of about 1,500 feet.

The south-facing escarpment of Cartridge Mountains forms the southern boundary of Great Bear Plain and overlooks *Great Slave Plain* whose surface of Paleozoic strata has generally little relief. Low scarps of resistant carbonate strata and small shallow lakes are characteristic of much of the surface below 1,000 feet elevation. Its central part, however, contains Horn Plateau underlain by Cretaceous strata, an outlier of the Alberta Plateau to the south.

Alberta Plateau (Holland, 1964) is composed of Cretaceous sediments and consists of a ring of plateaux separated by wide valleys. The plateaux include Cameron Hills and Caribou Mountains. On the north these hills form a high disconnected escarpment with summits between 2,500 and 3,200 feet elevation overlooking Great Slave Plain. On the east they overlook the north end of Saskatchewan Plain. On the southeast they embrace Cheecham Hills, 2,500 feet in elevation, and from there the south border of the plateau extends along the flanks of hills on the north side of the Athabasca River to join the Foothills of the Rocky Mountains. A smooth upland surface is the main feature of all the hills. They are generally higher to the southwest at about 4,300 feet elevation. The two main valleys that occupy more than 50 per cent of the area are termed the *Fort Nelson* and *Peace River Lowlands.* The rivers and their main tributaries are more or less entrenched into the valleys which rise from less than 1,000 feet in the north and northeast to about 2,500 feet elevation in the west.

South of Athabasca River, *Alberta Plain* (Acton, *et al.*, 1960) also largely composed of Mesozoic sediments but with some of Tertiary age in the west and south stretches southeastward to the International Boundary. Although virtually the continuation of the Alberta Plateau, it has a more even surface, with a few widely separated groups of low hills such as the Neutral, Cypress, and Porcupine Hills. Much of the plain is about 2,500 feet in elevation, river valleys entrenched 200 to 400 feet, and hills rising to 3,500 feet or more. Cypress Hills reach 4,700 feet and parts of their summit are believed to have escaped glaciation.

The eastern edge of the Alberta Plain (Pl. II-2) referred to as the Missouri Coteau constitutes a step down to *Saskatchewan Plain.* The Coteau, well marked at the International Boundary by a line of low, rounded hills partly formed by Tertiary sediments, gradually becomes indefinite northwestward. East of the Coteau, Saskatchewan Plain, formed on Mesozoic sediments and lower and smoother than Alberta Plain, is gently undulating and rolling, its surface ranges from 1,500 to 2,600 feet above sea level and relief is about 300 feet in the hillier parts. Saskatchewan River is now entrenched in bedrock across the plain. By the end of the Pleistocene its waters had incised a broad valley along a southeasterly course now only occupied by a comparatively small stream, the Qu'Appelle River. In the northwest the Ile-à-la-Crosse Lowland (Acton, *et al.*, 1960) around Peter Pond Lake forms a detached area generally below the surface of southern Saskatchewan Plain but is here included with it.

On the east, Saskatchewan Plain is bordered by the Manitoba Escarpment overlooking *Manitoba Plain* which is underlain by Paleozoic sediments. Streams flowing eastward have cut deep valleys in the escarpment dividing it into a line of separate hills, the highest of which, Riding Mountain, stands nearly 1,000 feet above Manitoba Plain. The surface of the Manitoba Plain has an elevation of about 800 feet and is very gently undulating to flat. It is largely covered by lakes and includes most of Lake Winnipeg. In the southern part its features have been

PLATE II-2

Alberta Plain and Missouri Coteau, with glacial moraine, near Assiniboia, Saskatchewan.

smoothed over by the deposition of the clays and silts of glacial Lake Agassiz. The beaches of this lake, marking successively lower water levels, wind along the lower part of Manitoba Escarpment.

Cordilleran Region

General Features

The Cordillera in Canada is divided longitudinally into three great belts, the Eastern System, the Interior System, and the Western System (Bostock, 1946 and 1961; Holland, 1964). Each has its own characteristic geology and likewise its physiography. The Eastern System is composed almost entirely of folded sedimentary strata. The Interior System is made of folded sedimentary and volcanic strata, massive metamorphic rocks, all intruded by large or small bodies of igneous rocks, with local areas of flat-lying volcanic rocks. In the Western System the largest unit, the Coast Mountains, is composed mainly of plutonic rocks whereas other parts contain a mixture of folded volcanic and sedimentary strata intruded by scattered bodies of massive igneous rocks. The three great systems are further divided into areas and subdivided into mountains, ranges, plateaux, hills, valleys, trenches, basins, plains, etc.

The Cordillera is also divided transversely into a number of segments by east–west belts of relatively low terrain. The broad northern part of the Interior Plateau, the most southerly and also the main feature, separates the two main segments of high and mountainous terrain in British Columbia. At the sixtieth parallel an area of low terrain including Liard Plateau, Liard Plain, and Yukon Plateau separates the Rocky and Cassiar Mountains from the Mackenzie, Selwyn, and Ogilvie Mountains to the north. The latter group, in turn, is separated from the Richardson Mountains by Porcupine and Peel Plateaux. The British Mountains in northern Yukon Territory are separated from the Richardson Mountains by the broad saddle that connects Porcupine Plateau and Yukon Coastal Plain.

Old Erosion Surfaces

Probably the most notable feature of the physiography of the Cordillera is that remnants of an old erosion surface

PLATE II-3

Unglaciated part of Yukon Plateau and Yukon River near Dawson, Yukon Territory.

are nearly always evident. This surface may not be the same in all parts, and indeed many features suggest that there are surfaces of different ages. An old surface is most conspicuous in the plateau areas of the Interior System. It has been referred to as a peneplain but its relief is not sufficiently low over large areas to qualify as such. Generally the accordant summits give an impressively even skyline, but the surface is undulating with some higher rounded summits. Locally, particularly in northern Yukon Territory, upland ridges are flat topped, and their structures bevelled to a remarkable degree. On the west flank of Coast Mountains the surface is impressive where it rises from Hecate Strait, truncating the island hills, bridging the fiords, and bevelling the mountain summits. On the higher peaks of the inland ranges it has been destroyed by erosion.

The old surface is thought to have been formed largely in the beginning of the Tertiary or possibly in the late Cretaceous, and to have gone through a complicated subsequent history of uplift, warping, subsidence, and renewed uplift that is just beginning to be understood in a few parts of the Interior System (Lay, 1940 and 1941). In the early Tertiary the old surface of erosion was uplifted, the rivers entrenched, and sediments deposited in the valleys and hollows. Early Tertiary volcanic rocks, chiefly lavas, then filled the valleys. They were later down faulted, warped, and bevelled by erosion accompanying renewed uplift and dissection. Lava has been extruded here and there up to the present.

Unglaciated Areas

Large unglaciated areas cover most of northwestern Yukon (Map 1253A) and give an indication of the character of the plateaux of the Cordillera before Pleistocene glaciation. There the topography is sculptured by the normal processes of subaerial erosion at northern latitudes. The classic area is that around Klondike River in Yukon Plateau where relief is 2,000 to 3,000 feet, and the metamorphic rocks are much the same as in the adjoining glaciated areas. The unglaciated plateau area is composed of long ridges spreading from a central divide, separated by closely spaced small creeks that merge into larger streams,

the valleys gradually widening. The gradients are even and uninterrupted by rapids or lakes. The valleys are V-shaped with sides flaring upwards and diminishing in steepness until the broad, rounded ridges of the upland are reached. These may be broken in places by castle-like outcrops on or near their summits. The general drainage is dendritic among smaller streams, but a few larger streams are straight, following some linear structural feature. Persistent bedrock terraces along many of the larger valleys are mantled by variable thicknesses of gravel, sand, and soil, and follow more gentle gradients than the present streams. In places stream reversal and capture are apparent. Lakes are generally lacking; a few ponds occur due to ice pushing on the valley flats, to damming of the rivers by lava flows, and to landslides; oxbow lakes occur along the larger rivers.

Glacial Features

Glacial ice covered the Cordillera with the exception of the area referred to above and some minor areas. In many ranges only the highest peaks projected above the ice, which left its imprint on the topography as both erosional and depositional features. Conspicuous in the mountains are cirques, arêtes, and horns, and along the valley sides ice-margin channels have been cut in bedrock, kame terraces, and moraines. On the valley floors are a host of features mainly formed of surficial materials: pitted till, outwash plains and terraces, drumlin fields, simple and compound eskers, lake terraces, and all manner of fluvial-glacial features.

Great U-shaped valleys furrow the country, most impressive where filled with lakes or inlets of the sea. A belt of long lakes stretches along the western or dry side of the Interior System from Kluane Lake in Yukon Territory to Taseko Lakes in British Columbia. Another zone lies on the eastern side, on the relatively wet western slopes of the mountains from Mayo Lake in the north to Shuswap and Kootenay Lakes in the south. It is, however, in the fiords of Coast Mountains that these glacially scoured valleys are most spectacular. Cut in a terrain formed almost wholly of hard crystalline rocks the fiords follow a pattern mainly controlled by fracture and joint systems on a grand scale. Many are several tens of miles long and in cross-section are deeply U-shaped as much as 2 miles wide, with a relief of 6,000 feet in places. Their floors may sometimes lie at more than 600 metres below sea level, rising seaward to a sill of small rock islands.

Trenches

Four great linear valleys, each at least 300 miles long, trend northwesterly through the Cordilleran Region, some of which delineate major physiographic and geological provinces. These are the Southern and Northern Rocky Mountain Trenches of British Columbia and the Tintina and Shakwak Trenches in the Yukon, which are impressive features where narrow, straight and steep-walled. The floors vary in width from less than a mile to more than 15 miles and are drained by several rivers whose low divides lie in the trenches. The floors are remarkably uniform in elevation rising gradually from about 1,800 to 3,000 feet except for Tintina Trench, much of which is near 1,000 feet elevation. A number of similar, smaller, and shorter trench-like valleys occur in the Interior System, such as the sinuous, northerly trending Purcell Trench of southern British Columbia and Teslin Valley in Yukon Territory.

Volcanic Features

In the Interior and Western Systems constructional landforms have been produced by volcanic processes. The most abundant are the plains, plateaux, and mesas formed from extrusion of basic lava, the Plateau basalts. Most striking, however, are three great shield volcanoes in the northwestern part of Interior Plateau and a group of similar volcanoes, such as at Edziza Peak, in Stikine Plateau. Also in the Stikine Plateau are a number of tuyas — flat-topped volcanoes which erupted in the midst of the Pleistocene ice (Mathews, 1947). A large number of small volcanoes and cinder cones occur singly, in line, or in groups. These range in age from pre-Pleistocene to within a few hundred years of the present, and vary in height from a few tens to a few hundreds of feet.

Eastern System

Porcupine Mountain Area

In the light of recent studies in physiography and geology in northern Yukon Territory a re-grouping of the physiographic units is made here. The Porcupine Plateau and its subdivisions formerly in the Northern Plateau and Mountain Area are termed the Porcupine Mountain Area and placed in the northern part of the Eastern System whose units they resemble. The ranges heretofore called the Northern Ogilvie Mountains are also similar and included in the Eastern System. The British Mountains and Old Crow Range are retained in the Interior System constituting the Brooks Range Area.

Richardson Mountains comprise a group of ranges having rugged peaks up to 5,500 feet elevation in its northern core. The narrow, lower southern ranges characteristically exhibit smooth, rounded profiles. These mountains do not appear to have been glaciated, but a tongue of Laurentide ice extended through them from the east via McDougall Pass.

Porcupine Plateau is almost entirely unglaciated. The northernmost part, Old Crow Plain, has an elevation of about 900 feet and is underlain by unconsolidated sills and peat. Closely spaced lakes and ponds have an oriented, rectangular pattern apparently produced by the prevailing winds (Plate II-4). Old Crow River and its tributaries meander elaborately and are entrenched in youthful valleys into the plain. In Eagle Plain, in the southern part of the plateau, long, even-topped ridges have broad, gently

PLATE II-4

Old Crow Plain, northern Cordilleran Region, Yukon. View northward, Old Crow River and rectangular lakes.

rounded summits typical of unglaciated areas. Relief reaches a maximum of about 900 feet in the highest part at the south where some ridges are 2,500 feet in elevation. Around the perimeter of the plateau the surface rises, notably in the west where bordered by the *Porcupine Ranges*. These ranges are underlain by folded stratified rocks that form linear ridges, hills, and low mountains, separated by broad irregular valleys. In Keele and Nahoni Ranges the summits exhibit remnants of an old erosion surface.

Mackenzie Mountain Area

Taiga Ranges and *Wernecke Mountains* comprise the westernmost part of Mackenzie Mountain Area. Taiga Ranges are separated from the Porcupine Plateau and Ranges by the broad, irregular valleys of Peel and Ogilvie Rivers. They were only slightly glaciated and their highest peaks and ridges reach 7,000 feet elevation. Wernecke Mountains are formed of phyllite and massive, nearly horizontal carbonate carved by glaciation into very rugged massive mountains. They are divided into several ranges by broad northwesterly trending valleys.

The interior part of *Mackenzie Mountains,* the Backbone Ranges, is a sea of peaks and ridges reaching to 8,500 feet. Some contain small alpine glaciers, and have been sculptured by alpine and valley glaciers. The more easterly ranges, the Canyon Ranges, are lower, divided by wide valleys or cut by deep canyons. During the Pleistocene ice from the east penetrated the valleys but otherwise the mountains show only local alpine and valley glaciation. Mackenzie Mountains, in the precipitation shadow of the Selwyn Mountains to the west, are relatively dry. The timberline is low, and the mountains present an aspect of bare, rock-covered slopes with a few cliffs.

Mackenzie Plain is a broad, rolling, drift- and tree-covered plain lying between Mackenzie and Franklin Mountains into which Mackenzie River is entrenched for part of its course. *Franklin Mountains* form a series of linear relatively low ranges and ridges, largely of resistant carbonates, that reach elevations of about 5,000 feet. They were over-ridden by ice moving from the east.

Liard Plateau south of Mackenzie and Franklin Mountains lies between South Nahanni and Liard Rivers. It is a region of tree- and tundra-covered hills, mostly less than 4,500 feet in elevation, and underlain mainly by shale and sandstone. Many summits are flat because of the attitude of the strata but extensive remnants of former erosion surfaces are evident. The valleys are narrow and deeply incised.

Rocky Mountain Area

This area extends more than 850 miles from Liard River to the Forty-ninth Parallel, and includes the Rocky Mountain Foothills, which form the eastern front of the southern part of the Cordillera, and the Northern, and the Southern Rocky Mountains. Each is divisible into

numerous subparallel ranges. The *Foothills* generally rise abruptly above the Interior Plains and are mainly linear ridges and hills of Mesozoic sandstones with some mountainous parts. The *Northern Rocky Mountains* are broadest and highest around Mount Churchill (10,500 feet in elevation) in the Muskwa Ranges. There the terrain is as rugged as any other part of the Rockies, having been carved by glaciation from great sections of stratified rocks. A number of alpine glaciers occur around the higher peaks. The Rockies are narrow where crossed by Peace River. To the south the Hart Ranges of the *Southern Rocky Mountains* rise gradually and form a long saddle of relatively subdued mountains with summits 6,000 to 9,000 feet in elevation. The Continental Ranges are broader and elevations increase to that of the highest peak, Mount Robson, at 12,972 feet. A number of high peaks on the continental divide cluster around Columbia Icefield — the largest of many alpine glaciers in the Rockies. Southward, peaks up to more than 10,000 feet elevation occur at intervals or in groups along the mountain backbone to near Crowsnest Pass, where they are generally lower, rising again south of the Forty-ninth Parallel. Continental Ranges are characterized by linear ranges with great cliffs and precipitous faces of bare grey rock, sculptured by glaciation from thick sections of carbonate strata.

Interior System

Brooks Range Area

British Mountains rise close to the sea, abruptly from the narrow Yukon Coastal Plain on the north and become lower inland, towards Porcupine Plateau. They comprise a maze of V-shaped valleys fingering among branching ridges. Many streams have cut courses radially across the ridges, and the valley of the largest, the Firth River, completely traverses the mountains. Only small areas in the highest part near the Alaskan Boundary are rugged. There the summits reach about 6,000 feet elevation and seem to have remained unglaciated. Southwest of Old Crow Plain *Old Crow Range* is a subdued range of large rounded hills commonly crowned by castle-like outcrops of granitic rocks.

Northern Plateau and Mountain Area

Ogilvie Mountains lie between Tintina Trench and Taiga Valley, south of Taiga Ranges. They are composed of sedimentary strata intruded by granitic stocks. Their highest peaks and ridges reach 7,000 feet elevation. During the Pleistocene these mountains contained alpine and valley glaciers which coalesced into continuous ice fields in their eastern part.

Yukon Plateau is a major physiographic unit containing many subdivisions. It is gently basin-like, its central parts lying at about 4,000 feet elevation. The surface rises towards the borders of the plateau and also lies at higher elevations in the local mountain ranges, such as the Pelly Mountains. The plateau is drained by the vast headwaters of the Yukon River system. Near its headwaters the river is entrenched about 2,200 feet below the plateau surface which lies at about 4,400 feet elevation. It declines at grades of 3 or 4 feet per mile, with few rapids, to less than 900 feet at the Alaskan Boundary. During the Pleistocene ice encroached from the mountains on all sides except the northwest but did not cover the Klondike Plateau.

On the northeast and east Yukon Plateau is bordered by *Selwyn Mountains,* which were extensively glaciated and comprise many rugged ranges separated by broad valleys. A few alpine glaciers occur on the highest summits between 7,000 and 9,000 feet elevation. Mount Keele, at 9,700 feet elevation, is the most outstanding peak.

Hyland Plateau is formed of rolling hills rising to 4,000 feet elevation and broad valleys, some aligned with structural features. The whole plateau was glaciated; the drift deposits form a widespread mantle and clog the main valleys. Along the southern boundary with Liard Plain are four isolated mountain groups reaching above 5,000 feet elevation. *Liard Plain* is a low-lying area into which Liard River is entrenched. The plain is less than 3,000 feet in elevation and much is at 2,000 feet. It is mantled with glacial and outwash deposits, including a great compound esker.

Central Plateau and Mountain Area

Stikine Plateau forms the southern continuation of the Yukon Plateau. It notably has a number of late Tertiary and Pleistocene volcanoes, the most prominent of which are the great shield volcano of Level Mountain, a low, dome-shaped mass reaching 7,101 feet whose lavas cover more than 700 square miles, and Mount Edziza, a complex cone, 9,143 feet in elevation.

Cassiar and *Omineca Mountains* form a belt of massive crystalline rocks, whose highest peaks are about 8,000 feet in elevation and carry a number of alpine glaciers. *Skeena Mountains* to the south and west are somewhat lower in general elevation and are composed largely of folded stratified rocks of uniform resistance so that structure is an important factor in determining the positions of mountains and valleys. Southwest of Skeena Mountains the *Nass Basin* is an area of low relief with a gently rolling floor for the most part lying below 2,500 feet elevation. The basin is almost encircled by mountains, but large gaps connect it with Skeena River valley and the sea via Nass River valley.

Hazelton Mountains comprise a group of ranges traversed by Skeena River. They are largely underlain by folded sedimentary and volcanic rocks and isolated intrusions of igneous rocks in contrast to the almost wholly granitic terrain of Coast Mountains to the west and the sediments of Skeena Mountains to the east. The highest peaks range between 8,200 and 9,200 feet in elevation.

Southern Plateau and Mountain Area

The main unit is the *Interior Plateau* which extends half the length of British Columbia north of the Forty-

ninth Parallel. Three large shield volcanoes stand near the middle of the western side, and flat-lying Tertiary to Recent lava flows form the bedrock over large parts. The plateau surface generally lies between 4,000 and 5,000 feet in elevation, rising from Fraser Basin in the northeast where the general level is below 3,000 feet to above 6,000 feet in Columbia Mountains. *Fraser Basin* has a flat, gently rolling surface mainly covered by glacial drift into which the Fraser River system and other main streams are commonly incised more than 1,000 feet. The glacial deposits include well-developed drumlinoid features, pitted terraces, simple and compound eskers, and large areas have glacial lake deposits.

Columbia Mountains contain many peaks more than 10,000 feet in elevation and are generally as high as the Southern Rocky Mountains east of the Trench. They constitute the main area of the interior wet belt of British Columbia. They were ruggedly sculptured during the Pleistocene glaciation, and their higher parts still contain many glaciers. *Columbia Highlands* to the west are lower and less rugged.

Western System

Coast Mountain Area

This area includes the Coast Mountains and the Cascade Mountains. The former are composed of crystalline gneisses and granitic rocks in contrast to the Rocky Mountains which are made up of stratified rocks. The two great mountain groups also differ in that the summits of the Rockies are relatively blocky whereas the peaks and ridges of the Coast Mountains are commonly serrate with tooth-like pinnacles. Only Peace and Liard Rivers traverse the Rocky Mountains, whereas nine or more large streams cross the Coast Mountains.

Coast Mountains include three major divisions, the Boundary, the Kitimat, and the Pacific Ranges. *Boundary Ranges* extend from southwestern Yukon along the boundary of the Alaskan panhandle. Their summits form a belt of rugged peaks generally 7,000 to 10,000 feet in elevation capped by several large ice fields. These ranges are cut into several segments by great transverse valleys containing Taku, Stikine, and Iskut Rivers. In places relief along the sides of the valleys reaches 9,000 feet. Large glaciers move down tributaries from nearby ice fields to 500 feet above sea level; in Alaska several reach the sea. The *Kitimat Ranges,* their peaks rarely above 8,000 feet elevation, form a saddle between the higher Boundary and Pacific Ranges. Glaciers are few and small. *Pacific Ranges* form the main southern part of Coast Mountains. Many peaks are between 9,500 and 11,000 feet elevation; the highest, Mount Waddington, is 13,177 feet elevation. Like the Boundary Ranges, the higher peaks are surrounded by ice fields; many large glaciers extend to low elevations but none reaches the sea. They are also cut into segments by great transverse valleys and fiords or inlets, the largest being those of the Klinaklini and Homathko Rivers.

Cascade Mountains are separated from the southeast part of Coast Mountains by Fraser River Canyon and continue into the United States. They are composed of the Skagit, Hozameen, and Okanagan Ranges. The highest peaks reach 8,000 to 8,500 feet elevation. In Skagit and Hozameen Ranges the high ridges are serrate, whereas lower ones are rounded by glaciation. In the Okanagan Range, although deeply cut by cirques, the summits still show the rolling contours of an old erosion surface rising from the Interior Plateau.

Outer Mountain Area and Coastal Lowlands

The Outer Mountain Area includes the St. Elias Mountains and the Insular Mountains forming Queen Charlotte and Vancouver Islands. The Coastal Lowlands border the Outer and Coast Mountain Areas.

St. Elias Mountains are the highest mountains in Canada and with their great peaks ranging upwards to the 19,850 feet elevation of Mount Logan, they are one of the great mountain belts of the world. In the *Icefield Ranges,* the heart of the mountains near the Alaska boundary, the main peaks stand as somewhat isolated blocks separated by broad valleys filled by ice fields to 8,000 feet or more. As the limit of permanent snow is at about 7,000 feet, these mountains present great masses and expanses of ice and snow. Mount Logan is the highest point of a large block on which at least four others rise to more than 18,000 feet. This tableland in consideration of the elevation of the long saddles comprising Mount St. Elias at 18,008 feet, Mount Lucania at 17,150 feet, and Mount Steele at 16,439 feet, suggests the former presence of an even erosion surface. The ice fields are the source of many great valley glaciers that radiate to the sea along the Alaskan Coast and inland towards Shakwak Trench in Canada. The lesser peaks, many more than 10,000 feet, tend to form groups or ridges between the valley glaciers. Northeast of Icefield Ranges the lower *Kluane Ranges* with peaks up to 8,500 feet flank Shakwak Trench. These ranges are much less rugged than the Icefield Ranges and contain only small alpine glaciers.

Hecate and *Georgia Lowlands* bordering Coast Mountains are formed by an old erosion surface that emerges from the sea bevelling hills of crystalline gneissic and igneous rocks and rises gradually inland. The limit is arbitrarily drawn at about 2,000-foot contour. Even in its lower parts the lowland has been dissected by glaciers and bedrock is exposed. Inland much of the surface is covered by muskeg. *Georgia Lowland* includes an area of soft folded strata along the east and south sides of Vancouver Island where differential erosion has formed cuesta-like ridges below 2,000 feet elevation. It includes the islands of the Strait of Georgia and a fringe of the mainland. *Fraser Lowland* adjoining Fraser River is composed largely of unconsolidated material with some hard bedrock forming rolling hills up to 1,000 feet

elevation. Part is formed by the Fraser Delta.

Queen Charlotte Ranges are the backbone of Queen Charlotte Islands, and in the southeast their summits reach above 3,500 feet elevation. These ranges and Skidegate Plateau to the northeast were glaciated by a local ice sheet (Holland, 1964). *Queen Charlotte Lowland* is formed of gently dipping Tertiary strata covered by a veneer of glacial till and thick outwash deposits in its northeast part. Inland, it rises southwestward to between 500 and 1,000 feet above sea level.

Vancouver Island Ranges form the main body of the island and their higher peaks reach 7,000 feet elevation. They were sculptured by local alpine glaciers but some ice came from the mainland to the east carving deep U-shaped valleys. *Nahwitti Lowland* on the north end of Vancouver Island is a rolling lowland carved of slightly folded strata, generally lying below 1,000 feet elevation. On the west coast of Vancouver Island a narrow, broken lowland forms *Estevan Coastal Plain.* It is underlain mainly by gently dipping, soft Tertiary strata forming a low and flat plain, but parts are cut on relatively massive rocks forming low hills and reach about 250 feet above sea level.

Pacific Continental Shelf

Off the British Columbia coast the Pacific Continental Shelf is narrow and its surface drops abruptly to ocean depths along a nearly straight line that closely parallels the headlands of the outer islands. West of Queen Charlotte Islands the rim of the shelf hugs the shore and at its closest point, 4 miles from land, descends below 1,000 metres. Off Vancouver Island the edge of the shelf is generally 20 miles or more to sea, reaching a maximum of nearly 50 miles at the entrance of Juan de Fuca Strait and a minimum of about 6 miles off Brooks Peninsula.

North of Queen Charlotte Islands, at Dixon Entrance, a broad channel, generally 200 to 400 metres deep, extends towards Portland Canal and branches among the Alaskan Islands. The width of Dixon Entrance is believed to have been occupied by Pleistocene ice moving from the Coast Mountains and the Alaskan Islands. The channel contains a transverse bank as shallow as 40 metres in the middle part, near the outer end.

At the entrance of Queen Charlotte Sound the edge of the shelf has four short but deep embayments at oceanic depths. From these, three broad channels more than 200 metres deep extend landward to near the islands off the mainland coast. The channels are separated by two broad banks. The northern and smaller one is a little less than 125 metres deep, whereas much of the larger one is less than 40 metres deep on its landward part. The north channel projects into Hecate Strait and lies mainly on the east or mainland side thereby leaving a broad shallow area shelving gently easterly and stretching across most of the strait. In the north the shallows nearly reach the islands of the mainland coast so that Hecate Strait is no more than 20 metres deep for about 4 miles. The southern channel extends towards the straits between Vancouver Island and the mainland. The straits are narrow, surround many islands, and contain numerous deep holes and channels more than 200 metres deep. This is characteristic also of many channels and fiords along the coast. These conditions extend through to the Strait of Georgia, a large part of which is occupied by an irregularly shaped basin, at 400 metres or more in several places.

St. Lawrence Lowlands

The St. Lawrence Lowlands borders the Shield on the southeast extending from the west end of Lake Huron and the head of Lake Erie northeasterly to the Strait of Belle Isle. It comprises three units; the West St. Lawrence Lowland, the Central St. Lawrence Lowland, and the East St. Lawrence Lowland. The province is floored by unfolded Paleozoic strata and the west and central lowlands are plain-like areas. The East St. Lawrence Lowland, though formed of widely separate parts, maintains the same general plain-like form and structure. The whole province was affected by Pleistocene glaciation and its surficial deposits and features are common phenomena.

West St. Lawrence Lowland is broken into two parts by the Niagara Escarpment which extends from Niagara River in a sinuous westerly and northwesterly course to Bruce Peninsula and the Manitoulin Islands. The escarpment is a northeasterly facing cuesta and is the result of the resistance to erosion of Silurian carbonates that dip gently southwest. The escarpment attains an elevation of about 650 feet in the south and a relief of 250 to 300 feet. Along the south shore of Georgian Bay it attains an elevation of 1,700 feet, about 1,000 feet above the bay. The surface west of the escarpment slopes gradually southwestward through an area of rolling topography of low relief to the level of Lake Erie, 572 feet above sea level. East of the escarpment the land rises gently northward from Lake Ontario at 246 feet elevation, to a maximum height of 1,000 feet south of Georgian Bay. At several places east of Lake Simcoe the boundary with the Shield is marked by a low escarpment. The Precambrian rocks of the Frontenac Axis separate West and Central St. Lawrence Lowlands.

Central St. Lawrence Lowland includes the area between the Ottawa and St. Lawrence Rivers, straddles the St. Lawrence as far as Quebec City, and extends a short distance beyond on the north shore only. East of the St. Lawrence River the lowland is bounded by 'Logan's Line,' a fault zone that marks the northwestern border of the hilly Appalachian Region. North of Ottawa and St. Lawrence Rivers the flat-lying Paleozoic strata underlying the lowland are either faulted against or lie upon the crystalline rocks of the Shield. The land is rarely more than 500 feet above sea level, except for the seven Monteregian Hills formed of intrusive igneous rocks.

East St. Lawrence Lowland includes Anticosti Island, the Mingan Islands, and several small areas bordering the Gulf of St. Lawrence and Strait of Belle Isle, and the Newfoundland Coastal Lowland. Anticosti Island is about 125 miles long with a maximum width of about 35 miles. It is a south-dipping cuesta of carbonate strata. Wave-cut terraces up to 400 feet elevation occur on both north and south sides, being generally wider on the south side. The Mingan Islands and two areas on the north coast of the Strait of Belle Isle are composed of southerly dipping Paleozoic strata. In all probability a great part of the floor of the Gulf of St. Lawrence around Anticosti Island and extending to the Newfoundland Coastal Lowland constitutes a submerged part of the East St. Lawrence Lowland. *Newfoundland Coastal Lowland* is formed of a belt of soft, mainly unfolded Paleozoic strata that extends along the northwest coast of Newfoundland Island and includes Port au Port Peninsula in the southwest. Most of the belt is less than 400 feet in elevation although the summit on Port au Port Peninsula is at 1,160 feet elevation and east of St. John Bay is 2,075 feet.

Appalachian Region

The Appalachian Region in Canada is divided into a large number of physiographic units, which here are grouped together and somewhat generalized. The physiography is dominated by a well-developed peneplain, probably of Cretaceous age, which is generally highest in the northwest and slopes gently southeastward to the ocean. The various subdivisions are formed by the differential erosion of soft and hard rocks to form lowlands, highlands, and uplands. Seaward the Appalachian Region is bounded by the Atlantic Continental Shelf.

On the island of Newfoundland the Appalachian Region comprises three highland, two upland, and four lowland areas. The highlands are collectively called the *Newfoundland Highlands.* As a rule they are rugged with steep slopes, and are formed of crystalline Paleozoic and Precambrian rocks. Their elevations vary from 600 to 2,670 feet. The upper surface, formed by the peneplain, slopes gently southeastward. The western border of the highlands may be precipitous or pass without sharp break to the higher areas of Newfoundland Coastal Lowland. Two small lowland areas occur within the highlands area, the St. Georges Lowland lying along the southwest coast and the Grand Lake Lowland extending from White Bay to Grand Lake. Both lowlands are underlain by little metamorphosed rocks and seldom exceed 200 feet in elevation.

The *Atlantic Uplands of Newfoundland* lie between 600 and 1,000 feet elevation and represent parts of the peneplain occurring at lower levels because of the southeasterly slope rather than because the rocks are less resistant than those underlying the adjacent highlands. Where stream erosion has cut deeply, the uplands are rugged and rocky but elsewhere they present a rolling terrain of low relief. The uplands surround the small Bay d'Espoir Lowland which is underlain by soft Paleozoic sediments.

The *Newfoundland Central Lowland* is underlain mainly by Paleozoic strata but includes a few intrusive bodies that form prominent hills. It extends from sea level up to 500 feet elevation; inland it is surrounded by the uplands carved from igneous rocks. The surface is gently rolling and generally immediately underlain by glacial drift.

Nova Scotia is divisible into three highland areas, three uplands, and several small lowlands. As in Newfoundland the same peneplain is present on the highlands and is also apparent on the uplands. *Nova Scotia Highlands* include Cobequid Mountains in the west, the Antigonish Highlands in the centre, and the Cape Breton Highlands to the northeast. Cobequid Mountains have a flat to rolling surface, are about 10 miles wide, and reach elevations of about 900 feet. Antigonish Highlands are more dissected than Cobequid Mountains, but have the same type of surface and reach about the same elevations. The Cape Breton Highlands are deeply dissected around the margins, but the interior has a remarkably flat surface lying at elevations of 1,300 to 1,500 feet.

The uplands of Nova Scotia include North Mountain and the Atlantic Uplands of Nova Scotia. *North Mountain* is a narrow, flat-topped ridge, averaging about 550 feet high, formed of hard Triassic basalt. It extends along the southeast side of the Bay of Fundy for 120 miles and rises abruptly above the Annapolis Lowland. The *Atlantic Uplands of Nova Scotia* lie along the entire southeast coast for some 350 miles and contain small irregular lowland areas on Cape Breton Island. The old peneplain surface is a main feature and slopes across it from elevations of about 600 feet on the northwest side to the shore of the Atlantic on the southeast.

The principal lowlands of Nova Scotia are: the Cumberland Lowland, part of the larger Maritime Plain, but lying on the north and east sides of Cobequid Mountains; the Minas Lowland surrounding Minas Basin and Cobequid Bay; and the Annapolis Valley. These lowlands are areas of soft, late Paleozoic and Triassic sediments.

New Brunswick falls naturally into three large units, highland, upland, and lowland areas. *New Brunswick Highlands* are U-shaped, with the west arm covering much of the central part of the province, the curved part occupying the southern part, and the east arm bordering the Bay of Fundy. In as much as the surfaces of the accordant summits of the highlands represent the southeast-sloping peneplain, the northwest parts reach elevations greater than 2,000 feet and are higher than those bordering the Bay of Fundy, which are only about 1,000 feet. Along the Bay of Fundy the highlands present considerable diversity. They are composed of ridges of hard rock with minor lowlands of weak strata.

Chaleur Uplands lie astride the provincial boundary of Quebec and New Brunswick. They are 800 to 1,000 feet

high, developed on folded Paleozoic strata. The uplands present remarkably uniform, concordant summits whose regularity is broken only by a few hills and ridges rising slightly above the general level. Valleys such as those of Saint John and Restigouche Rivers are deeply entrenched into it. The boundary between the New Brunswick Highlands and Chaleur Uplands is not well defined but the latter are considerably lower than Notre Dame Mountains of Quebec to the north.

Maritime Plain stretches around the coast of New Brunswick and Nova Scotia from the south shore of Chaleur Bay nearly to Cape George. It extends inland as far as New Brunswick Highlands and includes Prince Edward Island and the Magdalen Islands. The plain is an area of low relief. Inland it reaches 600 feet elevation and slopes gently towards the coast. The underlying rocks are mainly flat or gently dipping strata through which, particularly in the Magdalen Islands, small intrusions stand as prominent hills. It probably extends beneath the Gulf of St. Lawrence to join with St. Georges Lowland of Newfoundland.

The Chaleur Uplands are bounded on the north by *Notre Dame Mountains,* which extend from near Thetford Mines to Gaspé Bay, a distance of some 400 miles. The eastern part is also known as the Shickshock Mountains, the highest elevations being in excess of 4,000 feet in the north. To the southwest the summits are lower and merge with Eastern Quebec Uplands. Mountain tops present the flat to undulating surface of the old peneplain. In the southwestern part of Appalachian Quebec are two other highland areas separated by part of the Eastern Quebec Uplands. The western of these, the *Sutton Mountains,* is a continuation of the Green Mountains of Vermont; they are 40 miles in extent and have a maximum of 3,175 feet. *Megantic Hills* lie astride the International Boundary and are part of the larger White Mountains of the New England States. Sutton Mountains and Megantic Hills are both developed on anticlinoria and are highest in the south. To the northeast they blend with *Eastern Quebec Uplands* which has a maximum elevation of 1,000 feet decreasing gradually to the northwest and merging with the East St. Lawrence Lowland without a distinct topographic break.

Atlantic Continental Shelf

Adjoining the Grenville and Appalachian Regions and forming the continental margin of North America, are the Gulf of St. Lawrence and the Atlantic Continental Shelf. The floor of the *Gulf of St. Lawrence* is relatively flat and featureless with gentle rises, one of which breaks surface as Magdalen Islands, and linear lows which represent old, glacially deepened river valleys. The main feature, the Laurentian Channel, is 60 miles wide, steep-sided, and flat floored. It shelves from depths of 200 metres near Quebec to 400 metres as it extends across the continental shelf to the ocean basin. A major tributary joins it from the Strait of Belle Isle.

The *Atlantic Continental Shelf* is generally shallow, less than 200 metres and slopes gently at a gradient of less than 1:1000, to where the gradient increases sharply to more than 1:40. The shelf is divided by Laurentian Channel; to the south is the Scotian Shelf and Georges Bank, the part to the north is the Grand Banks.

Scotian Shelf has an average width of about 125 miles. Along its length and lying some 10 to 80 miles offshore is a series of 200-metre depressions such as La Have Basin and Emerald Basin. A nearly continuous ridge or 'bank' 40 to 120 metres deep extends along the seaward edge of the shelf, divided by low saddles into Browns Bank, La Have Bank, Emerald Bank, Sable Island Bank, and Banquereau Bank, and culminating at Sable Island, a low, sandy island 25 miles long. The banks are composed of flat-lying beds and are like mesas produced by erosion. Many submarine canyons occur in the continental slope and the continental rise, the largest of which is The Gully heading in the shelf about 25 miles east of Sable Island. The *Grand Banks,* north of Laurentian Channel, are up to 300 miles wide and 450 miles long. Northeast of Newfoundland relief is 100 to 200 metres, exceptionally large for a continental shelf. The shelf break lies at 300 metres, which is abnormally deep. The southern part of Grand Bank includes low depressions and several smaller banks, Saint Pierre Bank, Green Bank, and Whale Bank. Virgin Rocks is a shoal 130 miles southeast of Avalon Peninsula rising to within 18 feet of the ocean surface. It is part of a dissected bank which rises 200 to 300 feet above the shelf floor.

Flemish Cap, 400 miles east of Newfoundland, is considered part of Atlantic Continental Shelf but is separated from Grand Banks by a channel 650 fathoms deep. A broad ridge, 60 to 100 miles wide, extends southeasterly from the Grand Banks down the continental slope towards the Mid-Atlantic Ridge. This feature, the Southeast Newfoundland Ridge, is part of the continental rise and marks the boundary between the Newfoundland Basin to the north and the North American Basin to the south.

The southern part of *Labrador Shelf* extends about 400 miles from the coast and includes an area, relatively shallow and undulating, the deeper parts of which lie near 250 metres and large shallower areas lying at less than 80 metres. Between Hamilton Inlet and Hudson Strait the shelf is about 75 miles wide dropping from a rim at 250 metres to the depths of Labrador Sea. This part has a line of broad banks near 80 metres depth which are separated from the coast by wide hollows at 200 metres or more depth.

Davis Shelf lies beneath Davis Strait and Baffin Bay between Canada and Greenland. Off Baffin Island, below Cumberland Peninsula and Cape Chidley, it is generally shallow being little more than 900 metres deep in many parts. The shelf is, however, deeper and wider than farther north and its surface slopes to a depth of about 600 metres before the steep edge is reached some 100 miles or more off Hall Peninsula. Opposite Hudson Strait

the sea floor also drops to oceanic depths of about 3,000 metres and an embayment with depths of 600 metres or more leads across the shelf. At the head of Baffin Bay east of Devon Island, it is also comparatively shallow, few parts reaching 600 metres. The soundings although scattered suggest a rolling surface sloping mainly southeasterly from 300 to 500 metres. Off Lancaster Sound a broad channel 800 metres or more deep extends towards the northern part of the basin in the central part of Baffin Bay where depths of 2,000 metres or more are reached. Along the northeastern coast of Baffin Island the slope into the basin steepens and a narrow shelf up to 30 miles wide with a somewhat sinuous rim at 200 metres deeper drops abruptly into the basin. Three channels extend across the shelf off Pond Inlet, Buchan Gulf, and Home Bay.

SELECTED REFERENCES

Acton, D. F., Clayton, J. S., Ellis, J. G., Christiansen, E. A., and Kupsch, W. O.
1960: Physiographic divisions of Saskatchewan as established by Saskatchewan Soil Survey in cooperation with Geology Division; Sask. Res. Council Geol. Dept., *Univ. Sask.*

Ambrose, J. W.
1964: Exhumed paleoplains of the Precambrian Shield of North America; *Am. J. Sci.*, vol. 262, pp. 817 – 857.

Atlas of Canada
1957: Bathy-Orography of eastern Canada; *Dept. Energy Mines Resources.*

Bird, J. B., and Bird, M. B.
1961: Bathurst Inlet, Northwest Territories; Canada *Dept. Mines Tech. Surv.*, Geograph. Br., Mem. 7.

Bostock, H. S.
1946: Physiography of the Canadian Cordillera, with special reference to the area north of the fifty-fifth parallel; *Geol. Surv. Can.*, Mem. 247.
1961: Physiography and resources of the northern Yukon; *Can. Geograph. J.*, vol. 63, No. 4.

Cooke, H. C.
1931: Studies of the physiography of the Canadian Shield. III. The pre-Pliocene physiographies as inferred from the geological record; *Roy. Soc. Can.*, 3rd ser., vol. 25, sect. 4.

Craig, B. G., and Fyles, J. G.
1960: Pleistocene geology of Arctic Canada; *Geol. Surv. Can.*, Paper 60-10.

Donaldson, J. A.
1965: The Dubawnt Group, Districts of Keewatin and Mackenzie; *Geol. Surv. Can.*, Paper 64-20.

Douglas, R. J. W., Norris, D. K., Thorsteinsson, R., and Tozer, E. T.
1963: Geology and petroleum potentialities of northern Canada; *World Petrol Congr. Proc. 6th,* Frankfurt, Main, June 1963.

Dunbar, M., and Greenaway, K. R.
1956: Arctic Canada from the air; *Can. Defence Res. Board,* Queen's Printer, Ottawa.

Fortier, Y. O., *et al.*
1963: Geology of the north – central part of the Arctic Archipelago, N.W.T. (Operation Franklin); *Geol. Surv. Can.*, Mem. 320.

Fyles, J. G. *in* Thorsteinsson, R., and Tozer, E. T.
1962: Banks, Victoria, and Stefansson Islands, Arctic Archipelago; *Geol. Surv. Can.*, Mem. 330.

Hare, F. K.
1959: A photo reconnaissance survey of Labrador-Ungava; *Dept. Mines Tech. Surv.*, Geograph. Br., Mem. 6.

Heezen, B. C., Tharp, M., and Ewing, M.
1965: The floors of the oceans. Pt. 1: The North Atlantic; *Geol. Soc. Am.*, Spec. Paper 65, p. 122.

Holland, S. S.
1964: Landforms of British Columbia, a physiographic outline; *B.C. Dept. Mines Petrol Resources,* Bull. 48.

Hughes, O. L.
1964: Surficial geology, Nichicun – Kaniapiskau map-area, Quebec; *Geol. Surv. Can.*, Bull. 106.

Hume, G. S.
1925: The Palaeozoic outlier of Lake Timiskaming, Ontario and Quebec; *Geol. Surv. Can.*, Mem. 145.

Ives, J. D., and Andrews, J. T.
1963: Studies in the physical geography of north – central Baffin Island, N.W.T.; *Dept. Mines Tech. Serv.*, Geograph. Bull. No. 19.

Lay, Douglas
1940–41: Fraser River Tertiary drainage-history in relation to placer-gold deposits; *B.C. Dept. Mines,* Bulls. 3 and 11.

Lee, H. A.
1959: Surficial geology of southern District of Keewatin and Keewatin Ice Divide, N.W.T.; *Geol. Surv. Can.*, Bull. 51.

Lemon, R. R. H., and Blackadar, R. G.
1963: Admiralty Inlet area, Baffin Island, District of Franklin; *Geol. Surv. Can.*, Mem. 328.

Lord, C. S.
1953: Geological notes on southern District of Keewatin, N.W.T.; *Geol. Surv. Can.*, Paper 53-22.

Mackay, J. R.
1956: Mackenzie deltas; *Can. Geograph.*, Prog. Rept., vol. 7, pp. 1 – 12.
1958: The Anderson River map-area, N.W.T.; *Dept. Mines Tech. Surv.*, Geograph. Br., Mem. 5.

Mathews, W. H.
1947: "Tuyas", flat-topped volcanoes in northern British Columbia; *Am. J. Sci.*, vol. 245, pp. 560 – 570.

Reinecke, Leopold
1915: Physiography of the Beaverdell map-area and the southern part of the Interior Plateau of British Columbia; *Geol. Surv. Can.*, Mus. Bull. 11.

Rose, E. R.
1955: Manicouagan Lake – Mushalagan Lake area, Quebec; *Geol. Surv. Can.*, Paper 55-2.

Stevenson, I. M.
1965: Leaf River map-area, Quebec and District of Keewatin; *Geol. Surv. Can.*, Paper 64-28.

Stockwell, C. H.
1965: Tectonic map of the Canadian Shield; *Geol. Surv. Can.*, Map 4-1965.

Taylor, Andrew
1956: Physical geography of the Queen Elizabeth Islands; *Am. Geograph. Soc.*, New York, 12 vols.

Thorsteinsson, R., and Tozer, E. T.
1962: Banks, Victoria, and Stefansson Islands, Arctic Archipelago; *Geol. Surv. Can.*, Mem. 330.

Wright, G. M.
1957: Geological notes on eastern District of Mackenzie, N.W.T.; *Geol. Surv. Can.*, Paper 56-10.

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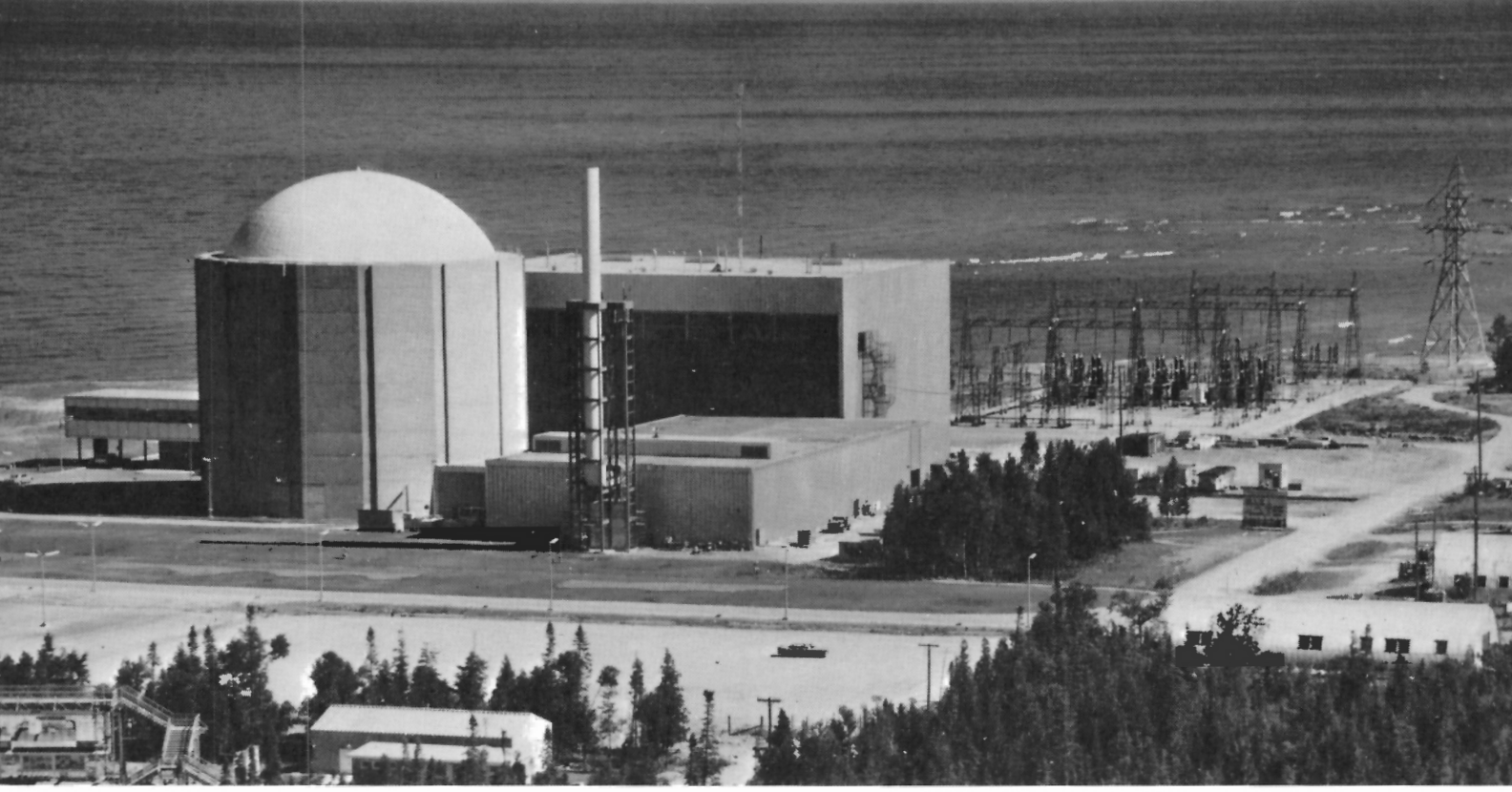


The Canadian mineral industry spans four centuries of development. In the first 300 years the record was one of intermittent activity, and even during the past 100 years progress in terms of production was comparatively slow until the end of World War II, when it began to increase rapidly (Table III-1). The industry had an output value of $64 million in 1900 and of $500 million in 1945, reaching $1 billion in 1950 and more than $4.7 billion in 1968. Relative growth since 1940 for the three sectors — metals, industrial minerals, and fuels — is illustrated in Figure III-1.

TABLE III-1 *Mineral production in Canada, selected years, 1890–1968* ($ millions)

Year	Metals (a)	Non-metals and Structural Materials	Fuels	Total
1890	3.6	6.4	6.8	16.8
1900	40.5	8.6	15.3	64.4
1910	49.4	24.7	32.7	106.8
1920	77.9	64.2	85.8	227.9
1930	142.6	69.1	68.2	279.9
1940	382.4	68.6	78.8	529.8
1950	617.2	227.0	201.2	1,045.4
1960	1,406.6	520.1	565.8	2,492.5
1965	1,907.6	761.4	1,076.5	3,745.5
1966	1,984.4	837.5	1,150.6	3,972.5
1967	2,285.5	854.5	1,258.9	4,398.9
1968	2,492.6	890.2	1,342.5	4,725.3

Source: Dominion Bureau of Statistics
(a) Does not include aluminum metal

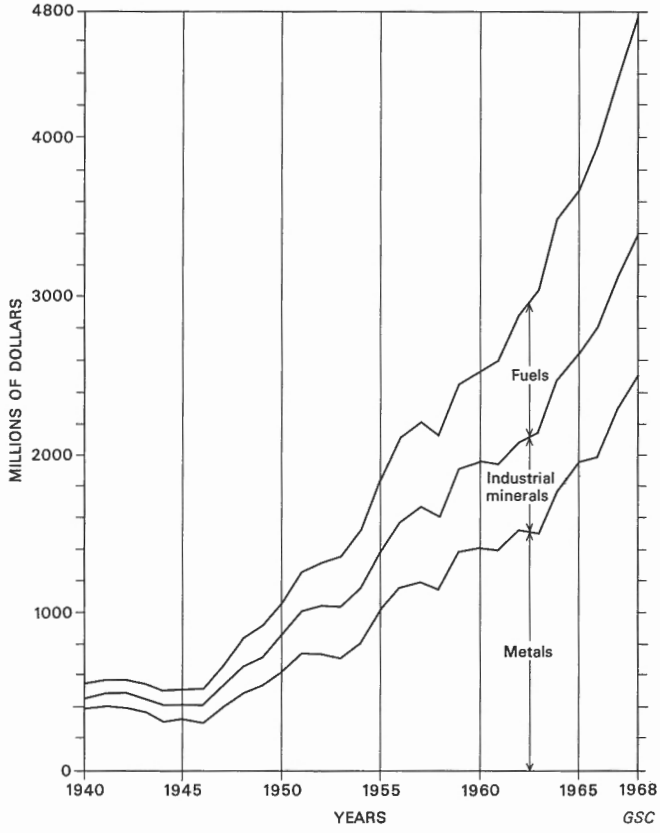


FIGURE III-1. Value of mineral production.

III

The Canadian Mineral Industry

R.B. Toombs[1]

Uranium-fueled electrical generating plant, Douglas Point, Lake Huron, Ontario.

ECONOMIC INDICATORS OF GROWTH

The importance of the mineral industry to the Canadian economy, and its recent growth compared with the general economic growth of the nation, can be assessed by means of economic indicators. They are particularly significant in judging the industry's importance and performance during its rapid postwar growth. One indicator is shown in Table III-2 by relating mineral production to gross national product (GNP). From 1945 to 1968 the value of mineral production increased 9.5 times while the GNP multiplier was 6.0. At the end of the war mineral value was less than 5 per cent of GNP, but it has since increased to almost 7 per cent. This comparison of mineral industry value at the primary stage is only a minimum assessment of the industry's importance to the economy.

Net value of production, a "value added" concept, affords a more direct indicator of the mineral industry as a producing sector in the Canadian economy. Net values

[1] Mineral Resources Branch

TABLE III-2 *Mineral production related to gross national product, selected years, 1930–1968* ($ millions)

Year	Mineral Production (a)	GNP	Mineral Production as % of GNP
1930	279.9	5,720	4.9
1940	529.8	6,713	7.9
1945	498.8	11,863	4.2
1950	1,045.5	17,955	5.8
1955	1,795.3	27,895	6.4
1960	2,492.5	37,775	6.6
1965	3,745.5	54,897	6.8
1966	3,972.5	61,421	6.5
1967	4,398.9	65,608	6.7
1968	4,725.3	71,454	6.6

Source: Dominion Bureau of Statistics
(a) Does not include aluminum metal

TABLE III-3 *Net values of production, 1950 and 1967, all industries* ($ millions)

	1950	1967
Mining	657.3	2,910
Mineral processing (a)	512.1	2,090
Total mineral industry	1,169.4	5,000
Agriculture	1,832.9	2,728
Forestry	487.1	687
Fisheries and trapping	97.4	175
Electric power	313.3	1,234
Total primary production	3,900.1	9,824
Construction	1,544.7	5,148
Manufacturing (ex. mineral)	5,430.0	14,915
Total secondary production	6,974.7	20,063
Canada total	10,874.8	29,887

Source: Dominion Bureau of Statistics
(a) Primary iron and steel, nonferrous smelting and refining, petroleum refining, non-metallic mineral processing.

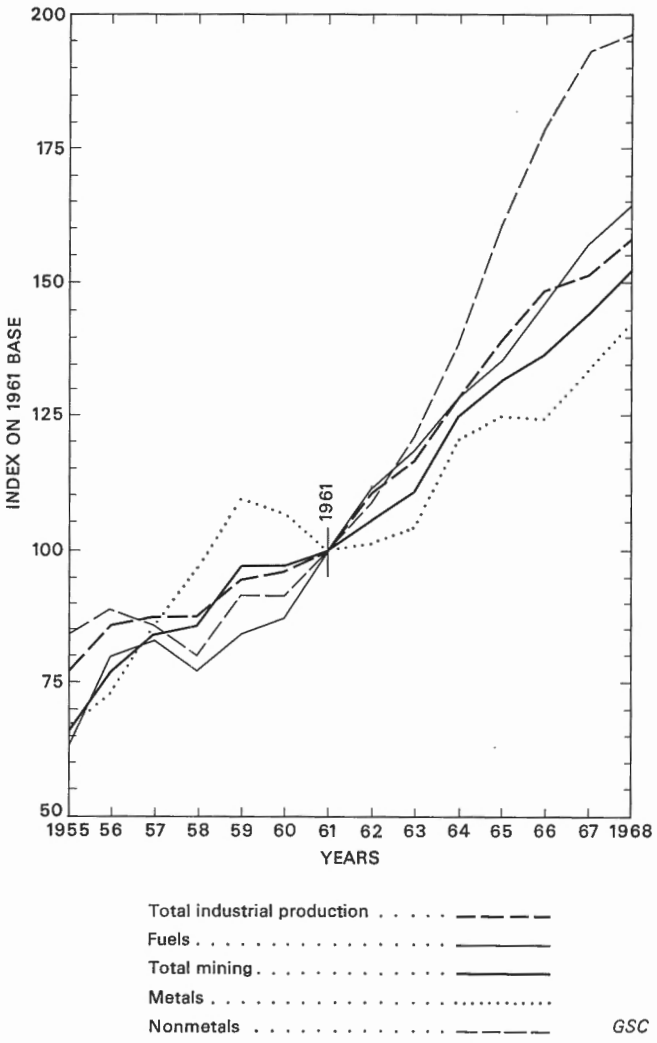


FIGURE III-2. Indexes of physical volume of mineral production and of total industrial production.

of production for mining[1] and mineral processing outpaced all other commodity-producing industries of the economy except electric power in the period 1950 to 1967 (Table III-3). The mineral sector increased from 30 to 51 per cent of primary production and from 11 to over 16 per cent of total primary and secondary industry production in the Canadian economy. During the 1960's, value added in mining itself, as a proportion of value added in all primary industries, remained well above one third and overtook agriculture.

Growth of the mining industry in terms of volume indexes is shown in Figure III-2. The mining index rose six times from 1946 to 1968 compared with slightly less than four times for the industrial economy as a whole, the greater increase in mining being due mainly to the rapid climb of the fuels index. Of the manufacturing indexes, those for petroleum refining, products of petroleum and coal, non-metallic mineral products, and primary iron and steel outpaced the index for total manufacturing.

A further indicator of growth is the gross domestic product at factor cost (GDP[2]). The mining sector GDP increased almost fourfold from 1950 to 1968 and in the late 1960's was nine tenths of the agriculture GDP, compared with one third in the early 1950's. In the same period mining moved ahead from less than double the value of the forest industry GDP to four times its value.

Although the mineral industry has provided direct employment in mining for less than 3 per cent of the total labour force in recent years, capital expenditures in the mining sector have been 6 to 7 per cent of the country's total annual expenditures. In the late 1960's, capital expenditures in mining and in mineral-based manufacturing industries, and in pipeline transportation and marketing related to petroleum and natural gas were about 12 per cent of total capital expenditures in the Canadian economy. This comparison considerably understates expenditure generated by the industry inasmuch as much of the railway expansion, many new townsites particularly in northern Canada, a number of electric power projects and communication systems, and some harbour facilities have been based wholly on mineral developments. The industry has a similar multiplying effect in the labour force, several times the number employed in mining being dependent directly or indirectly on mineral industry enterprises.

Export value has been usually about 60 per cent of the industry's production value, making the industry the

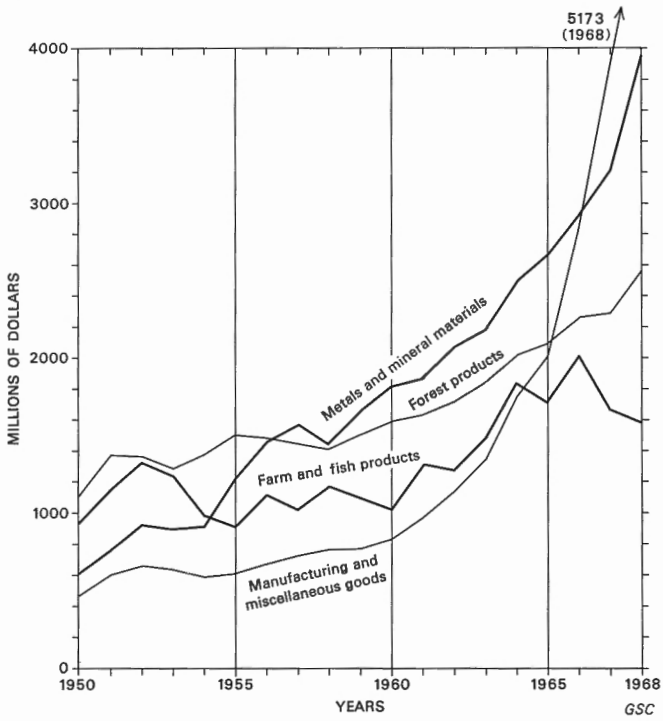


FIGURE III-3. Exports from Canada, 1950–68.

[1] Mining includes the primary production of metals, industrial minerals and fuels.

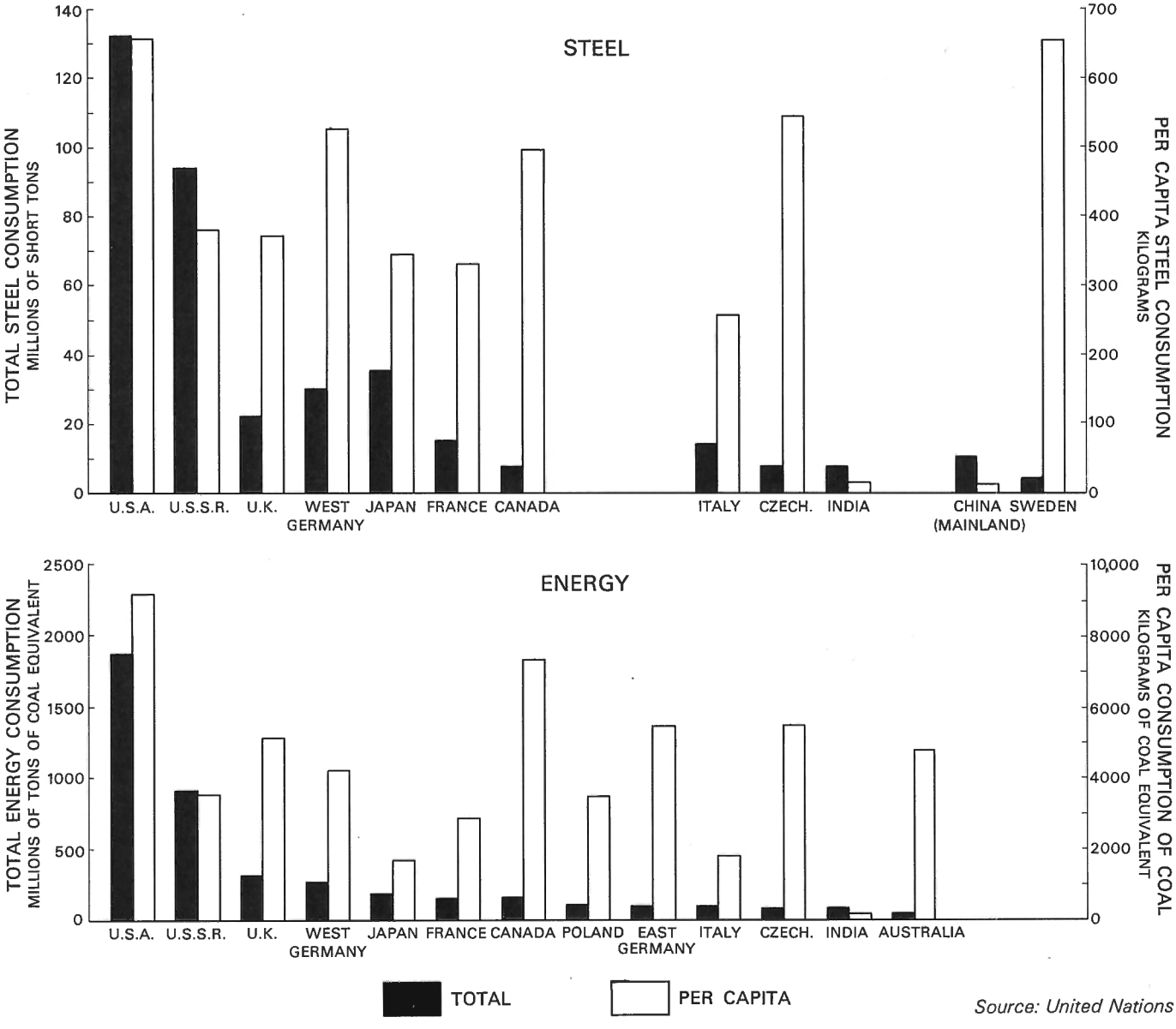
[2] GDP differs from the GNP by the exclusion of indirect taxes less subsidies and factor incomes paid to Canadian residents from production abroad, but including factor incomes paid to non-residents from production within Canada.

leading export sector in the economy. This position takes on added significance because 17 per cent of the GNP is accounted for by exports compared with 5 per cent in the United States. Figure III-3 illustrates mineral industry export trends relative to other exports.

The growth and magnitude of production, capital investment, and trade all illustrate the dynamic effect that expansion of the mineral industry has had on the economy since 1946. The multiplying effect of this expansion was possibly most apparent to 1956 during a time when the industry had to satisfy the accumulated demands of the post-World War II period and the strategic mineral requirements of the Korean emergency. Even in the late 1950's when the economy was less buoyant, there was little decline in the industry. By the mid-1960's the known resources were larger than those of the 1950's and the rate of industry growth was again increasing. In short, the mineral industry has been a dynamic force in times of industrial expansion and a strong support in less buoyant times.

Canada vis-à-vis Other Countries

In population Canada has about one half of one per cent of the world total and in area more than 7 per cent; the population density is one fifth that of the U.S.S.R., one tenth that of the United States, one hundredth that of Britain, and one twelfth of the world average. Canada holds third place among industrial nations in national income per capita and her high industrial activity provides an important domestic market for her minerals. However, because of a comparatively small population, Canada must export large quantities of mineral materials if her



Source: United Nations

FIGURE III-4. Total and per capita consumption of steel and energy in 1966.

mineral industry is to grow at a rate appropriate to the size of her resource base. Mineral exports do, in fact, help place the country in a prominent position in world trade. Canada is the world's fifth largest trading nation and is first in trade per capita among the world's leading traders; her growth and prosperity depend a great deal on international trade. The maturity of the country's economy vis-à-vis other nations is well indicated in energy and steel consumption comparisons. Per capita Canada ranks second in the world in the consumption of energy and fifth in the consumption of steel (Fig. III-4).

Canada's economic expansion in the 1950's was about equal to that of the United States. But some European countries, Japan, and U.S.S.R., starting from a very low level of economic activity in the late 1940's, made such major recoveries that their comparative rate of expansion outpaced that of both Canada and the U.S.A. in the late 1950's. However, Canadian mining and base-metals growth indexes kept pace with most of the world's highest; in the 1960's, the Canadian economy has been advancing rapidly due in considerable part to a buoyant mineral industry.

GROWTH OF THE INDUSTRY

The size, structure, and productive diversity of the Canadian mineral industry have been largely determined by resource developments, marketing progress, and government policies since the mid-1940's. Marked growth has taken place in recent years in all three sectors of the industry, the most outstanding being in the fuels sector. Value of total output increased more than ninefold in the period 1945 to 1968; the increase for fuels was more than fourteenfold, for industrial minerals (non-metals and structural materials) more than tenfold and metals eightfold. In volume, output increased almost sixfold, the increases for the fuels, industrial minerals and metals being ten, five and fourfold respectively. The all-time growth in value to 1945 was less than one eighth the increase that took place from 1945 to 1968.

Historical Background

The Canadian mineral industry has a long history dating from the days of the 16th- and 17th-century explorers Cartier, Frobisher, and Champlain. The coal and the iron-and-steel industries in the Maritime Provinces were well underway by the 1850's. In 1858 petroleum was discovered in southwestern Ontario and in the same decade placer gold discoveries were made in British Columbia. Asbestos was found in the Eastern Townships of Quebec in 1877 and nickel at Sudbury, Ontario, in 1883. A number of gold, silver, and base-metal discoveries were made during the 1880's and 1890's in southern British Columbia, including the Sullivan lead–zinc–silver deposits at Kimberley and the copper–gold deposits of the Greenwood and Rossland areas. Placer gold had been found on Yukon River in Yukon Territory in 1869; subsequent prospecting led to the famous Klondike gold-rush in 1897 and 1898 and to a peak value in Yukon gold production in 1900 of $22.3 million, a third of Canada's whole mineral production value for that year. The Cobalt strike of 1903 and the subsequent Kirkland Lake and Porcupine gold-camp developments opened up the northern Ontario mining region and led to the Noranda copper discovery in northwestern Quebec in 1921. Two years earlier, silver–lead deposits had been prospected in the Mayo district of the Yukon. The Turner Valley oil and gas field in Alberta was discovered in 1913. Each of these notable events in Canadian mining history was a forerunner of many others, all of which prepared the way for the greatly increased industry growth of recent years.

The Period 1946 to the Late 1960's

The 1946 to 1950 period was notable for important events in the development of the oil resources of western Canada, including the discovery of Devonian oil at Leduc; for a resurgence in gold and silver mining, and considerable expansion in asbestos and construction materials. There was comparatively little activity elsewhere in the mineral industry.

In the years 1951–55 there were a number of significant events that made an impact on Canadian mineral supply and demand that will continue for many years. Exploration, development, and new production in the Alberta and Saskatchewan oil lands, in the Quebec–Labrador iron-ore region, and in the uranium areas of Beaverlodge, Saskatchewan, and Elliot Lake, Ontario, made this a particularly important period. New copper deposits were opened up in the Gaspé and Chibougamau areas of Quebec, and major copper–zinc deposits at Manitouwadge, Ontario. Lead–zinc deposits at Pine Point, on Great Slave Lake, were explored. In the Bathurst–Newcastle district of New Brunswick important deposits of zinc–lead–copper were discovered. A nickel refinery was established at Fort Saskatchewan, Alberta; titanium-dioxide production facilities at Sorel, Quebec; and a ferrosilicon plant at Beauharnois, Quebec. Asbestos production commenced at McDame Creek in northern British Columbia, and there was good progress in developing other industrial mineral resources, particularly deposits of construction materials.

During the years 1956 to 1960, trends in development activities were mixed. Uranium production got underway on a large scale in the Beaverlodge, Elliot Lake, and Bancroft areas. Copper–zinc production began at Manitouwadge. Plans for producing nickel from the deposits of northern Manitoba were announced; mine and townsite development work at the Thompson nickel mine was started. Despite lead and zinc quotas imposed by the United States on Canadian imports, interest in the Matagami, Quebec, and Bathurst, New Brunswick, base-metal areas intensifed. In 1959, the United States Atomic Energy Commission announced that it would not take up its option for the purchase of Canadian uranium after 1962, and this had a dampening effect on uranium resource

development. The copper industry in Quebec, Ontario, and British Columbia was buoyant despite unsettled conditions of supply and demand in some other parts of the world. Iron-ore production rose significantly in 1959 in response to world demand and lengthy strikes in the United States. Canada prepared for a major role in world potash production following successful evaluation of the Saskatchewan deposits. During the late 1950's it became apparent that the U.S.S.R. was becoming as important an asbestos producer as Canada, but development and marketing of Canadian asbestos continued at high levels.

Large-scale expansion of natural gas production was made possible in 1960 by new export markets in the United States following completion of gas pipeline systems across Canada. Greatly expanded petroleum resources reached the point where production capacity began to exceed output by a large margin. Decline of the coal industry in the 1950's was arrested towards the end of the decade by increased federal government assistance and improved efficiency at some mines. During the late 1950's there were some indications of mineral industry retrenchment after the extensive expansion of the previous decade, but in the early 1960's this trend was reversed with increased activity in iron ore, petroleum, and the nonferrous mineral industries.

During the first half of the 1960's development of Canadian mineral resources again made rapid advances. Iron-ore development continued in Quebec and Labrador and new properties came into production in Ontario and British Columbia, establishing Canada as the world's fifth largest iron ore producer. Improvements in beneficiation processes to meet the requirements of changing steel technology permitted the opening up of deposits which even in the mid-1950's were considered too low-grade for economic operation. Canada's position as the world's main source of nickel was further strengthened by the opening of new mines in northern Manitoba and in Ontario and Quebec. Platinum metals production continued to grow, and Canada maintained its position as the world's second or third largest producer. In British Columbia and the Timmins area of northern Ontario, the development of copper deposits maintained Canada's position as fifth largest producer. Although the United States retained quotas on the imports of lead and zinc until late in 1965, important new mines were brought into production in the Bathurst area of New Brunswick, the Matagami area of Quebec, and at Pine Point, Northwest Territories. By the mid-1960's Canada was the world's leading producer of zinc and third largest of lead. Although gold and uranium production declined, some gold exploration continued, particularly in the Northwest Territories, and by the mid-1960's uranium exploration was again active in preparation for expected market growth in the 1970's. The search for other minerals also increased, and results were particularly successful for molybdenum in British Columbia and Quebec, putting Canada in second position in world molybdenum production by 1966.

In the industrial minerals sector of the industry, development of potash and sulphur raised Canada to a position of world prominence. The progress made in the Saskatchewan potash industry raised Canada's mine capacity to the equivalent of at least one third of the world's consumption by the late 1960's. In 1963 Canada became the world's second largest elemental sulphur producer as a result of expansion in natural gas production in western Canada, the sulphur being recovered as a byproduct. Year-by-year production increases continued for most non-metals and for the construction materials. An important deposit of asbestos was opened near Baie Verte on the north coast of the island of Newfoundland.

Increasing competition from other fuels led to a steep decline in coal production in the 1950's. Production was stabilized in the early 1960's as a result of large increases in government subsidies. The Cape Breton Development Corporation was formed in 1967 to bring about the transition of the economy of Cape Breton Island from coal mining to other forms of economic endeavour. In the mid-1960's, marketing prospects for western Canada coal began to improve. Natural gas resource development was accelerated following completion of continental pipelines in the late 1950's, and by 1964 annual output value reached sixth position in the mineral industry, a position it continued to maintain. Crude oil resource development more than kept pace with market growth; this has been Canada's leading mineral since 1953. New methods were being developed to open up the Athabasca oil sands, one of the world's greatest hydrocarbon reserves.

Structure and Capacity of the Industry

Although the ten leading mineral commodities — crude oil, copper, iron ore, nickel, zinc, natural gas, asbestos, cement, sand and gravel, and silver — account for almost four fifths of the annual value of mineral output, production of more than 50 other minerals is continually expanding. There is also increasing geographical diversification with pronounced effect on local economic development, particularly in areas outside the established mining camps. Company ownership is also quite diverse, although there are some exceptions for certain minerals. The large number of participants in the industry results in active resource development under a competitive free-enterprise economy. In the period 1955 to 1965 new mines brought into production numbered 125, most of which will operate for many years.

Extensive mineral processing facilities are continually being expanded, and as of 1968 they include aluminum plants at Arvida, Alma, Beauharnois, Shawinigan and Baie Comeau in Quebec and at Kitimat, British Columbia, with total annual capacity of 913,000 tons; copper or nickel – copper smelters at Sudbury in Ontario, Murdochville and Noranda in Quebec, and Flin Flon and Thompson in Manitoba, with capacity of 8.6 million tons annually. There are copper refineries at Montreal and Sudbury with total capacity of 452,000 tons annually, and nickel refineries at Port Colborne in Ontario, Thompson in

Manitoba, and Fort Saskatchewan, Alberta, with 166,000 tons capacity. The total productive capacity for all forms of nickel is 540 million pounds a year. There is a lead smelter and a refinery at Trail, British Columbia, with related refining facilities for the recovery of antimony, bismuth, cadmium, indium, and precious metals. Large zinc refineries operate at Trail, British Columbia, at Flin Flon, Manitoba, and Valleyfield, Quebec. More than four fifths of the steel ingot and casting capacity of 11 million tons is concentrated in four large plants at Hamilton and Sault Ste. Marie in Ontario and at Sydney in Nova Scotia; the remaining capacity is dispersed in 45 small plants throughout the country, many of which supply local needs. Capacity to supply the large-tonnage alloys, such as ferrosilicon, ferromanganese, and ferrochromium, has been more than adequate. There has also been sufficient capacity to meet domestic requirements of molybdic oxide, while requirements of ferromolybdenum, ferrocolumbium, and ferrovanadium may soon be met by domestic production. There have been adequate facilities for industrial mineral processing for many years. The country's petroleum refining capacity is usually capable of meeting domestic requirements, although imports are relied on to meet peak requirements of heating oils. Refineries at Montreal, Toronto, and Sarnia have accounted for about 60 per cent of total petroleum capacity in recent years. Natural gas processing capacity has expanded rapidly as new gas fields were opened up in western Canada; from 1955 to 1965 capacity increased thirteenfold to 6.1 billion cubic feet a year, and large annual increases have continued.

The expansion of production and facilities has been accompanied by an increase in foreign ownership of Canadian industry. In the period 1954 to 1963 nonresident ownership in mining and smelting rose from 53 to 61 per cent; in the petroleum and natural gas sector, it rose from 60 per cent to 64 per cent. This high degree of foreign ownership continued as the industry expanded further in the 1960's. Investment by U.S.-controlled companies accounts for well over four fifths of total nonresident ownership in petroleum and natural gas and in mining and smelting.

In the development of mineral resources during the period 1950 to 1968 annual capital expenditures on new plant, machinery and equipment, and repair expenditures, in the mining and oil industries to the production stage, rose from $163 to $1,100 million and aggregate expenditures in this period amounted to almost $12,000 million. About one half of these expenditures was related to oil and gas exploration, development, and production. Large amounts were also spent on mineral processing and fabricating facilities; in the mid-1960's these expenditures were of the same order of magnitude as expenditures on mineral resource development and production.

MINERAL RESERVES

Measured (proven) ore. Ore for which tonnage is computed from dimensions revealed in outcrops, trenches,

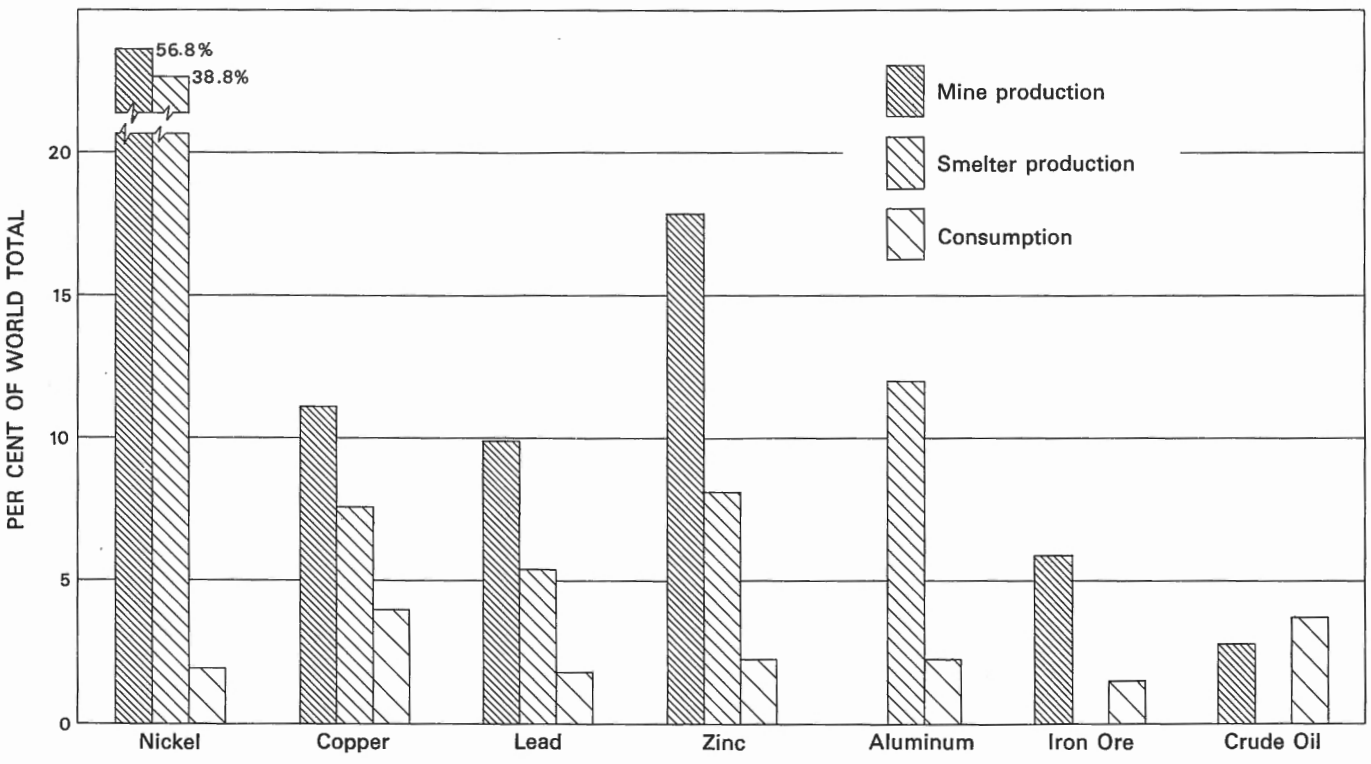


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FIGURE III-5. Canadian mineral production and consumption as a per cent of world total—1965.

workings, or drillholes, and for which grade is computed from adequate sampling. The sites for inspection, sampling, and measurement are so closely spaced, on the basis of defined geologic character that the size, shape, and mineral content are well established.

Indicated (probable) ore. Ore for which tonnage and grade are computed partly from specific measurement, samples, or production data, and partly from projection for a reasonable distance on geologic evidence. The openings or exposures available for inspection, measurement, and sampling, are too widely or inappropriately spaced to outline the ore completely or to establish its grade throughout.

Inferred (possible) ore. Ore for which quantitative estimates are based largely on broader knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. Estimates are based on assumed continuity or repetition for which there is geologic evidence; this evidence may include comparison with deposits of similar types. Bodies that are completely concealed but for which there is some geologic evidence may be included.

Potential ore. This category provides for the evaluation, as a resource, of mineral deposits the mining of which depends on improved prices, improvements in methods of mining or treatment, transportation facilities, etc.

Table III-4 gives measured and indicated reserves as established in 1956 and 1967 for some leading minerals. All reserves increased, notwithstanding the large aggregate production in the period covered by these two reserve surveys.

Reserves of nickel in 1967 in the measured and indicated categories totalled at least 7 million tons, about one half of world reserves, excluding the Communist bloc, of a grade of at least 1.25 per cent nickel. There are large additional resources of lower grade in the potential category throughout the world, particularly in the nickeliferous iron laterites of Cuba and Indonesia. The Canadian reserves consist of sulphides with an appreciable content of platinum and other metals.

Iron ore reserves are very large. The greatest of potential ores are in the Labrador Geosyncline, particularly in the southern part, from Wabush Lake in Labrador to Mount Wright, Mount Reed, and Lac Jeannine in Quebec, a distance of 100 miles, where the many deposits total over 10 billion tons of ore. There are many other deposits throughout Canada, particularly in central Quebec, northern Ontario, Baffin Island, and Yukon Territory, which give promise of large tonnages. In 1967, measured and indicated iron ore reserves in Canada were about 33 billion tons. This could be increased considerably when inferred and potential reserves are developed.

Reserves of uranium were rapidly increased during the active exploration period 1950–56 when more than 10,000 occurrences were discovered. One of the Elliot Lake, Ontario, deposits proved to be among the largest in the world. Only a relatively few deposits in Canada reached production, but a number retain economic interest. In 1967 measured and indicated reserves of uranium were 490,000 tons of U_3O_8 contained in ore mineable at a price range of less than $10 a pound of U_3O_8. In additon, there was an equally large volume of lower grade material which could be mined at higher prices. Canada, United States, and South Africa have almost 86 per cent of the known uranium resources in the non-Communist world recoverable at less than $10 a pound of U_3O_8.

TABLE III-4 *Measured and indicated reserves of some Canadian minerals, 1956 and 1967*

Mineral	Unit	Measured and Indicated Reserves 1956	1967
Copper	Millions of tons of contained copper	14.50	19.52
Iron	Millions of tons of ore	(1)	33,106
Lead	Millions of tons of contained lead	9.96	12.15
Nickel	Millions of tons of contained nickel	6.03	7.13
Uranium	Tons of U_3O_8	237,000	490,000
Zinc	Millions of tons of contained zinc	23.23	31.12
Asbestos	Millions of tons of rock	958	1,192
Molybdenum	Tons of molybdenum	1,920	613,810
Potash	Billions of tons of K_2O	5.0	6.4
Sulphur	Thousands of tons in natural gas	20,000 (2)	134,759
Crude oil (3)	Thousands of barrels	2,849,370	8,168,924
Natural gas (3)	Millions of cubic feet	19,621,637	45,682,051
Natural gas liquids (3)	Thousands of barrels	279,934	1,378,868

(1) Not available on same basis
(2) Reported in 1958 by Government of Alberta
(3) Measured reserves only
Sources: 1956 — Royal Commission on Canada's Economic Prospects
1967 — Mineral Resources Branch, Dept. of Energy, Mines and Resources.
Note: These reserve estimates do not include inferred and potential reserves and are therefore not a measure of the country's ultimate mineral reserves.

In 1967, measured and indicated reserves of copper contained in orebodies at producing and near-producing mines totalled 19.5 million tons. Canada's copper reserves were about 10 per cent of the world total. With 31 million tons, Canada led in zinc reserves, having about one quarter of the world total in the measured and indicated categories. In addition, there are large resources in the inferred and potential categories. Measured and indicated reserves of lead were 12 million tons, well over 15 per cent of the world total.

Of the other metallic minerals, Canada has large reserves of ilmenite, molybdenum, cobalt, and columbium, of which molybdenum reserves were particularly actively developed in the 1960's. The occurrences of manganese and chromium are large but too low grade to be mined economically at present. One small but high-grade deposit of tungsten has been brought into production. Metals such as silver, antimony, bismuth, cadmium, and selenium occur in significant quantities in the major base-metal deposits and their recovery proceeds at a rate controlled by the development of the major metals. Canada has always had an important gold industry, third largest in the world, and there are many undeveloped gold occurrences but, under the long-term condition of a fixed selling price and rising costs, there has been little incentive to establish new reserves.

Canada has important reserves of the non-metals, particularly asbestos, potash, and sulphur. It is first in the world in asbestos and potash and second in elemental sulphur.

Proven reserves of crude oil are about 2 per cent of the world total. There is a large potential in unexplored areas, and the reserves of the Athabasca oil sands of Alberta place Canada among the leading countries of the world as a potential source of hydrocarbons. Natural gas measured reserves are second only to those of the United States. Known coal deposits in western Canada are very large but are generally considered in the potential category. With the technological and marketing developments of the late 1960's, large quantities could be reclassified into the measured and indicated categories.

MINERAL SUPPLY AND DEMAND

In 1967 Canada was the world's leading producer of nickel, zinc, and asbestos; the second largest producer of uranium, molybdenum, gypsum, and selenium; the third largest producer of aluminum metal, cobalt, lead, gold, platinum metals, silver, sulphur (all forms), tellurium, and titanium concentrates (ilmenite); fourth largest of cadmium, iron ore, magnesium, and potash; fifth largest of copper and barite; and in the over-all record it ranked high among producing countries for a number of other minerals. The country's world position in mineral supply continues to exceed greatly its standing as a consumer of mineral materials.

Canada stands in third place in the value of production of metals and non-metals and seventh place in the production of mineral fuels. It is the world's third largest diversified mineral producer after the United States and the Soviet Union. On a world scale, the Canadian mineral industry is a major source of supply, and its large resource potential indicates that this position in the world economy will be maintained for many years.

Seven metals, asbestos, petroleum, and natural gas account for four fifths of the value of Canada's exports of minerals in raw and fabricated forms. The changing relationship of the leading exports since 1950 and the over-all growth to 1965 are shown in Table III-5. These data do not include gold exports but do include aluminum metal exports. Figure III-6 shows the principal destinations of Canadian mineral exports in raw and semi-processed forms, and the prominent position of United States as a market for Canadian minerals. Although the U.S. will no doubt continue to be Canada's most important mineral market, the outlook is for a more diversified world market.

TABLE III-5 — *Mineral exports from Canada, by principal commodity* ($ millions)

Commodity	1950	1955	1960	1965(b)
Iron ore	53.8	167.6	228.6	360.8
Aluminum	103.2	211.0	268.1	372.5
Copper	77.2	155.0	206.7	272.6
Lead	38.1	37.2	26.0	64.2
Nickel	105.3	215.2	258.3	397.2
Zinc	58.7	70.6	63.5	141.4
Uranium	—	26.5	263.5	53.7
Asbestos	62.6	94.8	120.1	160.7
Fuels (a)	3.2	41.1	119.3	419.9
All others	67.5	132.8	129.1	539.3
	569.6	1,151.8	1,683.2	2,782.3

Data source: Dominion Bureau of Statistics
(a) Only coal in 1950, with a slight increase in this commodity through the period. Crude petroleum accounted for 70% in 1965 and natural gas most of the remainder of the fuels group.
(b) Not exactly comparable with export values up to 1960 because of a change in D.B.S. trade classification procedures in 1961.

TABLE III-6 — *Exports of principal minerals in relation to production, 1967*

	Unit of Measure	Production	Exports	Exports as % of Production
Copper	s.t.	592,299	404,895	68.3
Iron ore	l.t.	37,787,859	31,406,530	83.1
Lead	s.t.	321,563	258,514	80.4
Nickel	s.t.	250,180	246,525	98.5
Silver	oz.	36,426,079	24,143,093	66.3
Zinc	s.t.	1,086,557	1,033,357	95.1
Asbestos	s.t.	1,400,708	1,342,044	95.8
Gypsum	s.t.	5,119,955	3,896,134	76.1
Potash	s.t.	2,204,231	2,004,504	90.9
Elemen'l sulphur	s.t.	2,322,223	1,773,671	76.4
Coal	s.t.	11,395,754	1,338,353	11.8
Crude oil	bbl.	351,287,792	150,344,567	42.8
Natural gas	Mcf	1,471,597,800	505,164,622	34.3

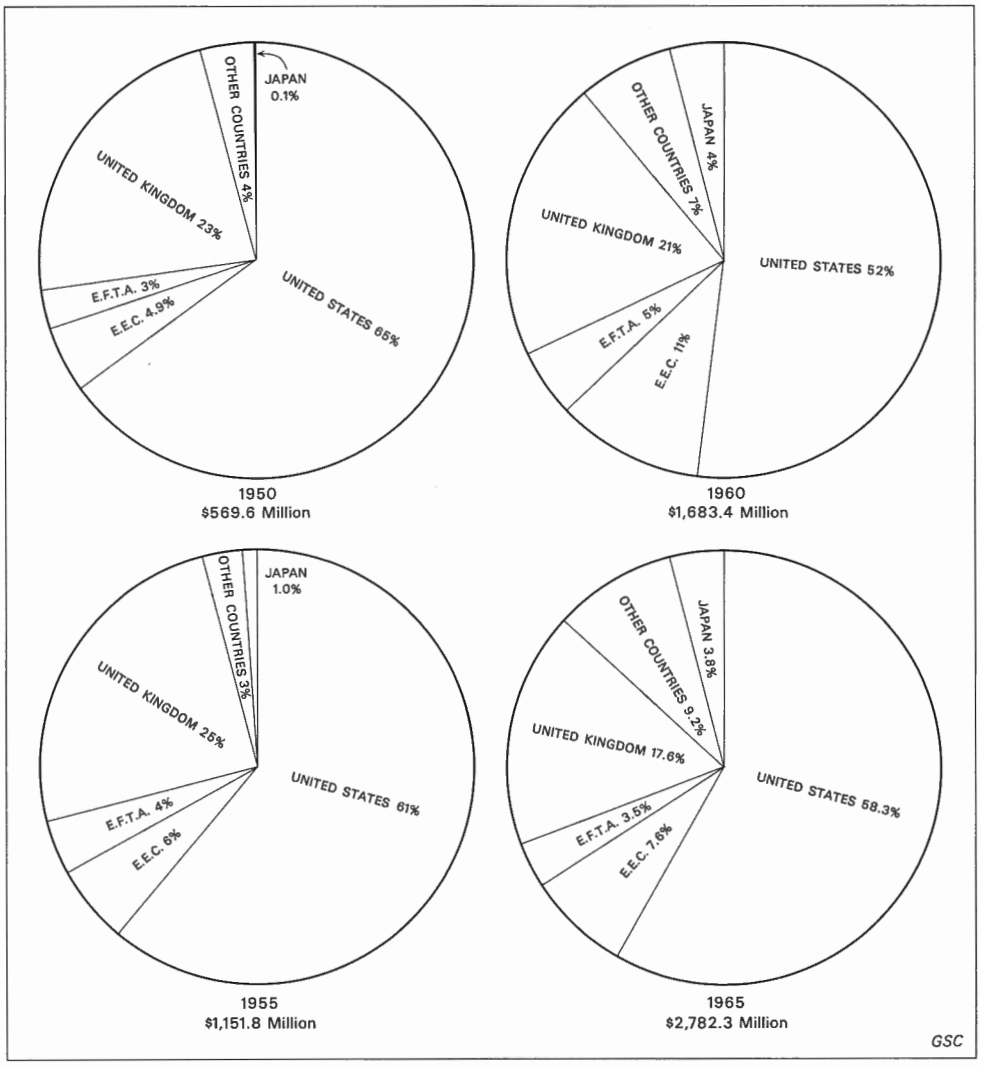

FIGURE III-6
Export market of Canadian minerals in raw and semi-processed form.

Although Canada imports some minerals, in recent years its exports in crude and fabricated forms have exceeded the value of its imports in these forms by as much as $1,500 million annually. Crude oil imports into eastern Canada to supply refineries beyond the economic reach of western Canadian oil have been accounting for two thirds of the value of mineral imports. Table III-6 illustrates the extent of export orientation for leading minerals by relating exports to production. Inasmuch as imports for all minerals, except crude oil and coal, are very small the percentages shown are a measure of the net surpluses available for export after domestic mineral requirements have been met. Canada is deficient in a relatively small number of minerals, the most important being manganese, chromium, tin, bauxite, and phosphate rock.

FUTURE DEVELOPMENTS

Beyond 1970, the opening up of the Athabasca oil sands on a large scale and of potential oil areas in the north and offshore, a resurgence in the demand for uranium, a breakthrough in the markets for iron ore and nonferrous metals in western Europe, markets for coal in Japan and a greater role for Canadian minerals in North American supply could lead to an accelerated growth rate in Canada's mineral output. In any event, mineral production volume in 1980 is likely to be at least double the output of 1965.

Inasmuch as Canada's mineral industry is strongly export-oriented, future developments will be determined in considerable part by the factors that affect international trade. These include matters relative to mineral surpluses throughout the world, trade restrictions, stockpile policies of leading consumers, and national policies governing development and marketing of minerals, particularly in the newly developing countries that are important sources of minerals. Such factors may add greatly to those problems of export market growth that are purely competitive in nature.

Resource development and production problems that arise in Canada stem from widespread distribution of resources in a large country, difficult conditions of terrain

TABLE III-7 *Value of mineral production in Canada by main geological regions, 1967*

	Metals		Industrial Minerals		Fuels		Total All Minerals	
	$ Millions	% of Total	$ Millions	% of Total	$ Millions	% of Total	$ Millions	% of Total
Canadian Shield	1,780.2	78.9	97.9	11.1	—	—	1,878.1	42.5
Appalachian Orogen	147.4	6.5	205.0	23.2	59.2	4.6	411.6	9.3
St. Lawrence Platform	2.6	0.1	283.9	32.1	9.3	0.7	295.8	6.7
Interior Platform	97.9	4.3	215.3	24.4	1,160.1	91.1	1,473.3	33.4
Cordilleran Orogen	228.9	10.2	81.7	9.2	45.0	3.6	355.6	8.1
Total	2,257.0	100.0	883.8	100.0	1,273.6	100.0	4,414.4(p)	100.0

(p) Preliminary

and climate, and a comparatively small population. In turn, these conditions give rise to high costs of operation in remote locations and high transportation costs. However, unlike problems arising from international trade barriers, the problems of the domestic industry can be lessened by increasing the efficiency of operation through the full use of newly devised scientific and technological methods. The extent of the economies that are so achieved will determine the rate of industry growth in so far as this, in turn, is affected by competitive marketing. The mineral production record of recent years is evidence of Canada's ability to develop an efficient producing industry.

The mineral industry in Canada receives strong support and encouragement from government. The various incentives designed to encourage mineral industry growth include attractive mineral rights legislation, tax incentives particularly related to exploration and new mine development, a government role in resource surveys and research, certain limited subsidies and bounties, trade promotion, and government appraisals of industry progress by means of economic studies. Canadian mining legislation provides for security of land tenure, the equitable disposition of mineral rights, and well defined regulations concerning mineral property development. Under the Canadian system of government, all mineral rights — with the exception of those in the federally administered Yukon and Northwest Territories, offshore areas, Indian Reserves, National Parks and some small areas within the provinces — are vested in the ten provinces as provided for in the British North America Act of 1867. The provinces enact legislation to administer and regulate the mineral industry within their boundaries. The stability of the legislative and tax system, and its many incentives, have attracted to the industry the large amounts of capital needed to ensure future growth.

Progress in exploration and production in the past 20 years and the favourable legislative environment in Canada give promise of even greater progress in resource development in the next 20 years. From a production value level of $4.7 billion in 1968, the mineral industry can look forward to an ever increasing role in the Canadian economy and to a major responsibility in helping to meet the rapidly growing mineral requirements of the world.

TABLE III-8 *Value of mineral production in Canada by provinces, 1950–1968* ($ millions)

Province	1950	1955	1960	1965	1968
Ontario	367	584	983	992	1,355
Alberta	136	326	396	794	1,092
Quebec	220	357	446	716	729
Saskatchewan	36	85	212	328	357
British Columbia	139	189	186	280	389
Newfoundland	26	68	87	208	310
Manitoba	32	62	59	183	210
New Brunswick	13	16	17	82	88
Northwest Territories	8	26	27	77	116
Nova Scotia	59	67	66	71	57
Yukon Territory	9	15	13	13	21
Prince Edward Island	—	—	1	1	1
Total	1,045	1,795	2,493	3,745	4,725

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INTRODUCTION

The Canadian Shield is a great region of Precambrian rocks that occupy nearly half of Canada and form the bedrock for a land area of about 1,864,000 square miles, mainly in Canada but extending south into the Lake Superior and Adirondack regions of the United States of America. Except on the northeastern side facing the Greenland Shield, the Canadian Shield is surrounded by Phanerozoic sedimentary rocks forming a platform cover that is but little disturbed, as it is protected by its virtually stable Precambrian basement. Several inliers of Precambrian rocks protrude through the platform cover and, in the bordering geosynclines, Precambrian rocks are involved in folding in the Appalachian, Cordilleran, and Innuitian Mountain Belts. The rocks of the platform cover may have at one time extended over the whole of the Shield but now remain only as the Hudson Platform, the Foxe Basin, and several scattered small erosional remnants and down-faulted blocks. Although the Shield has been virtually stable since the end of Precambrian time, it has been disturbed by Phanerozoic faults especially along the southern boundary and along the borders of the Boothia Uplift in the north. Phanerozoic faults are almost entirely absent along the more stable western boundary.

An estimate of the chemical composition of the Shield approximates that of granodiorite and it contains more silicon and potassium and less magnesium, calcium, and some other elements than are estimated to be present in the entire crust of the earth (Shaw, *et al.*, 1967). The greater part of the Shield has now been geologically mapped and much of it has been covered by gravity and aeromagnetic surveys. Geological studies have solved many of the local features of stratigraphic succession and orogenic relationships, and have permitted the subdivision of the Shield into structural provinces. Many of the local features have now been dated and correlated by isotopic age methods and an overall scheme of orogenic and time-stratigraphic classification has become possible. The several topics are summarized in the following sections and the summaries are followed by more detailed accounts of the geology of the structural provinces.

Structural Provinces

The subdivision of the Shield into a number of structural provinces and subprovinces is based mainly on overall differences in internal structural trends and style of folding. Boundaries between provinces are drawn where one trend is truncated by another, either along major unconformities or, in their absence, along orogenic fronts. The structural divisions, although based primarily

[1] The Introduction was prepared by C. H. Stockwell. The accounts of Superior, Slave, Bear, Southern, and part of Churchill Provinces were prepared by J. C. McGlynn. The sections on Labrador, Cape Smith, and Belcher Subprovinces are by J. A. Donaldson. R. F. Emslie is responsible for Nain and Grenville Provinces, and B. V. Sanford and A. W. Norris for Hudson Platform. W. F. Fahrig prepared the account of the diabase intrusions and K. L. Currie the shock metamorphic structures. When acknowledging, reference should be made to individual author and page number.

IV

Geology of the Canadian Shield

C.H. Stockwell, J.C. McGlynn, R.F. Emslie, B.V. Sanford, A.W. Norris, J.A. Donaldson, W.F. Fahrig, and K.L. Currie[1]

McDonald fault scarp bordering East Arm Fold Belt of Churchill Province, Northwest Territories.

on geological evidence, have been greatly strengthened by the isotopic dating of orogenies, discussed below. The provinces and subprovinces differ from orogens in that they have broader scope, containing not only orogenically deformed rocks but also virtually undisturbed cover material and a variety of post-orogenic intrusions.

Based mainly on structural criteria, the Shield has been divided into seven structural provinces and several subprovinces (Fig. IV-1). The divisions and their nomenclature are, in the main, a compromise between those recognized by M. E. Wilson (1939), J. E. Gill (1948, 1949), J. T. Wilson (1949), and Farquhar and Russell (1957). Structural trend lines are shown on the Tectonic Map of Canada (Map 1251A) and in more generalized form on Figure IV-2. These show the trend of gneissic and schistose structure, bedding, formational boundaries, and the crest lines of positive magnetic anomalies. Linear trends, for the most part, represent the surface trace of long tight folds whereas curved ones may represent more open folds or, more commonly, tight folds bent by batholithic intrusions; they may also represent complexly refolded folds and include gneissic domes and basins.

Superior Province

Superior Structural Province is characterized by a predominance of easterly trending structures, although northerly trends prevail in the large lobe east of Hudson Bay. In the western part of the province the easterly trends are most pronounced in the Cross Lake, English River, and Quetico Belts. Curved structures are more characteristic of the intervening areas in which batholithic intrusions predominate, such as in the Cat Lake, Wabigoon, and Wawa Belts. The Kapuskasing Belt trends northeasterly across the easterly structures and is flanked by northeast-striking faults. The folded rocks are overlain unconformably by unfolded or gently folded rocks of Mistassini Homocline and Cobalt and Nipigon Plates. Post-orogenic intrusions including bodies of syenite and carbonatite and dykes of diabase, occur within the Superior Province, as well as a few down-faulted blocks of Paleozoic sediments and a circular structure with Permian–Triassic volcanic material.

Slave Province

In Slave Structural Province trends are commonly curved, but on the whole are mainly northward. Post-orogenic features include an intrusion of syenite, gently folded rocks of the Bathurst Plate, and diabase dykes.

Bear Province

The boundary between Bear and Slave Structural Provinces is marked mainly by an unconformity. Rocks of the Wopmay Belt above the unconformity are in part, homoclinal at the base, but elsewhere are folded right up to the contact. The homoclinal and folded rocks are unconformably overlain by rocks of the Coppermine Homocline. Post-orogenic features include dykes of diabase. Closely related to Bear Province are two inliers in the Phanerozoic cover, the one comprising flat-lying material of the Brock Inlier in Interior Platform, and the other, gently folded rocks of the Minto Inlier in Arctic Platform.

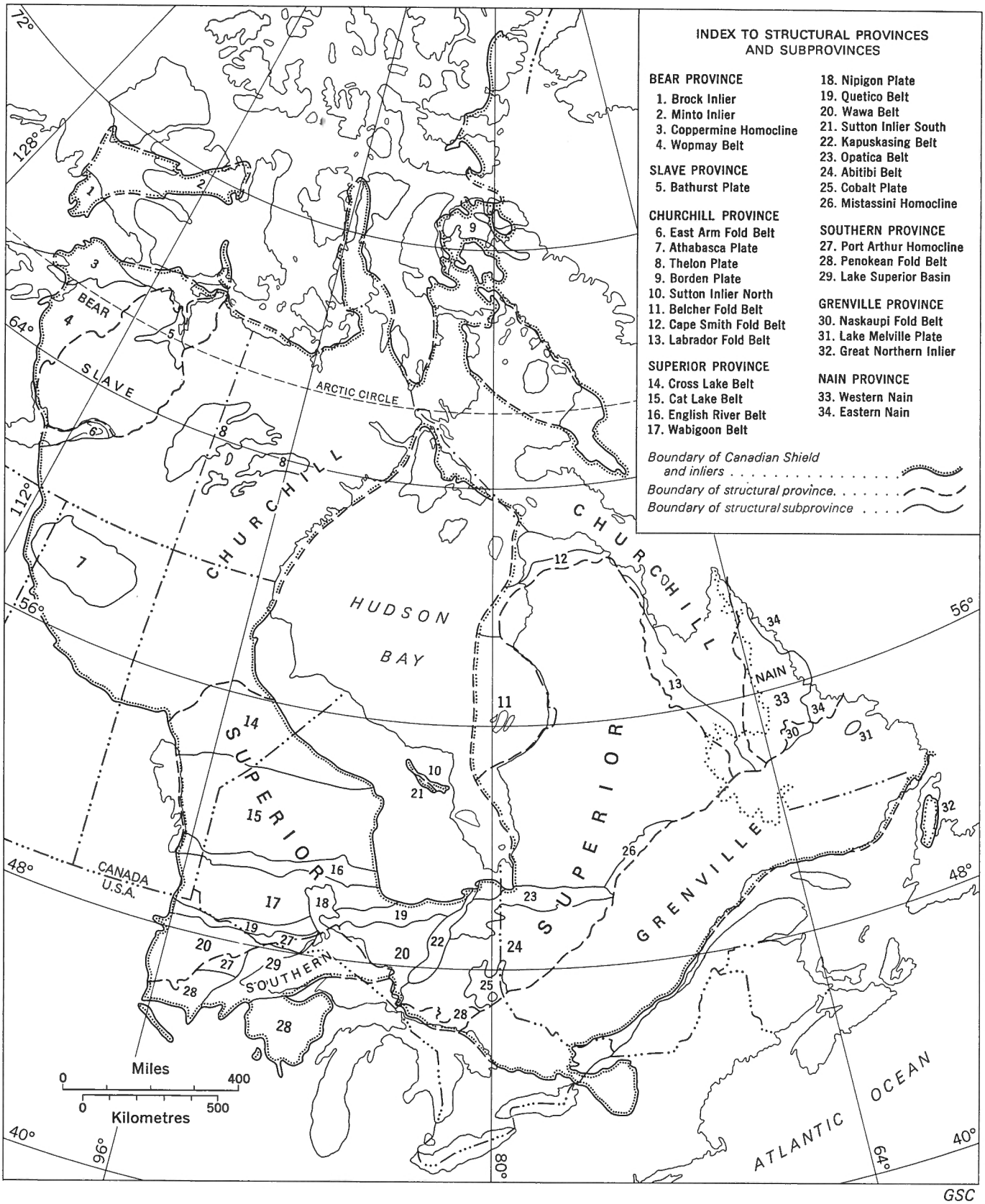

FIGURE IV-1. Structural provinces and subprovinces of the Canadian Shield (by C. H. Stockwell).

Churchill Province

Boundaries between Churchill Structural Province and Superior and Slave Structural Provinces are marked in places by profound unconformities, or, where these are absent, by orogenic fronts. The unconformities are well established at the base of the rocks forming the Labrador, Cape Smith, Belcher, and East Arm Fold Belts. Each is asymmetrical with, characteristically, a narrow homocline at the base, which passes outward into folded rocks with axial planes dipping away from the basement contact and which, still farther out, either grades into more highly metamorphosed rocks of the main body of Churchill Province or is separated from them by a fault. The Sutton Inlier of Hudson Platform comprises a homocline, obviously a continuation of that of the Belcher Fold Belt, lying unconformably on a basement. Boundaries along the east side of Slave Province and along the north part of Superior Province in Manitoba are defined, respectively, by the Thelon Front and the Nelson Front. In each of these localities the orogenic trends on the Churchill side tend to parallel the boundary and to truncate older trends on the other side of the front.

Within the main body of Churchill Province, curved structures predominate, but linear structures are well represented and, in a general way form a large arc, concave to the south, around Hudson Bay so that trends are mainly northeast in the western part, easterly close to Hudson Bay, and southeasterly in the extreme eastern part of the province. A smaller arc, concave to the east, lies in the country between Athabasca Lake and Great Slave Lake. In the interior of the province, the folded rocks are unconformably overlain by flat-lying or only gently folded rocks of the Athabasca, Thelon, and Borden Plates. Near the borders of the province, small bodies of nearly flat lying rocks unconformably overlie folded rocks of the Labrador and East Arm Fold Belts. A circular, possibly cryptovolcanic, structure is found in Athabasca Plate. Postorogenic diabase dykes and a few outliers of Paleozoic and one of Cretaceous sediments also occur within the province.

Southern Province

Southern Structural Province lies partly in Canada and extends into the Lake Superior district of the United States. The boundary between Southern and Superior Structural Provinces is defined, almost everywhere, by an unconformity. The Penokean Fold Belt is characterized by easterly trending folds and the Port Arthur Homocline by gentle dips to the south. These are overlain unconformably by gently folded cover rocks of the Lake Superior Basin.

Nain Province

Nain Structural Province and its division into eastern and western parts are not well known. Its western boundary appears to be an orogenic front for northerly trends in the Nain seem to truncate northwest trends in the Churchill, especially toward the southern part of the boundary. The division into two parts is tentatively made on the basis of differences in isotopic dates and on the presence of anorthosite in the western part. Small areas of nearly flat lying rocks unconformably overlie the folded rocks of both east and west parts.

Grenville Province

Grenville Structural Province lies mainly in Canada but extends into the Adirondack region of the United States. The fault-flanked, Great Northern Inlier in St. Lawrence Platform is closely related to rocks of Grenville Province. In one small area the boundary is an unconformity where homoclinal and folded rocks of the Naskaupi Fold Belt lie on rock of western Nain Province. Elsewhere the boundary is an orogenic front known as the Grenville Front, which extends northeast in a nearly straight line for 1,200 miles truncating along its course the easterly trends of Southern and Superior Provinces, cutting off the Cobalt Plate and the Mistassini Homocline, and continuing northeast to truncate the southeast trend of the Labrador Fold Belt and the northerly trends of Nain Province. For parts of its length the boundary is a fault; in other parts it is a sharp metamorphic front across which the rocks of the several provinces may be traced into more highly metamorphosed and more intricately folded equivalents in Grenville Province. Within the body of the province folding is exceedingly complex and on a small scale; irregular curved structures occur throughout, and numerous gneissic domes and basins have been formed. No large linear structures are apparent but there is an overall northerly preference to the curved trends, especially in the southern and central parts of the province, where they lie at an angle to the long axis of the province as a whole. Post-orogenic features include stocks of syenite along the southeast border, diabase dykes, flat-lying rocks of the Lake Melville Plate, bodies of carbonatite, several outliers of Paleozoic cover, and a circular structure with Permian–Triassic volcanic material.

Precambrian Orogenies

An orogeny is defined as a period of mountain building accompanied by folding. It is an abstract unit of time, and the folding may or may not be accompanied by approximately contemporaneous metamorphism and granitic intrusion. Relative ages between orogens are given by angular unconformities and by the truncation of older structures by younger ones. Isotopic dates confirm the relative ages as determined by geological studies and are invaluable in supplying a scale in years, in outlining the geographical extent of the several orogens, and in providing long range correlation.

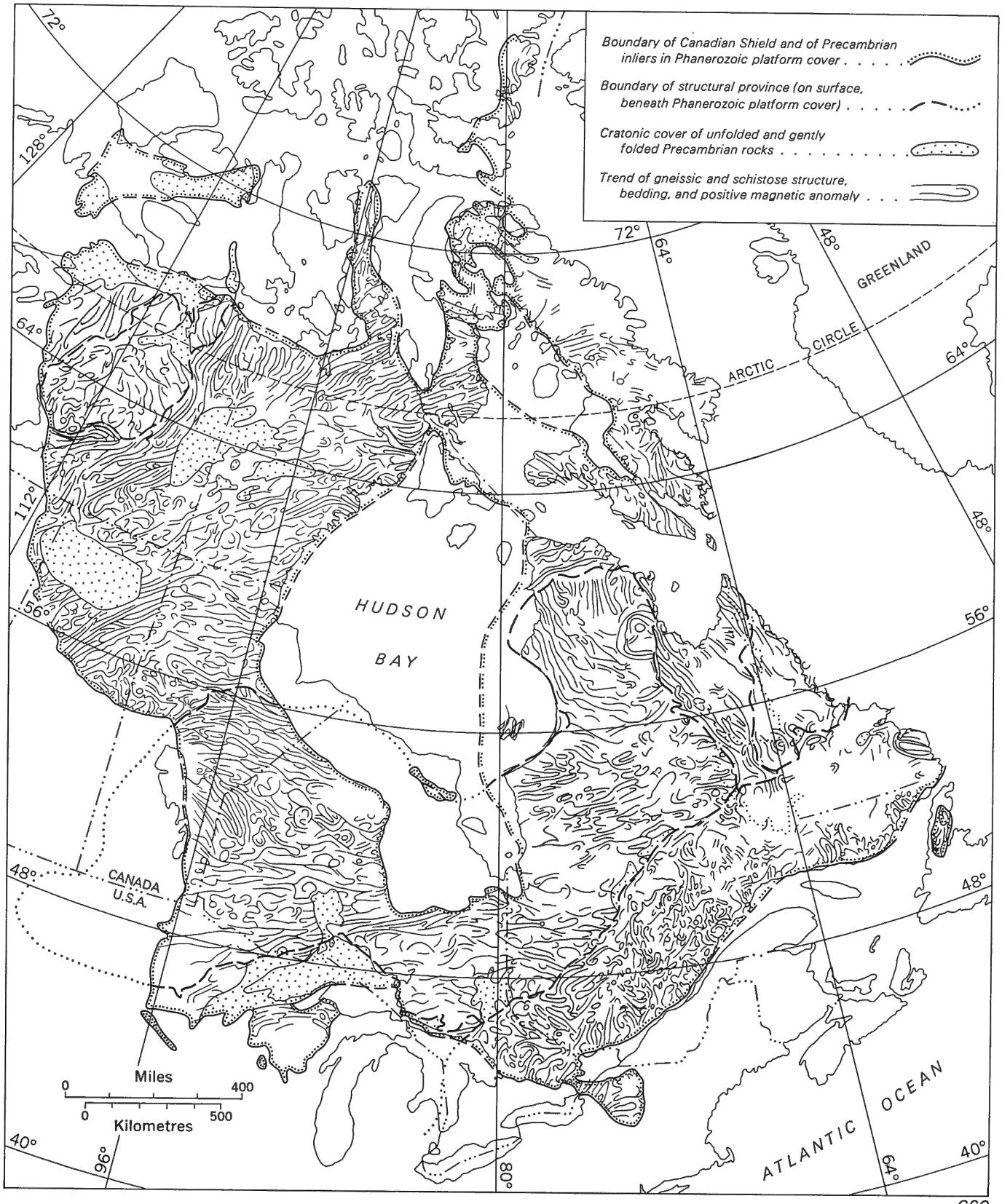

FIGURE IV-2. Structural trends in the Canadian Shield (by C. H. Stockwell).

Because of uncertainties in the interpretation of isotopic dates and because of their inherently large analytical error, it is not possible to define orogenies precisely in absolute time. Accordingly, following the principles recommended by the American Commission on Stratigraphic Nomenclature, the orogenies are defined by concrete rock in type regions rather than by abstract time. Type regions serve as standards for reference and any improvements in their dating or any mistakes made in correlation do not invalidate the units. Four orogenies have been recognized, named, and defined in the Shield. The Kenoran Orogeny is defined as the last important period of widespread folding, metamorphism, and intrusion in Superior Province, which is chosen as the type region. Similarly defined are the Hudsonian Orogeny of Churchill Province as the type region, the Elsonian Orogeny of western Nain Province as the type region, and the Grenvillian Orogeny of Grenville Province as the type region.

Numerous isotopic ages have been determined and are well distributed throughout the Shield. By far the largest number are K–Ar ages, mainly on micas, but a few have been determined by the Rb–Sr whole rock isochron method and by other methods. The K–Ar and Rb–Sr dates have been plotted on a histogram where they are arranged, objectively, according to structural provinces (Fig. IV-3). The K–Ar dates include only those for orogenic minerals whereas the Rb–Sr whole rock dates are from slightly metamorphosed sedimentary and volcanic rocks as well as from gneisses and orogenic intrusions.

The K–Ar mica dates show a considerable spread in each province but, more significantly, the histogram demonstrates that the majority fall in distinct groups indicating the dominant orogeny. In each group the number of determinations falls off rapidly on either side of a peak or mean value, forming a Gaussian probability curve that could result in considerable part from analytical error, which amounts to about ±80 m.y. for the older dates and ±40 m.y. for the younger. Consequently, the time interval from beginning to end of an orogeny is difficult to determine, but, because the analytical errors balance out, the mean values are more significant than the range. The mean K–Ar ages from orogenic micas for the several orogenies in their type regions are as follows: the Kenoran at 2,480 m.y., the Hudsonian at 1,735 m.y., the Elsonian less well defined at 1,370 m.y., and the Grenvillian at 955 m.y. Orogenies in structural provinces, other than those chosen as type regions, are correlated with greater or lesser degree of certainty with the type regions. Thus, the Kenoran Orogeny is well established in Slave Province where most K–Ar orogenic mica dates group around a mean of 2,460 m.y., and it also occurs in Nain Province. Similarly, the Hudsonian Orogeny is reasonably well established in Bear Province where the mean is about 1,785 m.y., and in Southern Province where most K–Ar dates group around a mean of 1,685 m.y. An orogeny in the Great Northern Inlier is correlated with the Grenvillian. These correlations seem valid because the dates used were determined by the same method on the same minerals formed under comparable orogenic conditions. As orogenies are time units, the names used in the type regions

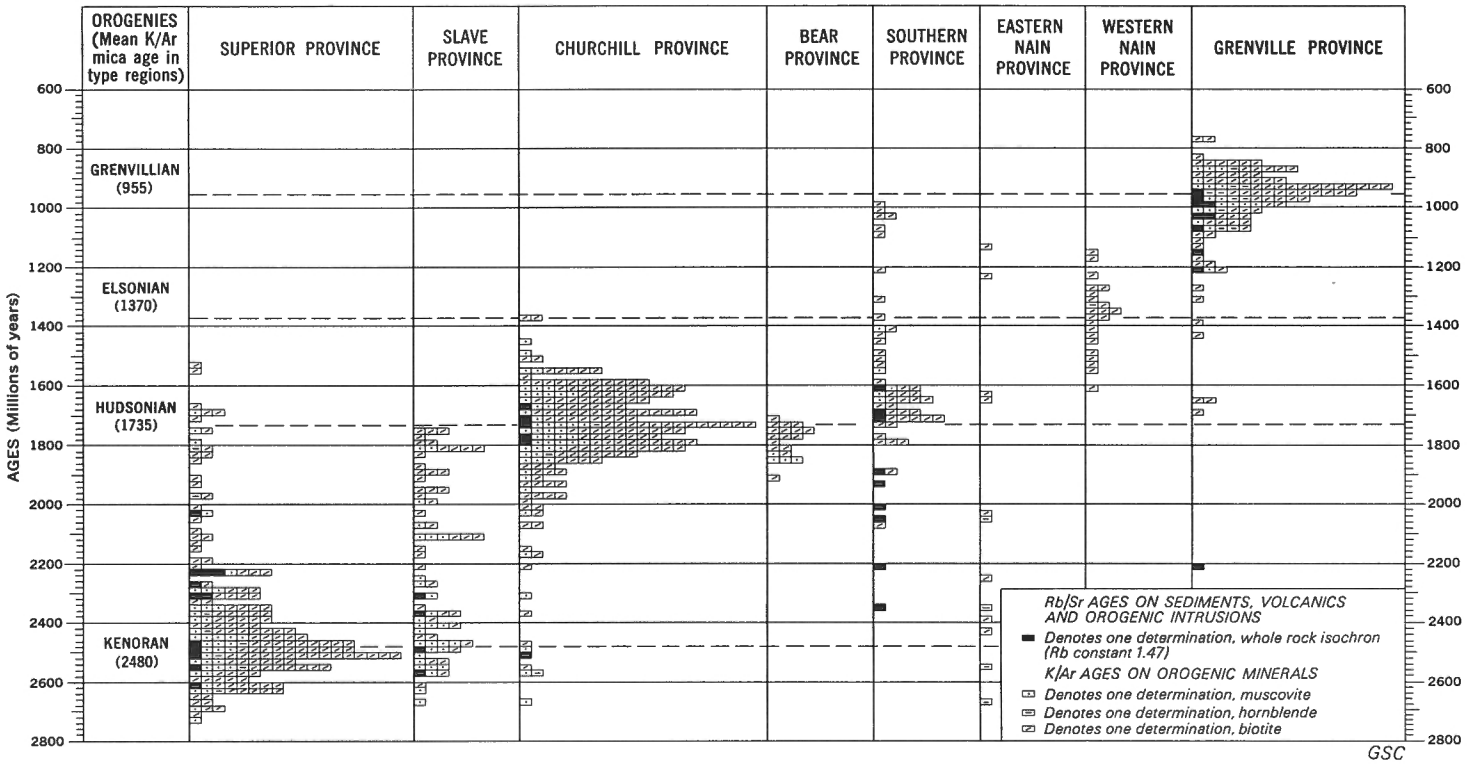

FIGURE IV-3. Histogram of K-Ar and Rb-Sr dates and derived mean K-Ar ages of orogenies of the Canadian Shield (by C. H. Stockwell).

are applied also to contemporaneous orogenies elsewhere, even though widely separated geographically. The orogenies form the basis for the map units on the Tectonic Map of Canada (Map 1251A).

Several of the provinces have been involved, in part, by orogenies older than the dominating one. For example, Superior Province contains profound pre-Kenoran unconformities where volcanics have been folded and intruded by granite, before the unconformable deposition of overlying sediments that were deformed during the Kenoran; but the effects of the Kenoran have been so strong that no distinctly older K–Ar dates have survived. Likewise, Churchill Province contains pre-Hudsonian unconformities, but, as shown by the histogram, a number of dates as old as the Kenoran have survived. Southern Province, dominantly affected by the Hudsonian, yields a few older K–Ar dates around 2,000 m.y. that possibly indicate a pre-Hudsonian orogeny. Grenville Province is known or inferred to contain rocks previously involved in the Kenoran, Hudsonian, and Elsonian Orogenies, all redeformed to some extent during the Grenvillian, but some older dates have survived. Because of the extensive re-working, the Grenvillian Orogeny, although the youngest in the Shield, is the most complex. In each province it is the last dominating orogeny that gives the province its characteristic structure. Several of the provinces have also been modified by local effects of orogenies younger than the dominant one. For example, the Kenoran of Superior Province has been modified locally as indicated by dates as recent as Hudsonian. A similar effect is more pronounced in Slave Province where, in a number of determinations on muscovite–biotite pairs from the same rock sample, the muscovite retains the Kenoran age, but the biotite gives much younger dates, as it is more susceptible to moderate effects of the Hudsonian.

The mean K–Ar ages so far considered are those of the two micas, biotite and muscovite, considered together. When these two minerals are considered separately, the mean muscovite age is found, as a rule, to be 5 to 20 m.y. older than the mean biotite age, which suggests a greater loss of argon from biotite on cooling. Ages obtained from other materials and those determined by other methods agree with the K–Ar orogenic mica ages in some samples but disagree in others. Thus, in Grenville Province a few Pb–Ur and Pb–Th dates for uraninite and thorianite from pegmatite average 960 m.y. as contrasted with coeval biotite dated by the K–Ar method at some 30 m.y. younger; again loss of argon from biotite on cooling is suggested. The 960 m.y. average is in essential agreement with a mean K–Ar muscovite age of 975 m.y. and with a mean hornblende date of 970 m.y. for the province as a whole, suggesting that 960–975 m.y. may be close to the true mean age of the Grenvillian Orogeny. In other provinces the few hornblende dates available likewise average slightly older than mica dates.

In all the provinces, the Rb–Sr whole rock isochron dates, using a Rb decay constant of 1.47, show a considerable spread, some agreeing with the mean mica dates for the orogenies, others being older or younger. Those that are distinctly older are generally interpreted as survival values from older orogens, and thus confirm the geological inferences and some old K–Ar dates, as in Churchill, Southern, and Grenville Provinces. In a small area of the southern part of Grenville Province, however, Rb–Sr dates range from 955 to 1,208 m.y., the older ones only slightly older than the inferred true mean age of the Grenvillian. The older dates could represent early stages of the Grenvillian or, more probably, Elsonian rocks variously up-dated due to effects of the Grenvillian which determined the time at which the Rb–Sr systems last became closed. Ur–Pb dates on zircons from this area range from 1,050 to 1,310 m.y., the oldest approaching the mean K–Ar age for the Elsonian Orogeny. The Rb–Sr dates that are younger than the K–Ar age of the dominant orogeny, as in Superior Province, are difficult to interpret but may have been up-dated by younger events. In Superior and Slave Provinces some Rb–Sr whole rock isochrons are from only slightly metamorphosed volcanic rocks but nevertheless give Kenoran dates. These can be interpreted either as the age of volcanism or, more probably, as the time of orogeny. In the Abitibi Belt of Superior Province modal Pb ages around 3,000 m.y. have been obtained from sulphide deposits and have been interpreted as the age of volcanism (Roscoe, 1965).

Precambrian Time-Stratigraphic Classification

The several Precambrian orogenies, each followed by a profound erosional interval, provide the framework for a natural time-stratigraphic classification of the sedimentary, volcanic, and intrusive rocks. Direct dating of time of deposition of stratified sequences, however desirable, has been largely unsuccessful in the Canadian Shield, probably because most such rocks have been metamorphosed. However, an indirect method of bracketing their time of deposition between maximum and minimum limits has been remarkably successful. The maximum age of a sequence that lies unconformably on a basement is obtained by dating the orogeny that affected the basement; the minimum is given either by dating the orogeny that affected the sequence itself or by obtaining ages from cross-cutting features such as dykes. The maximum may also be determined by dating detrital minerals or boulders in sediments. Intrusive rocks, where retaining their normal ratio of decay products, can be dated directly. The four dated orogenies provide the framework for five time-stratigraphic divisions, boundaries between which are drawn at the close of each orogeny. The close of an orogeny is difficult to define precisely in terms of isotopic age, mainly because of the large analytical error. This difficulty causes no problems in the mapping and classification of unconformity-based sequences in type regions, but, unavoidably at present,

TABLE IV-1 *Precambrian time-stratigraphic classification in relation to orogenies of the Canadian Shield (by C. H. Stockwell)*

Eon	Era	Sub-Era	Orogeny (mean K–Ar mica age, m.y.)
Proterozoic	Hadrynian		
	Helikian	Neohelikian	Grenvillian (955)
		Paleohelikian	Elsonian (1370)
	Aphebian		Hudsonian (1735)
Archean			Kenoran (2480)

leads to some uncertainty in correlation especially with non-orogenic rocks that formed under conditions of cooling very different from those of orogenic minerals. For example, dates obtained from post-orogenic dykes or flows in undeformed cover rocks might, in border-line cases, lead to uncertainties in correlation with the orogenic classification, especially as dates on anorogenic materials also have large analytical errors. Difficulties are encountered also when the basement has been rejuvenated by a younger orogeny and only the younger age can be determined.

The time-stratigraphic classification of Precambrian rocks in relation to the limiting orogenies is depicted in Table IV-1. The distribution of rocks of the several units is shown on the Geological Map of Canada (Map 1250A). For convenience in description, mapping, and discussion each of the time units has been named (Stockwell, 1964). The large first-order units are called eons and comprise the Archean and Proterozoic. These terms have been used in Canada for a long time and are still used in virtually the same sense as originally defined many years ago (Alcock, 1934). This major twofold division of all Precambrian time is useful for comparing or contrasting geological features of each and it also permits a gross time-classification of those rocks for which information is too meagre for more detailed assignment. The Archean Eon includes rocks involved in or emplaced during the Kenoran Orogeny and all older rocks. Profound unconformities are known within the Archean, but, because of strong overprinting during the Kenoran, it has not yet been possible to date the underlying rocks and, consequently, it has not been feasible to correlate them or to subdivide the Archean on a time-stratigraphic basis. The Proterozoic spans the time from the close of the Kenoran Orogeny to the beginning of the Cambrian.

The Proterozoic Eon is subdivided into second-order units called eras, as follows: the Aphebian, spanning the time from the close of the Kenoran to the close of the Hudsonian; the Helikian, from the close of the Hudsonian to the close of the Grenvillian; and the Hadrynian, from the close of the Grenvillian to the beginning of the Cambrian. The Helikian is subdivided into two suberas and the boundary between them is drawn at the close of the Elsonian Orogeny, which results in an older unit called the Paleohelikian and a younger one called the Neohelikian. If any more formal subdivisions are made, such as has been done for the Helikian, it would be highly desirable to choose a stratigraphic or structural boundary that is recognizable in the field and datable by isotopic methods. Informal subdivisions of the several time-stratigraphic units may be found useful. For example, a body of granite emplaced during the Hudsonian Orogeny may be classed informally as late Aphebian. Each of the terms may be used either for concrete time-stratigraphic units or for abstract geologic-time units. The units as defined above have the advantage that no part of the geological column or any gaps in it remain unnamed. The terms system, period, series, and epoch have not been used in the Precambrian classification because it is not yet possible to measure the time from beginning to end of deposition of a sequence of stratified rocks. Instead, the rock-stratigraphic terms, formation, group, and supergroup, have been used. Correlations can be made by lithological similarity, comparison of sequences, and relation to unconformities and intrusions.

Geological Summary

Archean

The Archean was a time of great volcanic activity and of deposition of immense thicknesses of sediments. Almost everywhere the volcanic and sedimentary rocks are, apparently, conformable with one another and many are interbedded, but angular unconformities have been recognized at several localities. Rocks beneath the unconformities include sedimentary, volcanic, and granitic rock, the last only rarely recognized with certainty, and conglomerate above contains pebbles and boulders of these materials. All these rocks were then folded, metamorphosed to some degree, and intruded by granitic rocks during the late Archean Kenoran Orogeny.

The Archean rocks are best preserved in Superior and Slave Provinces but have also been recognized in parts

of Churchill, Grenville, and eastern Nain Provinces. In Superior and Slave Provinces the volcanics are predominantly of basic composition, but more acid varieties are also found. The chemical composition as determined in several representative areas gives proportions of 65 per cent basalt, 25 per cent andesite, and 10 per cent rhyolitic material, and places them in the calc-alkaline suite typical of orogenic environments. In places, the basic volcanics have been metamorphosed to amphibolite and gneiss but more commonly are only slightly altered and primary structures such as pillows, flow lines, and amygdules are well preserved. Ash beds, tuff, and agglomerate are interlayered with the flows, and iron-formation is closely associated with them. Sills of basic rock are common and seem to be genetically related to the flows. The Archean sedimentary rocks are, as a rule, poorly sorted and consist mostly of greywacke, argillaceous material, arkose, and conglomerate but better sorted quartzite and limy beds are found locally. Primary features such as bedding, graded bedding, and crossbedding are well preserved in many places, but, in extensive areas, much of the sedimentary materials have been converted to gneiss and migmatite. During the Kenoran Orogeny, the folding and metamorphism of these materials was accompanied by widespread emplacement of bodies of granitic material leaving between them only isolated remnants and belts of the older rocks. Granulites are found in Superior Province near the Nelson Front, within the Kapuskasing Belt, and are widespread east of Hudson Bay.

In Churchill Province, Archean volcanic, sedimentary, and granitic rocks are less well known as they have been deformed and altered during the Hudsonian Orogeny. Their presence, however, is confirmed locally by isotopic dates of Kenoran age. In places they lie unconformably beneath folded Aphebian sediments and, where effects of the Hudsonian have been moderate, bear a close lithological resemblance to the Archean of Superior and Slave Provinces. Where converted to gneiss, which is widespread, the Archean is difficult to distinguish from the Aphebian. Archean rocks have been traced from Superior Province across the Grenville Front into Grenville Province where they have generally been re-worked to amphibolite and gneiss during the Grenvillian Orogeny. Their distribution beyond the border region is uncertain due to their highly altered condition and inadequate mapping and study. Kenoran dates on gneisses and granitic rocks of eastern Nain Province indicate the presence of Archean rocks in that area.

Proterozoic

Sedimentary rocks of the Proterozoic show a marked change in depositional environment for they are, on the whole, much better sorted and contain much more limestone than those of the Archean. The better sorting is evidenced mainly by the greater abundance of quartzite. As a result, the rocks are less monotonous and rock-stratigraphic units of formational rank have been recognized and mapped to a much greater extent than in the Archean. Along with volcanic materials they have been deposited as cratonic cover in some places as well as in geosynclines. They vary from almost undisturbed and unmetamorphosed types to highly folded and greatly metamorphosed varieties.

Aphebian

Rocks of Aphebian age occur both as cratonic cover and as geosynclinal deposits. The cover rocks lie unconformably on Archean rocks of Superior and Slave Provinces and, protected by their almost stable basement, are only gently folded and are, as a rule, unmetamorphosed. They are represented by the Cobalt Plate of conglomerate, arkose, greywacke, and shale, and by the Bathurst Plate and Mistassini Homocline of conglomerate, sandstone, greywacke, argillite, shale, and dolomite. Geosynclinal deposits of Aphebian age were deposited in regions bordering Superior and Slave Provinces, where typically they form the long narrow geosynclines of Labrador, Cape Smith, Belcher, and East Arm Fold Belts of Churchill Province, and the broader geosynclines of Bear and Southern Provinces. The deposits include conglomerate, arkose, greywacke, sandstone, siltstone, quartzite, limestone, dolomite, argillite, shale, greywacke, chert, iron-formation, and their metamorphic equivalents. Red beds are common and many of the limestones are stromatolitic. Volcanic rocks, mainly basaltic, are common in some parts of the succession and basic sills are found in association with both the volcanics and the sediments. In places, these rocks form virtually undisturbed homoclines adjacent to their Archean basement, but farther out have been folded, intruded by granite rocks, and converted to gneisses during the Hudsonian Orogeny. The Sudbury norite–micropegmatite of Southern Province was also emplaced during the late Aphebian.

Folded Aphebian rocks are also found in the interior part of Churchill Province where they have been converted to gneisses much more commonly than in the border regions, but some areas of less metamorphosed Aphebian rocks, such as conglomerate quartzite, limestone, dolomite, local iron-formation, and volcanics are well preserved, forming irregular areas rather than well-defined belts. Many of the gneisses are difficult to distinguish from rejuvenated Archean gneisses and are classed as Aphebian or Archean. All were involved in the Hudsonian Orogeny accompanied by widespread granitic intrusions. Aphebian rocks are also found in Grenville Province where they comprise marble, quartzite, iron-formation, volcanics, amphibolite, aluminous paragneisses, and migmatite. Structures are complex as a result of reworking during the Grenvillian Orogeny. These rocks have been traced into the province for some miles southwest of their less metamorphosed equivalents of the Labrador Fold Belt and eastward from those of Southern Province. In the intervening central part of Grenville Province, isolated remnants of lithologically similar material are probably also

of Aphebian age. Post-orogenic features of Aphebian age include a body of alkaline syenite cutting Archean rocks in Slave Province, carbonatite complexes in or near the Kapuskasing Belt (Gittins, *et al.*, 1967), and numerous diabase dykes in Slave and Superior Provinces.

Helikian

Rocks of undivided Helikian age consist predominantly of little deformed cratonic cover on Hudsonian Orogens. In Churchill Province they include the Athabasca Plate of conglomerate, sandstone, and shale, and the Borden Plate of conglomerate, sandstone, quartzite, siltstone, shale, limestone, dolomite, basalt, and andesite. Small areas of Helikian conglomerate, arkose, and sandstone also overlie the Hudsonian Orogen of East Arm Fold Belt. In the lower part of the succession of Coppermine Homocline and Lake Superior Basin, they include conglomerate sandstone, shale, and dolomite overlain by thick flood basalt interbedded with sandstone and shale; these rocks overlap onto the Kenoran Orogen of Superior Province to form Nipigon Plate. Post-orogenic diabase dykes of Helikian age are found in all provinces except Grenville.

Paleohelikian. In western Nain Province intrusive rocks accompanying the late Paleohelikian Elsonian Orogeny include bodies of anorthosite and related basic and granitic intrusions. Similar intrusions, probably also of that age, are scattered throughout large parts of Grenville Province where they have been moderately altered during the Grenvillian Orogeny. In Grenville Province the Hastings Group of conglomerate, greywacke, argillite, dolomite, limestone, and schist may also be Paleohelikian because it probably overlies the Grenville Group and granitic rocks unconformably (M. E. Wilson, 1965), and is cut by basic intrusions that were probably emplaced during the Elsonian Orogeny. Elsewhere in the Shield, and unaffected by the Elsonian or Grenvillian Orogeny, rocks of Paleohelikian age form little deformed cover on Hudsonian Orogens. In Churchill Province they include formations of the Thelon Plate comprising conglomerate, sandstone, siltstone, limestone, and alkalic volcanic rocks. The lower formation of this succession is cut by a post-orogenic body of Paleohelikian syenite. Also of this age are small areas of cover rocks on Hudsonian Orogens elsewhere in the main part of Churchill Province and in the Labrador Fold Belt.

Neohelikian. In Naskaupi Fold Belt, conglomerate, quartzite, slate, argillite, and volcanic rocks are of Neohelikian age as they lie unconformably on the Elsonian Orogen and were folded during the Grenvillian. The Wakeham Group, which also lies within Grenville Province, may be Neohelikian as it is probably younger than anorthosite, apparently lies unconformably on gneisses, and was folded during the Grenvillian. Some granites of Grenville Province were emplaced during the late Neohelikian Grenvillian Orogeny. Neohelikian rocks also occur outside the province. For example, a cover of Neohelikian sedimentary and volcanic rocks lies on the Archean of eastern Nain Province. Of Neohelikian age also, but apparently somewhat older than the Grenvillian Orogeny, are post-orogenic intrusions of the Muskox Complex of basic rocks in the Hudsonian Orogen of Bear Province, several carbonatite complexes, and the Caldwell syenite in the Kenoran Orogen of Superior Province, and the Logan sills of Southern Province.

Hadrynian

The Grenvillian Orogen is overlain unconformably by virtually unfolded conglomerate and sandstone of Lake Melville Plate which could be either Hadrynian or younger. Post-orogenic intrusions of Hadrynian age include diabase dykes in Grenville, Bear, and Churchill Provinces and syenitic stocks in Grenville Province. Also of Hadrynian age are sandstone, shale, and dolomite of at least the uppermost part of the succession of Coppermine Homocline, Brock Inlier, and Lake Superior Basin, and similar rocks together with basalt of Minto Inlier. Beyond the limits of the Canadian Shield the Hadrynian is well represented in the Appalachian and Cordilleran fold belts.

Geophysical Surveys

Gravity

The greater part of the Shield has been covered by reconnaissance gravity surveys (Map 1257A). Throughout much of the area covered the gravity pattern as shown by contours consists of irregular non-linear areas ranging from 0 to —70 milligals. This general rather featureless pattern contrasts with some definite linear trends. These are closely related to major geological features, especially to boundaries between structural provinces. Thus, a conspicuous low anomaly from —70 to —110 milligals closely parallels the Grenville Front for some 500 miles, lying for most of its length on the Grenville Province side. Also, the Nelson Front is closely paralleled, on the Kenoran side, by a high anomaly from —30 to 0 milligals that crosses the easterly trends of underlying rocks and continues beneath adjoining platform cover for a total length of 800 miles. This high anomaly, for part of its length, is paralleled on either side by complementary lows. Of less prominence, is a low anomaly along the Kenoran side of part of Thelon Front with a complementary high on the Hudsonian side. The contact between the Kenoran Orogen of Superior Province and the overlying deposits of Labrador and Cape Smith Fold Belts is closely followed by a low of —30 to —60 milligals and, within the Cape Smith Fold Belt, this trend is paralleled by other high and low anomalies which follow the geological structures.

In the interior of Superior Province high anomalies from —30 to 0 milligals follow the Kapuskasing Belt, and a less prominent one trends in part along English River

Belt. In Bear Province another linear gravity high from −30 to +20 milligals passes through and beyond the Muskox Complex.

Magnetism

Much of the southern and western parts of the Shield have been covered by total intensity, low altitude aeromagnetic surveys and the results are published as detailed contoured maps. For larger areas the regional magnetic gradient, due to deep-seated processes, has been removed leaving a pattern resulting from the relatively shallow magnetic part of the crust (Map 1255A). On this map the pattern of alternating areas and belts of low and high intensity reflect, for the most part and in a gross way, the pattern of geological structures. For example the dominantly northern trends in Slave Province and the easterly trends in the southern part of Superior Province are well shown. The northeast to east trends in the southwest part of Churchill Province are particularly well emphasized, and also the dominantly small-scale, irregular, contorted pattern reflecting the extremely complex structures in Grenville Province. The magnetic pattern also brings out opposing structures along orogenic fronts. A good example is a broad, featureless, magnetic low within Grenville Province, close to the Grenville Front and trending parallel with it for 250 miles. This low magnetic anomaly coincides with part of the long low gravity anomaly described previously. A series of magnetic highs, closer to the front and parallel with it, truncates the easterly magnetic trends of the adjoining Superior and Southern Provinces. Similarly, along the Nelson Front, the easterly magnetic trends of Superior Province are sharply cut off by a magnetic low and a complementary high that parallel the front on the Churchill side. Within Churchill Province, the McDonald fault, which marks the south boundary of East Arm Fold Belt, lies along the northern edge of a pronounced magnetic high. Within the Kapuskasing Belt, northerly trending magnetic highs cross the easterly trends of adjoining parts of Superior Province, and correspond in part with the gravity highs already mentioned. Likewise, the English River Belt, for much of its length, is marked by a magnetic high which coincides partly with a gravity high. The magnetic pattern over sedimentary cover depicts the structural trends of the basement. Dykes of diabase show very distinctly on the detailed maps as positive, and locally as negative magnetic anomalies, and numerous carbonatite and other basic intrusions stand out from their surroundings as high anomalies, as do also magnetic iron-formation and some basic lava flows.

Seismology

Crustal thickness beneath the exposed Shield and platform areas is not well known, but local seismic studies with chemical explosions indicate that the crust has a general thickness of the order of 35 to 45 kilometres, that it thickens to 50 kilometres beneath Lake Superior and Williston Basins, and that it thins to 25 kilometres beneath Hudson Platform.

SUPERIOR PROVINCE

Tectonic Summary

The oldest rocks in Superior Province are volcanic and sedimentary rocks of Archean age. These rocks were formed in a number of easterly trending eugeosynclines that were possibly of different ages and tectonically independent. These rocks are involved in the Kenoran Orogeny during which they were folded, faulted, metamorphosed, and intruded by granitic rocks. Many of the major shear zones in the volcanic belts may have been initiated during late phases of the orogeny. Archean sequences may also have been affected by older orogenies, the effects of which were masked by the last event. The mean K–Ar age of Kenoran granitic rocks is about 2,480 m.y.

After the Kenoran Orogeny the rocks were deeply eroded and Aphebian and Helikian sediments were deposited in a number of basins. At different times the Archean rocks were intruded by diabase dyke swarms, cut by major faults, and intruded by alkaline intrusions. At least nine swarms of diabase dykes occur in Superior Province. The oldest is about 2,200 m.y. and younger swarms are about 2,000, 1,900, 1,400, 1,200, and 1,000 m.y. Many sets of steep-dipping faults marked by zones of breccia, shearing, or mylonite cut Archean rocks. The orientation of these faults vary and their relative ages are usually unknown, but several periods of faulting occurred that may be related to the diabase intrusions and to deposition in the Aphebian sedimentary basins. These younger deformations may have occurred during the Hudsonian and Grenvillian Orogenies and formation of the Lake Superior Basin.

Volcanism and Sedimentation

The Archean sedimentary and volcanic rocks in the southern and western parts of the province occur in a series of long, easterly trending belts, separated by areas underlain by granitic rocks. The volcanic and sedimentary rocks have various stratigraphic relationships throughout the province and even in single belts. In most areas where

structural data are good, the volcanic rocks are the older and are conformably overlain by the sediments. However, in a few areas, the sediments occur at the base of the exposed sequence. In some belts the normal succession of volcanic and sedimentary rocks is followed by more volcanics and sometimes by a second volcanic-sedimentary sequence. Frequently the volcanic rocks, particularly the acidic types, appear to pass along strike through a transition zone of interfingering sediments and volcanics into a sedimentary sequence. There seems to be a gradual transition from volcanism to sedimentation without any significant time break, and at times the sedimentation and volcanism were proceeding simultaneously in different parts of the geosynclines (Fig. IV-4). Local unconformities are known but they may not be of regional extent. An exception is the angular unconformity between the Timiskaming rocks in the Abitibi Belt and underlying volcanic-sedimentary assemblage.

Thicknesses of Archean complexes vary between belts and within single belts (Fig. IV-5). Maximum thicknesses of 25,000 feet are common and as much as 50,000 feet has been reported. Volcanic rocks form the greater part of thick successions and the sediments are thickest where the volcanic part is thin (Moorhouse, 1965). Goodwin (1965) estimates that the Archean comprises about 80 per cent volcanic and 10 per cent sedimentary rocks. As these rocks are granitized no figure represents the true thickness, and the thicknesses of the sediments in particular may be underestimated by a large factor.

The Archean volcanic sequences have much in common. They comprise varying proportions of basalt, intermediate to acidic lavas, tuffs, and breccias with minor amounts of sediment. Basic lavas predominate in the lower two-thirds of most sequences while acidic flows, if present, are found in the upper parts. The intermediate to acidic phase is more local in distribution, occurring as thick sequences in scattered areas along individual volcanic belts that probably represent strato-volcanoes built on basic lava. In some areas this volcanic cycle is repeated or partly repeated producing variations in the stratigraphy of the belts. Sedimentation often appears to be contemporaneous with the buildup of the acidic volcanic rocks, erosion of which may then provide part of the detritus. A resurgence of volcanism after sedimentation has started usually results in narrow bands of basic or, more commonly, acid volcanic rocks near the base of the sediments. The lavas of Superior Province belong to the calc-alkaline suite; however, the basalts appear to be derived from a tholeiitic magma type (Wilson, *et al.*, 1965; Goodwin, 1965). Sills, dykes, and irregularly shaped intrusions of gabbro and diorite are present within the lavas, usually in the basic parts. Acidic, often porphyritic, fine-grained stocks occur in or near the acidic volcanic rocks. Both types of hypabyssal intrusion are probably contemporaneous with nearby volcanic activity. Ultrabasic rocks occur as parts of differentiated gabbroic masses or as small discrete masses that may lie in fault zones and whose ages relative to the surrounding granitic rocks are often not known. The constituent minerals are normally altered to serpentine. Little is known about these rocks but it may be that all of the ultramafic masses have been intruded along major fault zones, usually into volcanic rocks during an early stage of the tectonic cycle.

Typical Archean sediments in the various belts are interbedded greywacke and shale, whose composition varies considerably so that feldspathic, lithic, and quartz greywackes and subgreywackes are common. The shale or argillite is normally interlayered with the greywacke as the upper part of graded beds or as thick homogeneous units. Common primary structures, in addition to graded bedding, are flame structures, groove casts, small scale crossbedding, and parallel and convolute laminations.

Conglomerates occur within the greywacke sequences commonly near their base just above volcanic rocks. These

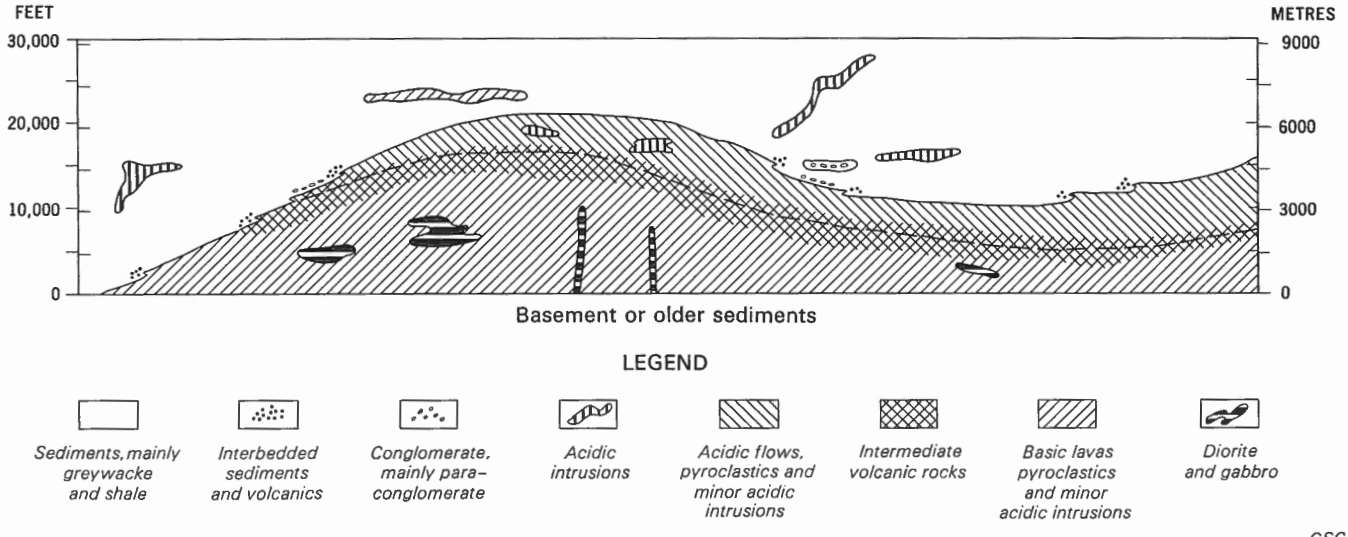

FIGURE IV-4. Diagrammatic section of an Archean volcanic-sedimentary complex (by J. C. McGlynn).

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units may be as much as several thousand feet thick, but often wedge out rapidly along strike. Such conglomerates are usually massive and poorly sorted and comprise phenoclasts that vary from granule- to boulder-size in a greywacke matrix. The phenoclasts are subangular to rounded, consisting of volcanic rock and quartz with some porphyritic rocks and minor amounts of granitic rocks, greywacke, and argillite. In the past, workers have termed as "granite" clasts of acidic porphyritic intrusions related in time to the volcanic rocks, and thereby have given the impression that granitic boulders form a large proportion of the clasts in Archean conglomerates. Donaldson and Jackson (1965) show that boulders of granitic rocks and some gneisses generally occur only in small amounts, less than 10 per cent.

Other sedimentary lithologies include iron-formation, relatively clean quartzite, and limy rocks. The iron-formations occur in beds that range in thickness from a few inches to several hundred feet and extend along strike as much as tens of miles. Typically they consist of thin chert layers interbedded with magnetite- and hematite-rich bands (Chapter V, *Frontispiece*). Some beds contain iron-rich silicates, sulphides, and iron carbonates, which commonly occur with the acidic tuffaceous phases of volcanic sequences, below layers of basic flows, or within other sediments just above the volcanic sequences. Because of the close spatial relationship with volcanic rocks, a common inference is that iron and silica in these sediments were produced during the volcanic activity. Iron-formations are often associated with sulphide-rich black shale. Limestones in the Archean are relatively rare and typically are thin beds associated with iron-formations or with black shales and thin quartzite beds usually in volcanic rocks, or are beds intercalated with tuffs. Donaldson and Jackson (1965) describe Archean sandstone with a carbonate cement that grades to quartzose carbonate. Archean sediments of Superior Province have most of the characteristics of flysch facies (Pettijohn, 1943), as the primary structures are compatible with deposition by turbidity currents in an eugeosynclinal environment.

There has been much speculation about the nature of the source of Archean sediments. It has been suggested

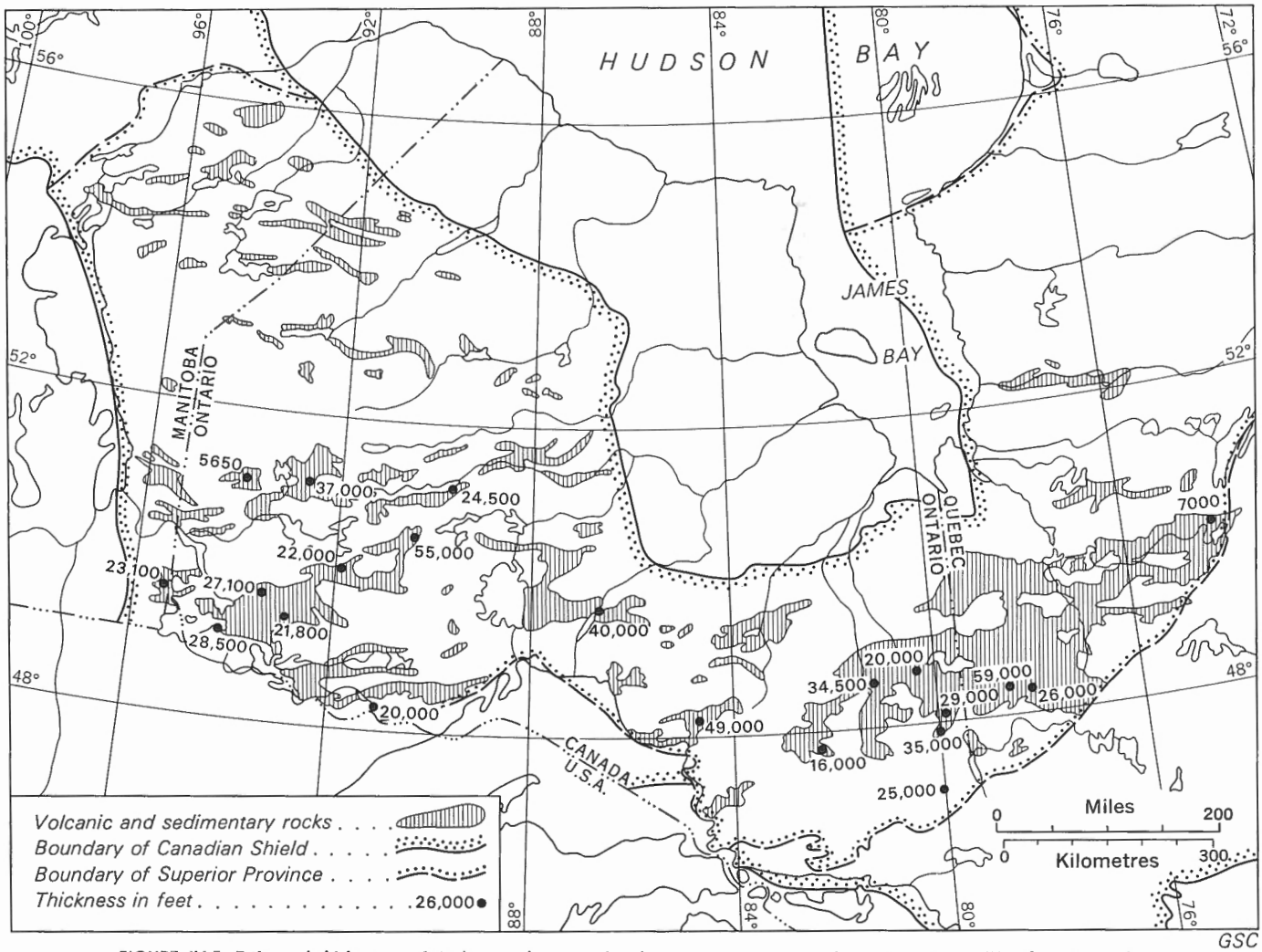

FIGURE IV-5. Estimated thicknesses of Archean volcanic and sedimentary sequences in Superior Province (Moorhouse, 1965).

that the bulk were derived from volcanic rocks. Certainly more than half the clasts in most conglomerates are volcanic material that can be related to nearby volcanic rocks. It is usually suggested that rapid erosion of the acidic piles, which was in part subaerial, supplied much of the quartz and feldspar of the greywacke. Donaldson and Jackson (1965) express doubt that volcanic rocks can be an adequate source for the quartz in the quartz greywackes of the North Spirit Lake area. Although quartz is a minor constituent of the basic lavas, in most acidic volcanic rocks it occurs in smaller grains than those found in the sediments. Furthermore, granitic and granite gneiss pebbles in the conglomerates must have had a source other than the volcanic sequences. In any single volcanic belt the acidic lavas and pyroclastics are scattered and form a relatively small part of the total volume of lava. They are a source, but only for neighbouring parts of the basin. The volcanic rocks flanking the sedimentary basins probably provided many of the coarse clasts in the conglomerates and part of the quartz and feldspar in the sands, and granitic and quartz boulders and some of the sand detritus were probably supplied by areas underlain by plutonic rocks. As the composition of greywacke type and the clasts in the conglomerates vary throughout the region the relative importance of the two sources also varies.

Whether the various belts represent the remnants of separate geosynclines of different age or of one large complex geosyncline, since distorted by orogeny, is unknown. It seems more likely, however, that the volcanism was localized along a number of easterly trending zones of weakness and that volcanic rocks never covered the whole region as a continuous sheet. Because of their thickness and resistance to granitization the rocks have survived subsequent orogeny and may have influenced the tectonic trends of that orogeny. As sedimentation also took place within and about these belts, source areas must have existed between some of the volcanic belts. These areas of ancient crust have since been modified or destroyed during subsequent orogenies as there is little direct geological evidence of the existence of basement. The granitic rocks along the margins of belts of Archean rocks invariably are intrusive into them. Archean rocks along the gneiss belts are either separated from the gneisses by faults or grade into them through zones of increasing metamorphism. One possible exception is reported from the Cross Lake area in Manitoba (Rousell, 1965) where sediments of the Cross Lake Group, said to conformably overlie basic lavas, rest unconformably on granodiorite gneiss that is, therefore, interpreted as basement to both volcanic and sedimentary rocks. Timiskaming rocks in the Kirkland Lake area are separated from older Archean volcanics and sediments by an angular unconformity. These sediments and associated potash-rich trachytic lavas which contribute debris to the sediments differ from normal Archean successions. Timiskaming rocks may be younger than normal Archean sediments, having formed in a special local environment not found elsewhere in the province.

Kenoran Orogeny

All the Archean rocks in Superior Province have been affected by the Kenoran Orogeny which involves a sequence of events, possibly complex but to a large extent undetermined, that include folding, shearing, metamorphism, and intrusion of granitic rocks. Archean rocks in most parts of the province are folded about easterly trending axes. The folds plunge at moderate angles either east or west. Some folds are modified by late cross-folds whose axial planes dip steeply and strike northwest, north, or northeast. The younger folds have fairly steep plunges. Thick bands of volcanic rocks commonly are broadly folded or occur as homoclinal successions; thin volcanic bands and sediments are more complexly folded. Chlorite–carbonate shear zones in thick volcanic sequences near or along volcanic-sedimentary contacts in many places are nearly parallel with the regional trend of fold axes and locally occur along the axial zones of folds. They may form during the folding and cut granitic rocks, but in some areas they appear to be older than late tectonic intrusions.

Granitic rocks of various compositions intrude Archean rocks and large volumes of the sediments, and some volcanic rocks have been converted to granitic gneisses by processes of granitization. Highly metamorphosed and granitized rocks are extensively developed in several long easterly trending belts, the Quetico and English River Subprovinces of western Ontario. Other unnamed belts are located in New Quebec and along the southern margin of the Noranda–Kirkland Lake volcanic belt. The zones of gneisses are locally separated from older rocks by major fault zones. In most areas, however, recognized sedimentary or volcanic rocks can be traced through increasing zones of metamorphism and degrees of granitization into these gneisses. The gneisses are cut by batholiths of more massive granitic rocks. The structural trends, probably foliation, in these belts tend to be regular and linear, striking in an easterly direction. These rocks appear to be Archean rocks transformed into gneisses in deeply depressed parts of the geosyncline. Relatively massive granitic masses are higher level intrusions. The areas between the Archean rocks and gneiss zones are underlain in large part by granitic rocks with curvilinear structural trends (Stockwell, 1964). The granitic rocks in these areas appear to be syntectonic batholiths of slightly gneissic granitic rocks separated by zones of older rocks or granitic gneisses and migmatites that are cut by late tectonic, massive, and slightly more acidic granitic instrusions. Similar rocks are intruded into the volcanic-sedimentary belts. Age determinations from samples of all these granitic rock types give ages that range from about 2,300 to 2,600 m.y. and average 2,490 m.y. Compositions of the various granitic masses vary but granodiorite, quartz diorite, and quartz monzonite appear to be most abundant with lesser amounts of granite and syenite. The potash-rich rocks are usually massive, younger than the other granites, and late tectonic.

Pegmatites and pegmatitic granites are common components of the gneiss belts, but pegmatite dyke swarms, concentrated around related granites, are found in several widely scattered areas in the province. The related granites are usually massive, late tectonic, albite granites or potash-rich, muscovite granites or granodiorites. Several of these pegmatite areas occur in gneiss zones. Pegmatites may or may not be internally zoned and are commonly zoned away from the related granite. Some contain spodumene, beryl, or tantalite–columbite.

The Archean rocks are always metamorphosed to some degree, varying from greenschist to amphibolite facies. Common mineral assemblages in greywacke and shales in the higher grade facies include plagioclase–biotite–garnet or andalusite, cordierite, staurolite, biotite and plagioclase and locally sillimanite. In lower grade facies, chlorite, sericite, biotite, and plagioclase are the essential minerals. In basic volcanic rocks blue-green hornblende, plagioclase, and locally garnet occur in the amphibolite facies, and in the less metamorphosed rocks chlorite or actinolite, plagioclase, and commonly epidote. In the gneiss zones metamorphism reaches amphibolite and locally granulite facies and in northern Quebec large areas are underlain by rocks of the granulite facies. As metamorphism increases primary textures and most structure may be progressively destroyed.

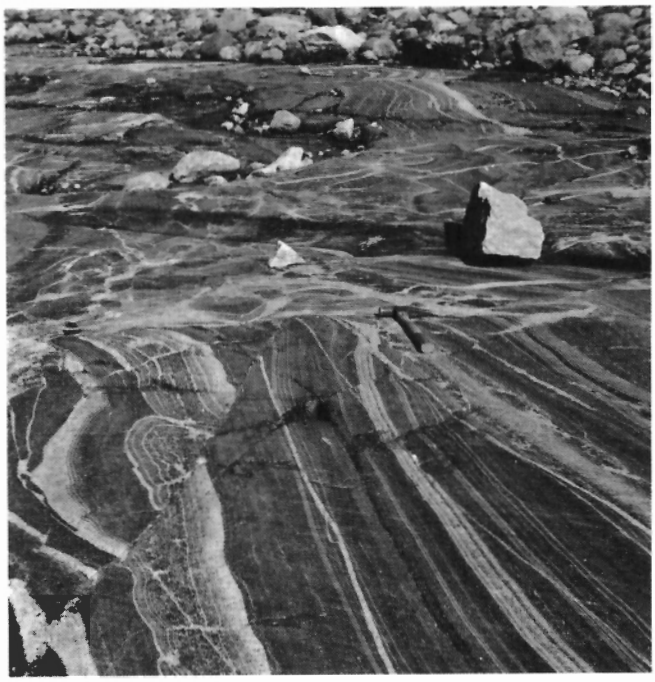

PLATE IV-1. Partly migmatized Archean greywacke, Superior Province, Povungnituk, Quebec.

Northeastern Superior Province

The geology of northeastern Superior Province differs from that of the rest of the province (Eade, 1966a; Stevenson, 1963, 1965). Recognizable Archean pre-granitic rocks are much less abundant; large areas are underlain by granitic gneisses and by metamorphic rocks of the granulite facies. Structural trends in the southern half are similar to those in the remaining part of Superior Province, but in the northern part strike almost at right angles. Lack of recognizable sedimentary volcanic rocks, high grade of metamorphism, and intense granitization all suggest that a deeper level of the orogen or crust is exposed in the northern part, which may also account for the change of structural style.

The oldest known rocks are basic lavas, intermediate and acidic lavas and pyroclastics, small ultramafic intrusions, some greywacke, quartzite conglomerate, and iron-formation. These rocks are best developed east of James Bay, occurring in two easterly trending belts separated by a wide zone of highly metamorphosed sediments, migmatites, granitized rocks, and granitic gneisses. Narrow bands of highly metamorphosed sedimentary and volcanic rocks that are possibly equivalents are scattered throughout the granitic rocks in the northernmost part of the province. The zone of gneisses between the two southern belts of Archean rocks apparently originally consisted largely of sedimentary rocks that have been metamorphosed, granitized, migmatized, and then intruded by granodiorites, presumably during the Kenoran Orogeny. Archean rocks also grade into granitic gneisses through zones of migmatites and mixed gneisses. These gneisses are also intruded by massive biotite and/or hornblende granites, granodiorites, and quartz diorites that are probably late tectonic.

In the southeastern and northern parts of the region hornblende-granulite facies rocks underlie large areas. They are coarse-grained, rusty or white weathering, faintly banded gneisses grading to strongly banded, rusty weathering paragneiss characterized by fine-grained, biotite-rich metasedimentary material. Greenish plagioclase with a greasy lustre, blue or dark grey quartz, hypersthene or augite, hornblende, and biotite are common constituents. Garnet is locally present. Because of the banding of these gneisses and the presence of biotite-rich bands, Eade (1966a) suggests that they are derived from sedimentary rocks, possibly of the greywacke type. Rocks of the amphibolite facies grade into the rocks above and contain similarly oriented minor structures. Quartz, plagioclase, biotite, hornblende, epidote, and usually microcline are characteristic minerals in the granitized varieties of this facies. The structure of the rocks in the area is not known in detail. South of about latitude 57 degrees, Archean rocks and their metamorphosed and granitized equivalents occur in easterly to east-northeasterly trending folds. These structures probably are modified by cross-folds along northwest and northeast axes. North of latitude 57 degrees the regional trend is northwest to north-northwest. This area is essentially underlain by granitic gneisses with few rem-

nants of recognizable volcanic or sedimentary rocks and may represent a deeper crustal level.

The gross chemistry of this part of the Canadian Shield is shown in Table IV-2, based on analyses by a combination of X-ray fluorescence and chemical methods, of 78 composite samples (Eade, *et al.*, 1966). No significant regional variations in chemical composition were found and therefore variation of primary rock type in the area is unlikely. A comparison of the average compositions of rocks of the amphibolite and granulite facies shows minor but probably significant differences. Values for Al_2O_3, total FeP_2O_5, TiO_2 and possibly MgO and CaO, are higher in the granulite facies than in the amphibolite, and the amounts of K_2O, H_2O, and possibly SiO_2 are lower. These differences are attributed to loss by upward movement of more mobile constituents during regional metamorphism.

Isolated patches of clastic sedimentary rocks are scattered along two belts in the southeastern part of the region. These rocks have been named the Sakami Formation by Eade (1966a). The lower part of the formation is a red bed sequence composed of boulder conglomerate, arkose, mudstone, and siltstone, and the upper part is quartzite. Exposed thicknesses vary from 1,600 to 1,800 feet. The rocks are unmetamorphosed and flat lying except near the bordering north to northeasterly striking faults and form tectonically preserved basins. The lower red beds may have been deposited in fault-controlled basins but the upper quartzites were probably much more extensive. The Sakami rocks are similar to other Proterozoic sequences such as the Dubawnt Group and the Martin and Athabasca Formations in Churchill Province.

The youngest rocks are diabase dykes that strike northerly, northwesterly, and east-northeast. The northwesterly striking dykes are abundant in the northern part of the area. They have been dated at about 2,150 m.y. (Fahrig and Wanless, 1963). North-northwesterly dykes in the southern part of the area yield ages of about 1,900 m.y.

TABLE IV-2 *Average chemical composition of rocks from northeastern Superior Province (Eade, et al., 1966)*

	1	2	3	4	5
SiO_2	64.5	64.7	63.4	65.26	60.3
Al_2O_3	16.1	16.0	16.7	15.67	15.6
Fe_2O_3	1.5	1.5	1.5	1.44	—
FeO	2.9	2.9	3.4	2.82	7.2*
MgO	2.3	2.3	2.2	2.55	3.9
CaO	3.3	3.3	3.6	3.51	5.8
Na_2O	4.0	4.0	4.0	3.83	3.2
K_2O	2.78	2.81	2.58	2.93	2.5
H_2O (total)	0.8	0.9	0.7	0.82	—
TiO_2	0.48	0.47	0.53	0.46	1.0
P_2O_5	0.16	0.16	0.19	0.02	—
MnO	0.08	0.08	0.07	0.07	—
CO_2	0.2	0.2	0.2	0.16	—
Total	99.10	99.32	99.07	99.54	99.5

1. Average composition of 200,000 square miles of northern Quebec, calculated from rapid rock analysis of 78 composite samples using X.R.F. and other methods.
2. Average composition of all amphibolite facies rocks of the area.
3. Average composition of all granulite facies rocks of the area.
4. Average composition of selected rocks determined by classical chemical analysis (J. A. Maxwell, analyst).
5. Average composition of the continental crust, one part basic and one part felsic rock (Taylor, 1964).

* Total iron.

Mistassini Subprovince

Three groups of sediments occur in the Lake Mistassini region that are probably Aphebian in age as they are present as a little-deformed cratonic cover on the Archean. The older rocks constituting the Chibougamau Group are between Lake Chibougamau and Lake Mistassini. They consist of paraconglomerate, arkose, and shale lithologically similar to those of the Gowganda Formation of the Huronian Supergroup of Southern Province and are probably correlatives.

The Otish Mountains Group, northeast of Lake Mistassini, is about 3,000 feet thick and consists of medium- to coarse-grained quartzite and subarkose, which near the base contain numerous layers of grit and lenses of quartz-pebble conglomerate (Bergeron, 1957b). These rocks are overlain by red subarkose, shale, and siltstone. They are not metamorphosed and are very gently folded. Deformation increases to the southeast near the Grenville Front. According to S. M. Roscoe, the Otish Mountains strata are similar to the Lorrain Formation of the Huronian Supergroup and they may be correlative.

The Mistassini Group occurs around Lake Mistassini. It has been divided into five formations (Bergeron, 1957a). The lowest formation, the Papaskwasati, comprises well-bedded quartzite and feldspathic quartzite with quartz-pebble conglomerate lenses near the base. The succeeding Cheno River Formation is composed of conglomerate, subarkose, and greywacke interbedded with dolomite. Grey dolomites with shale and ferruginous dolomite interbeds of the Lower Albanel Formation are followed by a thick sequence of sandy dolomites with stromatolitic zones, dolomite, and quartzite of the Upper Albanel Formation. The youngest formation, the Temiscamie, is composed, in order of succession, of quartzite with conglomerate lenses, slate, iron-formation, and slate. The thickness of the Mistassini Group is at least 6,500 feet and disconformities occur at the bases of the Upper Albanel and Temiscamie Formations. The Mistassini strata have a north–northeasterly to northeasterly strike and a regional dip to the southeast. They are gently folded about northeasterly striking axes and cut by faults that trend parallel with the fold axes. Along the southeastern margin of the basin, a

thrust fault that dips 44 to 55 degrees to the southeast separates Mistassini rocks from gneisses of Grenville Province. The sediments are sheared and steeply dipping near the fault and the gneissic rocks on the south side are crushed and sheared. On the basis of stratigraphic and lithologic similarities, particularly the presence of iron-formation, the Mistassini Group is tentatively correlated with Aphebian rocks of the Kaniapiskau Supergroup of the Labrador Geosyncline. The iron-formations, although much deformed in Grenville Province, are nearly contiguous. The relative ages of the Otish Mountains and Chibougamau sequences with Mistassini rocks are not established.

Strata of the Otish Mountain Group are intruded by gabbro sills that are dated at about 1,900 m.y. North–northwesterly diabase dykes intrude Mistassini, Otish, and older rocks.

Timmins–Noranda–Malartic Area

Volcanic and sedimentary rocks of the Timmins–Noranda–Malartic area are part of the largest and probably thickest Archean complex in Superior Province. These rocks underlie much of Abitibi Subprovince. Despite much geological work details of the Archean stratigraphy and of lateral facies variation within the belt remain largely unknown. The stratigraphy in local areas has been established but it is impossible to correlate between these areas with confidence.

In the Cadillac–Malartic area, Gunning and Ambrose (1939) have divided the Archean rocks into four groups (Fig. IV-6). The Malartic Group at the base consists of basic lavas and pyroclastics with acidic lavas and tuffs near the top. Numerous gabbroic and ultramafic masses occur in the basic lavas and felsic intrusions are included with the acidic volcanics. A minimum thickness of 10,400 feet has been estimated at one locale where the structure is known, but it seems likely that in other places at least 20,000 feet of flows may be exposed. The Kewagama Group overlies these rocks conformably. In several places interbedding of the sedimentary and volcanic rocks indicates a gradual transition from volcanism to sedimentation. The Kewagama Group comprises greywackes and argillites, which commonly occur as graded couplets, some quartzites, and scattered lenses of conglomerate that usually are present near the base of the group. Boulders in the conglomerates consist of volcanic debris with some rare cobbles of quartz and granitic rocks. North of Cadillac fault, the Kewagama sediments are 1,000 to 3,000 feet thick, and locally as much as 10,000 feet. The Blake River Group of volcanic rocks conformably overlies the Kewagama and the contact is characterized by interbedding and interfingering of sediments and volcanics. The Blake River Group comprises basic to intermediate flows and pyroclastics, and acidic flows and tuffs with related intrusive gabbros, diorites, and felsitic rocks. The acidic flows are most abundant in the upper part of the sequence, particularly in the thick sections. These volcanics thicken from west to east along strike from a few hundred to thousands of feet, mainly due to a greater amount of acidic material. Gunning and Ambrose estimate a minimum thickness in the Malartic area of about 16,000 feet and in the Noranda area to the east a section of 40,000 feet has been measured (Baragar, 1966). These rocks are overlain by the Cadillac Group which consists of greywacke, some conglomerate, and minor amounts of tuff, iron-formation, and quartzite. A minimum thickness of 15,000 feet of strata is exposed. Gunning and Ambrose (1939) consider that these rocks overlie the Blake River volcanics conformably. No structural discordance was noted and interbedding and interfingering along strike of the two units were found in several areas. However, to the east, south of Noranda, M. E. Wilson (1962) presents evidence for an unconformity at the base of the Cadillac Group. The stratigraphic relationship determined by Gunning and Ambrose is on the north limb of a syncline, the axis of which trends east to southeast and lies north of the Cadillac fault. The fold axis is within Cadillac sediments and these rocks are on opposite limbs of the fold. The stratigraphy of the older rocks on the south limb of the fold is certain. A wide zone of shearing along the Cadillac fault obscures relationships and the hinge of the fold is breached by the fault. A thin band of volcanic rocks occurs beneath the Cadillac sediments on the south limb of the syncline at the east end of the belt of sediments. The sediments and volcanics are structurally conformable and both face north toward the fold axis. Gunning and Ambrose (1939) on the basis of lithologic similarity, stratigraphic position, and orientation of minor structures include these volcanics with the Blake River Group. Metamorphosed greywacke and shale of the Pontiac Group lay beneath the volcanic rocks with apparent conformity and face north near the contact with the volcanics. The Pontiac Group is more highly metamorphosed and complexly folded than rocks north of the Cadillac fault and grades southward into granitic gneisses. Thin conformable bands of basic volcanic rock are present within the sediments which are correlated by Gunning and Ambrose with the Kewagama Group. The extensive distribution of the Pontiac Group and the lack of underlying Malartic rocks have been attributed to southward thickening of the sediments, thinning of the Malartic volcanics, or tectonic thickening of the less competent sediments. Latulippe (1966) postulates that the Pontiac sediments are the equivalents of both Malartic volcanics and Kewagama sediments (Table IV-3).

In the Noranda area great thicknesses of volcanic rocks are present that appear to be equivalent to the Blake River Group. They are overlain by sediments of

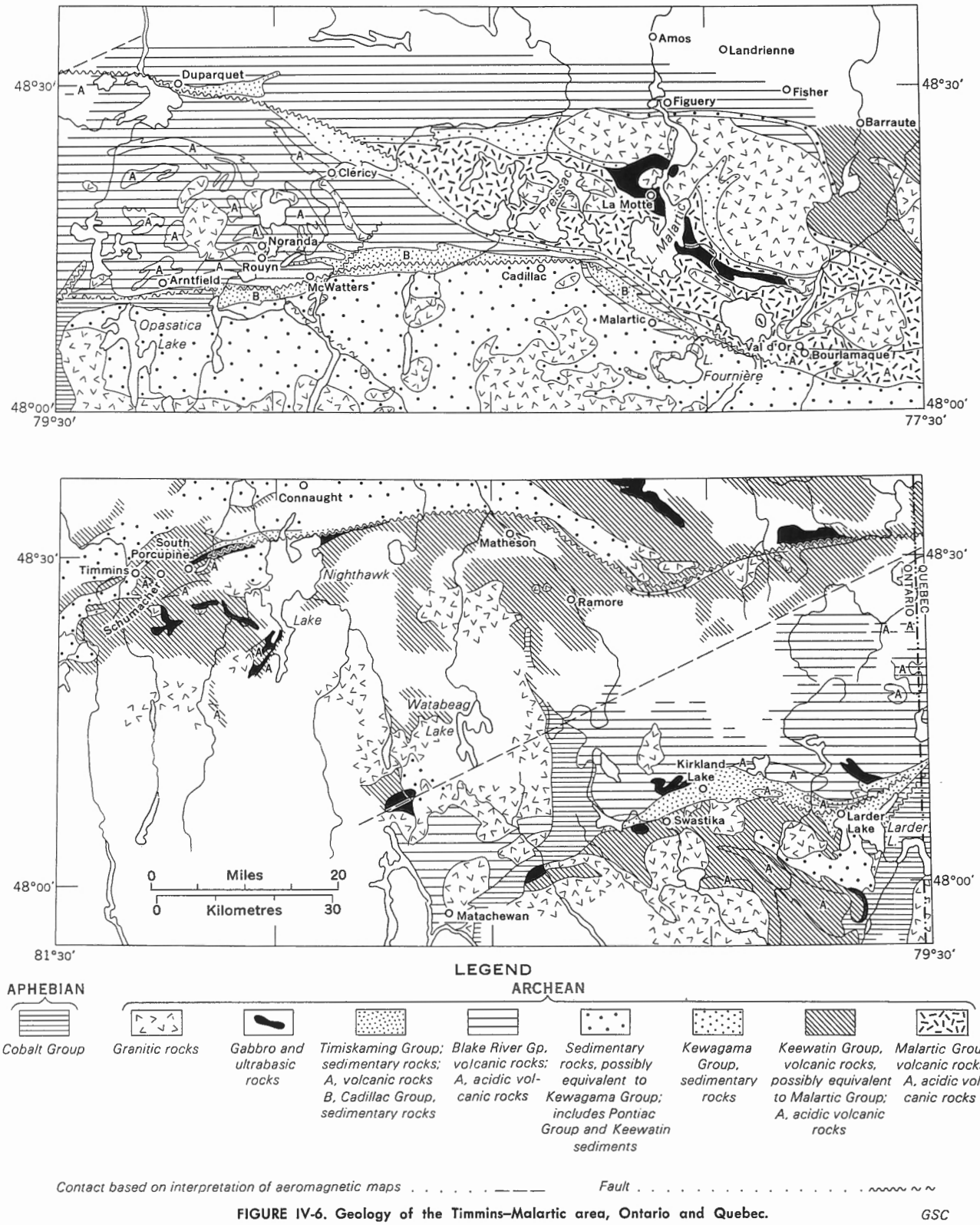

FIGURE IV-6. Geology of the Timmins–Malartic area, Ontario and Quebec. *GSC*

the Cadillac Group, separated at least locally by an unconformity. The Cadillac sediments also unconformably overlie the Pontiac Group which, although not in contact with volcanic rocks of the Blake River Group locally, contains bands of flow rocks. Lead isotope data from sulphide deposits in the volcanics can be interpreted to

yield ages of 2,900 to 3,000 m.y. (Roscoe, 1965). If these deposits are related to the volcanism then this is possibly the age of the Blake River rocks.

In the Kirkland Lake and Larder Lake areas of Ontario, similar rocks occur along the strike of those described above. The oldest rocks are the Keewatin volcanics which are similar to the Blake River Group and are no doubt part of the same volcanic sequence. Greywacke and shale occur within and overlie the volcanic rocks. The Timiskaming Group unconformably overlies the Keewatin near Kirkland Lake, although to the east near Larder Lake the rocks are structurally conformable and the contact is mapped as a disconformity (Hewitt, 1963). Typical Timiskaming rocks occur in the north limb of an easterly striking syncline, the south limb of which is cut off by the easterly striking Larder Lake fault. As much as 16,000 feet of rocks are exposed in this structure and as the top of the sequence is not present, this represents a minimum thickness for the Timiskaming Group. The succession comprises greywacke, shale, conglomerate, and trachytic flows and tuffs. The conglomerate, 4,000 feet thick, occurs as lenses at a number of places within the other sediments. Trachyte and acidic porphyry constitute the bulk of the pebbles; granitic pebbles are very rare. The volcanism and sedimentation were contemporaneous, as the volcanic rocks were eroded to provide the boulders in the conglomerates and probably also the tuffaceous debris in the fine-grained greywacke. Roscoe (1965) points out that the Timiskaming rocks are of a chemical suite unique to Superior Province. They are alkalic rocks rich in potash, soda, barium, and strontium. Lead–zinc veins within the sequence yield lead isotope ratios that have modal ages of 2,350 m.y. which suggests that the mineral deposits and possibly also their host rocks were formed during the Kenoran Orogeny. They would be, therefore, much younger than the Keewatin volcanics and sediments. Greywacke, shales, and conglomerates south of Larder Lake and the Larder Lake fault normally are correlated with the Timiskaming rocks described above, but do not contain trachytic volcanics. Also there are differences in the composition of the conglomerates in the two belts (Hewitt, 1963). Trachytic rocks are a major component of the pebbles in the northern conglomerates but are rare or absent in the south. Pebbles of chert, jasper, and iron-formation are more abundant in the northern conglomerates. It is possible that the two sequences are correlative, but the sediments south of Larder Lake may be equivalent to the Pontiac and Kewagama Groups, in which case the underlying lavas would be equivalent to the Malartic Group;

TABLE IV-3 *Alternative correlations of Archean rocks, Abitibi Subprovince*

Porcupine	Kirkland-Larder Lakes	Noranda	Malartic
Timiskaming sediments 1,500′ minimum	Timiskaming greywacke shale trachyte tuff (may be younger than Cadillac) 16,000′	Cadillac conglomerate greywacke shale	Cadillac conglomerate greywacke shale 5,000′
unconformity	unconformity or disconformity	unconformity	
	Keewatin basic volcanics acid volcanics tuff	Blake River basic volcanics acid volcanics tuff 40,000′	Blake River basic volcanics acid volcanics tuff 6,000′ minimum
Keewatin sediments greywacke shale conglomerate 3,000′	(may include sediments equivalent to Pontiac or Cadillac and volcanics equivalent to Malartic)	Pontiac greywacke shale metamorphic equivalents	Kewagama greywacke shale 10,000′ minimum
Keewatin basic volcanics acid volcanics tuff 6,000′ minimum		(sediments may be equivalent to Malartic)	Malartic basic volcanics acid volcanics tuff 10,000′ minimum

or they may correlate with the Cadillac Group which is likewise devoid of trachytic lava.

In the vicinity of Timmins, northwest of Kirkland Lake, a similar succession has been established (Ferguson, 1966). The oldest rocks are basic lava flows, about 4,000 feet thick, massive or pillowed, and with minor related phases such as variolitic flows, breccias, and basic tuffs. Gabbro, diorite, and related differentiates intrude the lavas, and thin layers of argillite and of cherty rocks are interbedded. The lavas are conformably overlain by as much as 2,000 feet of acidic pyroclastics with minor lavas and related intrusions. Roscoe (1965) points out that these volcanic rocks have a different expression on regional aeromagnetic maps than do the lavas in the Kirkland Lake area (Fig. IV-7). On such maps a northeasterly trending contact can be drawn between two magnetic regional patterns. A few top determinations indicate that flows on both sides of this line face south and therefore the lavas in the Porcupine area are oldest; they may be equivalent to Malartic flows. The lavas are conformably overlain by as much as 3,000 feet of greywacke and argillite commonly referred to as Keewatin or Keewatin-type sediments. They are overlain unconformably by a minimum of 1,500 feet of thinly bedded alternations of greywacke and shale of various types with a few beds of quartzites and conglomerate of variable thickness at or near the base. Basic and acidic volcanic rocks comprise the bulk of the pebbles in the conglomerate. The sediments are generally considered to be equivalent to the Timiskaming Group. Ultrabasic rocks appear to be intruded along faults such as the Destor–Porcupine and are later than the youngest sediments.

A fourfold division of the Archean rocks has been established at the eastern end of the Timmins–Noranda–Malartic belt. In other parts of the belt where the stratigraphy is known such a division may be valid but regional correlations are uncertain. All the Archean rocks are folded along easterly trending axes. These folds appear to be modified in places by cross-folds of various orientations, and are cut by several easterly trending faults with wide chlorite–carbonate shear zones. Major faults of this type, such as the Larder Lake, Cadillac, and Destor–Porcupine, occur at or near the axes of synclines. Lead isotope data from gold deposits within the fault zones or related structures suggest that they formed during the Kenoran Orogeny, and accordingly the shearing probably

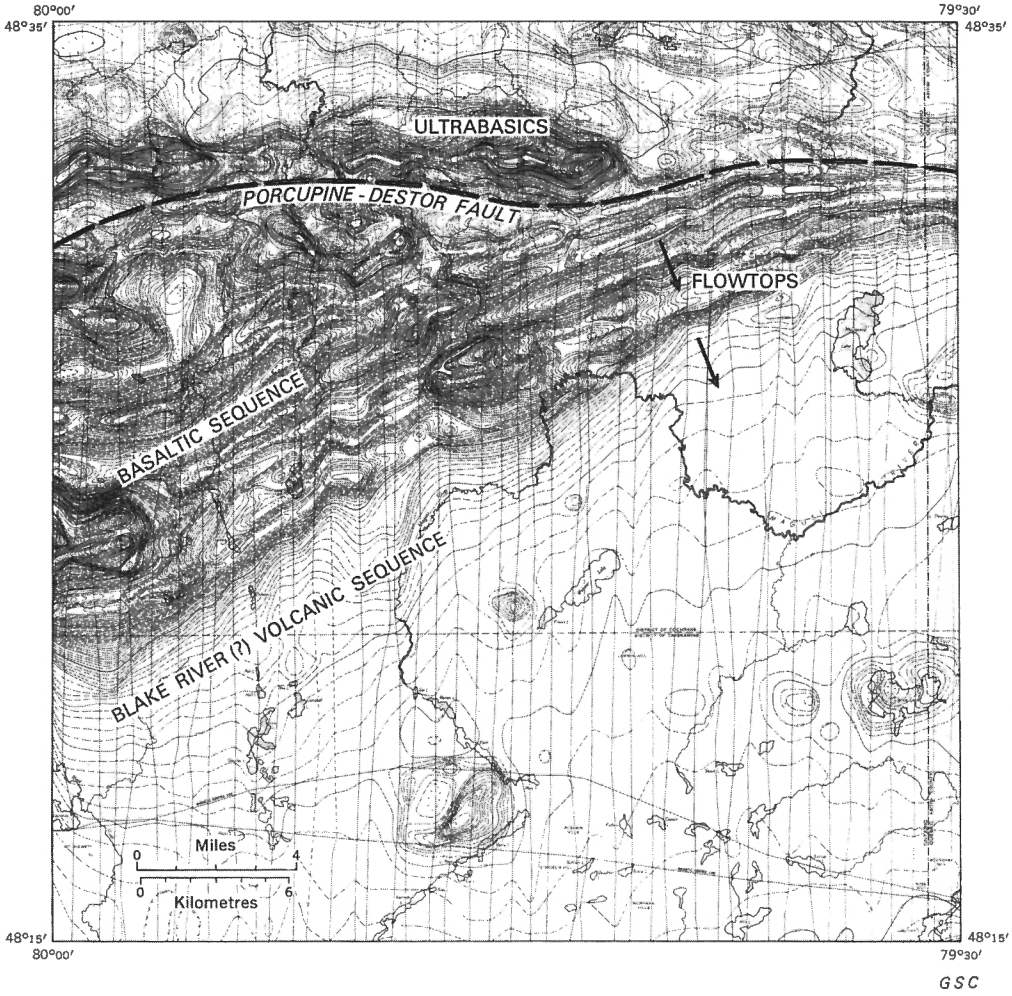

FIGURE IV-7
Aeromagnetic expression of the volcanic sequence in the Timmins-Kirkland Lake area, Ontario (Roscoe, 1965).

took place during the folding. The Archean rocks are cut by granites of various composition. The younger, higher level stocks tend to be richer in potash than the larger batholiths and granitic gneisses. Metamorphism, except near the contacts with granitic rocks, is generally in the greenschist facies. These rocks are cut by faults that trend northwest, north-northwest, and northeast and that are much younger. Some cut rocks of Aphebian age, displace diabase dykes that are as young as 1,200 m.y., or flank a graben of Ordovician and Silurian sediments.

Kapuskasing Subprovince

In Kapuskasing Subprovince the intensity of the gravity and magnetic fields is anomalously high (Fig. IV-8). Much of the geology is typical of Superior Province (Bennett, *et al.*, 1966). The oldest rocks are basic to acidic volcanic flows and pyroclastics with greywacke and shale. They occur in easterly trending belts, folded about easterly to southwesterly axes. Metamorphism is at the amphibolite grade, and along the margins of belts the sedimentary and volcanic rocks grade to biotite–hornblende–quartz–feldspar gneiss and migmatite. Banding is parallel with structures in the volcanic and sedimentary rocks and the gneisses are considered to be their highly metamorphosed and granitized equivalents. Basic rocks intrude the older rocks and possibly also the gneisses. All rock types are cut by synorogenic granitic intrusive rocks that include granodiorite, quartz monzonites, granite, and pegmatites. These masses occur as large batholiths or smaller stocks and are commonly bounded by migmatite. A south-southwesterly striking belt of amphibole–pyroxene–garnet–feldspar gneiss of the granulite facies of metamorphism is partly bounded by faults. Foliation is parallel with the trend of the belt and therefore transects the regional easterly structural trends of Superior Province. The belt is about 120 miles long and 6 to 12 miles wide. The pyroxene-bearing gneiss appears to occur in a zone of complex faulting in which individual faults strike north to northeast and are marked by zones of intense shearing and bands of mylonite. The gneiss is in blocks separated from each other by faults

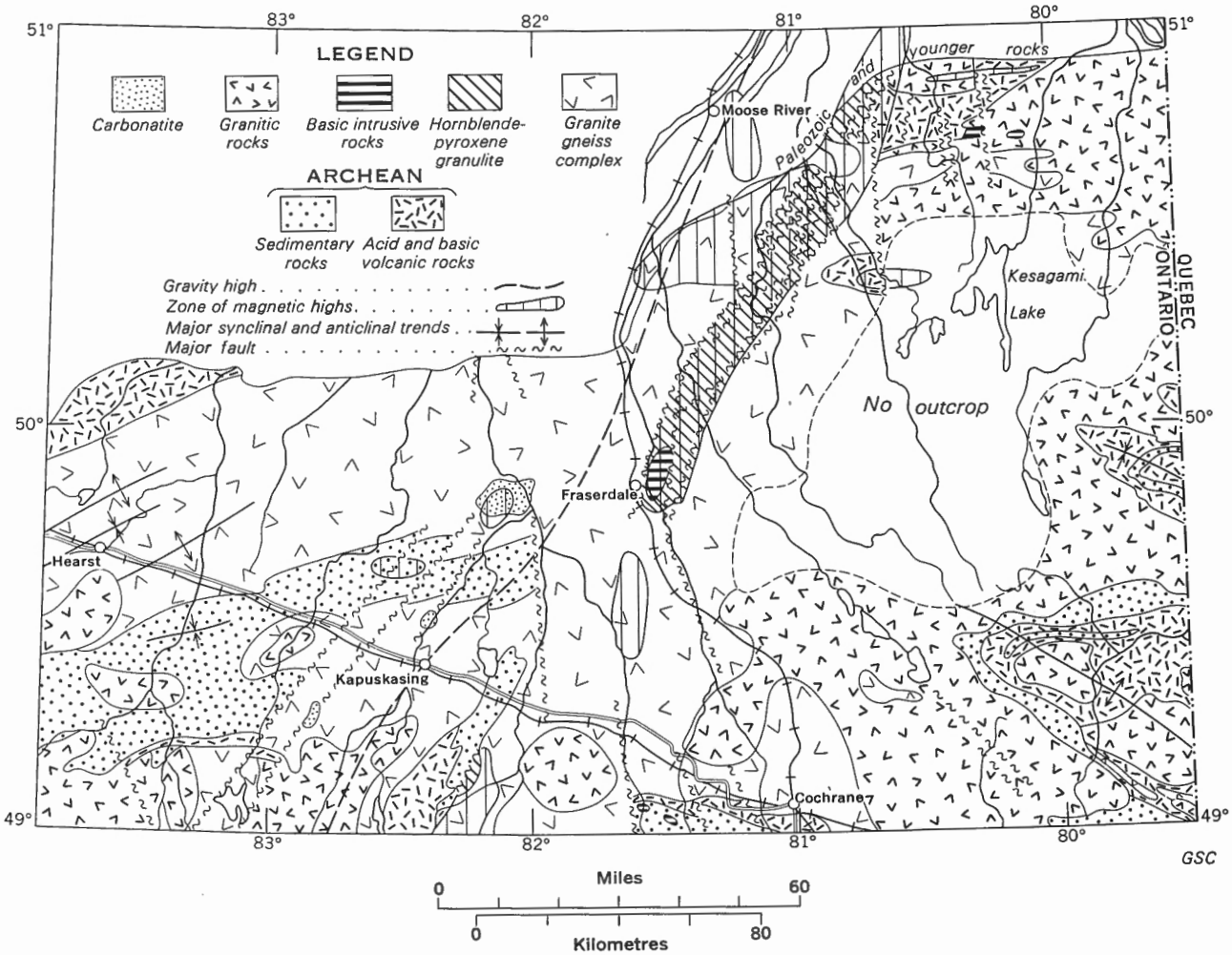

FIGURE IV-8. Geology of a part of Kapuskasing Subprovince, Superior Province, Ontario.

and appears to owe its present position to movement along the faults.

Of the fifteen known alkaline complexes in Superior Province ten are in the subprovince (Fig. IV-9). According to Parsons (1961) they are small, elliptical-shaped masses that cut granitic gneiss, basic volcanic rocks, or pyroxene-bearing gneiss. Individual masses generally have a central core of carbonatite bounded by nepheline syenite of variable composition and zones of pyroxenite or pyroxene and carbonate-rich rock. The essential minerals of the syenite are alkaline feldspar, nepheline, soda pyroxene, and ferric biotite. Parsons suggests that the sequence of events included first the drilling of a central diatreme by explosive gases and the ejection of alkaline volcanic rocks, since eroded; this was accompanied by alkaline metasomatism of the country rocks and followed by the carbonatization of the rocks of the volcanic neck and the emplacement of carbonatite and syenite. Many of the carbonatite complexes lie in or near major northeast-striking faults (Bennett, *et al.*, 1966) that are probably related to the faults that bound the zones of pyroxene-bearing gneiss. Eleven of the alkaline complexes have K–Ar dates that with one exception fall into two well-defined groups averaging about 1,050 m.y. and 1,700 m.y. (Gittins, *et al.*, 1967). One complex yielded a date of 1,560 m.y. These dates suggest that the faulting took place either almost continuously from about 1,700 to 1,050 m.y. ago or mainly during the two separate intervals that correspond approximately to the Hudsonian and Grenvillian Orogenies. The younger period of intrusion also roughly correlates in time with the extrusion of Keweenawan lavas in the Lake Superior region. It is possible, then, that this narrow fault complex was imposed on the stable Superior craton during the Hudsonian Orogeny and reactivated during the Grenvillian Orogeny.

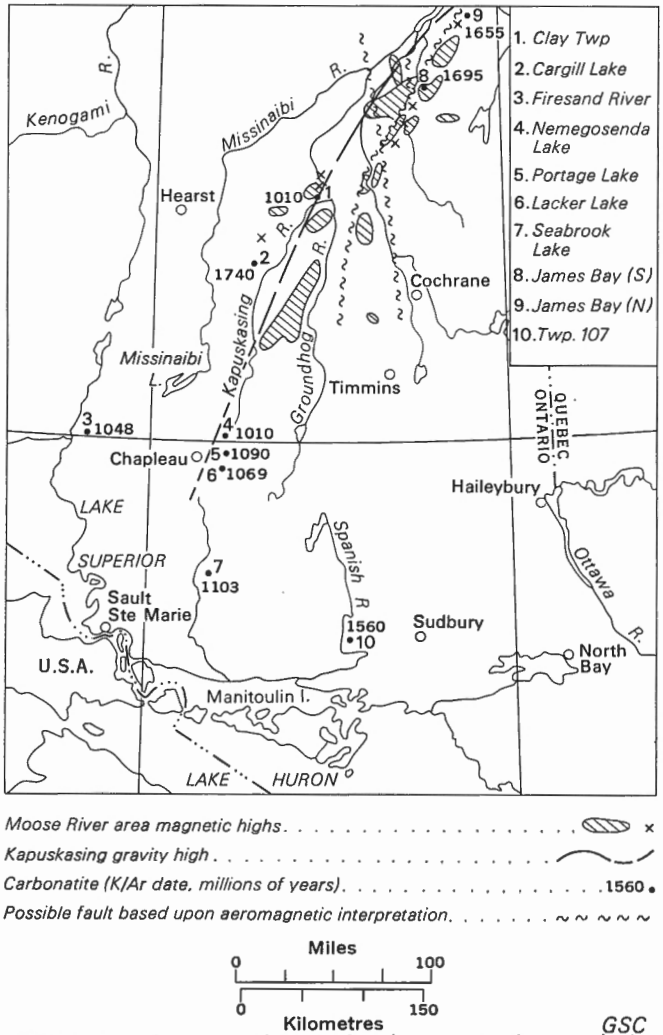

FIGURE IV-9. Location and ages of carbonatites in the Kapuskasing Subprovince, Superior Province, Ontario.

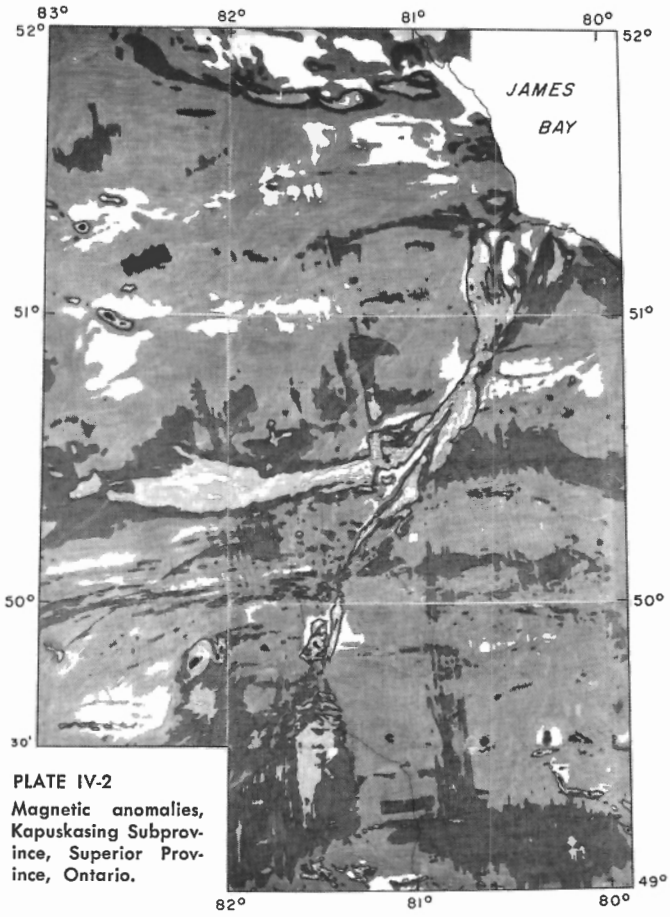

PLATE IV-2
Magnetic anomalies, Kapuskasing Subprovince, Superior Province, Ontario.

Two separate, but probably related, geophysically anomalous zones are present in the area. The zone of anomalously high magnetic intensity is in two parts (Pl. IV-2). In detail these regional highs are composed of a number of individual magnetic peaks separated by areas of lower magnetic intensity. The northern part corresponds approximately to the belt of pyroxene-bearing gneiss and also to a large gabbro intrusion. The southern part is underlain by foliated granitic rocks that include some zones of pyroxene-bearing gneiss. Other small

magnetic anomalies are related to the alkaline complexes or gabbro and ultramafic intrusions. Linear anomalies occur over diabase dykes and some faults. Two narrow linear belts of low intensity correspond with the complex of faults that bound the pyroxene-bearing gneiss. Gaucher (1966) considers that the aeromagnetic anomalies can be directly correlated with the magnetic susceptibility of the rocks presently exposed.

The Kapuskasing gravity high (Innes, 1960) is a broad regional feature, the axis of which trends southwesterly from Moosonee on James Bay to Chapleau and lies about 20 miles west of the magnetic high. Some local gravity anomalies appear to be related to the dense pyroxene-bearing gneiss or the basic intrusions. The regional gravity high, however, may reflect not only the exposed pyroxene gneiss, but also unexposed zones of these rocks or deeper seated crustal displacements involving the mantle.

Quetico Subprovince

Quetico Subprovince is characterized by linear structures that trend easterly contrasting with the curvilinear structures in the granitic terrains beyond the borders of the belt. The belt is as much as 60 miles wide and extends from Rainy Lake eastward for about 500 miles to Kapuskasing. The rocks are highly metamorphosed sediments, migmatites, granitized gneisses, and gneissic or massive granitic rocks of approximate granodiorite composition. Towards the margins of the belt the degree of metamorphism and granitization tends to decrease so that the nature of the original sediments can be studied. The belt of gneisses is bounded along a large part of the strike length by bands of Archean volcanic and sedimentary rocks.

Most of the sediments and their metamorphosed equivalents within the western part of Quetico Belt have at one time or another been referred to as Couchiching, a name applied by A. C. Lawson in 1888 to metamorphosed sediments that occur below the Keewatin lavas in the Rainy Lake area. The term has since been used for sediments and their metamorphosed equivalents in various parts of Quetico Belt, and it has been argued that such rocks occur stratigraphically below, within, and above Keewatin-type lavas or are separated from the lavas by a fault (Pettijohn, 1937; Goldich, *et al.*, 1961). The sediments are for the most part metamorphosed to about the amphibolite facies and consist essentially of quartz, plagioclase, and biotite. Muscovite, iron oxide, garnet, microcline, staurolite, hornblende, and cummingtonite occur in various combinations. The structure is gneissic, and the micas well oriented and concentrated in bands. Near the boundaries of the belt where the metamorphism is less intense, relict clastic textures and graded bedding can be found, which indicates that the rocks were originally a type of greywacke. Their chemical composition in the Lac des Mille Lacs area northwest of Port Arthur corresponds to that of greywacke. The thickness is unknown, but in a number of areas several thousand feet is exposed. In the interior of the belt, the sediments are granitized and intruded with granitic rocks. Migmatite zones varying in width occur along the margin of granitic rocks. The latter rocks vary in composition from granodiorite to granite and may be richer in potash than the granitic rocks outside the belt.

The Couchiching rocks are folded into easterly to southwesterly trending folds. Foliation is similarly oriented as a rule. Structures in other adjoining Archean rocks also have the same orientation so that Couchiching-type sediments are structurally conformable with Keewatin-type lavas and sediments. Faults are marked by rather wide shear zones containing chlorite and carbonate in volcanic rocks and by mylonite in the more siliceous rocks. They occur along the contact between the Couchiching sediments and Keewatin-type basic volcanics; one extends for 60 miles, from Lac des Mille Lacs to Steeprock Lake (Hawley, 1930); a second major fault occurs along the southern boundary of the belt in the Kashabowie Lake area. Top determinations, particularly in the sediments on both sides of these faults, indicate that the Couchiching strata underlie the volcanic rocks.

Recent work (Goldich, *et al.*, 1961) in the type area confirms Lawson's work and places the Couchiching metasediments conformably below Keewatin lavas. In Bennett and Tanner townships east of Atikokan Couchiching-type rocks are stratigraphically below and conformable with basic and acidic lavas and appear to be the lowest unit of the Keewatin Group. In Gorham township north of Port Arthur along the south boundary of the belt, many top determinations near the contact place Couchiching sediments below basic lavas. Interbedding of volcanics and sediments takes place near the contact, which suggests a transition to volcanism without an intervening break. East of Lac des Mille Lacs, the Couchiching-type sediments occur below lavas. All these areas are west of Lake Nipigon where most of the Couchiching-type sediment is found. East of Lake Nipigon in the Long Lake district, similar metasediments many thousands of feet thick occur along the margin of Keewatin-type lavas and sediments. On the basis of scattered top determinations and structural considerations, Macdonald (1941) places them stratigraphically below the lavas and considers them to be Couchiching type.

Along the margin of Quetico Subprovince in long, narrow, east-trending bands are conglomerate, greywacke, and shale with some iron-formation that are often referred to as Timiskaming or Timiskaming-type sediments. In the east they have also been given local names. They occur stratigraphically above Keewatin-type lavas, are conformable with them, and often are interbedded or interfingered with the lavas. At Steeprock Lake iron mine near Atikokan on the north border of the Quetico

Belt, Jolliffe (1966) includes in the Steeprock Group a basal conglomerate as much as 600 feet thick, a dolomite as much as 1,500 feet thick, iron-formation, and a tuffaceous unit. The conglomerate is lenticular and discontinuous and contains beds of greywacke. Pebbles include granite, diorite, basic rocks, and quartz. The dolomite includes chert beds and breccias and contains considerable amounts of iron and manganese. The strata containing the ore are separated from the dolomite by an erosional unconformity. They comprise three members of variable thickness, the lowest of which is a manganiferous, ferruginous chert. The middle member comprises goethite and hematite with minor quartz and bands of chert. The uppermost or pyrite member occurs as conformable lenses along the upper contact of the ore zone and consists of pyrite-rich, aluminous or cherty sediments, in part carbonaceous. The uppermost strata of the Steeprock Group are pyroclastics with a few intercalated basic pillowed flows and sills. Jolliffe suggests that the Steeprock sediments are Archean in age and that they rest unconformably on granite. He does not attempt to correlate the rocks with other sediments in the region. Shklanka (1965) reports that the conglomerate at the base of the Steeprock Group is probably separated from the dolomite by volcanic rocks and that the granite, reported to be beneath the unconformity at the base of the sediments, is separated in places from Steeprock strata by faults or intrudes them in places. He also reports Steeprock sediments to be conformably interbedded with Keewatin-type volcanic rocks, and it would appear therefore that the Steeprock sediments are part of the sequence of Keewatin-type volcanics and sediments. Similar sediments that include limestone and iron-formations occur within or overlie the Keewatin-type lavas in the Lumby Lake area about 25 miles northeast of Steeprock Lake and at Finlayson Lake 10 miles north of Steeprock Lake. The sediments appear to be conformable with the lavas and are cut by granitic rocks.

All K–Ar age determinations from micas from the various granitic and metamorphic rocks in the Quetico Belt give Kenoran ages ranging from about 2,300 to 2,600 m.y. Rb–Sr dates from granitic rocks at Bad Vermilion Lake in the Rainy Lake area give ages in the range 2,500 to 2,600 m.y. (half-life 50 x 10^9) (Hart, *et al.*, 1963). Rb–Sr ages from samples of Couchiching and Keewatin rocks in the Rainy Lake area are about 2,700 m.y. (half-life 50 x 10^9) suggesting that these rocks are nearly equivalent in age. Zircons from the sediments and volcanics have an age of 2,750 m.y. which confirms the Rb–Sr data. However, dates from the zircons from two granites, one of which is the Bad Vermilion Lake granite, are also 2,750 m.y. The lack of agreement of the two methods on material from these granites suggests that either the zircons were inherited from older rocks or the granites were altered and, therefore, the system did not remain closed for strontium. There is no good geological evidence, however, to support either hypothesis.

English River Subprovince

English River Subprovince is characterized mainly by linear structures that strike easterly in contrast to curvilinear structures in granitic terrains beyond the borders of the belt. The belt extends eastward from Lake Winnipeg to the Phanerozoic cover of the Hudson Platform and has a maximum width of 60 miles.

The rocks in the interior of the belt are highly metamorphosed sediments, their granitized equivalents, migmatite, and granitic rocks that range in composition from quartz diorite to granite. The latter occur as elongate masses parallel with the trends of the metasedimentary rocks. The grade of metamorphism of the sediments is in the amphibolite facies and at least locally in the granulite facies. The rocks grade through zones of migmatite and granitic gneiss to the quartz diorite, granodiorite, and granite. Metamorphism has generally destroyed the primary sedimentary structures and textures but the composition of the metasediments suggests that originally they were greywacke and shale. The borders of English River Subprovince are defined by belts of basic lava, intermediate to acidic lava, pyroclastic rocks, greywacke, and shale. The succession is conformable and usually the basic lavas are basal. However, near Birch and Uchi Lakes, sediments at the base of the succession appear to be conformable with the overlying volcanic rocks (Goodwin, 1964). At Lake St. Joseph greywacke-type sediments are also the oldest part of the succession (Dyer, 1934). As these rocks are followed into the English River Belt, they become highly metamorphosed and resemble the sedimentary gneisses within the belt. Dyer named these older rocks the Miniss Group and suggested correlation with Couchiching sediments, for which there is little evidence other than that they underlie the lavas. Sedimentary gneisses near Savant Lake are divided into three groups: basic lavas, sediments, and acidic lavas and pyroclastics. The sediments include conglomerate, iron-formation, and greywacke. South of Rice Lake, Manitoba, the Rice Lake Group consists of basal basic lavas overlain by acidic lavas, and thence greywacke and shale with bands of basic lava (Stockwell, 1945). The San Antonio Formation comprises little metamorphosed conglomerate and feldspathic quartzite that unconformably overlie the Rice Lake Group and quartz diorite. The strata have been thrust over the older rocks and thrown into folds with easterly trending axes. These rocks are not known to be cut by granite and may be Aphebian.

The metasediments within the English River Belt, and along its margins, are folded about easterly trending axes that commonly plunge east. Locally these structures are distorted by cross-folding about northwest-trending axes. Easterly striking faults occur within the belt, and in the Werner Lake area small ultrabasic bodies are intruded

along these faults. North-to-northeast-striking faults also occur. A belt of high gravity extends east of the Manitoba border for about 180 miles, lying entirely within English River Subprovince. The cause of this feature is unknown, but faults containing ultramafic masses and an alkaline intrusion west of Lac Seul may be related. Micas from the English River Belt have given K–Ar dates of about 2,400 m.y. Some yield dates of 1,700 to 1,800 m.y. The latter coincide with the age of the Hudsonian Orogeny but there is little other evidence of its effects. In the Rice Lake area, deformation of the possibly Aphebian San Antonio Formation may have occurred during the Hudsonian. It is possible also that some faulting and intrusion of diabase dykes took place at about this time.

Cross Lake Subprovince

Cross Lake Subprovince is characterized by volcanic and sedimentary complexes that occur in long, slightly sinuous, easterly trending belts (Fig. IV-10). These rocks are intruded and granitized by granodiorite and tonalite. In the northwest, the subprovince is bordered by a band of gneisses mainly in the granulite facies of metamorphism and by granitic gneisses. These metamorphosed rocks were originally sediments and possibly volcanic rocks.

The oldest exposed rocks are the Hayes River Group of massive, pillowed, or amygdaloidal basic flows. Dacite and tuffs occur in the upper part of the sequences but locally rhyolite, agglomerate, and tuff with minor inter-

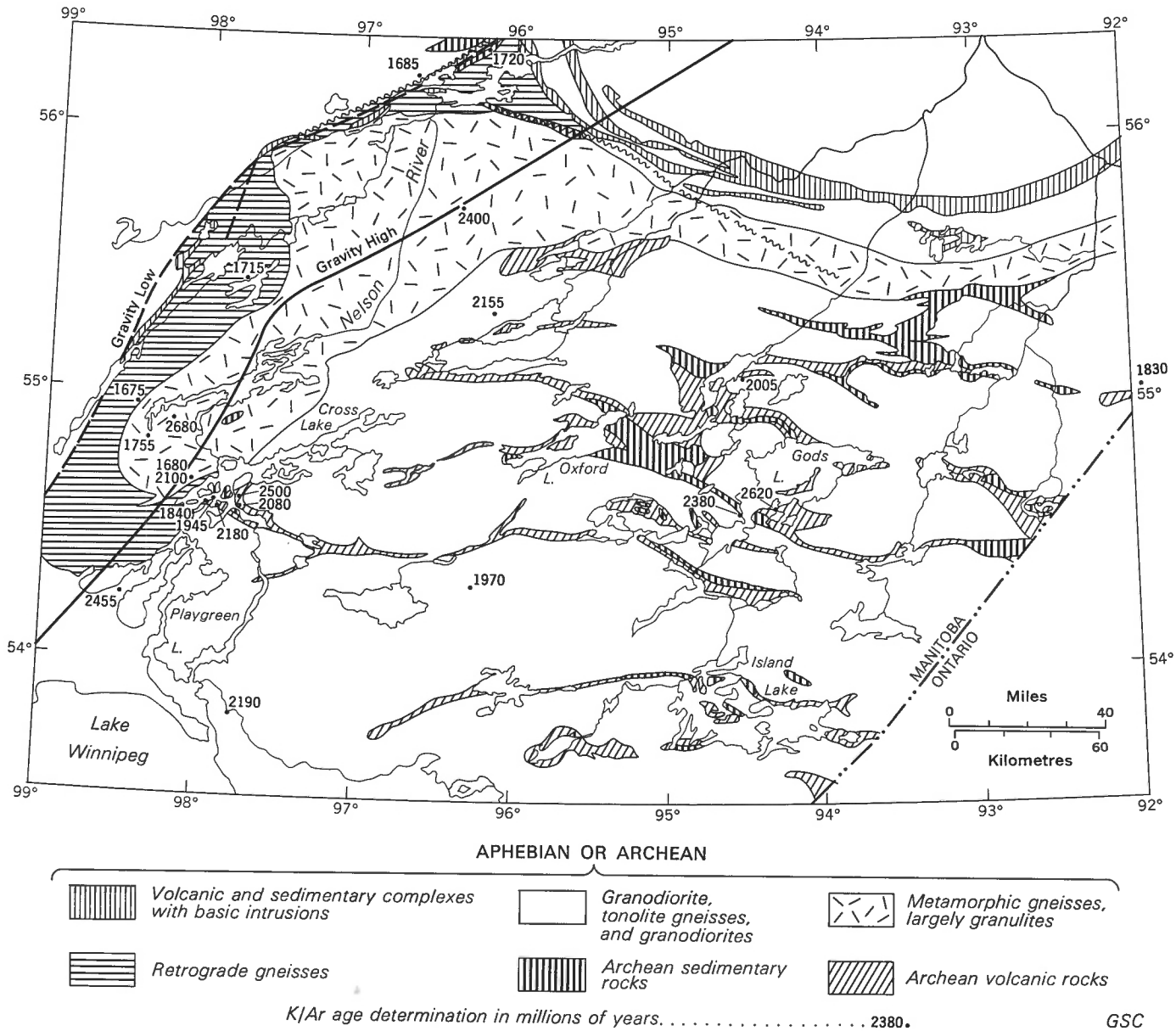

FIGURE IV-10. Geology of part of Cross Lake Subprovince, Superior Province, Ontario.

mediate or basic flows are the youngest beds. These lavas are generally named the Hayes River Group although there is no direct evidence for correlation from belt to belt. Basic and acid intrusives occur that are probably the intrusive equivalents of the volcanic rocks. Some of the quartz diorites contain quartz "eyes" that also occur as boulders in the overlying conglomerates, which suggests that an orogeny has intervened between the volcanism and sedimentation. However, the diorites may be only the intrusive equivalents of the volcanic rocks. Sediments overlie the lavas in most of the belts. Unconformities occur at Oxford, Knee, and God's Lakes but generally the rocks appear to be structurally conformable and interbedding of lava and sediment is common. It seems, therefore, that the sequence of lavas and sediments is essentially a conformable one with some local unconformities. The bulk of the sediments that comprise the Oxford, Cross Lake (Pl. IV-3), and Island Lake Groups consists of greywacke, subgreywacke, arkose, shale, and, in the upper part of the sequences, feldspathic quartzite. Graded bedding is common and the cleaner sandstones are crossbedded. The conglomerates occur as wedge-shaped masses generally near the base of the sequence. The pebbles are basic and acidic volcanic rocks, greywacke and other sediments, quartz, and granitic rocks set in a greywacke matrix. Composition of the pebbles varies with the different conglomerates. Granitic rocks appear to be more abundant in these conglomerates than in other parts of Superior Province. A large percentage are tonalites or granodiorites similar to rocks outcropping along the margins of the volcanic and sedimentary belts. The tonalite has been considered to be both older and younger than the Hayes River Group. The boulders in the conglomerates indicate, however, that such rocks existed in the source areas. Only in the Cross Lake area is the presence of basement established with certainty. Rousell (1965) reports on unconformity between sediments of the Cross Lake Group and a granodiorite and also suggests that, because the sediments are conformable with the underlying lavas, this granodiorite is the basement of the whole volcanic sedimentary complex.

The hornblende-bearing tonalites and granodiorites that are later than the Hayes River and Cross Lake Groups are usually gneissic and, particularly where their contact with older rocks is crosscutting, commonly grade into the older rocks through a zone of migmatite and gneiss. Locally, the tonalite–granodiorite complex is cut by stocks or small batholiths of massive pink granite or granodiorite with minor mafic minerals. They are probably late tectonic intrusions. The volcanic and sedimentary rocks are tightly folded along eastward and locally northeastward trending fold axes and locally, northward trending cross-folds are developed. They are cut by persistent easterly striking faults along which there probably has been considerable movement. Later faults striking northeast are common locally and appear to have had only small displacements.

In the Fox Lake Belt in the northern part of the subprovince are pillowed lavas, massive basalt or andesite, breccias, agglomerates, and tuffs. Slates, argillites, and schists are present within the volcanics. Quartz–feldspar–mica schist and gneiss with cordierite, garnet, or staurolite are along the northern part of the belt, apparently overlying the volcanic rocks (Davies, *et al.*, 1962). Basic and ultrabasic sills intrude the volcanic sequence. One sill, about 2,500 feet thick, is layered partly serpentinized pyroxenite, peridotite, dunite, and gabbro. The Fox Lake rocks may be Archean or Aphebian in age and may be

PLATE IV-3

Garnetiferous greywacke of Archean Cross Lake Group, Cross Lake, Manitoba.

the eastern extension of the sediments and volcanic rocks of the Thompson Belt.

The belt of gneisses in granulite facies of metamorphism along the northwest boundary of the province is considered to be the equivalent of Archean rocks of Cross Lake Subprovince (Bell, 1966; Rousell, 1965; Patterson, 1963). Chemical analyses of the paragneisses within this belt correspond to those of greywackes. The gneisses are commonly pyroxene-bearing and consist of mineral assemblages typical of various phases of the granulite facies. They are converted by granitization to granodiorites. Within the adjacent Churchill Province a zone of gneisses of the amphibolite facies is interpreted by Bell as representing the granulitic rocks retrogressively metamorphosed, possibly during the Hudsonian Orogeny. The granulites coincide approximately with a belt of high gravity (Fig. IV-11) and with one of high magnetic intensity (Pl. IV-4). In the north the granulite band trends easterly and the grade of metamorphism decreases to the amphibolite facies. The coincident gravity high becomes diffuse. The Fox River Belt of volcanic and ultrabasic rocks is marked by a gravity high that merges with the one over the granulites. Wilson and Brisbin (1961) have concluded that the gravity anomalies are produced by density contrasts resulting from major warps deep in the crust and are not correlative with the near-surface material. Faulting in the boundary zone, they suggest, may be related to the warping of the crust and also may have provided zones of weakness along which ultrabasic rocks of the Thompson Belt of Churchill Province were intruded. The zone of faulting coincides approximately with a belt of low gravity that lies parallel with the gravity high over the granulite belt. However, no evidence exists that the boundary between Churchill and Superior Provinces is a single fault or even a continuous zone of faulting. It is rather a metamorphic front within the Archean rocks. In mixtures of rocks such as granulites and granitic gneisses, there are significant density contrasts that affect gravity, and, in more recent work, Hall and Brisbin (1965) have tentatively concluded that the gravity anomalies are related in part to variation of density in the upper granitic layer of the

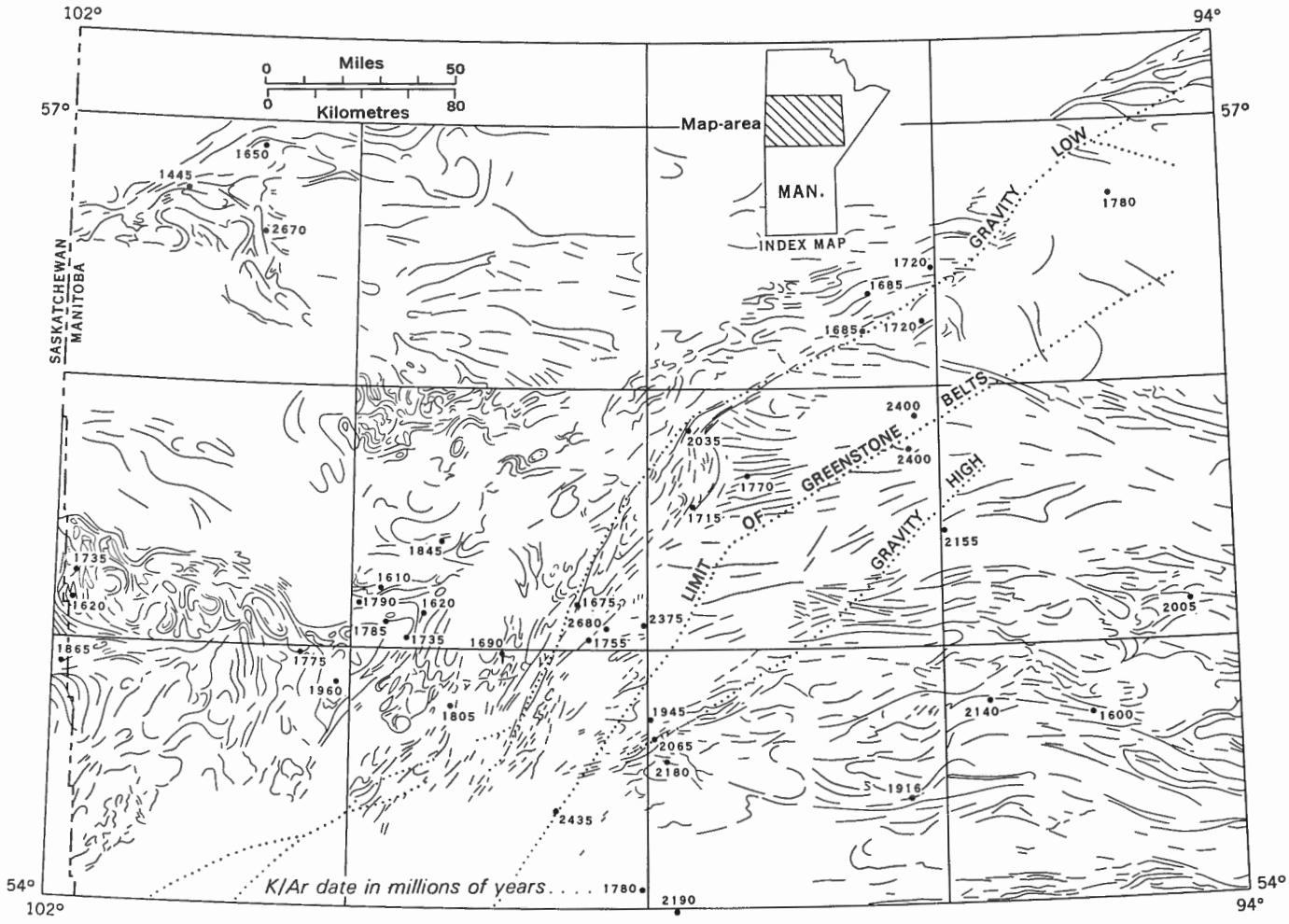

FIGURE IV-11. Magnetic and structural trends in the vicinity of the boundary between Superior and Churchill Provinces, Manitoba (Wilson and Brisbin, 1961).

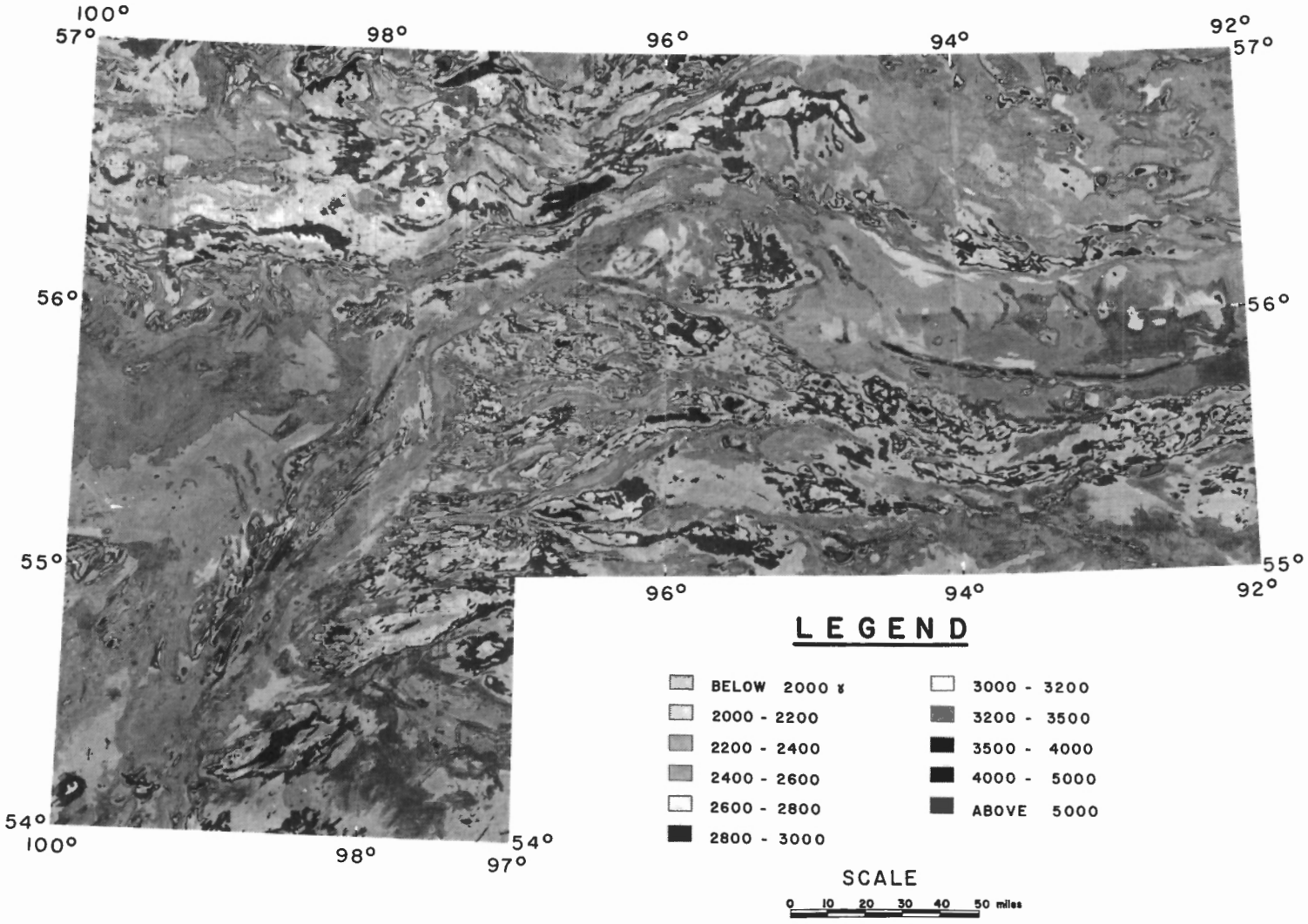

PLATE IV-4. Magnetic anomalies, vicinity of boundary between Churchill and Superior Provinces, Manitoba.

crust. The magnetic anomalies also correlate with the surface geology and appear, therefore, to be produced by near-surface material (Kornik and MacLaren, 1966).

K–Ar dates in Cross Lake Subprovince are unlike those for most other parts of Superior Province. Most biotites and hornblende from the granulitic rocks yield Kenoran ages that range from 2,100 to 2,700 m.y. A sample of biotite from the granodiorite beneath the Cross Lake sediments gives an age of about 2,500 m.y. (Rousell, 1965). Biotites from the granodiorite, tonalite, and metamorphosed equivalents of the volcanic-sedimentary rocks yield mainly younger ages ranging from 1,800 to 2,400 m.y. These anomalously young ages are presumed to have resulted from argon loss caused by heat effects of the Hudsonian Orogeny in the border zone of Superior Province. However, the granulitic rocks have yielded Kenoran ages and therefore appear unaffected by the orogeny.

SLAVE PROVINCE

Tectonic Summary

The oldest rocks in the province are Archean basic to acidic flows and pyroclastics and quartz-rich greywacke and shale. The volcanic rocks occur near or at the base of the generally conformable succession. They were probably extruded from various centres, possibly at different times, to form discontinuous belts so that, at times, volcanism and sedimentation proceeded simultaneously in different parts of the province. Most volcanism was subaqueous. The transition from volcanism to sedimen-

tation was gradual with local resumption of volcanism during sedimentation. The sediments were deposited in an eugeosynclinal environment.

The Archean rocks were folded, metamorphosed, and intruded by granite during the Kenoran Orogeny. A possible sequence of these events is: folding and low-grade metamorphism; granitization and intrusion of syntectonic granitic rocks and metamorphism overlapping in time, early folding, cross-folding and shearing; intrusion of high-level late tectonic granodiorites and pegmatites, and related metamorphism. The time separation of these events is unknown but to some extent they may be the result of roughly contemporaneous activity in different parts and levels of the orogen. K–Ar age determinations of these granites and metamorphosed equivalents of volcanic and sedimentary rocks give a mean age of 2,470 m.y.

After deep erosion, Aphebian sediments were deposited in a geosyncline and covered parts of Slave Province. Bathurst Subprovince includes Paleohelikian rocks. The Archean rocks were locally affected when the Aphebian rocks were deformed during the Hudsonian Orogeny. Three, and possibly four, diabase dyke swarms and at least as many fault sets of different ages and trends occur in rocks of Slave Province.

PLATE IV-5. Pillowed lavas of Archean Yellowknife Group, Slave Province, Yellowknife, Northwest Territories.

Archean

Volcanic and sedimentary rocks of the Archean Yellowknife Group occur in irregularly shaped areas, separated by masses of younger Kenoran granitic rocks. The Archean rocks underlie about a third of Slave Province. Volcanic rocks lie at the base of the Yellowknife succession in discontinuous belts along the margins of sedimentary units, except at Mesa Lake (Ross, 1959) where sediments occur below volcanic rocks. The thickness of the various volcanic sequences varies from about 1,000 to 40,000 feet and within individual belts the thickness also varies greatly. Basic flows form the bulk of the volcanic successions (Pl. IV-5), varying in proportion of massive, pillowed, and variolitic varieties and in amount of associated banded tuffs. Intermediate to acidic flows, tuffs, and breccias are commonly found in the upper part of the sequence and in the thickest parts of the volcanic belts. Acidic material forms less than 5 per cent of most volcanic sequences. Chemically, the common magma type is tholeiitic basalt with certain calc-alkaline characteristics that may result from modification by sialic contamination (Baragar, 1966). Sills, dykes, and irregularly shaped masses of massive fine-grained diorite or gabbro are found within the lavas and are their intrusive equivalents.

The lavas are overlain by thick monotonous sedimentary sequences. In most areas the contact is conformable and transitional with interbedding of flows or tuffs and sediments occurring in the contact zone. These rock types also interfinger along strike indicating some simultaneous sedimentation and volcanism. Relatively thin bands of volcanic strata occur within sediments above the main volcanic sequences, indicating local resumption of volcanism during sedimentation. The sediments are mainly quartz-rich greywackes or feldspathic greywacke with shale or argillite interbeds. Relative thicknesses of these interbedded and graded couplets vary but generally average less than a foot (Pl. IV-6). At some horizons argillite or greywacke occur as thick homogeneous units. Relative amounts of sand and shale as well as grain-size in the clastic units vary. Calc-silicate bands or lenses are common in the sandy portions in some areas. Primary structures such as graded bedding, groove casts, convolute lamination, flume structures, and parallel and ripple laminations are characteristic and suggest deposition by turbidity currents. Locally, thin beds of limestone or dolomite and dolomite breccia occur within the greywacke. They are commonly associated with feldspathic quartzites near the base of the sedimentary sequence and may have been deposited in shallow water around centres of volcanic activity. In some areas thin beds or lenses of paraconglomerate as much as 1,500 feet thick are interbedded with greywacke at or near the base of the sedimentary sequences above thick sections of volcanic rocks. Typically this rock consists of angular pebbles of basic and acidic volcanic rocks with some rounded cobbles of granitic rock and vein quartz with a greywacke matrix. Iron-formation is rare, but at Contwoyto Lake, bands of amphibolite, some of which are rich in iron, quartz, garnet, and iron sulphides, are interbedded with normal greywacke and may have been originally iron and aluminum-rich tuffs or sediments. The thick deposits of interbedded

greywacke–shale resemble the flysch facies of eugeosynclinal sequences. The source of these sediments is unknown, but the quartz-rich character of the greywackes and the presence of granitic cobbles and vein quartz in paraconglomerates that generally overlie the volcanics conformably suggest a source area consisting in part of granitic rocks and possibly metamorphosed sediments. Some material was also derived from the erosion of the underlying volcanic rocks.

East of Cameron River (Baragar, 1966) and in the Indian Mountain Lake area (W. W. Heywood) there is evidence to suggest the presence of a granitic basement beneath Yellowknife volcanic rocks. Metamorphosed basic dykes cut granitic and volcanic rocks but not the overlying sediments. The dykes may be temporally related to the volcanism and be feeders to the flows. However, Henderson (1941) has concluded that these granites were younger than lavas. Metamorphosed basic dykes also occur in the Yellowknife sediments in nearby areas. The metamorphism of dykes in the Cameron River area may be related to a young Kenoran granite that intrudes both the volcanic and granitic rocks.

The Wilson Island Group in the western part of the East Arm of Great Slave Lake is separated from the main part of Slave Province by younger Aphebian sediments. The age relationships of the Wilson Island and Yellowknife Groups accordingly are unknown but the Wilson Island is cut by a granite dated as 2,400 m.y. The group may represent a near-shore or shallow-water facies of the Yellowknife sediments. It is at least 11,000 feet thick and comprises acidic lava flows and pyroclastics with interlayered conglomerate and arkose that are overlain by cross-bedded quartzite, dolomite, and shale. These beds are succeeded by phyllite with thin interbeds of quartzites. Thin beds of iron-formation occur in the succession.

Kenoran Orogeny

Most of the K–Ar age determinations on minerals and rocks formed or metamorphosed during the Kenoran Orogeny fall in the range 2,300 to 2,600 m.y., and their mean value is 2,480 m.y. It has not been possible to date the rocks precisely enough to separate the various orogenic events.

During the Kenoran Orogeny the Yellowknife Group was folded, metamorphosed, and intruded by granitic rocks. The orientation of folds and the intensity of deformation vary throughout Slave Province but in most areas two directions of folding can be detected. The Yellowknife rocks were first deformed into northerly to south-northeasterly trending similar folds that plunge moderately north or south. The axial planes dip steeply. These folds in many areas were modifed by steeply plunging cross-folds, the axial planes of which generally strike in a northerly to northwesterly direction roughly at right angles to the axes of the early folds (Pl. IV-6). The sediments are tightly and intricately folded but the volcanic rocks are deformed differently probably because of their greater competency. Thin volcanic successions are thrown into broad folds that have the same orientation as the more intricate folding of the overlying sediments. In thick sequences the rocks generally form homoclinal successions that face away from the younger granitic rocks. Such sequences in some areas appear to be merely somewhat bent by the second folding. Shear zones in the volcanic rocks usually consist of chlorite–carbonate–sericite schists. These structures commonly are parallel with the strike of the lavas so that displacements cannot be measured. The shear zones probably occur during folding of the volcanic rock and may be caused by the second folding. Many shear zones in sediments result from shearing along limbs or axial planes of tightly closed folds, and may result from continuing compression after maximum closure is attained. In both rock types, shear zones may localize barren or mineralized quartz veins and, in some areas in the sediments, pegmatite dykes.

About two-thirds of Slave Province is underlain by granitic rocks of which possibly half are high-grade migmatite, mixed gneiss, banded gneiss, and granitic gneiss, while the remainder consists of batholiths of massive or slightly gneissic granitic rocks of various compositions. The gneisses are concentrated in the central and south-

PLATE IV-6. Graded beds of greywacke and shale of Archean Yellowknife Group, Yellowknife, Northwest Territories. The tight northwest-trending folds with vertical axes were produced in the late phase of Kenoran Orogeny.

eastern parts of the province and contain thin bands or septa of highly metamorphosed or partly granitized sedimentary or volcanic rocks. These rocks probably result from the granitization of Yellowknife rocks and form at a deep crustal level. Granitic rocks of at least two ages intrude rocks of the Yellowknife Group. The older intrusions are generally equigranular quartz diorite and granodiorite that contain biotite and commonly hornblende. They are faintly gneissic especially near their borders and are commonly bordered by migmatite and granitized sediments. These intrusions were probably emplaced during the metamorphism and early folding of the Yellowknife rocks at a higher crustal level than the granitic gneisses. The younger intrusions are granodiorite and quartz monzonite with biotite and muscovite as accessory minerals. They are generally massive and often porphyritic with megacrysts of potash feldspar. The younger intrusions are more potash rich than older plutonic rocks. The younger plutons commonly form oval or elliptical masses (Pl. IV-7) that in some areas are oriented roughly parallel with the axes of younger cross-folds. The stocks are partly concordant and partly discordant and in some, intrusion was achieved by pushing aside earlier deformed sediments. Contacts with older rocks are generally sharp, and migmatite zones, if present, are narrow or occur only along parts of the contact. The younger intrusions are surrounded by metamorphic aureoles and were emplaced after early folding and regional metamorphism. Pegmatites, commonly developed in the country rocks around the younger plutons, are usually simple, some bearing tourmaline, and lacking obvious internal zoning. East of Yellowknife, the pegmatites are complex and some are internally zoned. They contain such minerals as beryl, spodumene, ambligonite, garnet, and tantalite–columbite. They are arranged about the related granodiorites in zones defined by different mineral compositions.

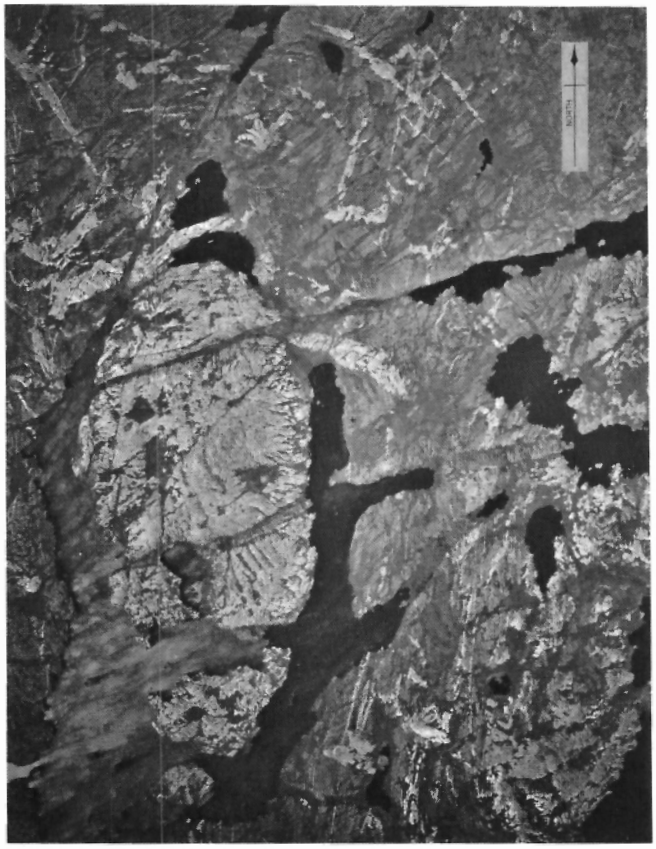

PLATE IV-7. Granite stock (light) intrusive into Archean Yellowknife meta-greywacke (dark), Staple Lake, Slave Province, Northwest Territories. Irregular white masses are pegmatite dykes and linear dark bands are diabase dykes. The east-trending diabase dykes are 2,150 m.y. old and the northeast one is 2,100 m.y. old.

All rocks of the Yellowknife Group have been metamorphosed. Degree of metamorphism varies from low greenschist to amphibolite facies. In the greywacke and shale in the lowest grade, chlorite, sericite–quartz, and plagioclase are the characteristic minerals. With increasing metamorphism, biotite is developed at the expense of chlorite and sericite and forms discrete grains and porphyroblasts. The transition to amphibolite facies is marked by the appearance of cordierite and andalusite metacrysts in the knotted schists. Staurolite and garnet are locally developed in this facies and chlorite is rare. Biotite is more abundant than in lower grades and muscovite is a common constituent. Cordierite and andalusite may occur together or separately. Sillimanite is formed in the upper amphibolite facies close to some granitic plutons and in areas where the sediments grade to migmatite. These rocks are coarse grained, and biotite, quartz, well-twinned plagioclase, and sometimes muscovite are also present. The basic volcanic rocks in the greenschist facies comprise plagioclase, actinolite, and chlorite. In the amphibolite grade, blue-green hornblende and plagioclase are the essential minerals. Initially, metamorphism accompanied deformation and some micas are oriented in minor structures related to folds. However, in some areas, in zones of higher metamorphic grade, metacrysts of andalusite and cordierite are not oriented and therefore metamorphism continued after deformation ceased. Some granitic plutons are surrounded by narrow zones of knotted andalusite- or cordierite-bearing schists but in other areas the development of these schists appears unrelated to the plutons, and is possibly a phase of progressive regional metamorphism. It seems likely that deformation, metamorphism, and intrusion of granites were elements of a sequence of overlapping events that began with folding and metamorphism and ended with intrusion of younger granitic rock in previously metamorphosed rocks. Older granitic plutons were probably intruded during metamorphism.

Post-Kenoran Events

Post-orogenic events in Slave Province include intrusion of diabase dykes, faulting, intrusion of an alkaline pluton, and, especially along the borders of the orogen,

some effects of the Hudsonian Orogeny. There were also some epeirogenic movements and erosion following the development of the present craton. Diabase dykes of three different ages and trends intrude the rocks of Slave Province (Fahrig and Wanless, 1963). The oldest dykes have an easterly trend and appear to be most abundant at Yellowknife and east of it, in the southern third of the craton (Pl. IV-7). Their age is about 2,150 m.y. A second group of dykes trend in a northeasterly direction and have been dated at about 2,100 m.y. At Indin Lake about 120 miles north of Yellowknife, a set of northwesterly and northeasterly trending, steeply dipping dykes are dated at about 2,100 m.y. These two sets of dykes appear to be restricted to Slave Province. The third set of dykes, the Mackenzie dyke swarm, trends north-northwesterly and occurs not only in Slave Province but also in the adjacent parts of Bear and Churchill Provinces. These dykes have been dated at about 1,200 m.y.

Archean rocks and rocks formed during the Kenoran Orogeny are cut by faults of several ages and orientations (Fig. IV-12). These faults are marked by narrow zones of gouge and mylonite within wider zones of crushed and brecciated rock; some are quartz veins and narrow stockworks. In the Indin Lake area, numerous vertically dipping faults trend northwesterly, northeasterly, or northerly. Largest displacements occur along the northwesterly faults that have left-hand strike slip. The diabase dykes that are dated at 2,100 m.y. have similar orientations and occur in fractures parallel with the faults. A few lie in the faults, and some are slightly sheared which suggests a close time relationship. A prominent set of faults in the southern and northern parts of the province strikes northeast to east. Those in the south are roughly parallel with the oldest diabase dyke swarm and could be related in time; most have right-hand strike-slip displacements. These older structures may be related to the development of the bordering Aphebian geosyncline. In the northern part of the province the northeast faults also cut Aphebian and Helikian rocks and are associated with northerly and northwesterly trending faults. They are probably about 1,200 to 1,300 m.y. old; those with the same orientation farther south are thought to be older. The most prominent fault set in the province strikes north-northwest to north and includes such well-known structures as the West Bay and other late faults near Yellowknife. Faults of this set extend well beyond the border of the province and cut rocks as young as Helikian. The main movement is left-hand strike slip, the horizontal component of which may be several miles. Within Slave Province these faults apparently are most abundant in the western part, and where they are numerous cross-faults of varying orientations connect the major structures. The Mackenzie diabase dyke swarm dated at about 1,200 m.y. is parallel with the fault system. Some dykes pass into the faults and locally are displaced by cross-faults related to the major structures. Accordingly, they have formed at about the same time. These faults and also the related

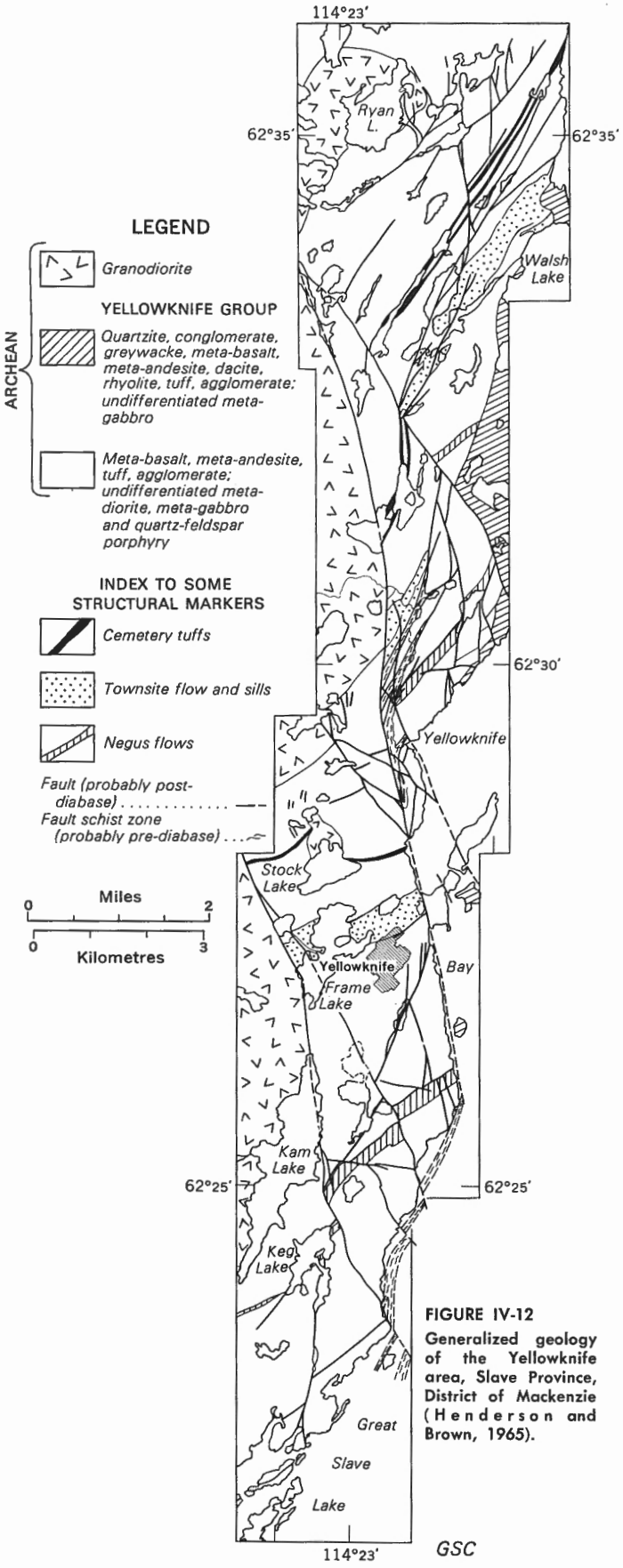

FIGURE IV-12
Generalized geology of the Yellowknife area, Slave Province, District of Mackenzie (Henderson and Brown, 1965).

diabase are later than all other faults in Slave Province including the northeast-trending faults in the northern section.

Important modifications of the rocks of Slave Province were caused by phases of the Hudsonian Orogeny. One, or possibly two, roughly circular masses of alkaline rocks that include nepheline- and sodalite-bearing syenite and possibly carbonatite were intruded during the Hudsonian Orogeny into the Kenoran granitic rocks at Big Spruce Lake, about 20 miles east of the boundary between Bear and Slave Provinces. Biotites from these rocks give ages of about 1,750 m.y. Many K–Ar age determinations have been made on rocks from northern Slave Province. Those for biotite give anomalous dates, less than the expected Kenoran ages, that range from about 1,800 to 2,300 m.y. In some samples muscovite that coexists with the anomalously young biotite gives Kenoran ages. These data suggest that the old rocks were heated during the Hudsonian Orogeny to an extent sufficient to drive argon out of some of the micas.

Other effects of the Hudsonian Orogeny are restricted to the borders of Slave Province. Along the western boundary of the province, Archean rocks have been involved in the folding of the younger Aphebian rocks. Much of the eastern border zone may be an extensive zone of shearing.

Bathurst Subprovince

Most of Bathurst Subprovince is underlain by the Goulburn Group that comprises a conformable sequence, about 15,000 feet, divided into five formations (Fraser, 1964). The sediments have been moderately folded about axes that strike north-northeast. Folding is more intense along Bathurst Inlet where fold axes strike in a northerly direction. The Goulburn Group lies unconformably on the Archean Yellowknife Group and Kenoran granites. These are cut by gabbro sills and diabase dykes that yield K–Ar whole rock ages of about 1,200 m.y. The basal formation of the Goulburn attains a maximum thickness of 3,500 feet and comprises, from the base up, grey to green quartzite and grit, dolomite with stromatolitic zones, and interbedded quartzite and maroon to grey argillite with local silty layers and stromatolitic dolomite. These rocks are overlain by as much as 7,500 feet of thick-bedded, massive, pink to red feldspathic quartzite and orthoquartzites with thin interbeds of conglomerate. These rocks are succeeded by about 2,000 feet of purplish green or grey argillites with thin interbedded grey limestone and dolomite overlain by about 800 feet of grey to pink dolomite with abundant stromatolitic zones. The uppermost formation is composed of interbedded red-grey or maroon siltstone and argillite with red crossbedded arkose near the top. The arkose contains granules of specularite.

The age of the Goulburn Group is not precisely known but it is thought to be Aphebian and to have been folded during a phase of Hudsonian Orogeny. The sediments are typical of those deposited in a shallow-water environment. Both marine and continental types occur in the sequence and several transgressions are recorded suggesting some tectonic instability during sedimentation. Formations are thickest near Bathurst Inlet and thin rapidly to the west and southwest. In the extreme western exposures near Contwoyto Lake only the lowest three formations are present and the total thickness is little more than 2,000 feet. The quartzite unit thins from 7,500 feet to 600 feet. The Goulburn Group is similar to the Epworth Group and a tentative correlation of these two sequences is suggested. J. A. Fraser points out that the basal unit of the Goulburn is lithologically similar to the lowest Epworth unit and part of the lower Epworth carbonate formation. The Goulburn quartzite formation is not well developed in the Epworth and may be absent as it thins rapidly to the west. It may be a facies of part of the lower Epworth carbonate unit. The upper three formations of each group represent similar lithologies and environments. The westward thinning of the Goulburn strata and distribution of basal sands along the eastern margin of the Epworth outcrop area suggest that the intervening basement may have been an arch during the time of deposition.

The Goulburn Group is overlain unconformably by cream, red, and buff quartzites of the Tinney Cove Formation that includes thin conglomerate beds with boulders of underlying strata. Kaolinite occurs in the matrix. Except near faults these rocks are very gently deformed. They are overlain, probably conformably, by the Parry Bay Formation that consists of at least 550 feet of thick-bedded, fine-grained, grey or buff dolomite and limestone with stromatolitic zones and minor amounts of interbedded brown dolomite and red or green shale and shaly dolomite. On islands in the mouth of Bathurst Inlet, but nowhere on the mainland, rocks of the Kanuyak Formation lie with slight angular unconformity on Parry Bay strata. Reddish brown dolomite and calcareous shales are the dominant lithologies. Basalts of the Coppermine Group with overlying sediments disconformably overlie rocks of the Kanuyak and Parry Bay Formations and are separated from older strata by an unconformity.

The Tinney Cove quartzites are lithologically similar to Hornby Bay quartzites and the Thelon Formation of the Dubawnt Group. On the basis of lithologic similarity and stratigraphic position, the Parry Bay dolomite is tentatively correlated with the Hornby Bay dolomite and the post-Thelon carbonate. Rocks of the Kanuyak Formation have no known equivalents in the region. These rocks are separated from Aphebian rocks deformed during a phase of the Hudsonian Orogeny by an angular unconformity and are cut by basic dykes and overlain by lavas that date from 1,000 to 1,400 m.y., indicating that the sediments are Paleohelikian in age.

Tectonic Summary

Bear Province is divided into four subprovinces. The Wopmay Belt contains the oldest rocks—Aphebian sedimentary and volcanic rocks that were folded and invaded by granitic ones during the Hudsonian Orogeny. Coppermine, Brock, and Minto Subprovinces are underlain by Helikian and possibly Hadrynian rocks that have been intruded by gabbro sills and dykes and are only gently folded.

The Aphebian rocks reflect two distinct sedimentary environments. The Snare and Epworth Groups are composed of miogeosynclinal shelf sediments deposited under shallow-water environments. They comprise quartzites, dolomites, shales, and siltstone–shales that occur in northerly trending belts along the margins of Slave Province, a craton of Archean rocks. These sediments were deposited in a geosyncline that probably also trended northerly. Snare sediments are overlain by basic volcanic rocks some of which are pillow lavas. These rocks are in a zone as much as 75 miles wide along the western margin of the craton. Farther west, the Echo Bay and Cameron Bay Groups of red beds and acidic volcanic rocks occur in north to east-northeasterly trending belts. These rocks are a late tectonic complex of molasse-type sediments consisting of conglomerate, arkose, red siltstone and shale, and volcanic piles of andesitic to trachytic compositions that contain great thicknesses of tuffs, breccias, and ignimbrites as well as flows. Intrusive equivalents of these volcanic rocks are common. Sedimentary rocks occur in basins that may be partly fault controlled. The Aphebian rocks are folded and intruded by granitic rocks; the intensity and complexity of the deformation in general increases away from the margin of the craton. In some areas the sediments have been converted to granitic gneisses after passing through zones of increasing metamorphism and the granitic intrusions are generally bordered by migmatites. The Cameron Bay rocks are less intensely deformed and metamorphosed and cut by high-level, late tectonic granitic rocks.

Within the part of the geosyncline affected by early orogenic events local zones of Archean basement may exist, but so far have not been identified except near its eastern margin. Likewise in the region south and east of Great Bear Lake in that part of the orogen involved in late tectonic activity, zones of granitic gneiss are present that probably were formed by earlier phases of the orogeny. Such rocks may be, in effect, basement to Echo Bay and Cameron Bay sedimentary and volcanic rocks. North of Great Bear Lake the deformed rocks are overlain unconformably by Paleohelikian sandstones and dolomites of the Hornby Bay Group which is conformably overlain by the thick Coppermine Group, a sequence of basalt with some red beds, succeeded unconformably by quartzite, dolomite, and shale. The Coppermine lavas are probably Neohelikian and the younger sediments may be either Neohelikian or Hadrynian. On Victoria Island the Neohelikian or Hadrynian Shaler Group of sediments and basalt rests unconformably on a basement of Archean rocks. These rocks are very gently folded about easterly to north-northeasterly axes. Faults, probably of different ages, and diabase dykes and sills of several ages cut the Hornby Bay, Coppermine, and Shaler rocks. The Muskox Intrusion, a differentiated gabbroic mass, intrudes Hornby Bay strata and is probably a little younger than the Coppermine flows. The Proterozoic rocks are overlain unconformably by Cambrian and Ordovician sediments that are broken by a few small normal faults.

Wopmay Subprovince

Aphebian

Aphebian rocks in Wopmay Subprovince are divided into the Snare, Epworth, Cameron Bay, and Echo Bay Groups. The Snare and Epworth rocks are separated by an area of granitic rocks. The Cameron Bay rocks are not in contact with the Epworth but may be in contact locally with Snare rocks.

Snare rocks occur in north-trending belts along the margin of Slave Province and as isolated patches within younger granitic rocks to the west. At Basler and Kwejinne Lakes, and to the southwest, Snare rocks lie with marked angular unconformity on the Archean Yellowknife Group and granitic rocks (Lord, 1942). Farther north the structural unconformity becomes less obvious due to gradual elimination of the angular discordance as a result of greater intensity of folding of the Snare rocks. The Snare Group consists of quartzite, dolomite, shale, and siltstone; the relative amounts of these sediments varies throughout the geosyncline. At Basler Lake and to the southwest the basal rocks are white or light grey, crossbedded quartzite with a few thin beds of shale. Near the base the quartzite is feldspathic and contains a few lenses of quartz-pebble conglomerate. At the base it contains a few fragments of basement rocks. Thickness varies from less than 100 to about 1,000 feet. At Basler Lake, a thin shale member near the top of the quartzite is overlain by sandy dolomite at least 300 feet thick. The quartzite at Kwejinne Lake is overlain by black shale, and west and southwest of Basler appears to be overlain by dark, finely laminated shale that contains another quartzite. North of Basler Lake the basal quartzite is overlapped by the dolomite that can be traced along the unconformity to the north end of the belt of sediments. The dolomite is overlain by alternating thin beds of siltstone and finely laminated shale of unknown thickness, and is probably several thousand feet thick. In many

places, the siltstone and shale beds are each less than an inch thick and the rock has a varved appearance. Locally the couplets increase in thickness to 3 or 4 inches. In the thicker couplets graded bedding and fine cross-laminations are evident. Within these rocks are units of quartzite, dolomite, and shales, each several hundred feet thick, the number and stratigraphic position of which are unknown because of the complexity of the structure. Some of the quartzite and dolomite units grade along strike into siltstone and shale.

The transition zone with dolomite is marked by zones in which calc-silicate lenses are numerous. West and south of Basler Lake quartzite, shale, and dolomite are present in various stratigraphic successions, whereas to the north metamorphosed equivalents of the siltstone–shale with minor quartzite or dolomite are dominant. At Grant Lake, the metamorphosed rocks are overlain conformably by basic lavas some of which are pillowed and that contain intercalated thin bands of cherty sediments and Snare-like sediments. Pink or red feldspathic sandstone and red or grey shale overlie the volcanic rocks and are tentatively included in the Snare Group. Snare rocks are of miogeosynclinal facies, deposited mainly in shallow water. The well-sorted, crossbedded quartzites suggest deposition in a shallow-water, rather turbulent, near-shore environment. The sandy nature of the dolomite also suggests a similar environment. The thick, finely laminated shales west of Basler Lake indicate a somewhat deeper-water environment. The facies change north of Basler to a sequence of siltstone and shale, and the wedging out of basal sands may also result from deposition in a somewhat deeper-water environment. In the original geosyncline near-shore conditions appear to have prevailed in the southern and southeastern parts, whereas, in the northern section, sediments were deposited into a slightly deeper-water, off-shore environment. Extrusion of basic submarine lavas in the north also indicates a transition to deeper-water environment.

The Epworth Group contains a conformable sequence of sedimentary and volcanic rocks with a thickness of at least 15,000 feet. The group lies on Archean volcanic rocks and granites with marked unconformity. Fraser (1966) has established five formations. The lowest consists of 2,000 to 3,000 feet of grey and pink quartzite with some beds of argillite and quartz-pebble conglomerate. It may be absent locally. The succeeding 2,000 to 5,000 feet is stromatolitic dolomite (Pl. IV-8) with a few interbeds of argillite. This formation locally forms the basal unit of the group. Thinly bedded, siltstone argillite and greywacke with thin bands of quartzite and dolomite, at least 3,000 feet thick, overlie the dolomite and are in turn overlain by 3,500 feet of limestone with interbedded grey and red argillite. The youngest formation, 1,200 feet thick, comprises red mudstone and siltstone that grades upwards into feldspathic, calcareous sandstone. Pillowed and massive andesite and related fragmental rocks are locally present within the sediments.

The siltstones and shales of the middle formation are metamorphosed to phyllites and andalusite-bearing or garnetiferous biotite schists where intruded by granite in the west. The metasediments also occur as patches within the granites and can be traced southward to where similar rocks are considered to be part of the Snare Group. It seems reasonable to assume that the middle unit of the Epworth Group is the stratigraphic equivalent of the Snare siltstones and shales and that the underlying dolomites and quartzites are also equivalent. The upper two Epworth formations may be equivalent to similar strata that lie above Snare volcanic rocks north of Grant Lake. The Epworth and Snare rocks appear to be approximately equivalent in time and to have been deposited in a single northerly to north-northeasterly trending geosyncline in water depths above wave base and probably just below it. The basal quartzites are probably wedge-shaped, near-shore deposits along the margin of the basin. Interbedding of shales and quartzites in the southern part of the geosyncline, and quartzite and dolomite strata within the siltstone shales in the north suggest some moderate tectonic instability during deposition of these sediments. Preservation of the thin silt–shale alternations, fine-lamination, cross-lamination, and graded beds suggests that deposition of the shale–siltstone sequences in quiet water below wave base took place.

The Cameron Bay and Echo Bay Groups are structurally conformable but may be separated by a disconformity. The Echo Bay rocks at Port Radium are usually separated into two units. The lower unit comprises tuff, green and red argillite, chert, arkose, and conglomerate with a few andesite flows and thin limy beds. Mudcracks, ripple-marks, and graded bedding occur in the arkose and shale. Conglomerates are present at several horizons. The upper formation consists of porphyritic andesite flows, breccia, tuffs, and agglomerates. The Cameron Bay rocks form a conformable sequence of conglomerate, purple and maroon arkose, siltstone, and shale. Pebbles in the conglomerate consist mostly of porphyritic volcanic rocks along with chert, argillite, and sandstone and occur in an arkosic matrix. About 30 miles north of Port Radium (Feniak, 1952) green and maroon, generally porphyritic andesite, dacites and trachytic flows, and agglomerate, and tuff are intercalated in typical Cameron Bay sediments. The volcanic rocks are similar to those of the Echo Bay Group at Port Radium.

Elsewhere in Bear Province, a separation into the two groups has not been made. For the most part the undivided volcanic complexes consist of maroon, green, or brown, commonly porphyritic andesites, dacites and trachytes with related tuffs, ignimbrites, and breccias. Included with the volcanic rocks, and often difficult to distinguish from them, are their hypabyssal, lithologically similar, intrusive equivalents. Usually associated with the volcanic rocks are sediments that form local, northerly trending belts. Typically these rocks consist of conglomerate, red, maroon, and purple arkose or feldspathic

PLATE IV-8
Stromatolites in dolomite of Aphebian Epworth Group, Takiyuak Lake, Bear Province, Northwest Territories.

sandstone, and shale. The clasts in the conglomerate are largely subrounded pebbles of the volcanic facies of the Cameron Bay and Echo Bay Groups, with some quartz, shale chips, and pink granodiorite or granite. The conglomerate occurs at several horizons within the sequence and in places forms the basal part of thick graded beds, the upper part of which is arkose. Crossbedding and chips from interbedded shales are abundant. The shales interbedded with the arkoses are red or maroon and commonly display mudcracks and sandstone dykes. The sedimentary sequences have been found below, above, and intercalated with the volcanic rocks. Exposed thicknesses of the various sequences vary from a few hundred to possibly as much as 10,000 feet, but precise correlation between the scattered exposures of these rocks is not possible. Basement to these rocks has not been identified with certainty. Some of the sedimentary basins may have been in part fault controlled.

The Cameron Bay and Echo Bay Groups are fundamentally different from the Snare and Epworth Groups, having formed in very different environments. The sediments, being largely red bed conglomerate and arkose were probably deposited in an environment ranging from continental to shallow marine. The mudcracks, shale chips, and scour channels suggest periodic subaerial exposure of the sea floor. The clastic units are products of rapid sedimentation from areas of considerable relief that are tectonically unstable. The volcanism that occurred at intervals consisted of andesite and trachyte flows and large amounts of tuffs and breccias from explosive activity. Rapid erosion of these volcanics produced many of the pebbles in the conglomerates and probably a considerable amount of the finer clastic material. Shallow intrusions related to the volcanic rocks cut both volcanic and sedimentary rocks. The sedimentary and volcanic rocks probably accumulated during a late tectonic stage of geosynclinal evolution, after the older miogeosynclinal Epworth and Snare rocks had been deformed in the early phases of the Hudsonian Orogeny.

Hudsonian Orogeny

During the Hudsonian Orogeny Aphebian rocks were folded, metamorphosed, and converted to granitic rocks, or intruded by them. Micas from these granitic rocks yield

K–Ar dates that range from about 1,700 to 1,870 m.y. The sequence of orogenic events is not known with certainty as the precision of the methods of dating is not great enough to isolate the various phases of the orogeny.

Folding of the Snare Group took place in two phases (Ross and McGlynn, 1965). The earlier and most important phase resulted in northerly to northeasterly trending folds. In the vicinity of Basler Lake, where deformation and metamorphism were not intense, and where competent thick quartzites occur in the succession, the folds are concentric, shallow, and open, plunging gently north, with northerly trending axial planes that dip steeply east. To the west, as the Snare rocks thicken, the trend of the folds gradually changes to northeast. North of Basler Lake, the folding is more intense and similar folds are present. The difference in style of folding may be partly due to facies changes in the sediments as the thick competent quartzite members grade to shale, but the change also coincides with an increase in metamorphic grade and probably is also related to more intense deformation at a deeper structural level. The axial planes strike north and dip steeply to the east; the folds plunge gently to the north. Andalusite and cordierite metacrysts developed during the metamorphism stage. The second phase folds are similar and have axial planes that strike southeasterly and dip steeply both southwest and northeast. They plunge at moderate angles to the northwest. Locally, they are related to the intrusion of the granitic rocks. The deformation affected basement rocks near the unconformity altering older structures within the Archean rocks and causing faulting and the formation of a schistosity in older granitic rocks. Early folds in Yellowknife rocks underwent further closure or were refolded about axial planes parallel with those in Snare rocks. The Epworth sediments are very gently folded along their eastern margin. To the west they are thrown into increasingly tight folds that trend northerly.

Aphebian rocks were converted to granitic gneisses and intruded by granitic rocks during the Hudsonian Orogeny. These plutonic events probably took place during the initial folding or just after it, and during the second phase of folding. During the intrusion of the granitic rocks and folding, Snare and Epworth rocks were metamorphosed to the point where andalusite, cordierite, and locally sillimanite metacrysts were developed. Gneissic to almost massive grey and pink granodiorites or quartz monzonites are the most abundant lithology in the granitic batholiths. These rocks grade into zones of varying widths of migmatites and mixed granitic gneisses that in turn grade to metamorphosed Snare or Epworth rocks. East of Wopmay River a broad zone of highly metamorphosed sediments, migmatites, and mixed gneisses intruded by a few, small granodiorite batholiths may represent the deepest level within the orogen. Farther south, east of Basler Lake, the grade of metamorphism of the sediments is lower and zones of migmatite rare. These factors along with the style of folding of sediments indicate that in this area a higher structural level within the orogen is exposed.

The phase of emplacement of granitic rocks was probably followed by a period of faulting, volcanism, and deposition of molasse-type sediments of the Cameron Bay and Echo Bay Groups. These sediments and the acidic volcanic rocks as well may have been deposited in basins bounded by faults such as the one along Wopmay River. This is a major, post-orogenic linear feature represented by zones of mylonite in the granitic rocks and by strong shearing in the sediments of the Snare Group. The Cameron Bay and Echo Bay Groups were intruded by feldspar porphyries of variable composition that probably are the intrusive equivalents of the volcanic rocks comprising the groups. These rocks are also intruded by nearly massive, hornblende-bearing, coarsely porphyritic granodiorites, and locally by massive pink granodiorite. Micas from these intrusive rocks yield K–Ar ages that range from 1,700 to 1,780 m.y. The latter intrusions are a high-level type with sharp contacts and narrow metamorphic aureoles. They are concentrated west of the Wopmay River in the area where the late geosynclinal and late tectonic Cameron Bay and Echo Bay rocks were deposited. A two-part division of granitic rocks, therefore, seems apparent. The oldest are syntectonic, rather deep-level granodiorites and attendant migmatites and gneisses that involve the Snare and Epworth rocks; these are followed by younger, late tectonic and possibly post-tectonic, high level granodiorites and granites that cut the Cameron Bay and Echo Bay and, to some extent, older rocks. The older intrusions are concentrated in the original miogeosynclinal environment whereas the younger ones occurring essentially in the late geosynclinal environment are probably closely related in time to the volcanic rocks.

Coppermine and Brock Subprovinces

Helikian

The Hornby Bay Group is best exposed north of Hornby Bay, Great Bear Lake. The basal units lie with angular unconformity or nonconformity on a deeply eroded surface underlain by rocks of the Epworth, Cameron Bay, and Echo Bay Groups and Hudsonian granitic rocks that cut these Aphebian sediments. Two formations are included in the group: a lower quartzite and conglomerate and an upper dolomite (Fraser, 1960). North of Great Bear Lake the lower unit may be as much as 4,000 feet thick but towards Coronation Gulf to the northeast it thins and finally disappears. The conglomerates are made up of pebbles of quartzite, quartz, and some quartz feldspar porphyry set in a white quartzite matrix. They are present as thin beds or lenses throughout the sequence of quartzites. The quartzites at the base of the succession are commonly thin bedded, reddish or purple, crossbedded, and ripple-marked. More typically, however,

the quartzites are white to light grey or pink, often cross-bedded, moderately coarse bedded, and coarse grained. They are composed of well-rounded grains of quartz with minor chert in a quartz cement. The upper unit of the group overlies the quartzites conformably. It consists of a shaly dolomite overlain by brown or reddish dolomite, and a buff to grey, finely crystalline dolomite with numerous stromatolitic zones. North of Great Bear Lake the dolomite is about 4,000 feet thick, but to the northeast towards Coronation Gulf it thins, and, where the lower unit is absent, lies unconformably on Epworth rocks and granite. To the west the dolomite is overlain probably unconformably by the early Paleozoic. Hornby Bay rocks are very gently dipping to horizontal except near some faults. The rocks appear to be folded into broad folds about northeast-trending axes.

The Hornby Bay rocks are conformably overlain by the Coppermine Group that on the basis of present knowledge is divided into two formations. The lowest formation is made up of basalt flows estimated as between 11,000 and 13,000 feet thick. The flows are brown, dark green, or purplish, fine-grained basalt and their composition appears to be fairly uniform throughout the sequence. Individual flows vary between 50 and 200 feet thick. They are largely massive but commonly the upper parts, and rarely the lower, are amygdaloidal. Calcite, quartz, chlorite, epidote, and locally native copper or chalcocite occur in the amygdules. The lavas dip very gently to the north at angles of 10° or less. Eight K–Ar age determinations on whole rock samples of these lavas yield dates that range from 735 to 1,200 m.y. There is no stratigraphic significance to this range of dates as some young ages have been obtained from flows near the base of the succession. Directions of natural remnant magnetization were measured on fifty-one oriented samples from twenty-four sites in these flows (W. A. Robertson, 1964), and yielded a pole position of 1°N and 176°W, placing the flows at a paleolatitude of 10°–15°. This pole position is very close to that of the Muskox Intrusion which is reasonably well dated at 1,150 m.y. It seems likely therefore that the Coppermine lavas are about 1,100 to 1,200 m.y. old and can be considered to be early Neohelikian.

The younger formation of the Coppermine Group comprises about 15,000 feet of sediments. Along Coppermine River the basal units are red sandstone, siltstone, and shale (Fraser, 1960). These rocks overlie the lavas conformably and may be locally intercalated as thin bands within the lavas. The red beds appear to be restricted to the Coppermine River and to be bevelled to the east and west. The basal units are overlain by grey shale which, according to Baragar (1967), is separated from the older rocks by a slight angular unconformity. The shale is overlain by buff, grey, or brownish dolomite with quartzite and shale beds near the top. North of Rae River, stromatolitic zones are present in a black limestone that may occur within the dolomite or overlie it. The stratigraphy of the Coppermine sediments underlying Brock Plain is not well known. The lowest beds are grey to black shales that probably are equivalent to those above the unconformity on Coppermine River. The shales pass upwards into a conformable sequence of pink, grey, and buff dolomite, and two beds of quartzite. Gypsum as much as 65 feet thick occurs in the carbonate unit on the Arctic coast and stromatolitic black limestone similar to that north of Rae River is found near Deas Thompson Point.

The basal red beds of the Coppermine sediments, because they are conformable with the lavas, and possibly interbedded with them, are probably closely related in age and may be Neohelikian. The sediments above the unconformity are cut by diabase sills from which three K–Ar whole rock age determinations yield dates that range from 445 to 718 m.y. They may be Neohelikian or Hadrynian.

Muskox Intrusion

The Muskox Intrusion is a layered basic intrusion that is dyke-like in plan and funnel-shaped in cross-section (Fig. IV-13). The intrusion cuts a basement complex of metamorphosed Epworth rocks, migmatite, granitic gneiss, and granodiorite, and the overlying quartzites of the Helikian Hornby Bay Group. The intrusion is not in contact with Coppermine rocks but the lavas and possibly some of the sediments probably formed the cover rocks. Age determination on micas and whole rock samples indicate an age for the Muskox Intrusion of 1,100 to 1,200 m.y. The remnant magnetism of the rocks has a pole position of 4°N, 175°W (W. A. Robertson, 1964). This position is very close to that of the Coppermine lavas and together with the radiometric data suggests time equivalence. Radiometric and paleomagnetic data also indicate that the diabase dykes of the Mackenzie swarm were emplaced at roughly the same time (Fahrig, *et al.*, 1965). There was accordingly an important period of basic magma intrusion in Bear Province in the early Neohelikian. According to Smith (1962), the shape of the intrusion is controlled to a large extent by the unconformity at the base of the Hornby Bay sediments, which dammed the magma moving up the northerly trending feeder dyke, causing it to spread out into a funnel-shaped form. A large volume of magma accumulated in which differentiation could take place. The feeder dyke is nearly vertical whereas the contacts of the funnel-shaped portion of the mass dip inwards at 57° in the south part, gradually decreasing to the northeast to 22°.

The intrusion has been divided into a number of structural and petrological units. The feeder forms the southern half of the mass and is about 37 miles long and from 500 to 1,800 feet wide. Bronzite, gabbro, and norite are the most abundant rock types, but as the dyke widens lenses of picrite occur and finally form an almost continuous zone in the centre of the dyke. The marginal zone of the intrusion is present in the northern part and varies in width from 200 to 1,200 feet. It consists of a gradational series of lithological types that, from the contact

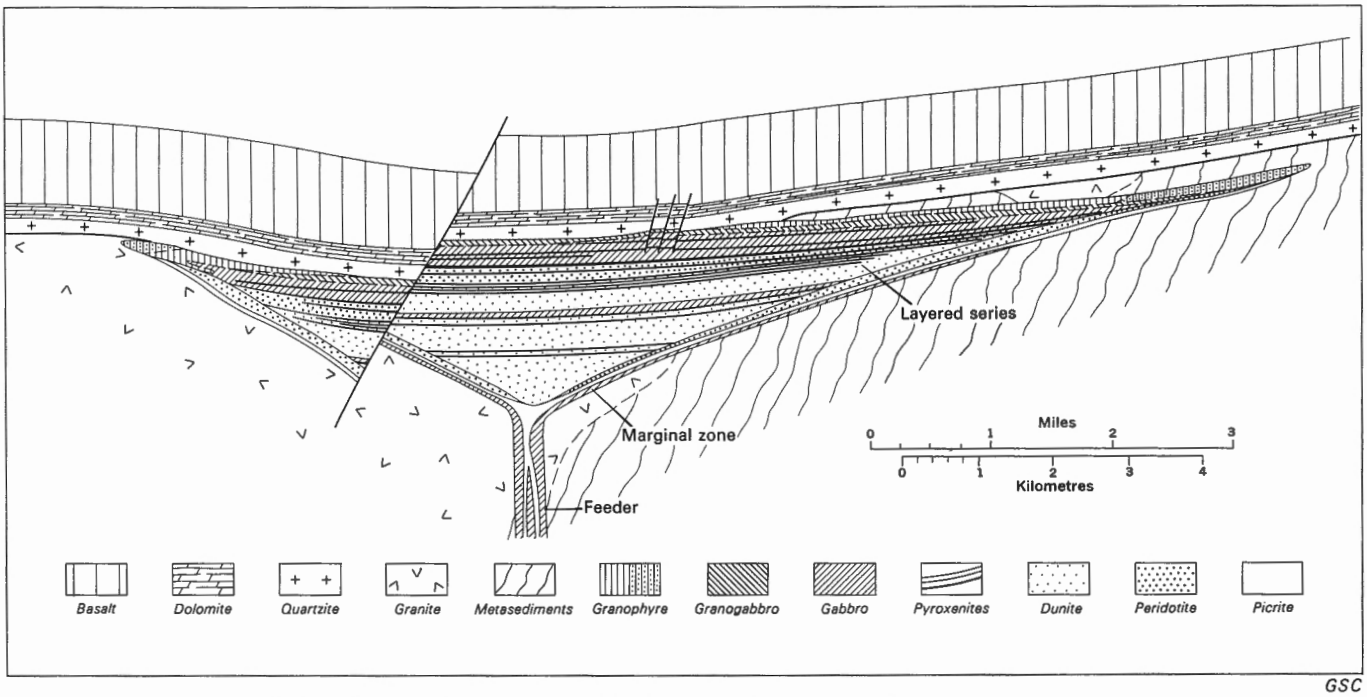

FIGURE IV-13. Typical cross-section of the Muskox Intrusion (by T. N. Irvine and C. H. Smith).

inward, include bronzite, gabbro, picrite, feldspathic peridotite, peridotite, and then dunite in places. The contact gabbro is chilled locally and thins northward to zero. The central layered series comprises alternating layers of dunite, peridotite, pyroxenites, and gabbro. Dunite is most abundant in the lower part of the series and gabbro in the top. The sequence is about 8,500 feet thick and is composed of thirty-eight main layers some of which are banded. The layers dip northwest at 10° about parallel with the dip of Coppermine flows. The layers continue to within 1,200 to 2,000 feet of the margin of the intrusion where they steepen slightly and then die out. The upper border zone is about 200 feet thick and consists of granophyre-bearing gabbro at the base that grades upwards into granophyre. Intrusive breccia is common along the top of the border zone, and consists of variably sized fragments of Hornby Bay quartzites and some fragments of the older basement rocks set in a granophyre matrix.

Diabase Dykes and Faults

The oldest known diabase dykes that cut rocks of Bear Province are northerly to north-northwesterly trending, vertical-dipping dykes of the Mackenzie swarm whose age is in the range 1,100 to 1,300 m.y. (Pl. IV-9). These dykes cut the Hornby Bay Group and probably also the Coppermine lavas. Dykes trending north of east are south of Great Bear Lake and possibly extend northeast to where they cut Epworth rocks. They have been tentatively dated at 875 m.y. (Fahrig, *et al.*, 1965). A few north-northeast striking dykes that occur south of the Coppermine lavas and also cut Coppermine sediments yield K–Ar dates that average 700 m.y. These latter rocks may be related to diabase sills in the Coppermine sediments that have similar dates. The Mackenzie dykes yield dates that compare with those of the Coppermine lavas and Muskox Intrusion, and paleomagnetic data from the three types of basic rock have given similar pole positions. Thus a major period of basic magma intrusion and extrusion took place in the middle Helikian. It was followed by a second period in the late Hadrynian, represented by diabase dykes, sills, and probably also the Natkusiak volcanic rocks.

Faults cut rocks of all ages in Bear Province but appear most common in rocks older than the Coppermine Group. Most strike northeasterly and northerly but some trend northwest. All are nearly vertical and marked by narrow zones of gouge, breccia, and mylonite. Quartz veins occur in related fractures and the "giant quartz-veins"—broad, long quartz stockworks—are localized along some faults, particularly those with a northeast trend. They contain massive quartz or crystal-lined vugs that are fractured and veined with younger quartz. The wall-rocks are silicified and cut by narrow, braided quartz veins. On some stockworks later faulting took place along one or both contacts. Localization of the stockworks is partly controlled by slight variations in strike, and possibly also dip, of the faults (McGlynn, 1957). In northern Bear Province, north- and northeast-trending faults displace the lavas and lower sediments of the Coppermine Group, as well as Muskox Intrusions and some diabase dykes of the Mackenzie swarm. However, many Mackenzie dykes are

known to be post-faulting and some cut the quartz stockworks. Either there are two ages of faults with the same orientation, or, more probably, the faulting and the intrusion and extrusion of basic magma are related events reflecting a period of tension during mid-Helikian times. It seems likely that many of the north- and northeast-trending faults in the southern part of the province are related to those in the north. However, there is movement on some of these faults which is later than the diabase dykes that are tentatively dated at about 875 m.y. Some old faults may have been reactivated at this time or new northerly and northeasterly trending faults may have formed at about the time of intrusion of the younger diabase dykes.

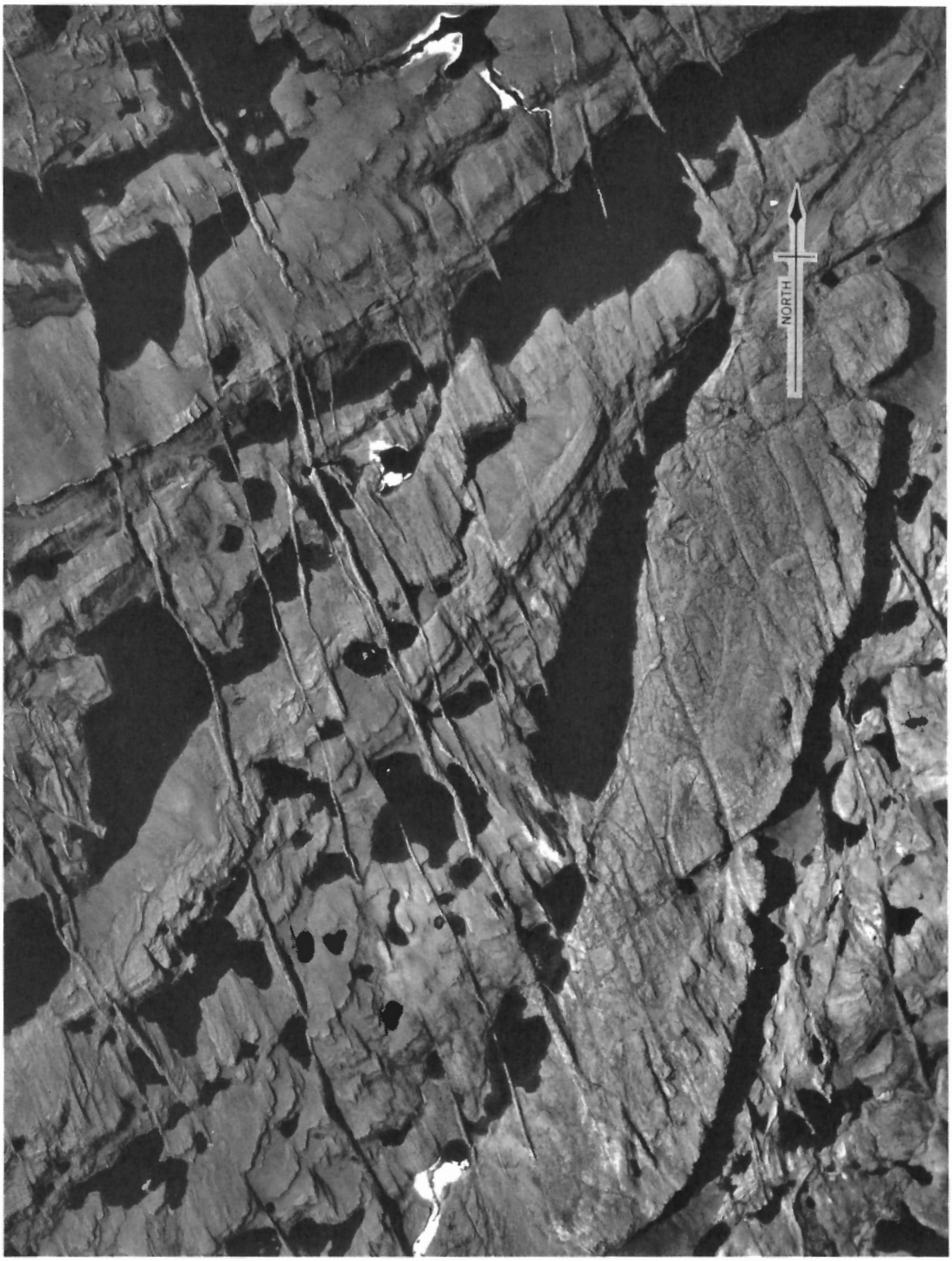

PLATE IV-9

Vertical air photo of northwest-trending diabase dykes of Mackenzie swarm cutting gently folded strata of Aphebian Epworth Group, Bear Province, Northwest Territories.

Minto Subprovince

The Precambrian rocks on Victoria Island range in age from the Archean to Hadrynian (Thorsteinsson and Tozer, 1962). The oldest rocks are exposed at the head of Hadley Bay and consist of north-northeasterly striking, moderate- to steep-dipping quartzite, schistose quartzite, and granodiorite thought to be younger than the sediment. Biotite from the latter rock yields a K–Ar date of 2,405 m.y., a Kenoran granite. The quartzite accordingly is Archean if cut by the granodiorite.

The thick conformable succession of the Shaler Group unconformably overlies the older rocks and is overlain disconformably by basic volcanic rocks of the Natkusiak Formation. The Shaler Group is intruded by numerous gabbro sills and dykes. The basal Glenelg Formation is divided into two members, the oldest of which consists of 2,000 feet of red, white, or grey, thin- to thick-bedded quartzite and sandstone, alternating with dark grey concretionary shale, siltstone, and very fine grained dolomite. The upper member comprises about 1,200 feet of thick-bedded, grey to light red quartzites with a thin unit of thick-bedded, reddish orange or brown, stromatolitic dolomite at the top. Tentatively correlated with the Glenelg are red, coarse-grained quartzites with quartz-pebble conglomerate on Richardson Islands and on the south shore of Victoria Island. On Banks Island, grey thin-bedded limestones, cherty limestone, and chert similar to the lower Glenelg in the type area are overlain by red sandstone or quartzite with minor grey shale and siltstone lithologically similar to the upper Glenelg.

The Glenelg Formation is overlain conformably by the Reynolds Point Formation that comprises a basal unit of grey, medium-bedded sandstone succeeded by 1,900 feet of grey, medium-bedded, argillaceous limestone with minor, interbedded sandstone, shale, and stromatolitic limestone. The conformably overlying Minto Inlet Formation varies from 300 to 1,200 feet in thickness. It is composed of white, thin-bedded gypsum and anhydrite with some grey or red sandstone, greyish green limestone, grey shale dolomite, and siltstone. The Wynniatt Formation rests with sharp contact on the Minto Inlet. It is composed of 2,700 feet of dark grey to black, thin-bedded limestone and argillaceous limestone with several stromatolitic and dolomitic horizons. The conformably overlying Kilian Formation is a mixed assemblage of thin-bedded, multicoloured sediments, about 600 feet thick. The lower member is composed of white, grey, or pink gypsum and anhydrite, grey gypsiferous or calcareous shale and reddish brown sandstone, siltstone and dolomite. Crossbedding, ripple-marks, and desiccation fractures are common, indicating a shallow-water environment of deposition. The upper member is similar but contains no gypsum or anhydrite. In the west the uppermost beds are buff, cross-bedded sandstone and conglomeratic sandstone that was eroded before the succeeding Natkusiak volcanics were extruded.

The Natkusiak Formation lies disconformably on the Kilian Formation. It has a maximum thickness of 1,000 feet and consists largely of basalt with minor amounts of tuff or agglomerate. Individual flows are as thick as 100 feet and are commonly massive with flow-top breccias and thin amygdaloidal zones at the base and top. Numerous diabase sills intrude all formations of the Shaler Group and possibly also the Natkusiak Formation. They are as much as 100 feet thick and extend for tens of miles along strike. They are probably closely related in time to the extrusion of the Natkusiak volcanic rocks. Whole rock K–Ar determinations from two samples from sills yield dates of 635 and 640 m.y. and those from three samples of the Natkusiak volcanics range from 390 to 483 m.y. These latter ages are probably too young; the volcanics are gently folded with the rest of the Shaler Group which is overlain unconformably by Middle Cambrian and Ordovician sediments. Except within a few feet of gabbro sills the Shaler Group is unmetamorphosed. The main exposures of the Precambrian rocks are along the Minto Arch, where the structural discordance between Paleozoic and Precambrian rocks clearly demonstrates that Shaler and Natkusiak rocks were folded before the deposition of Cambrian sediments. The Precambrian rocks have been gently folded about easterly-northeasterly axes. Rocks dip at 10 degrees or less and the folds plunge very gently to the east or west.

On the basis of present information correlations of Shaler strata with late Precambrian rocks on the mainland can only be speculative. The volcanic rocks and gabbro sills, although they yield K–Ar dates that range from 390 to 640 m.y. are probably pre-Middle Cambrian. The Shaler rocks that are separated from the volcanic rocks by a disconformity could be Neohelikian or Hadrynian in age. The range of dates from sills cutting Coppermine sediments is 445 to 718 m.y., which overlaps with dates from Natkusiak volcanics and related sills, suggesting an age equivalence. Quartzites on the Richardson Islands and adjoining mainland of Victoria Island that have tentatively been included in the Glenelg are on strike with Coppermine sediments and cut by sills that intrude Coppermine sediments; therefore they may be part of the Coppermine succession. Similarly, quartzites at the head of Wellington Bay on the south shore of Victoria Island may be part of the Coppermine or even related to older quartzites on the mainland in the Bathurst Inlet area such as the Tinney Cove Formation. The main part of the Shaler succession has the characteristics of sediments deposited in a shallow-water, marine environment with gypsum and anhydrite extensively developed. That part of the Coppermine sediments above the unconformity also appears to be a typical, marine, shallow-water succession but gypsum beds are only local. Coppermine sediments, accordingly, may correlate with at least part of the Shaler Group.

Tectonic Summary

The oldest rocks, probably Archean, in Churchill Province are composed predominantly of basic to intermediate volcanic flows and pyroclastics, overlain by flysch-type sediments of greywacke and shale with thin bands of volcanic rocks, quartzite, and dolomite. The various belts are isolated and trend north to northeast to easterly. The rocks are folded about northerly to northeasterly axes and metamorphosed to varying degrees, transformed into migmatite or granitic gneiss, and cut by massive or slightly foliated granitic rocks. Only in a few places is there positive evidence for the age of these strata and no basement has been found beneath them. Most K–Ar age determinations yield Hudsonian dates but a number of older Kenoran ages are obtained. All these probable Archean rocks have been affected to varying degrees by phases of the Hudsonian Orogeny. Before the deposition of Aphebian sediments, all of what is now Churchill Province is thought to have been underlain by deformed Archean supracrustal and granitic rocks.

Aphebian rocks occur in a number of separate belts in Churchill Province. In places these rocks are known to rest unconformably on older, presumably Archean rocks and Kenoran granitic gneisses. Deposition of the sediments probably took place in separate geosynclines possibly of significantly different ages. All Aphebian rocks have been folded, metamorphosed very slightly to intensely, and some have been intruded by granitic rocks and converted to granitic gneiss. This orogenic activity is referred to as the Hudsonian Orogeny. It may have separate phases as it is probable that several separate orogenic belts occur in Churchill and Bear Provinces that roughly coincide with the several geosynclines in which Aphebian sediments were deposited (Fig. IV-14). The structural trends vary from belt to belt and intensity and style of deformation, degree of metamorphism, amount of granitization, and number of granitic intrusions vary along individual belts as well as between belts. In the areas between the orogenic zones, the rocks are for the most part granitic genisses that commonly yield K–Ar ages in the range 1,700 to 1,900 m.y. However, a number of older dates have been obtained from these gneisses. These gneisses and granites are thought for the most part to have formed during the Kenoran Orogeny and, therefore, to represent basement to the Aphebian sediments. They were affected by phases of the Hudsonian Orogeny as indicated by modifications of the K–Ar ages and then were cut by major fault zones some of which were probably initiated during late phases of the Hudsonian Orogeny.

Late or post-tectonic sediments and volcanics were deposited in isolated basins that were probably largely fault controlled. The sediments include conglomerate, feldspathic sandstone, lithic sandstone, arkose, and shale. The volcanic flows and pyroclastics and their intrusive equivalents range in composition from basalt to trachytes. The moderate to slight folding of these rocks took place possibly during movement along the faults. They are slightly metamorphosed but are not cut by granitic rocks. These rocks are late Aphebian if the related tectonic activity is considered to be a late phase of the Hudsonian Orogeny, or Paleohelikian if the tectonic activity is post-orogenic. The major period of intrusion of basic rocks is about 1,200 m.y. at which time the Mackenzie swarm of north-northwesterly to northerly trending dykes were intruded in the western part of the province. Other smaller swarms of about this age were intruded in the eastern part of the province. South of Great Slave Lake the dykes trend west of north and yield ages in the range 1,500 to 1,600 m.y.

Helikian and possibly Hadrynian sandstones and dolomites are flat lying or very gently folded. They were deposited on deeply eroded basement underlain by Kenoran and Hudsonian gneisses and granitic rocks, and Aphebian sediments in western Churchill Province.

Aphebian

Aphebian sediments in Churchill Structural Province were deposited on a basement of deeply eroded Archean rocks and granitic gneisses formed during the Kenoran Orogeny. Known exposures of Aphebian strata appear to be rather small segments of formerly more extensive geosynclines. There may have been three separate geosynclines, the relative ages of which are not known. They may have been of quite different ages and unrelated tectonically.

In the western part of the province in the East Arm Belt, Aphebian rocks were probably deposited in a geosyncline that included Aphebian rocks in Slave and Bear Provinces. This geosyncline had a northerly to north-northeast strike. Part of what is now Slave Province was a positive cratonic area during Aphebian time and a source of some of the sediments. The stratigraphic order of the various groups thought to be remnants of the original geosyncline is grossly similar, which suggests that they may be time equivalents. Basal quartzite strata are largely fluvial but partly marine and include dolomite in some sequences. They are succeeded by argillite and dolomite. Thick stromatolitic sequences occur in the dolomites in parts of the sections. The limy rocks are overlain and locally grade into siltstone, shale, and greywacke that represent a somewhat deeper water facies. Red, non-marine sandstone and shale are the youngest rocks of the various groups. Basic to intermediate volcanic rocks are present in the lower part of some sequences and at or near the top of others. In general the sequences are miogeosynclinal, composed of rocks deposited in a shallow-water, shelf environment. Non-marine and red bed strata indicate a number of marine regressions. There are differences between the

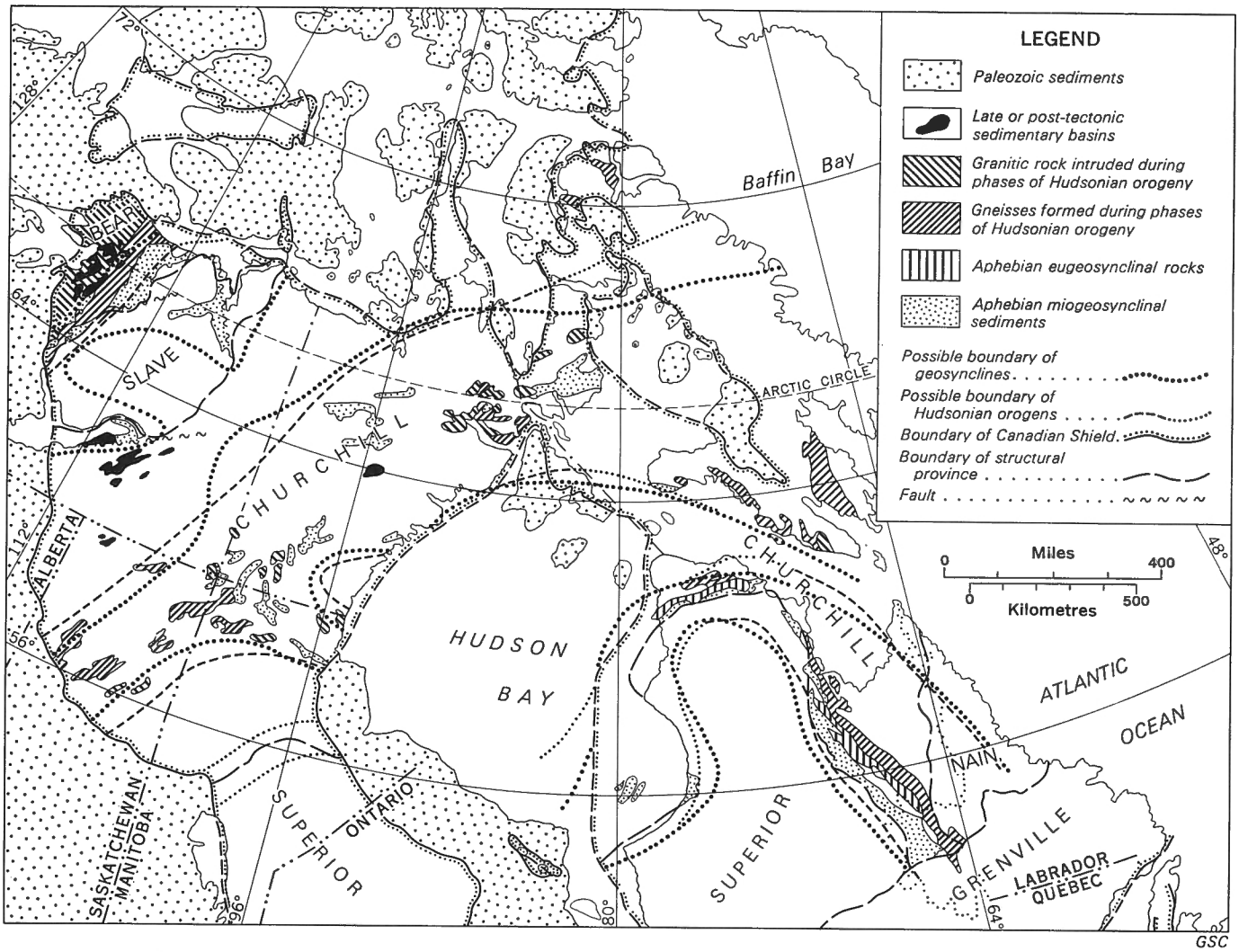

FIGURE IV-14. Possible extent of Aphebian geosynclines and Hudsonian orogens in Churchill and Bear Provinces of the Canadian Shield (by J. C. McGlynn).

various successions such as thickness of formations, variation in thickness of stromatolitic units, relative amounts of marine and non-marine sediments, and presence or absence of volcanic rocks.

In the central part of Churchill Province west of Hudson Bay, Aphebian rocks were probably deposited in a north-northeasterly to east-northeasterly trending geosyncline. The succession generally consists of a basal quartzite with lenses of conglomerate and greywacke overlain by argillite, carbonate, thinly bedded greywacke, and impure quartzite. Basic volcanic rocks occur locally near or at the top of the sequence. Where they are not in contact with younger granitic rocks the basal units rest unconformably on Archean rocks or granitic gneisses formed during the Kenoran Orogeny. The unmetamorphosed Aphebian sediments now exposed are generally miogeosynclinal rocks, generally shallow water or shelf facies, and largely marine types. Some of the clastic rocks are probably fluvial. The upper part of some sequences represents a transition to somewhat deeper water environments. Typical eugeosynclinal sequences, however, do not occur along the margins and if they were present in the interior parts of the geosyncline they have since been eroded or completely converted to gneisses. The limited evidence from paleocurrent and other studies indicates that the sediments were derived from the east, but the westernmost Aphebian rocks have not been studied in detail and their source is unknown.

East of Hudson Bay, Aphebian rocks occur that were probably deposited in a third geosyncline that includes rocks in the Labrador and Cape Smith Fold Belts and possibly also the Belcher Fold Belt in eastern Hudson Bay extending around the stable craton part of Superior Province. However it should not be considered to be a geosyncline marginal to a continental mass as Archean rocks are exposed north of the Cape Smith Fold Belt and east of the Labrador Fold Belt. Rocks of the Labrador Fold Belt consist of a western sequence of miogeosynclinal sediments that rest unconformably on Archean gneisses of Superior Province and an eastern sequence of eugeo-

synclinal sediments and volcanic rocks. Gabbro and ultrabasic sills probably related to the volcanism occur in both sequences. The eugeosynclinal sequence is partly a time equivalent of the miogeosynclinal formations, but is mostly younger than them. Basal unconformities are found in several places along the eastern margin of the belt but generally the Aphebian rocks are separated from mixed gneisses or granitic gneisses by a fault. The gneisses are probably metamorphosed equivalents of the sediments but locally may include Archean basement rocks. In Nain Province, Aphebian sediments occur which may mark the eastern boundary of the geosyncline. A western source area is indicated for the miogeosynclinal sediments and for at least some of the eugeosynclinal sediments. These rocks can be traced into Grenville Province where they become involved in the Grenvillian Orogeny. The geosyncline probably extended southwest to include the Aphebian rocks of the Mistassini Subprovince and some in Southern Province. In the Cape Smith Fold Belt the basal units along the southern margin of the belt that lie unconformably on Archean gneiss of Superior Province are miogeosynclinal sediments comprising quartzite, shale, dolomite, and iron-formation. They are overlain by thick basic volcanic rocks. In Belcher Fold Belt the sequence is essentially conformable and very thick, ranging up to about 30,000 feet. Most of the sediments are typical miogeosynclinal facies and record deposition in a shallow-water shelf environment; some are deposited in a fluvial environment.

The general distribution of Aphebian rocks suggests that they were deposited in three separate geosynclines that were not marginal to continent but were intracratonic. The sediments are for the most part miogeosynclinal facies but eugeosynclinal rocks are developed in some parts. An obvious difference between the various sequences is the occurrence of important thicknesses of iron-formation in Quebec and Labrador as opposed to the relatively insignificant development of these rocks in other areas. This reflects a difference in the nature of the source area or different conditions of deposition of the sediments. The presence of red beds and thick carbonate sequences that include significant stromatolitic zones in rocks that are probably more than 2 million years suggests that the chemistry of sea water and atmosphere has not changed in a fundamental way since Archean time.

In western Churchill Province several sedimentary basins have thick deposits of polymictic conglomerates, arkose, feldspathic or lithic sandstone, and shale. Basic to intermediate volcanic lavas and pyroclastics and hypabyssal intrusive equivalents occur in some. The sediments are largely non-marine or continental, often reddish and relatively immature. They are products of rapid erosion of a tectonically unstable terrain of considerable relief. The basins of deposition appear to be fault bounded with movement along the faults occurring during sedimentation. The rocks are moderately to gently folded and except near intrusions are unmetamorphosed. Volcanic rocks, where dated, yield maximum ages of about 1,730 m.y. The sediments and igneous rocks are typical of late tectonic, synorogenic activity and of post-orogenic tectonic activity. They may therefore be late Aphebian or Paleohelikian and may possibly correlate with similar rocks that occur in Bear Province.

Hudsonian Orogeny

The Hudsonian Orogeny in the late Aphebian affected the greater part of Churchill Structural Province as well as Bear and Southern Provinces. Within Churchill and Bear Provinces, it is possible to very tentatively outline three orogenic zones (Fig. IV-14) in which Aphebian rocks are folded, metamorphosed, converted to granitic gneisses, and intruded by granitic rocks. These orogens coincide approximately with the Aphebian geosynclines outlined in the preceding section. Although micas from rocks formed during these orogenies yield K–Ar dates that range between 1,650 and 1,850 m.y., the individual orogenies may not be precisely the same age. Accordingly, they are referred to as phases of the Hudsonian Orogeny.

The most westerly of the possible orogenic zones occurs essentially in Bear Province and is described in that section. Aphebian rocks in East Arm Subprovince are very slightly metamorphosed, but not cut by granitic rocks, and are moderately to gently folded about axes that trend northeast. The deformation may be of about the same age as the orogenic activity to the west and related to it, but these rocks, which are thought to be direct correlatives of Aphebian rocks in Bear Province, are thought to be east of the zone of intense orogeny.

In central Churchill Province, Aphebian strata are folded about north-northeasterly to east-northeasterly axes. In some areas these structures are refolded about north to northwesterly trending axes. Intensity of deformation, metamorphism, and granitization increases from the eastern margin to the interior of the orogen and along the axes of the orogen is most intense in the southwest and northeast sections. In the central part of the orogen, the exposed granitic gneisses may be largely Archean gneiss little affected by the orogeny. To the northeast in the Melville Peninsula and possibly on Baffin Island folding and metamorphism is again more intense. Granitic rocks are intruded along the length of the orogen and high-level intrusions of fluorite-bearing granodiorite are characteristic.

In Quebec and Labrador a third orogenic zone partly corresponds to the Aphebian geosyncline. Folding and metamorphism increase in intensity to the east and north. Fold axes in the Labrador Fold Belt trend northwest to north and are inclined to the east or northeast. Metamorphism increases to the east towards a belt of granitic gneiss and migmatite that include highly metamorphosed remnants of the Aphebian sediments and volcanic rocks. Similar gneisses occur along the northern margin of the Cape Smith Fold Belt. Zones of remobilized Archean basement rocks may be within these gneisses. The

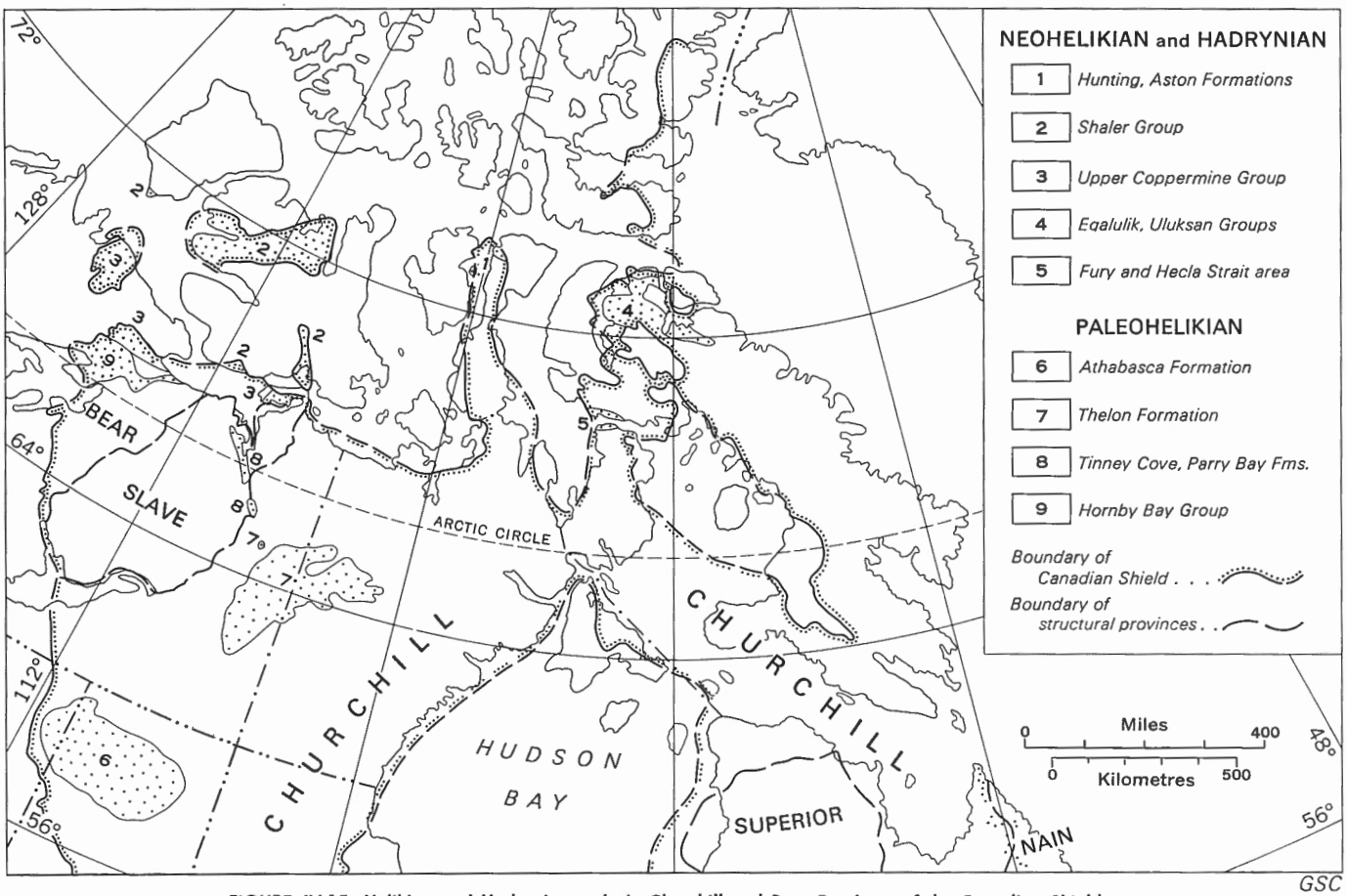

FIGURE IV-15. Helikian and Hadrynian rocks in Churchill and Bear Provinces of the Canadian Shield.

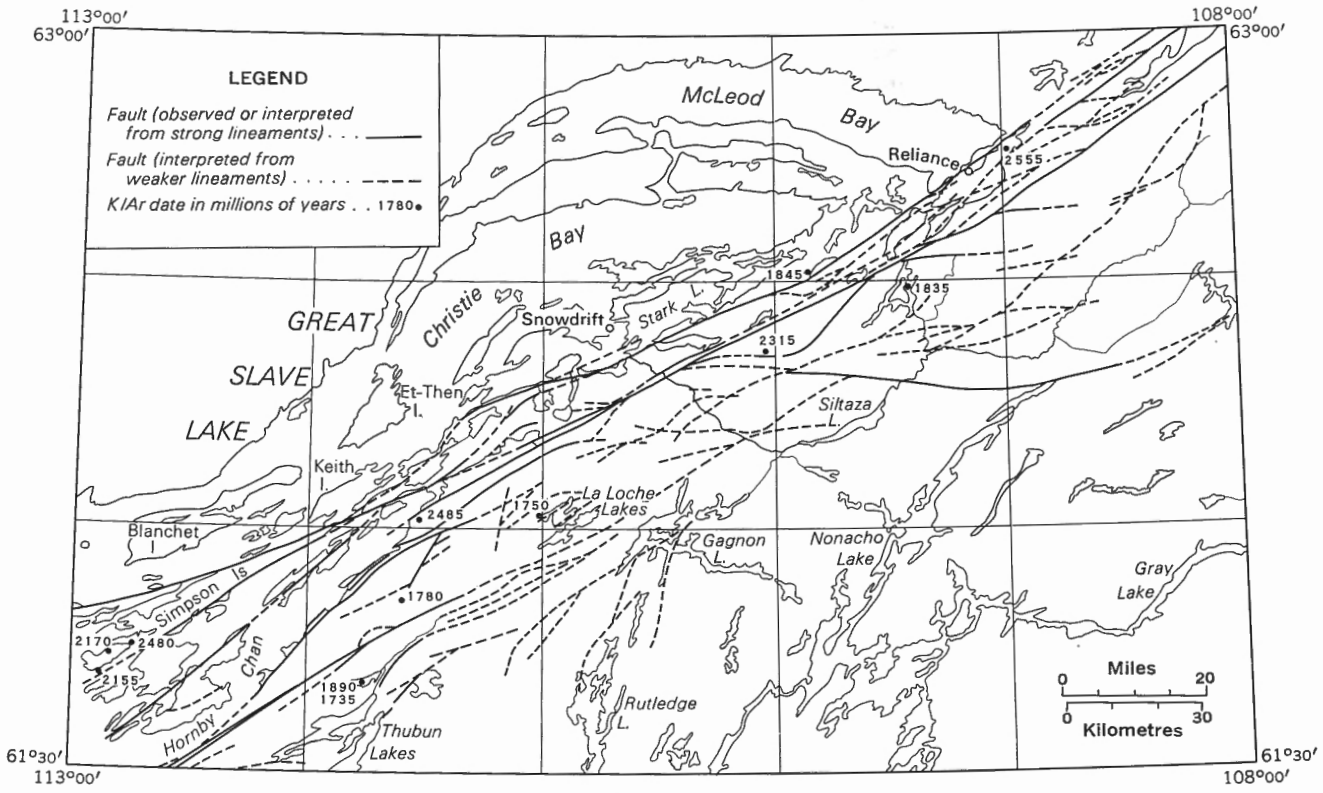

FIGURE IV-16. The McDonald fault system south of Great Slave Lake, Northwest Territories (by E. W. Reinhardt).

Aphebian strata of Belcher Fold Belt are moderately folded but little metamorphosed.

In the areas intervening between the orogenic zones in the Churchill Province rocks are granitic gneisses with volcanic and sedimentary rocks of possible Archean age. The granitic gneisses probably are also for the most part Archean rocks that have been little affected by the Hudsonian Orogeny. They have been cut by major fault zones that strike north, northeast, and northwest. Some are complex zones along which wide bands of sheared, brecciated, or mylonitized rocks are developed. They probably were initiated in the Hudsonian Orogeny but movement continued during the Helikian. Some zones occur near the boundaries of the structural province and others near the margins of the orogens. Syn- or post-tectonic sediments were deposited in basins developed along some of these fault zones.

Helikian and Hadrynian

Helikian rocks outcrop in several areas of Churchill Province (Fig. IV-15). The character of the strata in various basins is similar, being generally composed of quartzite, conglomerate, siltstone, shale, and stromatolitic dolomite. The basal quartzites were deposited on a deeply eroded basement during a period of tectonic stability in a fluvial environment as indicated by the sedimentary structures. The other strata were probably deposited in a near-shore marine environment. Remnants between the main exposures suggest that these sediments were more extensive, covering much of the western part of the shield particularly in Paleohelikian time, but parts of Slave and Bear Provinces may have been positive areas. Neohelikian and Hadrynian sedimentary and volcanic rocks are rare in Churchill Province. On northwestern Baffin Island and Somerset Island the sequences are grossly similar, comprising thick basal quartzites that grade upwards to dolomite, and then in the thickest sequences into silty shale and quartzites. Some basic volcanic rocks are near the base. They may be correlative with the Coppermine sediments of Bear Province, and the Shaler Group on Victoria Island which are shallow-water marine deposits that may have been deposited in the same basin.

Faults and Diabase Dykes in Churchill Province

The most prominent swarm of diabase dykes that cut the rocks of Churchill Province are north-northwesterly trending, vertical-dipping dykes of the Mackenzie swarm whose age is about 1,200 m.y. These rocks are about the same age and probably are related genetically to the Coppermine lavas, the sills in the Goulburn and Great Slave Groups, and possibly also volcanics in the upper part of the Dubawnt Group. A swarm of northwesterly striking dykes in Baffin Island yield dates in the range 1,000 to 1,200 m.y., and the volcanic rocks near the base of the Eqalulik Group may be related to these dykes. Other dykes and sills of gabbro and basic volcanic rocks that occur throughout the Proterozoic rocks in the Arctic Islands and northern mainland give K–Ar ages that range from 400 to 750 m.y. There seems to be two periods of major basic magma intrusion, at about 1,100 to 1,200 m.y. and 600 to 750 m.y.

Faults cut all rocks of Churchill Province but may be more abundant in the older rocks. They trend north, northeast, and northwest and are commonly steep-dipping. Relative ages of these structures or absolute ages of major movement are uncertain. Some of the major structures, such as the McDonald *(Frontispiece;* Fig. IV-16) and Bathurst fault zones, those near Lake Athabasca, and along the Slave–Churchill boundary, were initiated early, about 1,700 to 1,760 m.y. ago before and during deposition of late Aphebian or early Paleohelikian red bed sequences. Wide zones of intense crushing, brecciation, and mylonitization were formed during this early period of movement. Later movement took place and many new faults were formed. These structures are characterized by narrow breccia or shear zones and probably occurred at a higher crustal level. They are numerous in the gneissic terrain but also cut Paleohelikian and Neohelikian rocks. The faults may be temporally related to that period of tectonic instability during which the older diabase dykes and Neohelikian lavas were generated. After deposition of Neohelikian and possibly Hadrynian sediments some new faults formed and movement occurred along older structures. These structures may be related to the Hadrynian gabbroic intrusions and volcanic rocks. Along a few faults such as the McDonald, there is evidence of movement in Paleozoic time (Chapter VIII). Most faults appear to be strike-slip types with left-hand displacement being more common than right-hand. However, some of the older faults with a long history of movement appear to have a considerable vertical component.

Thompson Belt

The Thompson Belt includes a rather narrow part of Churchill Province along the boundary with Superior Province in northern Manitoba (Bell, 1966; Davies, *et al.,* 1962). The oldest rocks are greywacke, argillite, feldspathic quartzite, minor conglomerate, skarn, metavolcanic rocks, and amphibolite. These rocks occur as structurally conformable sequences in belts that trend northeast to east. The strata appear to be folded isoclinally and may be overturned. The sediments locally are called the Assean Lake Group. With increasing metamorphism they grade into well-banded, biotite quartz feldspar gneiss that may also contain hornblende, garnet, magnetite, or cordierite. The gneisses grade into or are intimately mixed with less well-banded granitic gneiss that grades into or is cut by massive to faintly gneissic grey to pink granodiorite, massive red porphyritic granite, and pegmatite. Ultrabasic and basic rocks intrude the sediments and volcanic rocks and their metamorphosed equivalents. They

occur as lenticular, concordant masses several hundred to a few thousand feet long and are restricted to a narrow zone of shearing and faulting, that strikes northeasterly to parallel with the Churchill–Superior boundary. The ultrabasic rocks are serpentinized, but where not sheared, textures indicate that they were originally peridotite composed of olivine and pyroxene. In places these rocks appear to be metamorphosed and pyroxene, amphibole, olivine, clinochlore, and spinel are developed. Some ultrabasic bodies are cut by pegmatite.

The zone into which the ultrabasic rocks are intruded coincides with a belt of low gravity which to the northeast is coincident with the boundary with Churchill–Superior Provinces. In Superior Province a belt of high gravity is coincident with a belt of high-grade metamorphic rocks, largely in the granulite facies. The various units have also their own magnetic expressions (Kornik and MacLaren, 1966).

The age of the volcanic and sedimentary rocks and the ultrabasic intrusions is a matter of uncertainty—they may be Aphebian or Archean. Bell (1966) suggests that they represent the redeformed western extension of the Fox Lake Belt, the age of which is also uncertain. The small ultrabasic masses, he suggests, were derived from differentiated basic to ultrabasic sills and were reintruded during the second deformation. The ultrabasic masses are considered to be Alpine-type intrusions by Davies, *et al.* (1962). The nature of the Hudsonian Orogeny in this area is not completely known; some of the presently observable effects may result from the older Kenoran Orogeny. The sediments and volcanics have been folded and probably refolded; they were granitized and intruded by some granitic rocks and pegmatites and certainly were metamorphosed, intensely sheared, and faulted. Northeasterly to easterly trending fault zones and faults are concentrated in the boundary area of the two provinces. The precise location of the boundary is a matter of some controversy. Stockwell (1961) places it along the zone where the easterly trending structures of Superior Province are abruptly cut off by northeasterly striking structures of Churchill Province (Fig. IV-11). Bell (1966) suggests that the boundary be placed along the north contact of the zone of high-grade gneisses of the granulite facies. Kornik and MacLaren (1966) place the junction along a narrow continuous magnetic low (Pl. IV-4). The latter boundary almost coincides with that of Stockwell and may be considered a refinement of it.

Flin Flon–Lynn Lake Region

The oldest rocks of the Flin Flon–Lynn Lake region are basic to acidic volcanic flows, related tuffs and agglomerates, arkose, greywacke, and shale. These rocks are in two belts that trend east through Lynn Lake and Flin Flon. The intervening area is underlain by a complex of granitic gneisses and intrusions. In the Flin Flon Belt the oldest rocks are generally considered the Amisk Group, which contains thick massive or pillowed basalt and andesite that are overlain by intercalated basic flows, dacite and rhyolite, tuffs, breccias, and agglomerates. In some areas these rocks are conformably overlain by greywacke and shale, or grade along strike into them. Gabbroic sills or plutons occur in the volcanic rocks and locally also in the sediments and are probably intrusive equivalents of the lavas. Similarly, intrusive masses of quartz feldspar porphyry and rhyolite porphyry are considered equivalents of the acidic lavas. Minimum thickness of the group varies from a few thousand to at least 20,000 feet.

In the vicinity of Flin Flon, Amisk rocks are overlain by the Missi Group. At Flin Flon, Stockwell (1960) considered the base of the Missi to be an unconformity. West of Flin Flon, Byers and Dahlstrom (1954) also found an unconformity at one locality but considered the two groups are regionally structurally conformable and that no major time break exists in the sequence. The basal unit of the Missi Group is normally composed of a conglomerate that consists of angular to subrounded boulders or pebbles of the various lithologies in the underlying Amisk along with minor amounts of chert, jasper, and quartz and very rare cobbles of granite in a greywacke or arkosic matrix. The unit grades upwards to greywacke and subgreywacke with thin beds of conglomerate. The minimum thickness of the Missi appears to be at least 5,000 feet. Sediments that have been given various local names in the area between Flin Flon east to Wekusko Lake have been tentatively correlated with the Missi by Harrison (1951) and others. They are essentially greywacke and shale with local limy beds and, in places, considerable thicknesses of volcanic rocks. Conglomerates are commonly not present. The sediments are structurally conformable with the underlying Amisk and in places interbedded with Amisk flows. Locally sediments and Amisk volcanics are separated by faults. All sediments were probably deposited near the end of the Amisk volcanism, or just after it, and volcanic activity continued in places during the deposition of sediments. The Amisk and Missi rocks may have occurred originally in easterly trending belts.

The Kisseynew Complex occurs in easterly trending belts north of the Amisk and Missi Groups, extending from east-central Saskatchewan easterly to the Paleozoic cover of Hudson Platform. East of Sherridon, Robertson (1953) has subdivided the Kisseynew into the Nokomis and Sherridon Groups, based largely on structural interpretation. The Nokomis Group is a hornblende gneiss consisting essentially of hornblende and plagioclase with variable amounts of quartz, garnet, biotite and epidote and quartz–plagioclase–biotite gneiss with variable amounts of garnet, hornblende, microcline, cordierite, and sillimanite. The hornblende gneiss occurs as thin bands interbedded with the more abundant biotite gneiss and

grading into it. The Nokomis is overlain conformably by the Sherridon Group which consists of quartz-rich gneiss, hornblende gneiss, limestone, and a band of anthophyllite-bearing rock. The transition between the two groups is marked by graphite in the upper fine-grained parts of the Nokomis succession, and by discontinuous orthoquartzite and limestone near the base of the Sherridon sequence, which grade upwards into quartz-rich gneiss. Quartz forms more than half these latter rocks along with some plagioclase, garnet, and usually biotite. The hornblende gneiss is composed of plagioclase and hornblende with lesser amounts of quartz, biotite, garnet, and epidote. Relict pillows occur in some bands but other hornblende gneisses grade into the quartz-rich gneiss which suggests a sedimentary origin. Chemical analyses indicate that the Nokomis sediments are close to the average composition of greywacke and that the Sherridon sediments are approximately the average composition of subgreywacke. This stratigraphic division of the Kisseynew Complex has been extended only short distances beyond the original map-areas. Elsewhere Kisseynew rocks are commonly divided into hornblende gneisses and biotite gneisses but the stratigraphic sequence is usually unknown. Robertson (1953) suggests that Nokomis represents eugeosynclinal deposits of greywacke and shale and that the Sherridon sediments were more mature and possibly deposited in a shallow-water shelf environment.

The relationship between rocks of the Kisseynew Complex and the Amisk and Missi Groups is not entirely understood. The unresolved problem has been ably treated by Harrison (1951) and more recently by D. S. Robertson (1951, 1953), Kalliokoski (1953), Byers and Dahlstrom (1954), and McGlynn (1959). Four hypotheses have been proposed: (1) the Kisseynew gneisses include Amisk and Missi rocks and possibly also older and younger strata; (2) the gneisses are younger than the Amisk, but conformable with it, and older than the Missi; (3) the gneisses are the metamorphosed equivalents of Missi strata only; (4) the gneisses are separated from Amisk and Missi strata by a major fault and the relative ages are, therefore, unknown. It is certain that in some areas Kisseynew rocks are separated from Amisk and possibly also Missi strata by faults. In other parts of the contact zone, rocks that can be traced into Amisk volcanics are structurally conformable with Kisseynew gneisses and in still other segments, Amisk and Missi strata have been traced through zones of increasing metamorphism to rocks indistinguishable from Kisseynew gneisses. Conglomerates have been found in the Kisseynew Complex that are lithologically similar to Missi conglomerates (Byers and Dahlstrom, 1954). Kisseynew rocks are generally more highly metamorphosed and granitized than the Amisk and Missi rocks but the latter attain an equivalent grade of metamorphism near areas of Kisseynew gneisses. Much of the Kisseynew metasediments and hornblende gneisses could be derived from greywackes and volcanic rocks similar to the Amisk and Missi strata. The Sherridon Group of more siliceous and limy sediments in the Sherridon area has no known lithologic equivalents. It seems likely that the Kisseynew Complex is in large part the metamorphosed equivalent of the Amisk and Missi Groups and their equivalents, and that the Sherridon Group may represent a facies variation or a sequence younger than the Missi sediments.

In the Lynn Lake Belt the oldest rocks belong to the Wasekwan Group and consist of a conformable sequence of basic, intermediate, and acidic volcanic rocks, related tuffs, agglomerates and breccias, and greywacke, and shale. These rocks are very similar to Amisk strata. In the Lynn Lake area the volcanic rocks form the oldest exposed units, but to the southeast around Granville Lake, the oldest exposed strata are sediments that have intercalated thin volcanic horizons; east of Lynn Lake the sediments and volcanic rocks are also interbanded. These rocks occur in easterly trending belts. Gabbro sills and plutons and acidic porphyry intrusions that are probably intrusive equivalents of lavas occur in the Wasekwan sequence. Rocks of the Sickle Group overlie Wasekwan strata. Regionally the sequences appear conformable although locally some evidence of unconformity has been found. The basal unit of the Sickle is usually conglomerate, consisting of subrounded to subangular pebbles or cobbles of sedimentary or volcanic rocks of the Wasekwan Group with very minor amounts of quartz and granitic rock in a greywacke matrix. The conglomerate varies in thickness from a few feet to more than 1,000 feet and grades upward to arkose and greywacke through a transition zone of fine clastics with lenses of conglomerate. Arkose and subgreywacke with minor amounts of shale constitute the upper unit of the Sickle Group. Cross-bedding, and less commonly graded bedding, are present throughout the sequence. Calc-silicate lenses and irregularly shaped zones occur in the arkose. Around Granville Lake several bands of massive and pillowed basic volcanic rocks, indistinguishable from the older Wasekwan volcanics, occur within the Sickle sediments. Minimum thickness of Sickle rocks is 10,000 feet.

Both the Amisk–Missi and Wasekwan–Sickle sequences appear to be typical eugeosynclinal deposits. Volcanic rocks are most abundant in the lower part and recur within the flysch deposits of the upper part of the sequences. Local unconformities appear to exist in the Flin Flon area. Volcanic rocks provided most of the clasts in the conglomerates but the proportion of potash feldspar and quartz in the finer clastics, particularly the Sickle sediments, suggest a source area partly underlain by granitic rocks. Sickle strata appear to have been deposited in a shallower-water environment than the Missi greywackes. Age relationships between these widely separated rocks are not known but they are usually considered correlative. The Amisk and Missi Groups extend to the west and then northerly. It is possible that they could be traced through the belt of high-grade meta-

morphism and granitization into recognizable Wasekwan and Sickle rocks.

In the Lynn Lake region the older rocks and their metamorphosed equivalents have been folded about eastward to southeastward and locally northward striking axes. These folds have moderate plunges and axial planes dip steeply, mainly south. These structures have been refolded about northwestward and, locally, northeastward trending axes. Amisk and Missi rocks are folded about northward to northeastward striking axes that commonly are westward dipping and the folds generally plunge to the north. As the structures are traced north towards the Kisseynew Complex the foliation and relict bedding strike easterly and the folds are refolded and wrapped around granitic intrusions. Kisseynew rocks are complexly folded and various interpretations of the structures have been made. A generally applicable interpretation involves folding about westerly trending axes, overturned to the south, and refolding about northerly trending axes.

All rocks of the Wasekwan and Sickle Groups are regionally metamorphosed to the amphibolite facies with local zones of epidote–amphibolite or even high greenschist facies. Basic volcanic rocks are, therefore, converted to hornblende–plagioclase schist or finely banded gneisses with variable but minor amounts of epidote and biotite; the sediments are converted to biotite–muscovite–feldspar–quartz schists and gneisses that locally contain garnet and sillimanite. The rocks grade southward into coarse-grained, biotite–quartz–feldspar gneiss, hornblende–plagioclase gneiss, and granitoid gneiss containing pegmatites and extensive zones of migmatite. With increasing amounts of granitic material the rocks grade into granitic gneisses. This gneiss complex is lithologically similar to Kisseynew Complex of the Flin Flon area. The complex is intruded by and grades into batholiths of gneissic to massive grey biotite–hornblende or biotite tonalite and granodiorite, and pink granodiorite.

In the Flin Flon region Amisk and Missi rocks and their assumed equivalents are metamorphosed to the epidote–amphibolite or amphibolite facies with smaller areas of rocks in the greenschist facies. As these strata are traced to the north they grade into rocks in the high amphibolite facies similar to Kisseynew gneisses and which, in some areas, are grouped with the Kisseynew Complex. The Kisseynew Complex is consistently in the high amphibolite facies and locally may reach hornblende–granulite facies. Included in the Kisseynew Complex are granitoid rocks, migmatite, and gneissic granodiorite. The Amisk and Missi Groups and their equivalents are intruded by granitic rocks, commonly granodiorite, and locally grade into these rocks through zones of migmatites or granitized gneiss. Most granites that intrude Amisk–Missi units also are younger than Kisseynew rocks. The large batholiths are biotite or hornblende–biotite granodiorite or quartz diorite. Smaller masses that cut these rocks and appear to be higher level intrusions consist of pink biotite granodiorite and granite, or diorites and syenodiorite. These rocks are late, in part post-tectonic, and limited in distribution (McGlynn, 1959). "Quartz-eye" granites appear to be the oldest granites in the region and are quartz diorite in composition. They are found only in Amisk volcanic rocks and are distinguished by the common occurrence of blue quartz eyes. Some appear to be metamorphosed. The "quartz-eye" granites are probably of diverse origins and probably include intrusive quartz diorite batholiths, metamorphosed or granitized acidic pyroclastics, and intrusive equivalents of acidic volcanic rocks.

With one exception minerals from all granitic rocks and metamorphosed older rocks yield Hudsonian dates in the 1,700 to 1,800 m.y. range. Muscovite from metamorphosed Sickle sediments gives an age of 2,670 m.y.; a coexisting biotite from the same sample yielded an age of 1,650 m.y. On the basis of the older date and because of lithological similarities to rocks in Superior Province, Wasekwan–Sickle and Amisk–Missi strata are tentatively classified as Archean. The granitic rocks may be Hudsonian but also may be Kenoran granites that have been updated by effects of the Hudsonian Orogeny.

Southwestern Churchill Province

This region includes that part of Churchill Province between Great Slave Lake and Lake Athabasca and south and southwest of the latter lake. This area is underlain chiefly by granitic rock types but both older and younger sedimentary and volcanic rocks occur.

Archean. The oldest rocks are the Tazin Group north of Lake Athabasca. At Uranium City the Tazin (Tremblay, 1957) consists of greywacke, shale, quartzite, limy quartzite, dolomite, iron-formation, and amphibolites of uncertain origin. The sediments are metamorphosed to the amphibolite facies or granitized to banded gneiss, quartzitic granitic gneiss, and gneissic granite. Greywacke and shale were probably the dominant rock types in the original sequence which may have been at least 12,000 feet thick. Some of the amphibolites may have been basic flows or sills but the numerous narrow bands interbedded with the metasediments were probably tuff or sediments. In northwest Saskatchewan and southern District of Mackenzie, rocks tentatively correlated with the Tazin Group are thinly bedded greywacke and shale with some chert. They have metamorphosed to granitic gneiss, or graded into it, and only small remnants remain. West of Nonacho Lake and south of Great Slave Lake metamorphosed basic volcanic rocks, subgreywacke, and shale grade into migmatite and granite. Correlation with the Tazin is uncertain. Similar rocks and their granitized equivalents occur northeast of Uranium City in the Snowbird Lake area (Taylor, 1963). All these deposits are similar lithologically and appear to have been deformed and altered in a

similar style so that they can be considered as possible equivalents. Tazin rocks and possible equivalents to the northeast are highly folded about northeast striking axes that in places are curved suggesting later cross-folding. Northwest of Uranium City folds trend north to northeast, whereas at Uranium City easterly trends predominate. The rocks of granitic composition form belts of migmatite, banded granitoid gneiss, and porphyroblastic granitic gneisses. These rocks, although variable, consist essentially of plagioclase, microcline, quartz, and biotite, with or without hornblende, and with variable amounts of muscovite, chlorite, and garnet. Pegmatites are common. The gneisses are intruded by batholiths of massive granodiorite, partly porphyritic. East of the Nonacho Belt are pyroxene-bearing gneisses of the granulite facies. Foliation is parallel with bedding in the metasediments and trends northeasterly to northerly. K–Ar dates range from 1,700 to 1,850 m.y. but a few are in the range 2,000 to 2,300 m.y.

Hudsonian Orogeny. The main expression of the Hudsonian Orogeny in the region may be faulting. Extensive zones of mylonites and brecciation occur at Uranium City and to the northeast and northwest. In Alberta and south of Great Slave Lake, numerous northerly trending fault zones are marked by brecciation and mylonization. A single zone of complex faulting may extend from northeast of Uranium City to northwest Saskatchewan and then north to the Nonacho Belt. A similar wide zone occurs along the McDonald fault south of Great Slave Lake *(Frontispiece)* and another at Snowbird Lake. The zones appear to have formed before the late Aphebian, Nonacho, and Martin sediments were deposited. Later movement took place along many of the faults displacing the sediments and the mylonite zones. The late faults are not restricted to older zones of movement but have the same trends, that is, northeast, northerly, and northwest. They are steeply dipping and marked by narrow zones of brecciation and fracturing. Relative ages of the three sets of faults have not been clearly established. The early phases of faulting with the development of mylonites and breccia zones may have occurred during the Hudsonian Orogeny possibly as a late phase. K–Ar ages on muscovite along the McDonald fault, and from the sheared basement of the Nonacho sediments are in the 1,700 to 1,800 m.y. range. Movement on the later faults is probably post-orogenic because Helikian rocks are cut by some of these faults.

Aphebian or Paleohelikian. At Uranium City, the Martin Formation was deposited on an erosion surface of considerable relief formed on the Tazin Group and Hudsonian intrusions. The northeast-trending belts of Martin rocks are probably fault-preserved remnants of more extensive basins. The formation (Tremblay, 1957) consists of a minimum of 13,000 feet of conglomerate, arkose, siltstone, and basaltic or andesitic flows and sills. The basal conglomerates comprise angular to subangular boulders of basement rock in an arkosic matrix (Pl. IV-10). The arkose is orangish red and consists of feldspar, quartz, and rock fragments. It is crossbedded and ripple-marked. The sand grains are angular to subrounded and poorly sorted. Numerous conglomerate lenses and thin beds are intercalated. The boulders in these units are smaller and better rounded than in the basal conglomerate, but also consist largely of recognizable basement lithological types. The siltstone beds are deep red, feldspar-rich, and mud-cracked. The volcanic rocks are basaltic in composition, usually amygdaloidal, and commonly porphyritic. K–Ar whole rock samples are as much as 1,700 m.y. old. These

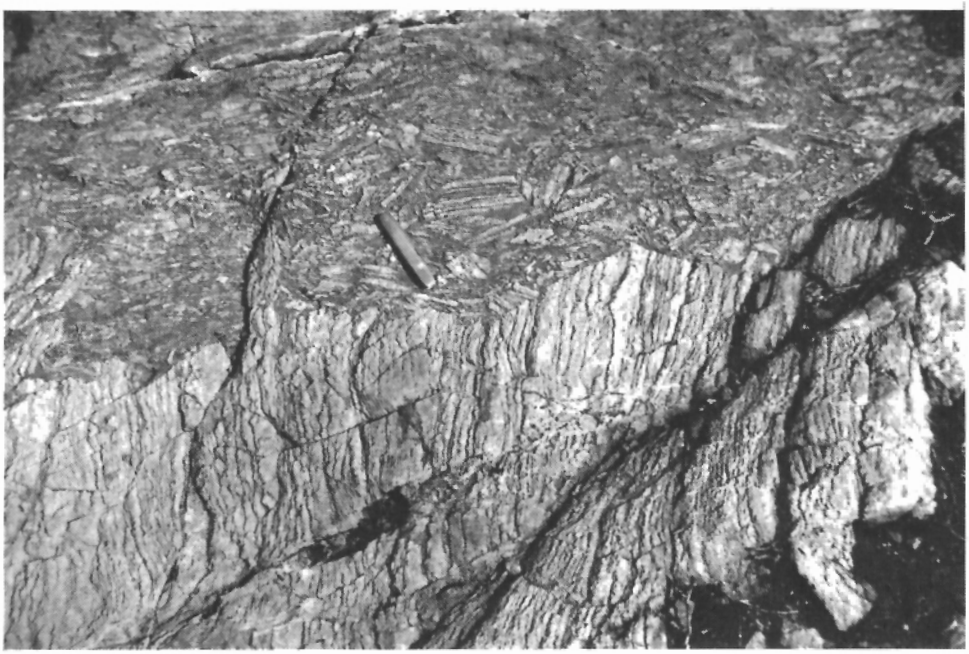

PLATE IV-10
Unconformity between late Aphebian Martin Formation and gneisses of the Archean Tazin Group, Churchill Province, Uranium City, Saskatchewan.

continental sediments are typical red bed deposits, the products of rapid erosion and deposition under tectonically unstable conditions deposited in a fluvial environment. The basins of deposition may have been partly fault controlled. Deposition took place after or possibly contemporaneous with fault movements that produced the early mylonite and breccia zones in the basement rocks. Paleocurrent studies by L. P. Tremblay indicate a transport direction that varies from southeast to southwest and suggests a source to the north. The Martin has been gently folded about northeasterly trending axes. The rocks are not cut by granites but are displaced by late faults with northeasterly strikes. They are thought to be late Aphebian sediments that were deposited during a late phase of the Hudsonian Orogeny.

Rocks of the Nonacho Group are exposed south of Great Slave Lake. They are lithologically similar to the Et-Then and Martin Groups and were deposited in similar environments. The Nonacho Group comprises a conformable sequence of polymictic conglomerate, and conglomeratic sandstone that include lithic sandstone, arkose, and feldspathic quartzites, siltstone, and shale. Along the southern contact with the basement the basal units are sedimentary breccia composed of angular boulders of granitic rocks from the nearby gneisses in an arkosic matrix. The breccias grade upwards into arkose with scattered boulders of granite and beds and lenses of disintegrated granite. Below the unconformity the basement rocks are broken into large blocks sealed by seams of muddy arkose. The lower arkose is overlain by coarsely bedded polymictic conglomerate containing closely packed subrounded boulders, chiefly of granitic rocks and gneisses, but with some quartz, quartzite, and basic to acidic volcanic rocks. The conglomerate is overlain by buff and grey lithic sandstone, arkose, and feldspathic quartzite in which laminations and crossbedding are common. These rocks consist of variable amounts of quartz, feldspar, and lithic grains that are subrounded to subangular and cemented by carbonate. Thin red or green shale beds occur and lenses or thin beds of conglomerate or clusters of pebbles and shale chip conglomerate are abundant. Within the sandy unit is a fairly thick band of conglomerate distinguished by large boulders of white quartzite as well as granite. Siltstone and shale units may be fairly thick, particularly in the north. In shaly units mudcracks and sandstone dykes are found. Crossbed orientation (McGlynn, 1966) in the southern part of the belt indicates that paleocurrents were from north to south along the eastern margin and south to north along the western margin of the belt. They probably do not correspond to sedimentary transport directions. Source areas, in addition to nearby basement highlands, may have been to the north as quartzite boulders in the conglomerates are lithologically similar to the quartzites of the Archean Wilson Island Group exposed on islands in Great Slave Lake.

Nonacho rocks rest on a basement of granitic gneiss, migmatites, and massive granitic rocks. In the south they are not cut by younger granites and are unmetamorphosed. The strata are moderately folded about axes that strike north-northeast to northeast and plunge to the north. The folding is most intense in the western part of the belt. Basement rocks are cut by northerly trending faults along which extensive breccia and mylonite zones are developed. Nonacho rocks, especially near contacts with the basement, are cut by northerly and northeast-striking faults, movement on which is post-folding.

The Athabasca Formation, locally overlain conformably by the Carswell Formation, outcrops over a large area south of Lake Athabasca. The Athabasca is separated from the Tazin and granitic gneiss by an unconformity and is not in contact with the Martin Formation. The Athabasca Formation consists of orthoquartzite with rare interbeds of shale and quartz-pebble conglomerates (Fahrig, 1961). The sandstone is composed almost entirely of rounded, moderately well sorted quartz grains in a quartz cement. Both trough and planar crossbedding are abundant throughout the sequence and indicate sedimentary transport from the east and southeast, or locally, from the northeast. Grain-size distributions and ripplemark orientations corroborate this conclusion. The Carswell Formation consists of a pink or buff, finely laminated dolomite, grey dolomite with many stromatolitic zones, and dolomite breccias. It is strongly deformed and forms the margin of a circular structure, within which are outcrops of the orthoquartzite and granitic basement. The Athabasca sandstone is considered to be a product of slow erosion of a tectonically stable source area to the east and southeast of present outcrops. Sediments were deposited in fluvial environment. Part of the sequence may be marine and probably the Carswell Formation was deposited in a shallow-water, marine environment. They are post-Hudsonian and seen to be separated from the orogenic event by a period of erosion. They are then probably younger than the Martin strata. Except for the deformation in the circular structure the Athabasca rocks are unfolded but may have been gently tilted. They have been cut by a northeast-striking fault and intruded by a few diabase dykes, one dated at 1,230 m.y. The Athabasca Formation is considered Paleohelikian and tentatively correlated with the Thelon Formation of the Dubawnt Group.

East Arm Subprovince

In the East Arm Fold Belt are Archean rocks of the Wilson Island Group and the Kenoran granitic rocks that have been described under the section on Slave Province. Aphebian rocks are from the Union Island, Great Slave, and Et-Then Groups. The Union Island Group outcrops in only a small area on Union and adjacent islands. It consists of black and grey shale, pillowed basalt, dolomite, and greywacke. The group is older than

the Great Slave Group and separated from it by an unconformity (Hoffman, 1967).

The Great Slave Lake Group has been divided by Stockwell (1936) into six formations, the basal units of which rest on a deeply eroded surface. It is about 20,000 feet thick and the strata occur in an easterly trending synclinorium. Along the north flank the strata dip very gently south but are folded in the central and southern parts. The rocks are cut by sills, laccoliths, and possibly also stocks of hornblende–biotite diorite or quartz diorite. A biotite from one of these intrusions yielded a K–Ar age of 1,845 m.y., which indicates that the rocks are Aphebian and were folded during an early phase of the Hudsonian Orogeny.

The basal Sosan Formation is from 3,000 to 5,000 feet thick and composed of feldspathic quartzite, a sandy stromatolitic dolomite member, and, near the top, red or pink siltstone and shale. The Kahochella Formation is as much as 7,000 feet thick and consists of red shale, siltstone, arkose, carbonate, and a few beds of oölitic iron-formation. In the central part of the basin, andesite flows and pyroclastics with intercalated red sandstone and shale occur within the sequence. The Pethei Formation comprises about 1,500 feet of limestone and dolomite with abundant stromatolitic zones (Pl. IV-11) along the north limb of the synclinorium. Lateral equivalents (Hoffman, 1967) in the southern part of the basin are fine-grained limestone and interbedded limestone and argillite and in the southwest are graded beds of greywacke and shale, with interbeds of chert and limestone (Pl. IV-12). Conformably overlying the Pethei are red mudstone, dolomite, and limestone forming the Stark Formation. Breccias, probably of different origins, are common in the carbonate rocks. The Tochatwi Formation comprises about 3,000 feet of non-marine, molasse-type red sandstone and shale. The youngest rocks of the Great Slave Group form the Pearson Formation which consists of 500 feet of basalt, commonly vesicular and amygdaloidal, with related tuff and thin beds of argillite. Orientations of crossbedding and other current structures suggest a source area to the west and north of the present basin for most clastic sediments

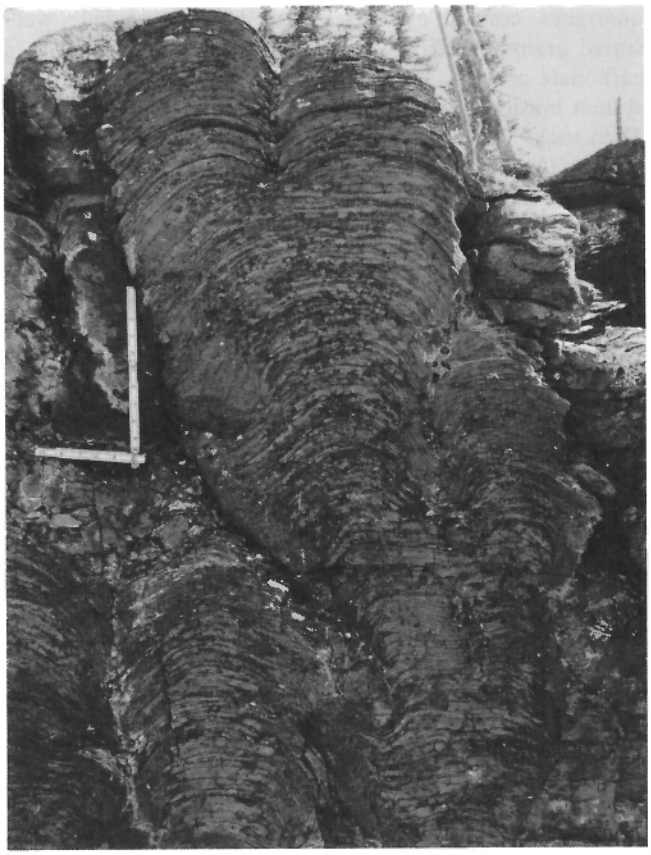

PLATE IV-11. Algal stromatolites in the Aphebian Pethei Formation, Great Slave Group, East Arm Fold Belt, Great Slave Lake, Northwest Territories.

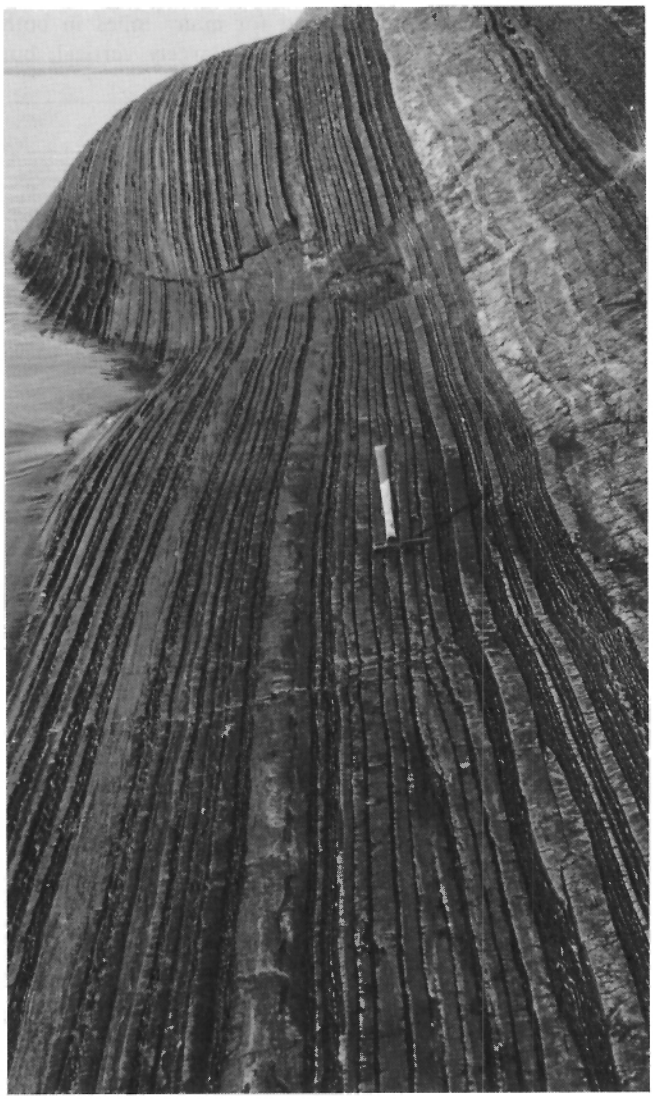

PLATE IV-12. Thin, graded beds of greywacke and argillite of Aphebian Pethei Formation, Great Slave Group, Great Slave Lake, Northwest Territories. The thick light bed is chert.

(Fig. IV-17). The sequence includes near-shore sediments deposited in fluvial non-marine, shallow marine, and deep-water marine environments. The youngest reddish sediments were deposited in a shallow-water, near-shore, partly marine environment and were subject to subaerial exposure.

The Great Slave is overlain unconformably by the Et-Then Group, which rests on truncated folds in Great Slave strata and is later than the diorites that intrude the older rocks. Et-Then rocks are cut by diabase sills and dykes. The dykes are part of the north-northwesterly striking Mackenzie swarm that yield K–Ar whole rock dates of about 1,200 m.y. but the sills which are cut by these dykes are not dated. Et-Then rocks are gently folded about easterly trending axes and along with older rocks are cut by the northeast-trending McDonald fault and related parallel faults (Fig. IV-16). The McDonald fault *(Frontispiece)* forms the southeastern margin of the subprovince and extends beyond for many miles in both directions. Movement appears to be largely vertical, but the history is more complex as both transcurrent and normal movements may have taken place. Most displacement appears to have been completed before the intrusion of the Mackenzie diabase dykes and probably began during the late stages of the Hudsonian Orogeny.

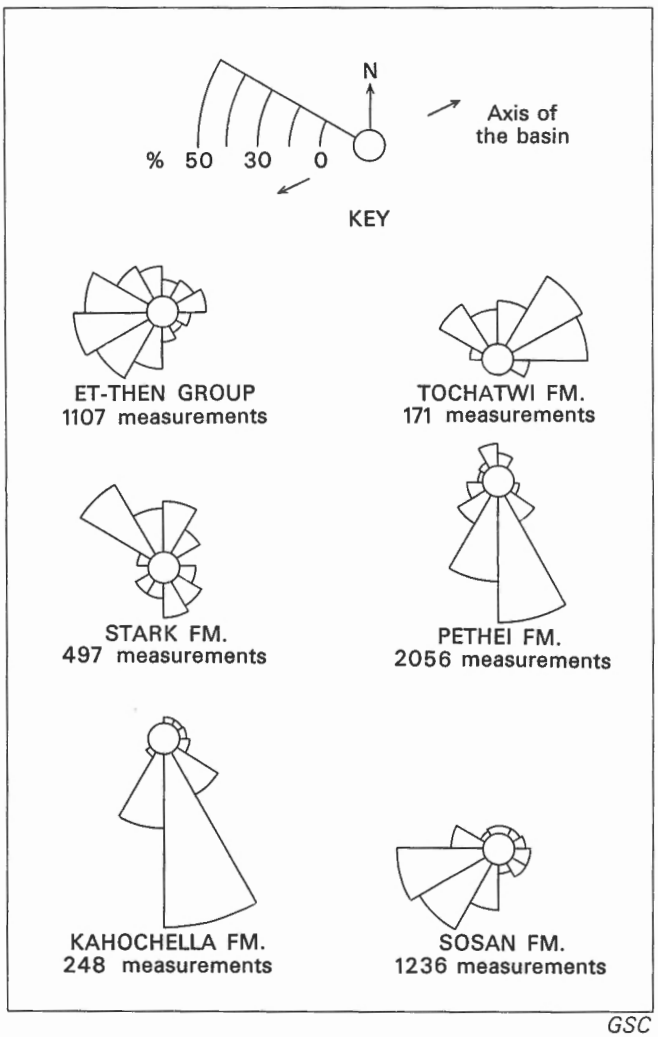

FIGURE IV-17. Paleocurrent orientations, Great Slave and Et-Then Groups, East Arm Subprovince, Northwest Territories (Hoffman, 1967).

The Et-Then Group is divided into two formations, the oldest of which, the Murky, is composed of several thousand feet of conglomerate with minor arkose and shale. The sequence is made up of cyclical alternations of coarse boulder-conglomerate that grade upwards, with decreasing pebble-size into thin, commonly lenticular arkose and rare shale beds. The cycles vary in thickness up to 50 feet. The boulders and pebbles are rounded and vary in composition. Near McDonald fault, granitic rocks and granitic rocks and granite gneiss predominate, whereas to the north, clasts of the Great Slave Group are most abundant. The conglomerate may thin to the north and the clasts appear to decrease in size in the same direction suggesting a source to the south. These strata pass through a transition zone in which the amount of sandstone increases into the Preble Formation which consists of at least 4,000 feet of buff, pink, or red lithic sandstone and feldspathic quartzites with intercalated thin beds of pebble-conglomerate, shale-chip conglomerate, and red shale. Crossbedding and thin laminations are common and mudcracks are found throughout the sequence. The quartzites consist of rectangular to subrounded, well-sorted grains of quartz, rock fragments, and feldspar in a carbonate cement. It is possible that the McDonald fault system bordered the original sedimentary basin. The Et-Then rocks were deposited in a non-marine fluvial environment. They are typically late or post-tectonic clastics and were probably deposited during a late phase of Hudsonian Orogeny, or after it.

North-central Churchill Province

The north-central part of Churchill Province extends to latitude 66° and includes northern Manitoba and northeastern Saskatchewan. The oldest rocks occur in a northeasterly trending belt that extends through Ennadai Lake. They unconformably underlie the Aphebian Hurwitz Group and are considered Archean. They consist of a conformable sequence of basic to intermediate volcanic rocks and greywacke argillites and tuffs. The volcanic rocks are massive or pillowed andesite with minor amounts of intercalated dacites and quartz biotite rhyolite. Tuff and agglomerate are associated with the acidic phases and irregular masses of medium-grained gabbros occur within the basic flows. Greywacke, subgreywacke, and shale occur both below and above the volcanic rocks (Eade, 1966b). The sediments are thin- to thick-bedded and graded beds are abundant. Locally, a considerable thickness of lithic or crystal tuff occurs within the sedimentary sequence. One thin band of impure shaly dolomite has

been mapped and iron-formation, usually a quartz–magnetite type, occurs as discontinuous lenses up to 150 feet thick within the greywacke.

The Archean rocks are folded about north-northeast to northeasterly trending axes. The folds generally plunge north. Near or within large masses of granitic gneiss, the basic volcanic rocks are converted to massive or well-foliated amphibolites and the sediments to quartz–biotite–feldspar schist and gneiss. The rocks commonly grade to granitic gneiss through a zone of migmatites and mixed gneisses. The granitic rocks are either well-foliated, massive, or porphyritic, pink or grey, and contain biotite or less commonly hornblende. Their composition is generally that of a granodiorite. The volcanic and sedimentary rocks and possibly the granitic gneisses are cut by high-level nearly massive granodiorite and quartz diorite plutons that are bounded by sharp contacts or narrow migmatite zones and metamorphic aureoles. Cordierite, garnet, and in places andalusite are developed in the sediments of the aureoles. In the Kognak Lake area (Eade, 1966b) the granitic rocks and the Archean strata are overlain unconformably by the Aphebian Hurwitz Group. Some granitic rocks are thought to intrude Hurwitz strata and probably two ages of granites exist. Micas from granitic rocks in the region yield K–Ar dates in the range 1,675 to 1,800 m.y. One date of 2,375 m.y. suggests Kenoran intrusions.

The Hurwitz Group underlies scattered areas along a northeasterly trending belt that roughly coincides with the belt of Archean rocks and also occurs north and northwest of Baker Lake (Wright, 1955). The group, as defined by Eade (1966), comprises five conformable formations. The lowest, a local conglomerate, contains rounded pebbles or cobbles of granitic rocks, andesite, greywacke, quartz, and tuff in a greywacke matrix, grading upwards into greywacke with a few scattered pebbles. The overlying orthoquartzite is fine to medium grained, glassy, white, thin to thick bedded, and contains scattered lenses of quartz-pebble conglomerate. Crossbedding is rare but ripple-marks are common at several horizons and have a preferred northeasterly orientation. The formation varies in thickness from 700 to at least 4,000 feet commonly over short distances. Poorly exposed slate, shale, and siltstone overlie the quartzite. They are grey, black, or red, finely laminated, and contain lenses of greywacke. These rocks are succeeded by dolomite, argillite, and siltstone. The dolomite is cream or grey laced with quartz or chert veinlets, and contains a few, thin, stromatolitic horizons. It grades upwards into black or grey, finely laminated argillite with siltstone interbeds. Locally quartz–jasper–hematite or quartz–magnetite iron-formation occur as lenses within the dolomite. These rocks are generally overlain by a variable thickness of greywacke composed of thin-graded sandstone and shale couplets. The youngest exposed formation of the Hurwitz Group consists of grey to buff impure quartzite composed of quartz and sericite, thinly bedded, ripple-marked and crossbedded. A few thin horizons of siliceous dolomite are intercalated. North and northwest of Baker Lake Hurwitz rocks have a similar stratigraphic sequence. They are locally overlain by basic volcanic rocks and intruded by gabbro sills of unknown age.

The Montgomery Lake Group unconformably underlies the Hurwitz Group and unconformably overlies the Archean in the Kognak Lake area (Eade, 1966b). It consists of quartzite, dolomite, siltstone, and argillite. The group is not extensively exposed and little is known about it, but in northern Manitoba there may be some correlatives.

The Aphebian sediments and igneous rocks are folded moderately about northeastward and locally northwestward trending axes. The sequence of folding is uncertain but the northeasterly trend may be the oldest. Contacts between the Hurwitz and Archean rocks are often sheared indicating movement. Hurwitz strata are for the most part only very slightly metamorphosed. In the Kognak River area Eade found one granodiorite pluton bounded by a narrow metamorphic aureole in which cordierite and garnets are developed in the sediments and, therefore, he considers the granodiorite to be post-Hurwitz.

In northeastern Saskatchewan and northern Manitoba are sediments similar to the Hurwitz. In northern Manitoba pyroxene-bearing granulites appear to be older (Davison, 1966). The sediments comprise quartzite, feldspathic quartzite, argillite, greywacke, and dolomite. Orthoquartzites so characteristic of the Hurwitz are much less common and do not form basal units. The oldest rocks appear to be feldspathic quartzite and greywacke. These rocks are intensely folded about northeasterly to easterly trending axes. Grade of metamorphism varies but usually is rather high, commonly in the amphibolite facies. The metasediments grade into biotite–quartz–feldspar gneiss that contains potash feldspar, masses of pegmatitic granite, and migmatite. These rocks grade to foliated and locally massive granodiorite. All rocks are cut by high-level, intrusive, porphyritic, or fluorite-bearing granodiorite. Micas from all granitic rocks yield K–Ar ages for the range 1,700 to 1,850 m.y. as does a Rb–Sr whole rock isochron of the fluorite-bearing granodiorite and they are considered to have been formed during the Hudsonian Orogeny.

On Seal River in northeastern Manitoba the Great Island Group comprises a conformable sequence of shale, quartzite, dolomite, and minor greywacke (Davison, 1966). These rocks are known to be exposed in only a small area. They are fresh to very slightly metamorphosed, are not known to be cut by granitic rocks, and are gently folded about north-northwesterly fold axes. They appear to lie unconformably on the surrounding granitic rocks and older sediments. If older sediments are Aphebian this sequence is probably of Helikian age. An alternate correlation is that of Great Island rocks with the Hurwitz, whereas the rocks below the Great Island sequence are equivalent to the Montgomery Lake strata.

In Thelon Subprovince, the Dubawnt Group comprises relatively undisturbed sedimentary and volcanic rocks that rest with profound unconformity on a deeply eroded basement underlain for the most part by granitic rocks of Kenoran and possibly Hudsonian age. Donaldson (1965) has divided the group into six formations. The oldest, the South Channel Formation, consists of conglomerate with a few interbeds of sandstone, varying rapidly in thickness to a maximum of 5,000 feet. It is composed of rounded to angular pebbles and cobbles of granitic rocks with minor quartzite, quartz, granulite, mylonite, basalt, and felsite in a red sandy matrix. The overlying Kazan Formation comprises about 12,000 feet of maroon pink to reddish brown feldspathic sandstone with calcareous cement and minor amounts of interbedded maroon siltstone and mudstone. The sandstones are well

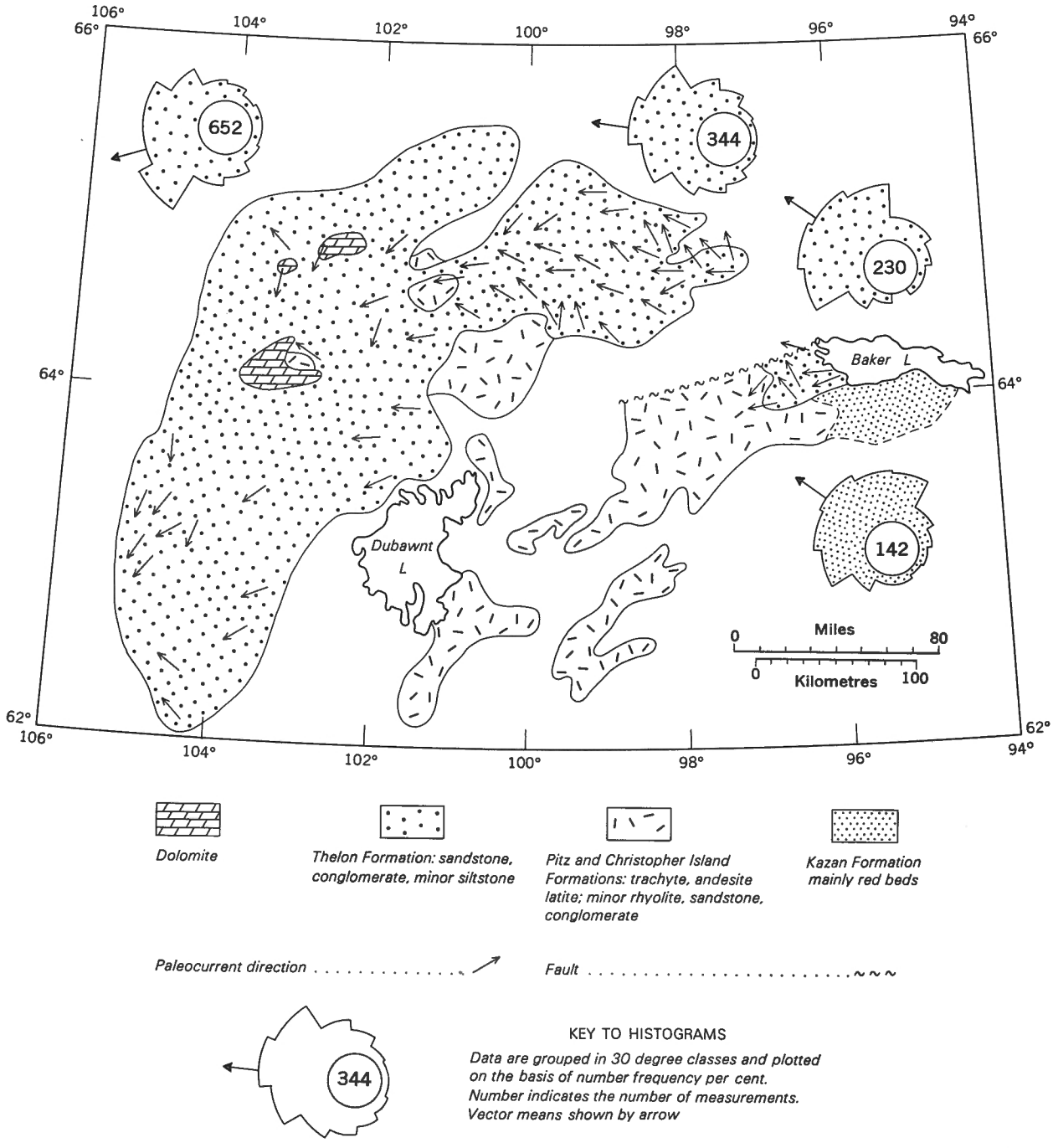

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FIGURE IV-18. Paleocurrent orientations, Dubawnt Group, north-central Churchill Province, Northwest Territories (J. A. Donaldson).

sorted and display thin laminations and crossbedding, the orientations of which indicate northwesterly transport of sediment (Fig. IV-18). Mudcracks and ripple-marks are abundant in the silty shale. South Channel and Kazan strata occur only south of Baker Lake. These rocks were gently folded and eroded before volcanic rocks of the Christopher Island Formation were extruded. Reddish brown or purplish grey porphyritic andesite, latite, and trachyte form the bulk of this formation which attains an exposed thickness of about 200 feet. Basal tuff and agglomerate contain cobbles of older formations. A second volcanic unit, the Pitz Formation, is composed of trachyte characterized by abundant chalky white phenocrysts of feldspar and quartz phenocrysts in a purple to red or maroon groundmass. The volcanic rocks have been intruded by sills or laccoliths of massive, fine- to medium-grained, grey to reddish black syenite. The volcanic rocks appear to be only slightly deformed. Whole rock samples of these rocks yield K–Ar and Rb–Sr whole rock isochrons up to 1,735 m.y., a minimum age for the sequence. These rocks are overlain disconformably by the relatively flat lying sequence of the Thelon Formation. Thin basal conglomerates contain pebbles of the Kazan, Pitz, and Christopher Island Formations. The Thelon sandstone is composed of quartz but near the base contains feldspar and interstitial white clay. The sandstone is cream, light grey, buff or pink, and in contrast to the Kazan, is friable, ripple-marked, and festoon crossbedded. Orientations of crossbeds indicated westerly and northwesterly transportation of sediment (Donaldson, 1965). Well-rounded pebbles and bands only one pebble thick are common in the lower part. The Thelon Formation is overlain by dark grey, thinly bedded dolomite, partly stromatolitic, and locally by a thin layer of basalt. The stratigraphic relationship between the two younger units is uncertain.

The sediments of the lower part of the Dubawnt south of Baker Lake comprise a red bed sequence and were probably deposited in a continental and possibly partly shallow marine environment and subjected to frequent subaerial exposure. Westward thinning of the South Channel conglomerates and the crossbedding orientations suggest a source to the east and southeast with northwesterly and westerly sediment transport. The immature nature of the clastic sediments suggests rapid deposition from a tectonically unstable area of rather rugged relief. Faults may have partly controlled the location of the southern margin of the basin and the rate of sediment accumulation. The sedimentary and volcanic rocks are typical of late or post geosynclinal and tectonic environments. The age of the volcanic rocks suggests that sedimentation and volcanism occurred either late in the Hudsonian Orogeny or just after the orogeny and, therefore, these rocks are considered to be late Aphebian or Paleohelikian. The Thelon sediments, which were deposited after the above rocks were eroded to some extent, are compositionally and texturally mature, and probably were deposited on a surface of low relief and under stable tectonic conditions. The sandstones probably were deposited in a fluvial environment. Sedimentary structures indicate a source area to the east or southeast. Possibly the upper part of the Thelon and the carbonate sediments were formed in a shallow-marine environment. These rocks are cut by diabase dykes of Helikian age and are, therefore, considered to be Paleohelikian.

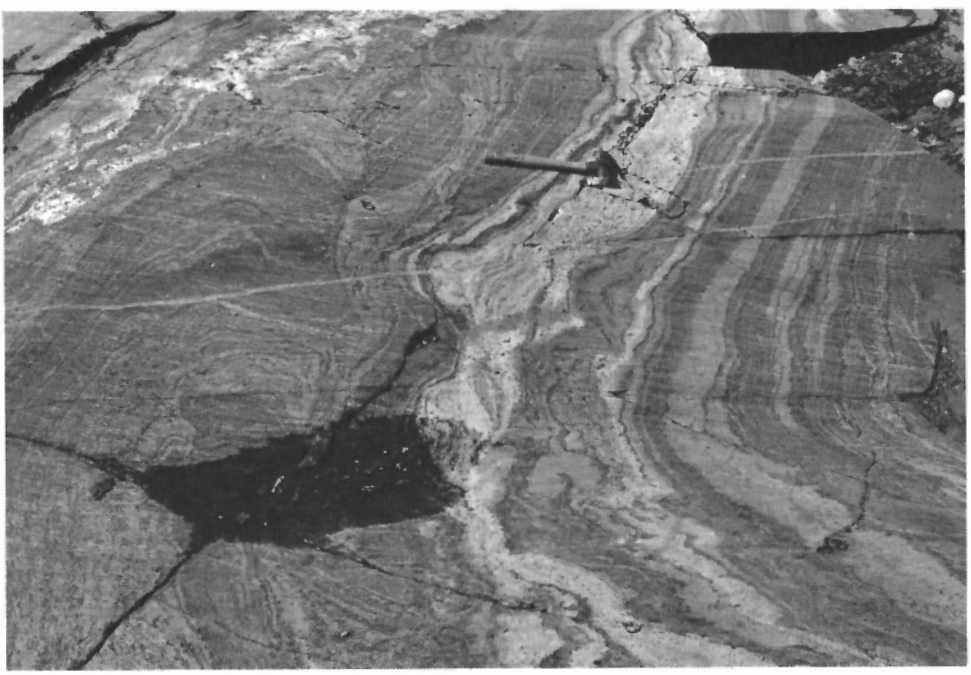


PLATE IV-13

Banded metasedimentary gneiss, possibly Archean, near mouth of Back River, northern Churchill Province, Northwest Territories.

Northern Churchill Province

The northern part of Churchill Province includes the Precambrian rocks of the eastern Arctic Islands, Boothia Peninsula, and the northeastern mainland west of Hudson Bay. Geology of the mainland part of this area has been studied by Fraser (1964), Heywood (1961, 1966), and Blackadar and Christie (1963).

Northeastern mainland. Much of the region is underlain by granitic rocks of various types that include pink or grey granitic gneiss with zones of migmatite, mixed gneiss, and highly metamorphosed volcanic and sedimentary rocks (Pl. IV-13). The gneissic rocks are variable in composition and may be rich or poor in hornblende or biotite, and otherwise consist of plagioclase and quartz with varying amounts of microcline partly porphyroblastic. These rocks are intruded or grade into foliated to massive granodiorite or quartz diorite that are equigranular and less commonly porphyritic. Foliation trends north to north-northeast in the western part of the area but to the east gradually changes to northeast to easterly. East of the Bathurst Inlet and on Wager Bay and Melville Peninsula are ill-defined zones of pyroxene-bearing gneisses or granulites of uncertain origin. Small masses of gabbro, peridotite, and anorthositic gabbros are scattered throughout the region. K–Ar age determinations on micas from the granitic rocks of all types yield ages that fall in the range about 1,650 to 1,850 m.y.

Within the gneisses are zones of metamorphosed volcanic and sedimentary rocks of various types and probably different ages. South of Queen Maud Gulf northerly to north-northeasterly trending bands of amphibolite with associated biotite gneisses are probably metamorphosed equivalents of basic volcanic and sedimentary rocks. Calc-silicate, quartzite, and iron-formation are present locally. These rocks may be polymetamorphosed equivalents of the Archean Yellowknife Group. North of Wager Bay and on Melville Peninsula are variably metamorphosed basic volcanic rocks that only locally contain primary structures. Metamorphosed sediments, now biotite schists, tuffs, and locally quartzite and iron-formation are intercalated. These formations seem to be remnants of an eugeosynclinal sequence and are similar to rocks in the Ennadai belt to the south that may be Archean. The rocks are folded about northeasterly trending axes.

The Chantrey Group occurs in a northeasterly trending belt south of Boothia Peninsula and consists of a succession of crystalline limestone and quartzite with lesser amounts of conglomerate, shale, greywacke, and chert. These rocks are deformed into northeasterly trending folds and are slightly metamorphosed. Contacts with granitic rocks are obscured by shearing, which suggests separation of the two units in many places by faults. Pegmatites cut the sedimentary rocks. Chantrey rocks are lithologically similar to rocks of the Hurwitz Group to the south and may be correlative. On Melville Peninsula is an apparently conformable sequence of sediments in which quartzite and limestone predominate in the lower part and quartzite, argillite, and greywacke in the upper. These rocks are folded about easterly to northeasterly trending axes, and may have been refolded. The sediments are metamorphosed and cut by or altered to granitic gneiss. Locally the metasediments are present in domal structures, mantling cores of foliated granitic gneisses that range in composition from granodiorite to granite (Heywood, 1966). Contacts between core gneisses and the sediments are generally sharp but locally migmatite occurs at the contact. The sediments are cut by granitic rocks that yield Hudsonian dates and were probably deformed and metamorphosed during this orogeny. They are assumed to be Aphebian in age. Granitic rocks in the area are partly older than the sediments and may possibly be Kenoran intrusions that have been involved in the Hudsonian Orogeny.

On northern Boothia Peninsula and Somerset Island, unconformably overlying the mixed gneisses, is a conformable sequence of unfossiliferous sedimentary strata comprising the Aston and Hunting Formations. The Aston Formation consists of as much as 2,000 feet of well-sorted red sandstone with minor pebble bands and shale-chip conglomerate. Ripple-marks and crossbedding are common. A thin basal member of white quartzite is overlain by a thin stromatolitic dolomite bed. The contact with the overlying Hunting Formation is gradational and conformable. It comprises 8,000 feet of fine-grained dolomite with minor interbedded shale and some stromatolitic horizons. These sediments are thought to have been deposited in a marine, shallow oxidizing environment. Orientation of crossbeds suggest transport to the northeast away from basement rocks on Boothia Peninsula. These rocks are cut by numerous sills and dykes of diabase particularly in the Aston rocks. Blackadar and Christie (1963) suggest a Proterozoic age because of lithologic and stratigraphic similarities to other Proterozoic sequences in the Arctic Islands, and because they are cut by diabase dykes not found in the fossiliferous strata. Tuke, *et al.* (1966) suggest a Paleozoic age because they appear to be overlain conformably by Ordovician rocks and are lithologically similar to Cambrian rocks on Boothia Peninsula. The evidence for either age is inconclusive.

Eastern Arctic Islands. The oldest Precambrian rocks in Baffin Island are a heterogeneous assemblage of complexly folded granitic gneisses that include bands of highly metamorphosed sediments and volcanic rocks, and which are intruded by relatively small masses of faintly foliated to massive granodiorite. Those in the north are composed of plagioclase, quartz, microcline, varying amounts of biotite and hornblende, and locally some garnet. Zones of migmatite and mixed gneisses occur within the gneisses. Amphibolites that are metamorphic equivalents of basic to intermediate volcanic flows and related tuffs, and biotite schists that are probably metamorphosed greywacke, occur as thin discontinuous bands. Iron-formation and small masses of ultrabasic rocks are found in a number of places.

Foliation has a regional trend of north to northeast. The grade of regional metamorphism is amphibolite facies. The gneisses on Devon and Ellesmere Islands are similar to those in northern Baffin Island. The gneisses on southern Baffin Island are more variable and include ill-defined zones of pyroxene- and hornblende-bearing granulite. They are intruded by massive granitic rocks. Metaquartzite, crystalline limestone, and metamorphosed pelitic rocks are common. Regional trends of foliation are variable but in a general way trend southeast. In large areas the grade of metamorphism is amphibolite facies.

Micas from granitic gneisses both in the north and south yield K–Ar dates that range from 1,590 to 1,975 m.y. but most samples range from 1,700 to 1,800 m.y., indicating that the gneisses were formed during the Hudsonian Orogeny, or affected by it. The age of the metamorphosed volcanic and sedimentary rocks is uncertain. Jackson (1960) has pointed out the similarity between the iron-formations in northern Baffin Island and those on Melville Peninsula. The associated volcanics and sediments of both areas are also similar and the structural trends are consistent over the region. Such rocks may be Archean and the younger gneisses may have been formed during the Kenoran Orogeny and then affected by the Hudsonian Orogeny. In southern Baffin Island the remnants of metamorphosed sediments include much quartzite and limestone and this sequence may correlate with similar Aphebian rocks on Melville Peninsula. The granitic gneisses would then have formed during the Hudsonian Orogeny.

Gently deformed and relatively unmetamorphosed Helikian and Hadrynian rocks occur in the northwestern part of Baffin Island in Borden Subprovince and north of Fury and Hecla Strait. The Eqalulik Group (Lemon and Blackadar, 1963; Blackadar, 1965) is composed of a basal formation of massive and amygdaloidal basalt about 1,000 feet thick, with thin beds of tuff and quartzite and an upper formation of more than 4,000 feet of pale orange to reddish brown quartzite with arkose and quartz-pebble conglomerate. The uppermost 50 feet is shale and quartzite. The group is conformably and transitionally overlain by the Uluksan Group, a conformable sequence 23,000 feet thick. The Arctic Bay Formation is the oldest of seven formations in the group and consists of 1,000 feet of black argillaceous limestone and dolomite that grade laterally into the Fabricius Fiord Formation of black shale, siltstone, and sandstone. These formations are succeeded by 1,000 feet of massive grey dolomites of the Society Cliffs Formation. The Victor Bay Formation is composed of dark to light grey dolomite, chert, and dark grey limestone and mudstone and contains units of edgewise conglomerate in which the dolomite fragments occur in finely laminated dolomite. Red mudstone, shale, siltstones, and sandstones form the Strathcona Sound Formation conformably overlying the Victor Bay. The Elwin is the youngest formation of the Uluksan Group and comprises a sequence of reddish or orange quartzites, siltstones and shales. Near Tremblay Sound, Victor Bay strata are overlain by grey and black limestones and argillaceous limestone of the Athole Point Formation. The relation of these rocks to other units younger than the Victor Bay strata is unknown.

Along the shores of Fury and Hecla Strait, 10,000 to 15,000 feet of sediments is exposed. The lowest unit that unconformably overlies basement gneisses is a thick succession of orange to pale and dark red sandstone with minor shale and conglomerate. These rocks may be equivalent to the Eqalulik Group. They are conformably overlain by about 1,500 feet of black siltstones, shales, and ferruginous dolomite, similar to the lower Uluksan Group.

The Eqalulik and Uluksan Groups are cut by diabase dykes, most of which trend northwest, and by diabase sills. The basic rocks do not cut overlying Cambrian and Ordovician strata. K–Ar age determinations on whole rock samples of these rocks yield ages of 475 and 693 m.y. in Fury and Hecla Strait area and 635, 915, and 1,140 m.y. near Arctic Bay. One sample of the Eqalulik volcanic rocks gives an age of 903 m.y. The range of these dates is puzzling but when considered along with ages of other gabbroic and basaltic rocks in the Arctic region a possible interpretation is that there were two ages of diabase intrusion; an older with a probable age of 1,100 to 1,200 m.y. followed by younger late Hadrynian. The Eqalulik strata are probably Paleohelikian in age and the Uluksan Group is Neohelikian or Hadrynian.

Labrador Subprovince

Labrador Subprovince is a belt of folded Aphebian rocks, as much as 65 miles wide, extending south of Ungava Bay for more than 600 miles. The belt probably represents only a small part of the original Aphebian geosynclinal deposits. Aphebian rocks in the south that have been involved in the Grenvillian Orogeny are described in the section on Grenville Province. The western boundary of the geosynclinal sequence in most places is a well-defined unconformity along which relatively unmetamorphosed sedimentary rocks rest on Archean crystalline rocks of Superior Province that have yielded K–Ar ages of 2,400 to 2,500 m.y. The eastern boundary is less well defined, and, although a basal unconformity has been recognized at the northern end of the belt, and for short distances in several areas in the south, the eastern boundary along much of the central region is marked by either a major fault or a zone within which metamorphic grade increases eastward. K–Ar ages of 1,600 to 1,800 m.y. predominate in the metamorphic terrain to the east and similar ages have been obtained for low-grade metamorphic rocks within the geosyncline. These ages indicate that the major deformation of the Labrador Geosyncline took place during the Hudsonian Orogeny, and that the deformed rocks are Aphebian. Early accumulation of the geo-

synclinal sequence followed closely by metamorphism prior to the main orogenic event is suggested by a date from the Aphebian strata of 2,060 m.y. (Beall, *et al.*, 1963). Other dates that fall between 1,400 and 1,500 m.y. may record a final period of low-grade metamorphism. The Aphebian rocks comprise a western sedimentary sequence, and an eastern volcanic sequence that contains numerous gabbroic and ultrabasic sills. Gabbroic sills also occur in the western sequence, but there they are thinner and rather rare. In the vicinity of Schefferville the major sedimentary, volcanic, and intrusive units are, respectively, the Knob Lake, Doublet, and Montagnais Groups. Stratigraphic nomenclature for these and other units has recently been reviewed by Frarey and Duffell (1964), who proposed the formal rock-stratigraphic name, Kaniapiskau Supergroup, to designate the assemblage of all sedimentary and extrusive units of the Labrador Geosyncline.

The Knob Lake Group is a miogeosynclinal sequence consisting mainly of sandstone, siltstone, shale, dolomite, chert, and iron-formation. It has a maximum thickness of more than 5,000 feet, but thins westward, and several units wedge out near the western boundary of the geosyncline. To the east is the Doublet Group, a eugeosynclinal sequence consisting mainly of basaltic flows and basic pyroclastics, that is estimated to be more than 15,000 feet thick. Volcanic rocks are intercalated with sedimentary units of the Knob Lake Group, indicating some volcanism concurrent with sedimentation, but the Doublet Group apparently formed subsequent to the main period of sedimentation. In the vicinity of Ahr Lake, Baragar (1960) has demonstrated that the gabbros and basalts are predominantly tholeiitic, and this composition may prevail. Gabbro and peridotite sills of the Montagnais Group were emplaced prior to, and during the early stages of, the orogenic episode that resulted in folding about axes parallel with the trend of the geosyncline. Composite sills have been recognized and many of the sills are differentiated.

In the Schefferville area the Knob Lake Group comprises the Attikamagen, Denault, Fleming, Wishart, Ruth, Sokoman, and Menihek Formations. Of these, the Denault Formation, consisting largely of dolomite, and the Sokoman Formation, containing the main units of iron-formation, are particularly distinctive and serve as markers for regional correlation. Stratigraphic sequences throughout the geosyncline show close similarity to the sequence established for the Schefferville area. Differences, variously attributable to non-deposition, local unconformities, and facies changes, have been recognized, but regionally uniform conditions of deposition are indicated for most units. Some clastic units show marked variability of thickness, and for basal arenaceous strata this characteristic appears to be related to initial topographic relief. Southeast of Schefferville the Attikamagen Formation is underlain by the Seward Formation composed mainly of arkose and conglomerate. Near Cambrian Lake to the north, similar sedimentary rocks form a basal sequence probably more than 5,000 feet thick. Faults that flank areas underlain by these rocks may have been active during deposition of the immature sediments, and nearby exposures of basement within the geosyncline suggest the existence of rugged landmasses during the early stages of geosynclinal deposition. Younger arenaceous units such as the Wishart Formation are orthoquartzitic, reflecting stable shelf conditions and probable low relief of adjacent landmasses. The Wishart sandstones are typically well sorted, which suggests deposition in shallow agitated water, and similar environments are indicated for the locally arenaceous and stromatolitic Denault Formation, penecontemporaneously reworked Wishart cherts, and the granule- and oölite-rich beds of the Sokoman Formation. Three main facies are recognized in the Sokoman Formation: a magnetite–silicate facies, a magnetite–hematite, and a silicate–carbonate (Gross, 1961). The Sokoman Formation, more than 600 feet thick over wide areas, is predominantly cherty, and is the host rock for the extensive iron ore deposits that developed by natural enrichment processes, probably for the most part during the Mesozoic Era. Enrichment, possibly related to Cretaceous or post-Cretaceous faulting, is recorded near Schefferville by small trough-fillings of fossiliferous iron-formation comprising the Redmond Formation. This formation, more than 300 feet thick, consists of reworked iron-formation rich in jasper fragments enveloped by iron-oxide layers, poorly consolidated pink to pale grey clay, and minor fossiliferous argillite (Blais, 1959). The formation is bounded by faults and rests unconformably on Kaniapiskau strata.

The lowermost unit of the Doublet Group is the Murdoch Formation. A basal unconformity is indicated by lenses of polymictic conglomerate that contain fragments of Knob Lake strata. The predominant lithologies are basic tuff and agglomerate that commonly are altered to chloritic schists. Sedimentary rocks of the Doublet Group are included mainly in the Thompson Lake Formation, a unit probably less than 2,000 feet thick. Although texturally and compositionally immature greywacke characterized by graded bedding occurs in this formation, moderately sorted lithic sandstones containing primary structures indicative of deposition in shallow water are locally abundant (Donaldson, 1966). These rocks may have been partly derived from the cratonic landmass to the west. The overlying Willbob Formation, more than 15,000 feet thick, consists of basaltic lavas that are commonly pillowed, thin sedimentary interbeds, and intercalations of tuff, flow breccia, and agglomerate.

Axial planes of folds typically are inclined east or northeast, and some folds, particularly within the central part of the belt, are overturned. In contrast to the less competent sedimentary rocks, the stratified igneous rocks are characterized by simple, large scale folds. Thrust faults parallel with the axial planes, formed both during and after the period of folding, are particularly abundant in areas of intensely folded sedimentary strata. As many as five generations of folds and cleavages have been

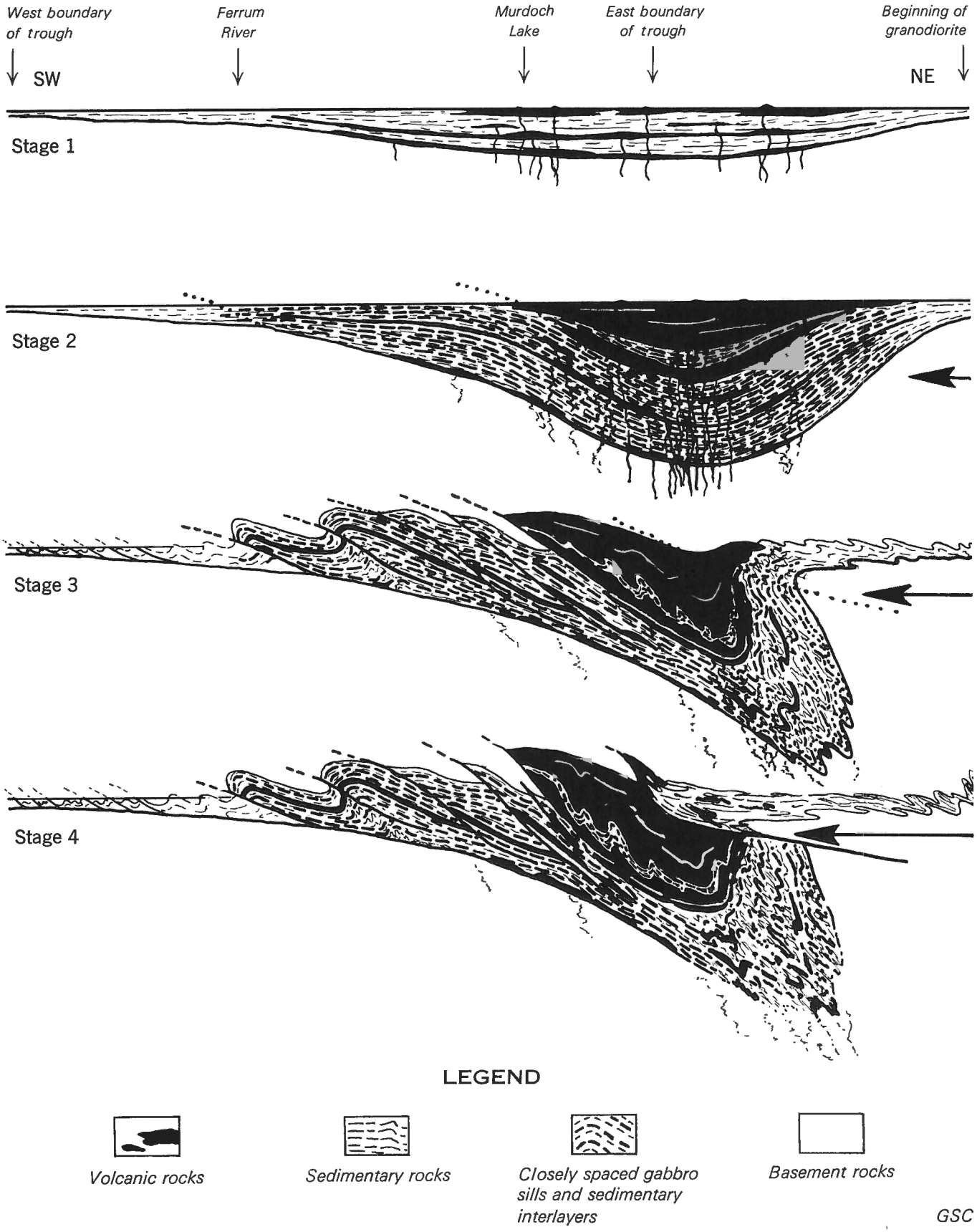


FIGURE IV-19. Schematic cross-section of the Labrador Fold Belt at successive stages in its development (by W. R. A. Baragar).

recognized in some areas. The probable stages of development of the orogenic belt are shown in a series of schematic cross-sections (Fig. IV-19). Metamorphic grade increases northward, as the Kaniapiskau rocks west of Ungava Bay are mainly in the epidote–amphibolite facies. In the north, the deformed Aphebian rocks terminate in a broad syncline in which beds of iron-formation can be traced continuously around the structure (Béland and Auger, 1958). In the south the geosynclinal sequence has been involved in deformation and metamorphism related to the Grenvillian Orogeny.

Because the eastern part of the region has not been studied in sufficient detail, the relative abundance of migmatized and granitized Kaniapiskau strata in relation to basement rocks is unknown. Northeast of Schefferville, metasedimentary rocks of the Laporte Group, predominantly biotite schists, are separated from Kaniapiskau strata by the eastern boundary fault, and in all probability are Kaniapiskau equivalents (Fahrig, 1957). Biotite-, amphibole-, and pyroxene-bearing quartzo-feldspathic gneisses and granites that occur east of the Laporte rocks and which in some areas are in direct fault contact with low-grade Kaniapiskau strata may represent basement rocks that were uplifted during the Hudsonian Orogeny, or may be high-grade metamorphic equivalents of the Kaniapiskau Supergroup. Taylor (1968) has recently indicated that metamorphosed rocks derived from Kaniapiskau strata may extend far to the east of the presently defined western segment of the geosynclinal sequence.

Folded strata of the Kaniapiskau Supergroup are unconformably overlain by flat-lying sandstone and conglomerate of the Sims Formation at Sims Lake, 75 miles southeast of Schefferville (Wynne-Edwards, 1961). The Sims consists mostly of white, pink, and yellow orthoquartzite containing local layers and lenses of rounded jasper and vein-quartz pebbles. The formation, at least 700 feet thick, contains some crossbedded units, but characteristically is massive, consisting of well-rounded and well-sorted quartz grains in a microcrystalline matrix of quartz and sericite. Quartzites possibly correlative with the Sims are present south of the main outcrop areas, and show evidence of Grenville deformation, suggesting a Helikian age for the Sims. In this region, large areas are underlain by the Shabogamo gabbro, both north and south of the Grenville Front. Diabasic gabbro and anorthositic gabbro of this unit form discordant bodies texturally and compositionally distinct from sills of the Wakuach gabbro, and intrusive relationships demonstrate that at least some of the Shabogamo plutons are younger than the Sims Formation. The gabbro typically is fresh, containing labradorite, augite, hypersthene, and olivine, but where altered amphibole and garnet are abundant. South of the Grenville Front the gabbros have been transformed to augite–hypersthene gneisses in zones of cataclastic deformation.

In northeastern Superior Province, widely scattered outliers of relatively undisturbed sandstone, conglomerate, and mudstone rest unconformably on the Archean. These outliers, named the Sakami Formation by Eade (1966a), may be equivalent to either the Sims Formation or the basal arkosic beds of the Kaniapiskau Supergroup. Between Cambrian and Chakonipau Lakes about 140 miles northwest of Schefferville, according to E. Dimroth, carbonatites intrude Kaniapiskau strata in diatremes as much as half a mile in diameter, and in north-trending dykes. Their age is unknown. Calcareous tuffs that may be related to these intrusions occur nearby.

Cape Smith Subprovince

The Cape Smith Fold Belt of Proterozoic rocks in New Quebec extends from Smith Island in the northeast corner of Hudson Bay to the shore of Hudson Strait near Wakeham Bay. The 230-mile belt has a relatively linear southern boundary but a sinuous northern boundary, and attains a maximum width of about 50 miles near the middle of the belt. The south and central parts contain two lithological sequences separated by an unconformity (Bergeron, 1959). The lower sequence, the Povungnituk Group, unconformably rests on Archean basement. The overlying Chukotat Group that composes the central part of the belt is separated by a major fault from the northern part of the belt which appears to be an upthrust segment of the Povungnituk Group. The northern limit of the belt is an irregular boundary beyond which migmatitic gneisses are abundant. In the west, parallel thrust faults occur between the Povungnituk Group and the basement, and between the Povungnituk and Chukotat Groups. Much of the eastern part of the belt has not been investigated.

The Povungnituk Group is more than 10,000 feet thick, and consists of basic and intermediate lavas, basic sills, rare ultrabasic sills, and sedimentary rocks that occur both at the base of the sequence and as thin interbeds within the volcanic units. Basalt, locally pillowed, is the most abundant volcanic rock, greatly exceeding andesite and other less basic lavas. The sediments include argillite, black shale, sandstone, limestone, dolomite, minor iron-formation, and schistose, low grade metamorphic equivalents of these rocks. The Chukotat Group has a thickness greater than 15,000 feet, and consists of abundant pillowed basalt and andesite, sills of gabbro and peridotite, and sedimentary rocks that largely are confined to a thin basal unit. The Chukotat sediments include arkose, quartzite, shale, chert, greywacke, and a basal conglomerate rich in fragments of quartzite and dolomite. Folds and faults in the Cape Smith Fold Belt show two main trends. One trend is parallel with the belt and is most pronounced south of the major thrust fault that separates the Chukotat and Povungnituk Groups. Faults and axial planes of folds that show this trend typically are steeply inclined to the north. The other trend is nearly normal to the main trend, and is marked by cross-folds that increase in

development and abundance northward. North of the major fault this second structural trend is as prominent as the first, or more so. The gabbro and peridotite sills were altered largely to meta-gabbro and serpentinite during folding.

The Chukotat Group is generally less metamorphosed than the Povungnituk Group, with greenschist facies prevailing; rocks in the northern part of the belt are predominantly paraschists and amphibolites that, where least metamorphosed, show lithological similarity to units of the Povungnituk Group. The paraschists and amphibolites may be Povungnituk equivalents that have been more intensely metamorphosed and upthrust along the north-dipping fault that marks the northern boundary of the Chukotat Group. In the north these rocks are intruded by small irregular bodies of granite, diorite, and syenite. Migmatitic gneisses that underlie the area extending northward to Hudson Strait are largely of sedimentary origin, and in part may represent a more intensely metamorphosed extension of the Povungnituk Group.

Eight K–Ar ages on rocks of the Cape Smith Fold Belt fall in the range 1,430 to 1,650 m.y. (Beall, *et al.*, 1963). Four samples from the Povungnituk Group give the oldest values, about 1,600 m.y., and, because geological evidence indicates deformation of the Povungnituk Group prior to deposition of the Chukotat Group, this value serves to provide a maximum age for the Chukotat as well as a minimum age for the Povungnituk. Determinations for the other four samples are about 1,450 m.y., the probable age of metamorphism of the Chukotat Group. The Chukotat Group is, accordingly, Paleohelikian. Although K–Ar ages of basement rocks near the basal contact reflect recrystallization concurrent with Povungnituk metamorphism, whole-rock Rb–Sr ages for two samples reveal that the basement rocks immediately south of the belt were involved in the earlier Kenoran Orogeny, and are therefore Archean.

Belcher Subprovince

Along the east coast of Hudson Bay, extending north and south of Richmond Gulf for a total distance of more than 350 miles, Proterozoic sedimentary and basic igneous rocks underlie parts of the coast and nearby islands in a belt as much as 20 miles wide. These rocks dip gently towards the Belcher Islands, and may be older than the thick succession there, or more likely are equivalent to it. Other Proterozoic rocks occur in the Sutton Inlier and other small inliers within the Paleozoic rocks of Hudson Platform.

R. Bell in 1879 recognized an unconformity within the succession bordering Richmond Gulf and the sequences below and above this unconformity subsequently were named the Richmond Gulf and Nastapoka Groups. A second unconformity was reported within the lower sequences by Woodcock (1960), who introduced the name Pachi Group for rocks below this unconformity. Eade (1966) used the name Manitounuk Group for the undivided succession, and also discussed the problems of stratigraphic nomenclature. The Richmond Gulf and Pachi strata are recognized only in the vicinity of the type area. The Pachi Group consists of arkose and conglomerate overlain by a massive andesite less than 100 feet thick. The sediments, more than 500 feet thick, rest on Archean basement rocks along an uneven surface locally mantled by a regolith. The Pachi rocks were faulted and slightly folded prior to deposition of the overlying strata, and appear to be restricted to the vicinity of Richmond Gulf. The overlying Richmond Gulf Group consists of more than 1,500 feet of arkose, argillite, and a local basal conglomerate rich in boulders of the Pachi volcanic rocks. The unconformity at the top of the Richmond Gulf Group is partly obscured by faulting, but in most places, an angular unconformity is evident (Pl. IV-14). Arkoses and associated immature sediments of the Pachi Group probably were deposited rapidly in a continental environment. Kranck (1951) suggested that Richmond Gulf occupies a graben with an east-trending axis, and Woodcock (1960) mapped faults that have this trend within the Pachi and Richmond Gulf sequences, noting their greater abundance in the former. Because none of the major faults extend into the younger Nastapoka rocks, contemporaneous faulting during the interval of red bed sedimentation is suggested.

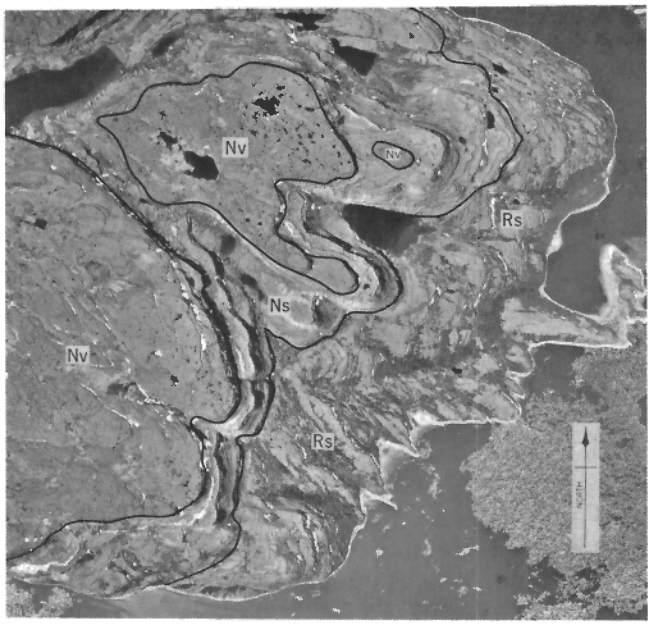


PLATE IV-14. Aphebian Nastapoka Group (Nv–basalt; Ns–sediments) unconformably overlying southwest-dipping Richmond Gulf Group (Rs), Belcher Subprovince, Richmond Gulf, Quebec.

PLATE IV-15
Orbicular diorite sill, in Aphebian Nastapoka Group, Richmond Gulf, Quebec.

The Nastapoka Group extends far to the north and south along the east shore of Hudson Bay, resting nonconformably on Archean crystalline rocks. The trace of this unconformity is relatively linear and commonly marked by a carbonate-cemented conglomerate. Nastapoka lithologies include, in general order of decreasing age, sandstone and siltstone, dolomitic and cherty limestone, quartz sandstone, sporadic lenses of iron-formation, and volcanic rocks with associated gabbro sills, one of which formed phases of orbicular diorite (Pl. IV-15). The Nastapoka strata, in contrast to those of the older groups, must have been deposited in a stable tectonic environment following an interval of erosion sufficient to create an extensive shelf. Sandstone, shale, dolomite, chert, iron-formation, and interlayered basalt compose the Nastapoka Islands, dipping gently westward in apparent conformity with the mainland strata, but at a lower angle. They may represent younger rocks of a continuous sequence, part of which lies beneath Nastapoka Sound, or they may be part of the mainland sequence repeated by vertical uplift or overthrusting. If the sequence is unfaulted, the minimum total thickness of the Nastapoka sequence is more than 2,500 feet.

Proterozoic rocks folded about north- to northeast-trending axes form the Belcher Islands, a cluster of arcuate ridges that outline gently plunging synclines and anticlines in southeastern Hudson Bay (Pl. IV-16). The main group of islands outlines four synclines and four anticlines that are intersected by only a few faults of relatively minor displacement. The synclines are more open than the anticlines, and the folds range from upright-symmetrical in the west to asymmetrical about an eastward-inclined axial plane for the easternmost fold. Grade of metamorphism apparently is in the greenschist facies, but many of the rocks show no evidence of metamorphism. All strata belong to the Belcher Group, within which Jackson (1960) recognized sixteen units of formation rank, including the earlier-named Kipalu Formation. The known thickness of the sequence ranges from about 20,000 feet to almost 30,000 feet but because the base of the sequence is not exposed, the total thickness may be greater. No major unconformities occur, and the lateral continuity of individual units is impressive. The units are relatively uniform in thickness except for the upper volcanic unit, which shows a marked increase in thickness westward. Basic intrusions occur mostly as sills, one of which occurs above the iron-formation and varies little from an average thickness of about 100 feet. The maximum thickness of the other sills is 900 feet, and the thicker parts of these sills are composite. Some basic dykes cut the sills, but because neither sills nor dykes occur in the upper sedimentary sequence, the intrusions probably were emplaced when the flows of the upper volcanic unit were extruded.

The sedimentary rocks for the most part record deposition in shallow water on a stable shelf. Crossbedding and intraformational conglomerates occur in several

units, and stromatolite zones are abundant. In the sedimentary sequence below the iron-formation dolomite and orthoquartzite together greatly exceed the amount of greywacke and argillite. Thick units of basalt and greywacke above the iron-formation reflect less stable tectonic conditions and probably accumulated in a deep-water environment. Hematite-cemented arkose caps the greywacke, suggesting continental deposition, the last-recorded sedimentary event. Three whole rock K–Ar ages, two from cores of basalt pillows and the third from a basic sill, fall in the range 1,600 to 1,700 m.y. Two samples of pillow rims analyzed by the same method gave ages of 830 and 1,019 m.y. G. D. Jackson (1960) regards the younger ages as the result of alteration related to emplacement of young basaltic dykes, one of which has been dated as 880 m.y., and interprets the older values as indicating the minimum age of the Belcher Group. Thus, although the Belcher Group is probably Aphebian, a Paleohelikian age cannot be ruled out.

Although not unequivocally established, correlation of the Belcher and Manitounuk Groups is generally accepted on the basis of information now available. Units of the Richmond Gulf succession, particularly those of the Nastapoka Group, are lithologically similar to units of the Belcher Group. Differences in stratigraphic detail may be attributed to lateral facies changes. Lithological similarities include the presence of iron-formation and stromatolitic carbonate, the abundance of quartzose sandstones, and the widespread flows and sills. The eastward convergence in thicknesses suggests proximity to the border of the geosyncline and possibly also the shore line. The upper basaltic unit of the Nastapoka Group yielded a K–Ar whole rock age of 1,385 m.y. Because the basement to this group is Archean, the single age determination suggests an Aphebian or Paleohelikian age. Bergeron (1957a) noted the lithological similarities and the possibility of continuity of the Aphebian rocks of the Belcher Islands, the Cape Smith Fold Belt, with those of the Labrador Fold Belt and he suggested that they once formed a continuous geosyncline.

In the Hudson Bay Lowland, Proterozoic rocks are exposed as inliers within the unconformably overlying Ordovician and Silurian strata (Sanford, *et al.*, 1968). These Proterozoic rocks are lithologically similar to the succession on Belcher Islands and bordering Richmond Gulf and are probably Aphebian. They dip gently towards Hudson Bay and may be correlative with the latter succession, outcropping also on several small islands in James Bay. Strata of the inliers, more than 200 feet thick, comprise a lower unit of dolomite, in part stromatolitic, and an overlying unit of greywacke, argillite, quartzite, chert, carbonate, and conglomerate. These strata are intruded by sills of gabbroic diabase and rest unconformably on gneisses and granitic rocks, presumably Archean.

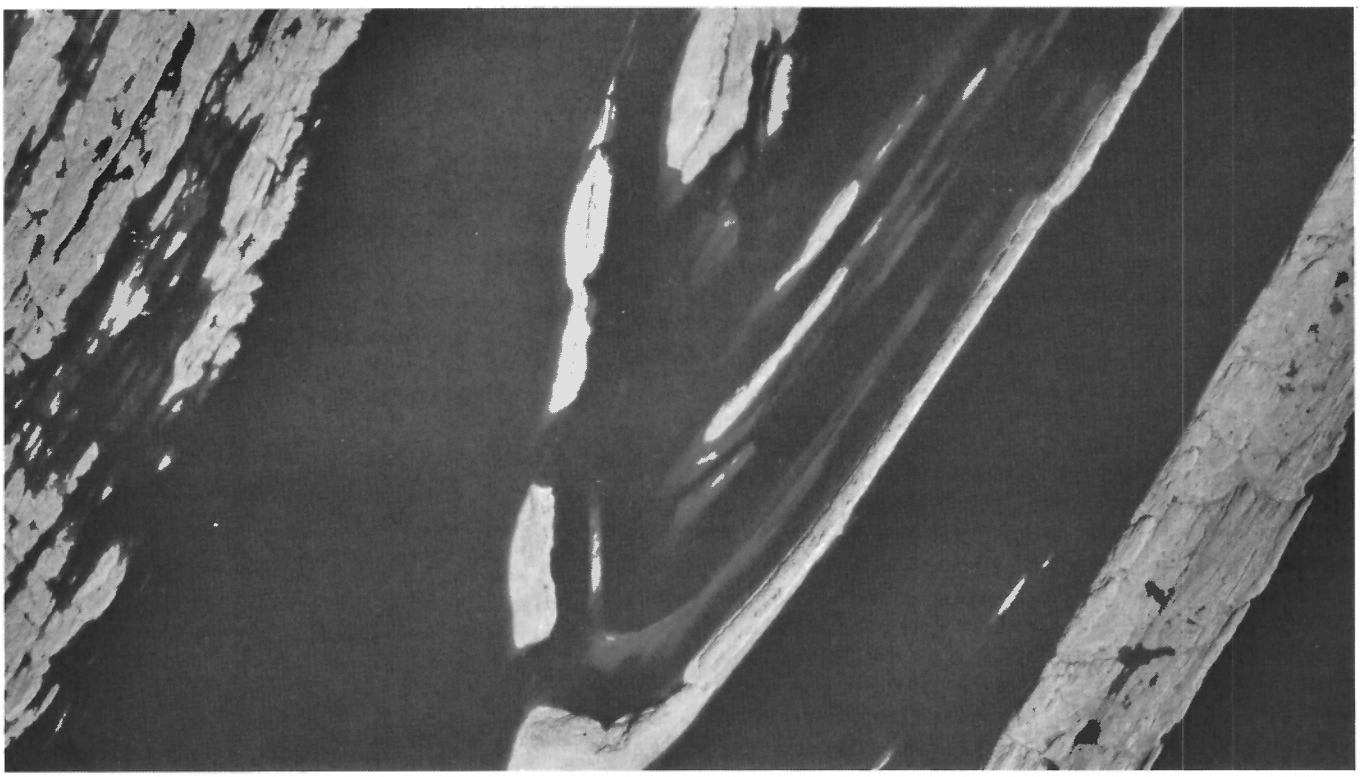


PLATE IV-16. Gently south-plunging anticline in Aphebian Belcher Group, Belcher Islands, Northwest Territories.

Tectonic Summary

Southern Province, south of Superior Province, is divided into three subprovinces: Penokean Fold Belt, Port Arthur Homocline, and Lake Superior Basin. Southern Province comprises Aphebian or younger sedimentary and volcanic rocks that lie unconformably on Archean rocks of Superior Province. The Aphebian rocks have been intruded by basic rocks of several ages and in the Penokean Fold Belt they have been folded, locally metamorphosed, and intruded by small granitic batholiths and then affected by the later Hudsonian or Penokean Orogeny. Three separate sequences of Aphebian rocks are found in Southern Province. In the Port Arthur area the Animikie Group comprises a conformable sequence of chert, jasper, iron-formation, carbonate, interbedded carbonate and chert, argillite, and tuffs. These rocks were deposited in a shallow-water, near-shore environment during a time of relative tectonic stability. Some chert and iron-formation may have been partly deposited in rather restricted near-shore basins and the argillite and slate in somewhat deeper water below wave base. These rocks are very little deformed and have a shallow southerly dip.

Two sequences of Aphebian rocks occur in the Penokean Fold Belt, the most extensive of which is the Huronian Supergroup consisting of four groups. The oldest, the Elliot Lake Group, comprises oligomictic conglomerate, argillite, siltstone, and greywacke or subarkose. The younger Hough Lake, Quirke Lake, and Cobalt Groups each represents a similar cycle of sedimentation that produced a basal assemblage of paraconglomerates, conglomeratic greywacke or subarkose succeeded by argillite, siltstone with some greywacke or subarkose and terminated with the deposition of subarkose and quartzite. The geosyncline in which these rocks were deposited was oriented in an easterly direction and the source of the sediments was to the north. The paraconglomerates are probably tillites and indicate that glaciation took place in early Aphebian times. The clastic sediments reflect rapid sedimentation in a fluvial environment from tectonically unstable areas. Sedimentation appears to have been continuous in the geosyncline but local disconformities occur. The presence of sediments that are probably Huronian equivalents in the Lake Mistassini area of Superior Province and in Grenville Province indicates that the geosyncline was originally very extensive. Sediments of the Whitewater Group are found only within the Sudbury Basin and include a thick sequence of tuffs, tuff-breccias, and bedded tuffs followed by argillite and siltstone, and then arkose. The Whitewater rocks are younger than Huronian strata and separated from them by an unconformity.

Correlation of the three Aphebian sequences in Southern Province with each other and with other Aphebian sedimentary sequences in the Canadian Shield is not well established. The glacial environment that resulted in some of the Huronian sediments must have been widespread during Huronian time. As evidence of glacial conditions is found only in the Huronian sequence, then the other Aphebian sediments in the Shield must be of a different age but whether they are older or younger is not known. Whitewater sediments are younger than Huronian strata and are commonly tentatively correlated with rocks of the Animikie Group on the basis of certain common features such as presence of carbonaceous sediments, tuffaceous rocks, and algae structures, but the evidence is not conclusive. Animikie rocks are also correlated with the Kaniapiskau or Belcher sequences chiefly on the basis of the occurrence of iron-formations. It is possible that the Animikie, Whitewater, Mistassini, and Kaniapiskau sediments were all deposited in a continuous geosyncline and that they are younger than Huronian rocks.

In Canada, Animikie rocks are very gently deformed but their equivalents to the south and west in Minnesota have been folded and mildly metamorphosed. Goldich, *et al.* (1961) define this event as the Penokean Orogeny and the K–Ar ages of metamorphic minerals presumably formed during this orogeny average about 1,700 m.y. In the Iron Mountain district of Michigan the major metamorphic event affecting Animikie rocks or their equivalents took place at about 1,900 m.y. Stockwell (1964) points out that the range and mean of K–Ar ages in Southern Province is about the same as for the Hudsonian Orogeny in Churchill Province, and suggests that the orogeny in Southern Province be referred to as Hudsonian. Whitewater rocks in the Sudbury Basin are older than the Sudbury Irruptive dated at 1,720 m.y., but the age of folding of the sediments depends on whether the irruptive was emplaced along the base of deformed or undeformed Whitewater rocks. Rocks of the Huronian Supergroup were folded about easterly trending axes, then intruded by gabbro sheets that date about 2,150 m.y. and then intruded by several masses of granitic rocks and locally metamorphosed. Ages of post-Huronian granites near Sudbury appear to be over 2,000 m.y. The oldest K–Ar age from the Cutler granite on the north shore of Lake Huron is 1,750 m.y. but Fairbairn, *et al.* (1965) suggest that this granite may be older because a sample of it along with samples of other granites in the region define a Rb–Sr isochron of over 2,000 m.y. K–Ar ages of metamorphic minerals range between 1,500 and 1,900 m.y. It is possible, therefore, that Huronian rocks were affected by a series of orogenic events, the earliest of which was folding followed by metamorphism and intrusion of small granitic masses possibly of differing ages but probably over 2,000 m.y. old. The range in radiometric ages may be due to intermittent movements along the major faults that cut Huronian rocks or the intrusion of the Sudbury Irruptive, or, near the Grenville Front, to the effects of

the Grenvillian Orogeny. It is possible, however, that Huronian rocks were affected by an early orogeny at about 2,000 m.y. and that Animikie rocks were involved in a later orogeny, the Penokean or Hudsonian, at about 1,700 to 1,900 m.y., that also affected Huronian rocks to some extent.

Several periods of basic magma intrusion took place in Southern Province. The Nipissing and Sudbury gabbros occur in Huronian rocks as sheets, sills, and dykes. These rocks yield radiometric ages of about 2,150 m.y. The Sudbury Irruptive is dated at about 1,720 m.y. and is of major economic importance. The Logan sills intrude Animikie rocks, probably are about 1,000 m.y. old, and may be related to the Duluth gabbro and to Keweenawan flows. On the margins of Lake Superior sediments and flows of the Keweenawan Group rest unconformably on the Aphebian and Archean rocks. The sediments consist of sandstones, conglomerates, limestone, and shale overlain disconformably by thin conglomerate, sandstone, and a great thickness of basaltic flows. The flows have yielded K–Ar dates that range from 900 to 1,100 m.y. indicating a Neohelikian or possibly Hadrynian age.

Huronian Supergroup

The name Huronian has been applied to a sequence of sedimentary and volcanic rocks of Aphebian age that lies unconformably on the Archean which is deeply eroded and has a rugged topography. The Huronian occurs in a belt at least 270 miles long and as much as 80 miles wide that extends from Lake Superior along the north shore of Lake Huron from Sault Ste. Marie to Sudbury and then north to Kirkland Lake and Noranda (Fig. IV-20). Remnants of equivalent rocks probably occur in the Chibougamau and Lake Mistassini regions previously described under Superior Province. The Huronian rocks were first systematically studied by Collins (1925) who defined the stratigraphic nomenclature that was accepted for many years and made regional correlations, some of which have been disputed. Difficulties were created because much subsequent geological work was concentrated in the vicinity of Sudbury and near Blind River after the discovery of uranium in that area. Collins' work was modified in each locality but lack of information from the intervening area made correlations difficult. Recent work by the Ontario Department of Mines between Blind River and Sudbury has provided new data for a stratigraphic nomenclature that can be applied with some confidence throughout the Huronian sequence. Problems have also been created by the usage of the term Huronian as it has been applied as a rock-stratigraphic, a time-stratigraphic, and a time term. It is used herein as a rock-stratigraphic term with the rank of a supergroup (Table IV-4), divided into groups and formations following Roscoe.

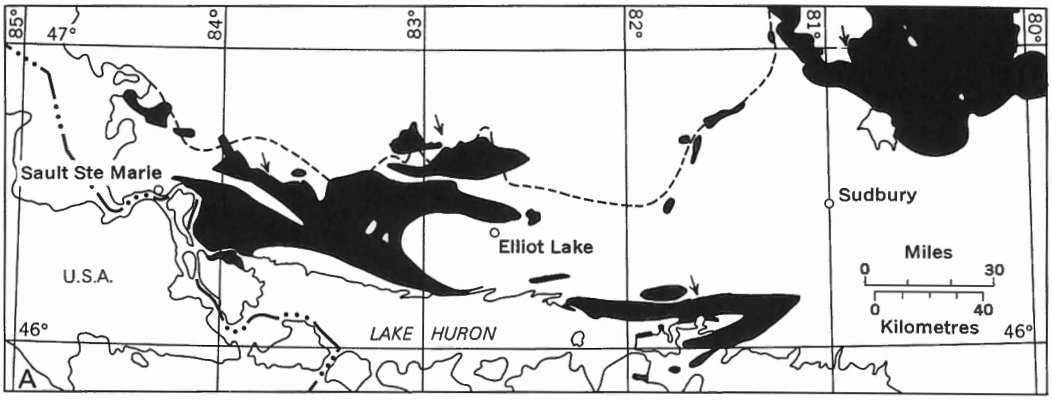
The Elliot Lake Group is the oldest in the Huronian Supergroup and is composed of two formations, the Matinenda and McKim. The group was originally defined in the Elliot Lake area and the upper formation was named the Nordic but this unit has since been correlated with the McKim in the Sudbury area and abandoned. The thickness of the group varies from about 100 feet to at least 13,000 feet. The basal formation, the Matinenda, is composed of subarkose or feldspathic quartzite, quartzite, and oligomictic and polymictic conglomerate. In the Elliot Lake area, the formation varies in thickness from a few feet to roughly 800 feet, which is probably the maximum. The thicker sections are in topographic lows in the basement that trend southeast and may correspond to valleys eroded in the Archean volcanic and sedimentary rocks. The subarkose is greenish yellow, thin to coarse bedded, crossbedded and coarse grained. It is composed of immature, moderately well sorted, subangular to subrounded grains of quartz and feldspar (mostly potassic) with minor amounts of sericite and chlorite. The oligomictic conglomerates, some of which are uraniferous and pyritic occur in beds that range in thickness from an inch to 10 feet. The conglomerates are thicker, more persistent and abundant in the lower parts of the thickest sections. Well-rounded quartz pebbles form 95 per cent of the clasts; chert is the next most abundant rock type and minor amounts of acidic volcanic and feldspar pebbles also are present. The clasts range in size from pebble to cobble and the size decreases down the paleoslope in the Elliot Lake area (Pienaar, 1963). The matrix is composed of subangular quartz and potash feldspar sand grains with some white mica and pyrite. In the ore horizons, pyrite, brannerite, uraninite, and monazite occur as subrounded grains in the matrix. The upper part of the Matinenda Formation is composed of subarkose with lenses or beds of polymictic conglomerate that grade upwards to quartzite. Pienaar reports local disconformities between the upper and lower parts of the formation and the upper units overlap the basement. The polymictic conglomerates occur at the base and are composed of rounded, tightly packed pebbles or boulders of quartz, metavolcanic rocks, chert, and minor granite in a subarkosic matrix. These rocks are not uraniferous.

The McKim Formation of the Elliot Lake Group comprises interbedded argillite, siltstone, greywacke or subgreywacke, and feldspathic quartzite. In the Elliot Lake area the formation is as much as 300 feet thick but it appears to thicken to the south and east in the Sudbury area to the point where it may attain a thickness of 10,000 feet. The argillites are thinly bedded, often laminated, and commonly greenish or black. The greywacke and feldspathic quartzite are thinly bedded and often interbedded with argillite. Both graded bedding and crossbedding occur. Volcanic rocks occur near the base of the Matinenda Formation or underlie it. They are considered part of the Elliot Lake Group but have been assigned various names: the Duncan Formation near Sault Ste. Marie, the Thessalon in the Bruce Mines area, the Pater in the Espanola area, and the Stobie, Copper Cliff, Frood,

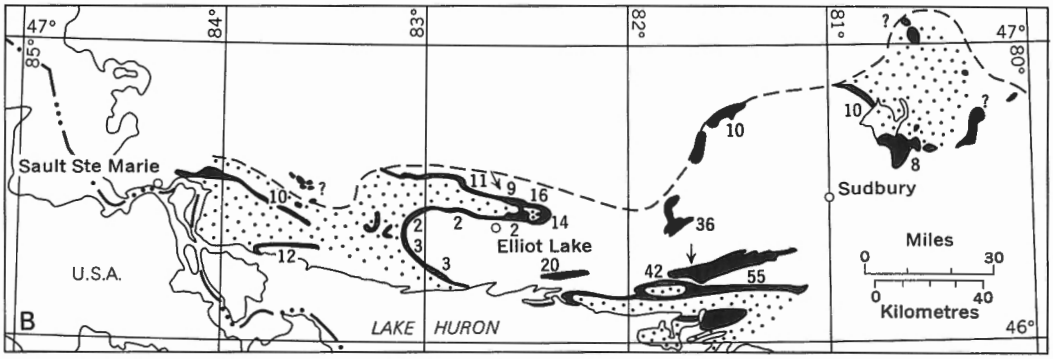
TABLE IV-4 *Comparison of stratigraphic nomenclature of Huronian rocks, Southern Province*

	Collins (1925) North Shore of Lake Huron and Sudbury		Coleman (1914) Sudbury		Cooke (1946) Sudbury		Thomson (1962) Lake Temagami, Sudbury, Blind River		Roscoe (1960) Quirke Lake, Elliot Lake		Robertson (1963) Elliot Lake, Blind River		Roscoe (personal communication, 1967) Sault Ste. Marie, Blind River, Sudbury, Lake Temagami	
	Series	Formation	Series	Formation	Series	Formation	Group	Formation	Group	Formation	Group	Formation	Group	Formation
PROTEROZOIC			Whitewater		Whitewater	Chelmsford Onwatin Onaping							Whitewater	
HURONIAN	Cobalt	Upper white quartzite Banded chert quartzite Lorrain Gowganda			Cobalt	Gowganda	Cobalt	Lorrain Gowganda	Cobalt	Lorrain Gowganda	Cobalt	Lorrain Gowganda	Cobalt	Bar River Gordon Lake Lorrain Gowganda
HURONIAN	Bruce	Serpent Espanola Bruce Mississagi		Ramsey Lake	Bruce	Serpent Espanola Bruce Mississagi Ramsey Lake McKim Copper Cliff	Bruce	Serpent Espanola Bruce Mississagi	Quirke	Serpent Espanola Bruce	Bruce	Serpent Espanola Bruce Upper Mississagi Middle Mississagi Lower Mississagi	Quirke Lake	Serpent Espanola Bruce
									Hough	Mississagi Pecors Whiskey			Hough Lake	Mississagi Pecors Ramsey Lake
									Elliot	Nordic Matinenda			Elliot Lake	McKim Matinenda[1]
	Unconformity		Unconformity			Fault	Unconformity		Unconformity		Unconformity		Unconformity	
ARCHEAN	Sudbury	McKim Copper Cliff	Sudbury	Wanapitei McKim Copper Cliff	Stobie Hill Coneston		Whitewater	Onwatin–Chelmsford Onaping						
							Copper Cliff							
							Sudbury	Scadding Falcon Wanapitei Ramsey Lake McKim						
	Keewatin	Schist complex	Keewatin				Keewatin Type	Stobie and other volcanic-sedimentary rocks	Pre-Huronian Basement		Keewatin		Pre-Huronian Basement	

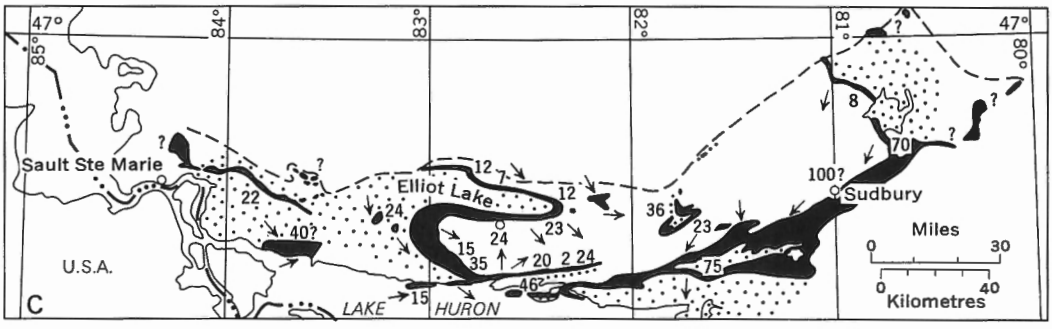
[1] Within or below the Matinenda are volcanic rocks named Thesalon in the Sault Ste. Marie area, Pater in the Blind River area and Stobie and Copper Cliff in the Sudbury area.



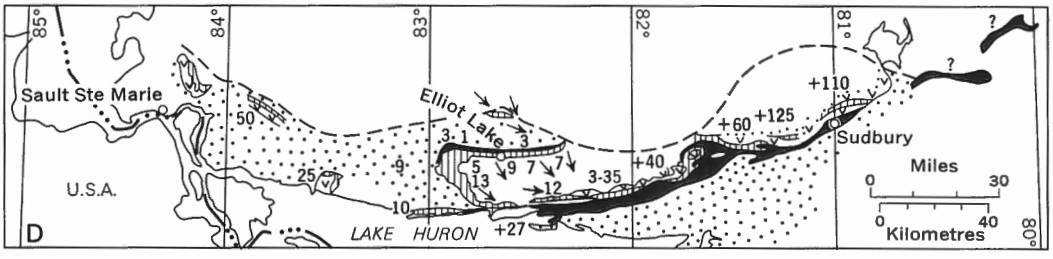
Cobalt Group: Gowganda, Lorrain, Gordon Lake, and Bar River Formations



Quirke Lake Group: Bruce, Espanola, and Serpent Formations



Hough Lake Group: Ramsay Lake, Pecors, and Mississagi Formations



Elliot Lake Group: Livingstone Creek, Thessalon, Pater, Stobie, Matinenda, and McKim Formations

Outcrop areas of groups in A, B, C, and McKim Formation in D

Matinenda Formation

Volcanic rocks of Livingstone Creek, Pater, and Stobie Formations

Subsurface extent of groups

Paleolimits of groups . . . . . ------

Paleolimit of Gowganda Formation . . . . . ----

Predominant direction of primary inclination of crossbeds in major arenaceous units . . . . . →

Estimated thickness of groups in hundreds of feet . . . 12

GSC

FIGURE IV-20
Distribution of the Huronian Supergroup, Southern Province, Ontario (by S. M. Roscoe).

and Elsie Mountain in the Sudbury area. In the Bruce Mines area the volcanic rocks occur within the Livingstone Creek Formation (Frarey, 1967) which is equivalent to the Matinenda. Near Sudbury the volcanic rocks conformably underlie and are intercalated with the Matinenda. They conformably underlie the McKim and are considered to be Huronian strata (S. M. Roscoe). The rocks are basic to intermediate and acidic lavas with interbedded basic and acidic pyroclastics.

The Hough Lake Group of the Huronian Supergroup includes the Ramsay Lake, Pecors, and Mississagi Formations. The basal formation in the Elliot Lake area was originally named Whiskey by Roscoe (1957) but it is now correlated with the Ramsay Lake conglomerates of the Sudbury area. The Ramsay Lake Formation consists of a paraconglomerate with some interbedded greywacke and subarkose. The thickness varies from a few inches to possibly 400 feet. The thicker sections include a greater proportion of conglomeratic subarkose. The clasts in the paraconglomerate are subrounded, vary from pebbles to large boulders several feet in diameter, and consist of granitic rocks, quartz, chert, volcanic rocks, and rarely quartzite. Relative amounts of each lithology vary from place to place as does relative proportion of clast to matrix. Generally there is an excess of matrix relative to clasts so that the clasts are loosely dispersed in a disrupted framework, the paraconglomerates commonly grading to conglomeratic greywacke. The matrix is greywacke or subarkose and siltstone composed of subangular grains of quartz, plagioclase, and lithic fragments set in fine white mica and chlorite. The Pecors Formation comprises interbedded argillite, siltstone, greywacke, and subarkose and varies in thickness from about 100 to 2,000 feet. The formation appears to be thickest in the area between Blind River and Sudbury. At Sudbury, rocks of this formation have been included with either the Ramsay Lake or Mississagi Formation. The lower part of the formation is composed of argillite and siltstone and the upper part is thinly to thickly bedded greywacke or feldspathic quartzites; the latter is more abundant in the Espanola region. The ratio of sand grains to matrix varies but the regional pattern is not established. Crossbedding, graded bedding, ripple-marks, and mudcracks have been observed, and the argillites commonly are finely laminated. The Mississagi Formation is a relatively thick sequence of coarse- to medium-grained subarkose and subgreywacke. Thin interbeds of siltstone or shale are common. The rocks range in thickness from about 600 feet to possibly 10,000 feet, the thickest sections occurring in the south and east. The quartzites are composed of fairly well sorted subrounded to subangular grains of quartz, microcline, and plagioclase in a sericite matrix. Rocks in the lower part of the sequence are generally more feldspathic than those in the upper. The ratio of clasts to matrix varies throughout the formation.

The Quirke Lake Group is composed of three formations: the Bruce, Espanola, and Serpent. Its thickness ranges from 200 feet in the Elliot Lake area to about 5,500 feet south of Espanola. The lowest formation, the Bruce, is a paraconglomerate that varies in thickness from 20 feet to more than a thousand. It is composed of a mixed assemblage of subrounded to subangular boulders, cobbles, and pebbles that range from less than an inch to 3 or 4 feet in diameter. The clasts tend to be more abundant and larger in the lower part of the unit. They are composed of grey and pink granitic rocks, quartz, metavolcanic rocks, and rarely metasediments. The proportion of clasts in the matrix varies but is usually less than 20 per cent and they are dispersed in a greywacke or subarkose matrix composed of sand and silt-sized grains of quartz, microcline, plagioclase, and lithic fragments in a chlorite–sericite matrix. Some parts of the unit are conglomeratic greywacke or subarkoses. This heterogeneous assemblage rarely shows evidence of bedding or stratification. However, in a few localities the exposed long axes of clasts show a preferred orientation north-northwest to north-northeast (S.M. Casshyap). Contacts with underlying and overlying formations are generally sharp or gradational over a few feet. The Espanola Formation is composed of limestone, siltstone, argillite, and calcareous sandy units with some breccias and intraformational conglomerates. It is generally divisible into three members comprising a lower thinly bedded limestone with thin silt interbeds, a calcareous greywacke or siltstone and argillite sequence with silty limestone interbeds and sedimentary breccias, and an upper unit of interbedded silty limestone, calcareous siltstone, subarkose and thin dolomite. The three members are not everywhere present. The thickness of the unit varies from about 400 to 2,000 feet. The relative amounts of limestone or limy beds vary throughout the sequence as do the relative thicknesses of the three members. The Serpent Formation, the youngest unit of the Quirke Lake Group is composed of subarkose with some argillite and conglomerate. It has a characteristic pure white porcellaneous appearance and is well bedded, crossbedded, fine grained, and fairly well sorted. The subarkose is composed of subrounded grains of quartz, plagioclase, and microcline in a matrix of white mica.

The Cobalt Group, the uppermost group of the Huronian Supergroup, is composed of four formations of which the lowest two are most extensively exposed and best known. The basal Gowganda Formation consists of paraconglomerate, argillite, siltstone, subarkose, and greywacke. In Southern Province it generally overlies the Serpent Formation conformably or locally disconformably but, in Superior Province, it overlaps the other parts of the Huronian and lies unconformably on Archean rocks. Exposed thicknesses range from less than 1,000 to 10,000 feet but the true thickness of the formation is generally unknown as it is often the uppermost unit exposed. In the Lake Timagami area it is divided into series of units comprising a basal fluvial granite conglomerate overlain by the other members of alternating units of paraconglomerate or conglomeratic greywacke and thinly bedded

argillite and quartzite (Schenk, 1965). In the Cobalt area the Gowganda is divided into a lower paraconglomerate and greywacke and upper bedded greywacke or siltstone–argillite (Thomson, 1957). South of Espanola, S.M. Casshyap has established four members that in ascending order comprise a paraconglomerate or conglomeratic greywacke, a laminated or massive argillite and siltstone unit, conglomeratic greywacke, and a mixed unit containing subarkose, conglomerate, and argillaceous siltstone. There seems to be a decreasing amount of conglomerate from the bottom to top of the sequence. The paraconglomerates are composed of very poorly sorted subangular to subrounded clasts of granitoid rocks with less abundant amphibolite, siltstone, quartzite, and metavolcanic rocks dispersed in a generally massive matrix of subarkose or greywacke. Striated pebbles are reported from a number of localities. The clasts rarely exceed 20 per cent by volume of the rock. They range in size from very small pebbles to large boulders. The matrix is composed of poorly sorted angular grains of quartz, feldspar, and rock fragments in a sericite–chlorite matrix. In a few localities exposed long axes of clasts have a preferred orientation north-northwest to north-northeast (Pettijohn, 1962), which indicates the line of movement but not its sense. The interbedded argillites, siltstones, or subarkoses are commonly conglomeratic, containing scattered clasts of lithologies similar to those in the conglomerates that range in size from fractions of inches to several feet. Sedimentary structures such as graded bedding, current ripples, load casts, convolute bedding, and clastic dykes (Pl. IV-17) are common in these rocks. Locally the argillite–siltstones are thinly bedded or laminated and have the appearance of varved sediments (Pl. IV-18). These units contain pebbles or boulders that puncture and disrupt bedding but are overlain by undisturbed beds. Such clasts are thought to result from ice-rafting.

The Lorrain Formation overlies the Gowganda conformably and gradationally. It ranges in thickness from 6,500 feet in the Bruce Mines area to 20,000 feet in the Lake Panache area. In Superior Province, the Lorrain

PLATE IV-17
Sandstone dyke with central zone of pebbles in Espanola siltstone, Aphebian Quirke Lake Group, Southern Province, Espanola, Ontario.

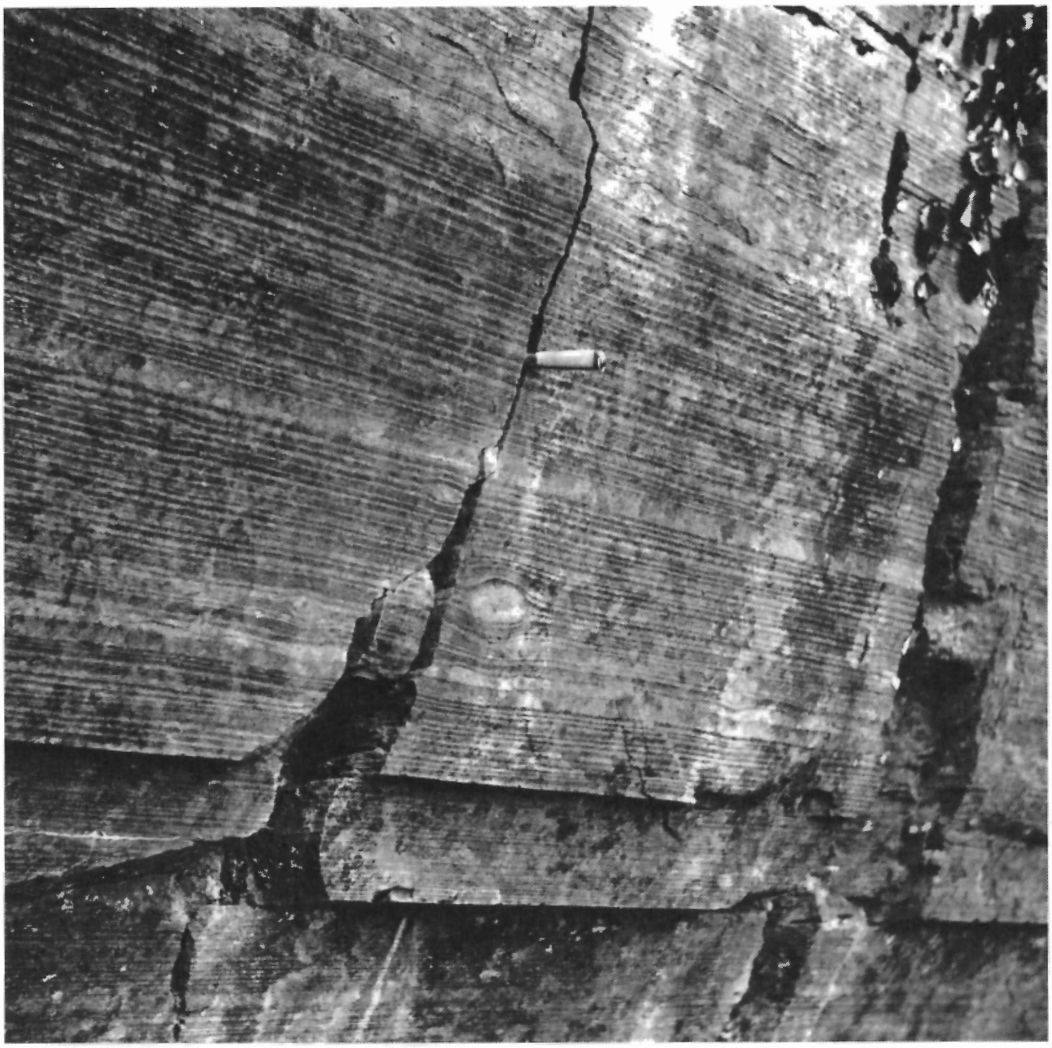


PLATE IV-18

Rafted pebble in Gowganda varved sediments, Aphebian Cobalt Group, Espanola, Ontario.

is the uppermost exposed formation of this group and only a maximum thickness of 1,000 feet is known. The formation is composed of a number of lithologies, some of which appear to be local whereas others persist throughout the basin. In the Bruce Mines area the Lorrain is divided into five units that from the base upwards include pink arkose or subarkose with minor siltstone and argillite, purple siltstone and quartzite, red to pink well-crossbedded quartzite with numerous thin beds or lenses of quartz-pebble conglomerate, jasper conglomerate and pale green feldspathic quartzite, and white quartzite with interbeds of pebble-conglomerate. The red quartzite and jasper conglomerate are apparently restricted to the western part of the geosyncline, to the Bruce Mines and Sault-Ste-Marie areas. Farther east in the area south and southwest of Sudbury where thick sections are preserved the Lorrain Formation comprises a basal pink, red or grey subarkose succeeded by coarse-grained greenish subarkose whose colour is caused by a greenish sericite that forms the matrix to the quartz and feldspar sand grains. The youngest unit is pink to white feldspathic quartzite and quartzite. The quartzite is much more mature than the older arenites in the sequence. Thin lenses of quartz-pebble conglomerate occur throughout the units of subarkose and crossbedding is common in all lithologies.

The uppermost two formations referred to by Collins (1925) as the "banded cherty quartzite" and "upper white quartzite" have been named by Frarey (1967) the Gordon Lake and Bar River Formations, respectively. The Gordon Lake is composed of thinly bedded siliceous and argillaceous siltstones with some quartzite beds and very fine grained quartzite beds that are chert-like. The sequence varies in thickness from about 1,000 feet at Bruce Mines to 3,500 feet at Lake Panache. Its lower contact is conformable and gradational with the Lorrain. The conformably overlying Bar River Formation comprises white to cream-coloured, medium- or fine-grained quartzite with ripple-marks and crossbedding. In the Bruce Mines area it is about 1,000 feet thick but in the Lake Panache area it exceeds 4,000 feet, and includes laminated quartzite, grey argillite, multicoloured siltstones, and several beds of hematite-rich quartzite.

In a general way the thickness of most Huronian formations increases from north to south and from west to east. Paleocurrent determinations based on crossbedding orientations in the various clastic formations indicate that the prevailing direction of sediment transport was from the northwest, north-northwest or north, and, in the easternmost part of the geosyncline, also partly from the north-northeast. The paleocurrent trends as presently known appear to be consistent throughout the time of deposition of the Huronian rocks.

Certain sedimentary features are common to the three paraconglomerate formations, the Ramsay Lake, Bruce, and Gowganda, and suggest that their depositional and tectonic environments were similar. Most studies have been concentrated on the Gowganda, and the more recent, such as those by Pettijohn (1962) and Schenk (1965), have favoured a glacial origin. Pienaar (1963) has suggested that they were deposited by coalescing mudflows triggered by tectonic activity, but the weight of evidence favours a glacial origin. Their great thickness and remarkable lateral extent of individual paraconglomerate horizons, the variety of lithologies in the boulders, the size of boulders and the great distance that the boulders must have been transported, and orientation of the boulders all argue against a mudflow mechanism of transport. In mudflow deposits individual horizons generally have a more limited lateral extent; the clasts are usually angular and unorientated, of local derivation, and lack lithological variety. Structures in underlying sediments are commonly disrupted. Similarly, the large dimensions of boulders, the distances of transport from nearest possible source areas, the lack of stratification and vertical or horizontal facies changes suggest that these rocks are not turbidites. Furthermore, Cooke (1923) and Schenk (1965) describe striated glacial pavements under the Gowganda where it is in contact with Archean rocks. In the thinly bedded siltstones and argillites or the varve-like laminated argillites of the Gowganda, pebbles or boulders puncture and disrupt the bedding and are best interpreted as examples of ice-rafted clasts. The thickness and apparent great lateral extent of the paraconglomerates, the numerous lithologies of distant source represented in boulders, the presence of varved sequences, the absence of phenoclasts of the underlying sediments, the preferred orientation of the clasts in the conglomerates, and the rare occurrence of striated boulders are all lines of evidence that support a glacial origin for the paraconglomerates. If these rocks are in fact tillites, then during Huronian time there were four or more glacial advances. The associated fine-grained sediments within the conglomeratic units may represent interglacial or glacial-fluvial sediments deposited in shallow water as indicated by sedimentary structures such as crossbedding and current ripples. Also structures such as graded bedding and convolute bedding suggest that these sediments were locally reworked by slumping and related turbidity currents. The generally conformable and often gradational contacts with underlying sediments suggest that the tillites may have been deposited subaqueously.

The Huronian sediments record deposition of sediment, largely immature, from a northerly source area that was generally tectonically active and had a rugged topography. The source area was underlain largely by granitic rocks. Most of the sediments were deposited in a fluvial environment but some reflect a deeper water domain just below wave base. There is evidence for periodic transgressions and regressions of the shoreline. The geosyncline into which the sediments were deposited was oriented in an easterly direction and probably extended much farther to the east and west than present exposures indicate.

Deformation of the Huronian Supergroup

Huronian rocks were deformed by a number of separate tectonic events. The earliest deformation in Southern Province is expressed by a series of folds whose axes trend west-northwesterly to easterly to east-northeasterly (Fig. IV-21). This deformation is generally moderate but the intensity seems to increase south of the Murray fault. At Elliot Lake and to the west the folds plunge gently westward but in the east they plunge eastward. In that part of the Cobalt Group north of Sudbury that is in Superior Province, the rocks are undeformed or very gently folded about northerly striking axes. These folds plunge to the north at low angles. The temporal and tectonic relationship of these structures to those of Southern Province are unknown. In Southern Province small folds and cleavage suggest that the earlier folds were redeformed and locally cross-folding is evident. The age of the major folding is not precisely known but in the Blind River area, diabase sheets appear to be either folded with the sediments or intruded along folded strata. In the Espanola area, the gabbro sheets seem to be later than folding (Ginn, 1965) but synchronous with faulting. J. A. Robertson (1967) and Pienaar (1963) conclude that south of Blind River the sheets are later than major folding. The Sudbury gabbros appear to be post-folding. The evidence is somewhat ambiguous but generally supports a post-folding age of intrusion which means that major folding of Huronian rocks took place before 2,150 m.y., the age of Nipissing diabase as determined by Van Schmus (1965).

Huronian rocks are cut by at least three sets of faults. The most obvious set dips steeply south and strikes easterly, roughly parallel with the trend of fold axes. On many the movement is north side down and to the east. Some faults occur along or near the axial planes of the longer folds. Initial movement may have taken place during folding of the Huronian strata but movement continued intermittently over a long period of time as late diabase dykes were displaced by some of these faults. The longest fault of this set, the Murray, can be traced from south of Sudbury almost to the Bruce Mines area, and it has a vertical and horizontal displacement of about a mile (Thomson, 1962). The northeast-trending faults are vertical; they have right-

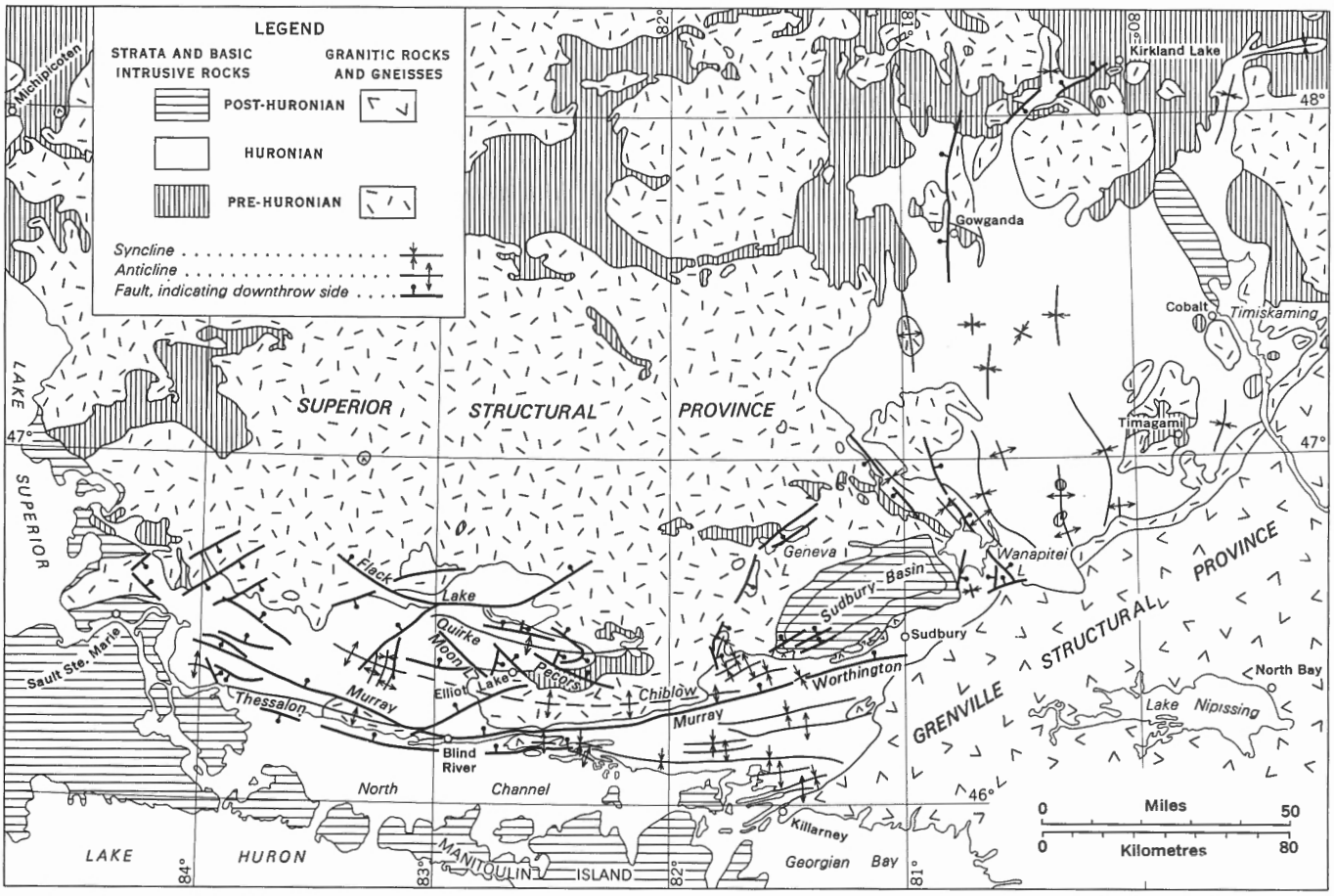


FIGURE IV-21. Major structures in the Huronian Supergroup, Southern Province, Ontario.

or left-hand displacement and either the northern or southern sides are downthrown. These faults cut the easterly striking faults and so are later. They displace the Sudbury Irruptive and some diabase intrusions. A third set of faults strike northwest and dip nearly vertically. Many with right-hand displacements are later than the easterly trending faults and displace the Nipissing diabase as well as younger diabase dykes. Locally, northerly striking vertical faults occur. Fault zones are distinguished by shearing and intense brecciation or hematite-stained quartz stockworks.

Metamorphism and Granitic Intrusions

For the most part Huronian rocks are only slightly metamorphosed to very low greenschist facies. However in certain relatively restricted areas assemblages of the epidote–amphibolite facies are found that include such minerals as staurolite or cordierite and garnet (Card, 1965a; J. A. Robertson, 1967). This higher grade metamorphism is later than the major folding in the region and is not entirely related spatially to intrusions of granitic rocks. Near Sudbury, Huronian rocks are metamorphosed near the Creighton, Cutler, and Murray granite masses. Along the boundary with Grenville Province Huronian rocks are metamorphosed to the amphibolite facies during the Grenvillian Orogeny.

The Cutler granite, along the north shore of Lake Huron, is a grey, medium-grained, equigranular aggregate of plagioclase quartz, potash feldspar, biotite, and muscovite. It may be massive or gneissic and commonly zones of cataclastic structures are developed by post-crystallization shearing. These structures are parallel with those related to early deformations. The Creighton granite is a massive or gneissic, commonly porphyritic, pink to reddish rock and is generally considered to be older than the Sudbury Irruptive. The Murray granite is composed of quartz, feldspar, and biotite and generally considered later than the irruptive but the evidence is contradictory. Remobilization of the granite during intrusion of the irruptive may have taken place. The Croker Island Complex north of Manitoulin Island cuts Huronian sediments. The pluton is circular and about 6 miles in diameter. It is composed of an outer zone of quartz monzonite, an interior ring of monzonite and syenodiorite, and a diorite–gabbro core (Card, 1965b). The order of intrusion of the various lithologies is from mafic to silicic types. Card suggests that the pluton was emplaced by forceful intrusion.

The age of the Croker Island Complex as determined by the Rb–Sr method is about 1,450 m.y. (Van Schmus,

1965). The Cutler granite has yielded a maximum radiometric age of 1,750 m.y. (Wetherell, *et al.*, 1960). The granites near Sudbury yield a range of ages. Early work using the Rb–Sr whole rock method indicated ages of about 2,000 m.y., but more recent work (Fairbairn, *et al.*, 1965) indicates ages of about 2,140 m.y. It seems reasonable to conclude that the Creighton and Murray granites are more than 2,000 m.y. old.

Gabbroic Rocks

The Nipissing diabase intrudes the Huronian sediments in numerous and extensive tabular masses as sills, slightly discordant sheets, or more steeply dipping dykes, many of which trend in an easterly direction. Thickness of individual intrusions varies from a few feet to 1,000 feet. In the thicker bodies differentiation has produced granophyre and diorite phases. The dark green rock is generally composed of labradorite, hornblende partly altered to chlorite, and lesser amounts of quartz, sphene, and iron oxides altered to leucoxene. In the Sudbury area, similar rocks are known as the Sudbury gabbro and they are probably time equivalents of the Nipissing diabase. These intrusions result from a major magmatic event, the Rb–Sr age of which is about 2,150 m.y. (Van Schmus, 1965). Some easterly trending diabase dykes in Huronian rocks yield K–Ar dates that average about 1,677 m.y. (Fahrig, *et al.*, 1965). Northwesterly striking diabase dykes occur throughout the region but are abundant in the Sudbury area and yield an age of about 1,220 m.y.

Sudbury Irruptive

The Sudbury Irruptive, an intrusion of great economic importance, is younger than the Huronian rocks and the overlying sediments of the Whitewater Group. The irruptive is composed of three zones: a lower norite and an upper micropegmatite or granophyre separated by a relatively narrow transition zone. The norite is a gabbroic rock composed of variable amounts of basic plagioclase commonly zoned and saussuritized, augite, hypersthene, and hornblende that may have formed from the original pyroxenes. Biotite and sulphides occur in small amounts along with variable amounts of interstitial micropegmatite or quartz and potash feldspar. The upper micropegmatite consists of a medium- to coarse-grained quartz, potash feldspar, plagioclase, and hornblende partly altered to chlorite.

The irruptive occurs as an elliptical ring enclosing an asymmetric basin, the long axis of which trends northeast. It is 37 miles long and 17 miles wide. The thickness of the intrusion is one to two miles and the micropegmatite phase is generally thicker than the norite. Breccia of fragments of irruptive and country rock commonly occurs as a narrow zone along the basal contact. The irruptive rocks intrude the Whitewater sediments, Archean granitic rocks and volcanic rocks of the Huronian Supergroup. Huronian rocks south of the irruptive face south, are folded about fold axes that trend easterly or slightly north of east, and are cut by granitic rocks and metamorphosed. The Whitewater sediments are gently folded about northeasterly trending axes. They are not metamorphosed or cut by granitic rocks. Regional structural relationships suggest that before intrusion of the irruptive, which has a Rb–Sr whole rock base of 1,720 m.y., the Whitewater rocks must have been separated from Archean and Huronian rocks by a profound unconformity.

The shape or form of the irruptive and its origin are still a matter of controversy. The weight of opinion probably favours the concept that the intrusion was emplaced horizontally along an unconformity between Whitewater sediments and older rocks, and after differentiation into its several phases it was warped or folded, together with the overlying sediments, to form the present basin structure, and then faulted. Recent paleomagnetic work suggests that the intrusion may have had an initial dip and been emplaced therefore along the deformed unconformity (Sopher, 1963). The nature of the irruptive body is not entirely known. Thomson (1956) however argues that the irruptive is a composite intrusion in a ring complex. H.D.B. Wilson (1956) considers that the norite and micropegmatite are the uppermost phases of a differentiated funnel-shaped intrusion, the lowest members of which are unexposed ultrabasic rocks. Dietz (1964) has proposed that the structure is a deformed astroblem and suggests that magma generated by force of impact of a giant meteor differentiated into the various phases of the irruptive.

Whitewater Group

Rocks of the Whitewater Group are restricted to the Sudbury Basin and are in contact only with the Sudbury Irruptive which intrudes them. The Whitewater Group is divided into three formations that are conformable and grade into each other. The lowest unit, the Onaping Formation, is composed of andesite tuff, tuff–breccia, lapilli tuff, minor bedded tuffs, rhyolite breccia, and, very locally, amygdaloidal and spherulitic andesite flows. The sequence has a maximum thickness between 4,000 and 5,000 feet. Thomson (1956) and Williams (1956) conclude that these rocks were formed from glowing avalanche debris. The Onaping grades upward into the Onwatin carbonaceous slates with minor limestone, cherty carbonate, and greywacke about 4,000 feet thick. The carbon content of the shales is characteristic. The Chelmsford Formation is composed of arkose with very thin interbeds of argillite. The arkose has angular to subangular grains of quartz and plagioclase. Crossbedding and ripple-marks are common and the rocks are generally thin bedded. Carbon also occurs in these sediments and limy, iron-rich ellipsoidal-shaped concretions are abundant in the sandstone. The Whitewater rocks, which are older than the Sudbury Irruptive, are Aphebian in age and probably younger than the Huronian rocks. They are tentatively

correlated with rocks of the Animikie Group of the Port Arthur area. The Whitewater strata are gently folded about axes that trend approximately northeast roughly parallel with the basin. The folding is stronger towards the southeast. Plunges of folds are gentle and are in both directions. The Whitewater and older rocks are cut by many faults, most of which strike northeasterly to east-northeasterly. The faults dip to the southeast at high angles and have considerable displacement. Steep-dipping faults that strike northeast, diagonally to the set above, may be related. The north rim of the basin is cut by a number of steeply dipping faults that strike northerly to north-northwesterly.

Port Arthur and Lake Superior Subprovinces

In the Port Arthur region the Archean rocks were eroded and a relatively flat featureless surface was produced preceding deposition of Aphebian sediments, the northernmost part of the extensive Animikie Group of Minnesota. In Ontario the group is composed of three conformable formations, the Kakabeka, Gunflint, and Rove. The Kakabeka Formation is a thin discontinuous conglomerate unit as much as 5 feet thick. It is generally included as the basal member of the succeeding Gunflint Formation. The conglomerate is composed of well-rounded pebbles of quartz, chert, jasper, and granite in a matrix of quartz sand. Pebbles are generally less than 2 inches in diameter. The Gunflint Formation includes a large number of lithologies that exhibit very rapid facies changes. Few members can be traced throughout the outcrop area. The formation has an average thickness of about 400 feet, and generally thickens from north to south. Many of the sedimentary units are iron-rich, and the formation is often referred to as the Gunflint iron formation.

In the Whitefish Lake area west of Port Arthur the Gunflint has been divided into two divisions (Goodwin, 1960). The lower division comprises a unit of algal chert, bedded chert and taconite, a soft black fissile pyritic argillite, and a unit of greenalite, magnetite and cherty taconite. The upper division is composed of algal chert, jasper, tuffaceous shale, taconite, and limestone. In Loon Lake area east of Port Arthur, a threefold division is evident comprising a lower unit of ferruginous carbonate, cherty taconite, and carbonate beds, followed by argillite with interbeds of carbonate and tuffs, and an upper unit of thin-bedded carbonate and chert and taconite. The uppermost limestone is only present locally. Individual units thicken or thin sharply and grade laterally into one another. The intermediate argillite east of Port Arthur is thought to be equivalent to the upper shale in the western section and appears to be the only unit that can be traced with confidence throughout the whole region. The taconites are composed of granules, about a millimetre in diameter, of chert, iron oxide, carbonate, and iron silicate in a matrix of chert and carbonate. The cherty carbonates are composed of thin, interbanded layers of chert and carbonate that contain minute spheroidal structures. The carbonates are commonly ferruginous dolomite or siderite.

The Rove Formation is composed of black, thinly bedded argillite with a few layers of red and green argillites, limestone, and greywacke. Certain zones contain large calcareous concretions as much as 8 feet in diameter. The formation attains a maximum thickness of 2,000 feet in Ontario and 3,000 feet in Minnesota. The formation thins as its northern margin is approached and this may be partly a characteristic of the original basis of deposition but is also partly due to erosion that preceded deposition of the overlying Keweenawan sedimentary rocks.

The Animikie Group is disconformably or unconformably overlain by Keweenawan rocks of the Sibley Formation that extends along the north shore and nearby islands of Lake Superior and inland to Lake Nipigon. The Sibley rocks rest on Rove shales and on several units of the Gunflint, and overlap the Archean rocks. The Sibley Formation is as much as 500 feet thick and composed of a discontinuous thin basal conglomerate that contains pebbles of underlying rocks in a quartz or carbonate sand matrix, succeeded by white to yellowish sandstone with thin interbeds of limestone and chert, and by carbonate and shale that in the south are deep red or maroon and iron-rich, but in the north are more typically white or light grey. The carbonates apparently are composed of carbonate grains with some quartz or feldspar grains in a calcite cement. Shale interbeds are common in the carbonate strata. The Sibley is disconformably overlain by about 50 feet of conglomerate, sandstone and mudstone of the basal Osler Formation. The upper part consists of thick basaltic lavas with interbeds of conglomerate or sandstone. Individual flows are as much as 200 feet thick. The thickness of the Osler is 6,000 to 10,000 feet. Similar rocks on the east shore of Lake Superior at Mamainse Point are estimated to be 15,000 to 17,000 feet thick (Thomson, 1953).

Intrusions into the Keweenawan and older rocks are gabbro sills or sheets and diabase dykes. In the Port Arthur area, the Logan sills intrude the Animikie strata at several horizons. They vary in thickness from a few feet to 200 feet, but in the Lake Nipigon area are as thick as 1,000 feet. Some sheets that cut the strata at low angles to the bedding probably were intruded after regional warping. The thicker sills are differentiated and contain a number of lithological phases, the uppermost being a granophyre. Diabase dykes occur in a northeasterly striking swarm in the Port Arthur area. Rocks of the Animikie and Keweenawan Groups are very gently folded. They dip to the south at a low angle of 5 to 10 degrees. Locally, tight folds are related to movements along faults or may be due to volcanic activity. The slight regional angular discordance beneath the Sibley Formation suggests a period of erosion and moderate

warping. All the rocks in the region have been cut by steep-dipping faults apparently with normal displacement that strike east to northeast and north to northeast. They are marked by narrow breccia zones and locally contain quartz veins.

In Minnesota the Animikie rocks have been folded and metamorphosed during the Penokean Orogeny. Minerals from metasediments yield K–Ar ages in the 1,650 to 1,800 m.y. range. The Animikie rocks are therefore Aphebian but are isolated from the Huronian rocks in the eastern part of Southern Province, with which they have little stratigraphic or lithological similarity. The Animikie rocks have many features in common with parts of the Kaniapiskau Supergroup or the Belcher Group. The Keweenawan rocks are similar to those in other parts of the Lake Superior Basin. K–Ar age determinations on whole rock samples of basic volcanic rocks, gabbro intrusions, and diabase dykes fall in the range 900 to 1,100 m.y. They are, therefore, Neohelikian or possibly Hadrynian.

NAIN PROVINCE

The Nain Province is defined chiefly on the basis of K–Ar age determinations. Known structural trends are generally north to northwest, subparallel with the structural grain of the adjacent Churchill Province to the west. Most of western Nain Province is characterized by K–Ar dates ranging from 1,300 to 1,500 m.y. and by granitic gneisses that are intruded by large masses of Elsonian anorthosite and mangerite. Eastern Nain Province is represented in the coastal region by gneisses giving K–Ar ages that have been referred to the Kenoran Orogeny and one or two dates possibly referable to the Hudsonian Orogeny. The boundary between the eastern and western parts has been drawn arbitrarily to include all the anorthosite–adamellite rocks in the western part. Knowledge of the geology of Nain Province is so limited that a tectonic synthesis is considered premature.

The most widespread and the largest intrusive masses in Nain Province are members of the anorthosite suite. K–Ar determinations on biotite have yielded dates averaging 1,400 m.y. In the Nain area (Wheeler, 1960) the anorthosite–adamellite association is sufficiently similar to the anorthosite–mangerite complexes of Grenville Province that it is difficult to doubt a common origin. The Kiglapait layered gabbroic intrusion is probably related to the same igneous episode as the Nain anorthosite and it may also be inferred that basaltic magma played a role in the origin of the anorthosite–adamellite series. The Michikamau intrusion (Emslie, 1965) has a fine- to medium-grained gabbro margin which is regarded as evidence that basaltic magma was an important component in the development of the intrusion. Late differentiates are not volumetrically abundant at Michikamau but some are similar to the Nain adamellites. The anorthosite–adamellite plutons of western Nain Province are believed to be essentially non-orogenic. This is indicated by the presence of well-preserved layered structures and unzoned

PLATE IV-19

Layered leuco-troctolite of the Michikamau anorthosite intrusion, Michikamau Lake, Labrador. Gravity stratified rhythmic layering of olivine-rich lower parts (dark, left side) grading into plagioclase-rich upper parts (light, right).

minerals of coarse grain-size, and the lack of metamorphic effects. Accordingly, the major orogenic activity in the region preceded their emplacement, and in all probability it was the Hudsonian. The widespread post-Hudsonian K–Ar ages found in western Nain Province may be due to extensive heating of the crust at the time of emplacement of the anorthosite–adamellite plutons.

Lake Michikamau area. Much of the area is underlain by foliated to gneissic quartzo-feldspathic rocks with large or small remnants of paragneiss. Mineral assemblages typical of the amphibolite facies are common west of Lake Michikamau, but, bordering a large north-south elongated complex of pyroxene-bearing syenitic and granitic rocks, the gneisses are in granulitic facies. The mineralogy of the syenitic rocks is similar to that of the Nain anorthosite–adamellite complex described later. Granulite facies rocks, although sporadic in distribution, are present over large areas east and northeast of Lake Michikamau. The gneissosity and foliation strike northwesterly except where deflected about the Michikamau intrusion.

The Michikamau anorthositic intrusion (Emslie, 1965) is about 800 square miles in area. Biotite gave an age of 1,400 m.y. Large volumes of leuco-troctolite, commonly layered (Pl. IV-19), together with gabbro, leuco-gabbro, and anorthosite make up the bulk of the intrusion, which has a chilled margin of fine-grained gabbro. Late differentiates are extremely rich in ferrous iron. An older group of paragneisses can be recognized at many places forming the wall-rocks of the Michikamau intrusion. These comprise mainly pelitic, semi-pelitic, and impure quartzitic gneisses; the biotites yield a metamorphic age of 1,520 m.y. Several large, medium- to coarse-grained, biotite- and pyroxene-bearing granitic masses occur throughout the region. Some may be younger than the Michikamau intrusion. Granite that cuts the anorthosite has an age of 1,360 m.y. Biotite from the large mass southeast of Lake Michikamau gave a similar age of 1,395 m.y. The Neohelikian is represented by remnants of flat-lying arkose, sandstone, and conglomerate, believed to be correlative with the Seal Lake Group to the east. The conglomerates commonly contain numerous pebbles of intermediate to silicic volcanic rocks, some with abundant feldspar phenocrysts. The only known source of these pebbles is the Croteau Lake Group unconformably underlying the Seal Lake Group.

Nain area. The oldest recognized rocks are a gneiss complex consisting partly of paragneiss. Granulite facies mineral assemblages are typical of much of the area north of Davis Inlet and amphibolite facies assemblages occur to the south. Marble bands are few and thin; quartzites are absent. Ultramafic layers and lenses occur in the gneisses. An Archean age is indicated by several K–Ar determinations on biotite and hornblende and ranges from 2,390 to 2,665 m.y. In the vicinity of Hopedale the migmatitic gneisses include several sill-like altered peridotite bodies. Large, northeast-striking, vertically dipping, uralitized diabase dykes are common. The Nain anorthosite and related bodies are intrusive into the gneiss complex. Composition varies from meta-gabbro to anorthosite and leucodiorite. Chatoyant plagioclase is widely distributed. The chief mafic minerals are monoclinic and orthorhombic pyroxenes, and olivine is locally common in the mafic facies. Medium to very coarse grained textures are typical. Cataclastic zones are spatially related to the margins of the intrusion (Wheeler, 1960). The adamellite intrusions vary in composition from granodiorite to granite and show both intrusive and transitional

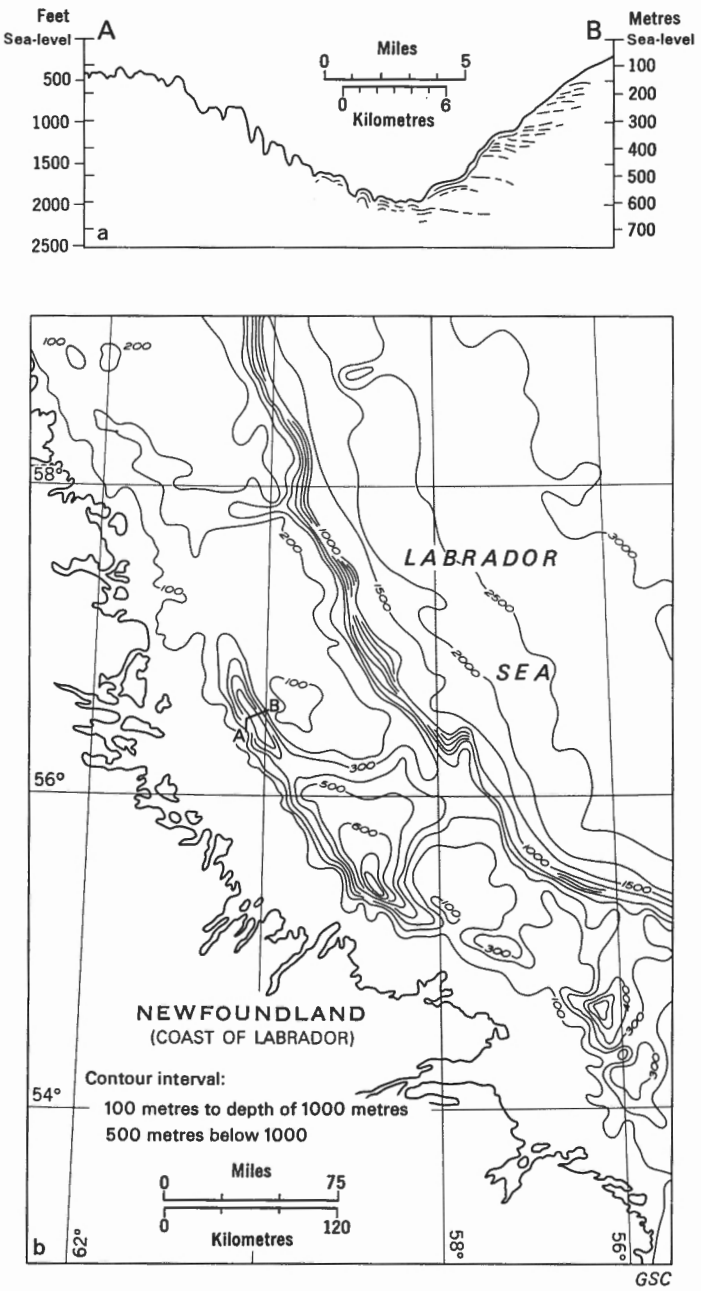


FIGURE IV-22. Labrador Shelf of the Atlantic Continental Shelf (Grant, 1966): (a) Seismic cross-section of the "marginal channel" (vertical exaggeration 15X); (b) Bathymetry.

relationships to the anorthositic rocks. Hornblende is the chief mafic mineral but biotite, orthopyroxene, clinopyroxene, and fayalitic olivine also occur. These rocks are similar in composition and associations to the mangerite intrusions in Grenville Province. The Kiglapait intrusion is a layered basaltic pluton that has extremely iron-enriched differentiates and is comparable in many respects to the Skaergaard Intrusion of East Greenland. Several K–Ar biotite dates from granitic rocks in the district (Beall, *et al.*, 1963) support an age of about 1,400 m.y. for the Nain anorthosite and the Kiglapait intrusion.

Northwest of Nain, the Siamarnekh Formation unconformably overlies adamellite. It consists of about 380 feet of flat-lying red subarkose similar to the Neohelikian Seal Lake Group.

Northern Labrador Coast. North of the Nain district granitic gneisses and granite outcrop along the coast. At the head of Hebron Fiord and northward to Saglek Fiord pyroxene-bearing gneisses are reported. Near the head of Nachvak Fiord, a northwest-striking zone of ultramylonite and pseudotachylite separates the hypersthene-bearing gneisses on the east from fine-grained gneiss carrying some marble to the west. Rocks of the Ramah Group are exposed in fiords from Saglek Fiord north to Nachvak Fiord. These consist of an estimated thickness of 4,000 to 6,000 feet of quartzite, argillite, slate, ferruginous quartzite, dolomite, and chert. As much as 240 feet of volcanic rocks are present near the base of the sequence. The rocks are gently dipping and rest unconformably on older gneisses; locally they are folded and faulted.

The Kaumajet Mountains are underlain chiefly by the Mugford Group of volcanic rocks comprising basalt, andesite, trachyte, and tuff. The volcanic rocks at some places unconformably overlie as much as 150 feet of quartzite, ferruginous quartzite, argillite, and dolomite that may correlate with the Ramah Group. Elsewhere the Mugford Group lies unconformably on the older gneisses that have yielded dates of 2,045 and 2,255 m.y. Parts of the group are slightly folded and block faulted but otherwise little disturbed. The Ramah Group could correlate with the Aphebian rocks of the Labrador Fold Belt, although there is a closer resemblance to the succession of the Cape Smith Fold Belt as the thick volcanic Mugford Group unconformably overlies a sedimentary succession with lean iron-formation. A single K–Ar date of 948 ± 90 m.y. suggests that the Mugford Group is much younger.

The bathymetric configuration of the Labrador Shelf (Fig. IV-22) indicates a narrow marginal channel, paralleling the coastline of northeastern Labrador for hundreds of miles, which could be a fault zone formed during Cenozoic uplift of the continent. From a seismic profile across the channel southeast of Nain, A. C. Grant (1966) concludes that the eastern flank of the channel is underlain by flat-lying layered rocks. These could be post-Precambrian in age or the relatively undisturbed Ramah and Mugford Groups.

GRENVILLE PROVINCE

Tectonic Summary

Highly metamorphosed Archean and Aphebian rocks have been recognized within Grenville Province because the Kenoran and Hudsonian folded belts are truncated by the Grenville Front and it is possible that rocks of the older orogenic belts may extend well into Grenville Province. Southwest of Chibougamau, Archean mafic, intermediate, and silicic lavas, pyroclastics, quartzo-feldspathic and slaty metasedimentary rocks in Grenville Province are metamorphosed into mica schist, biotite and hornblende paragneiss, and amphibolite. In the Wabush – Mount Wright district granitoid gneiss with granulite facies mineralogy similar to those in Superior Province are probably also Archean. Aphebian marble, quartzite, and iron-formation of the Labrador Fold Belt extend into central Grenville Province.

The Grenvillian orogenic cycle begins with the deposition of sediments of the Paleohelikian Grenville Group, accompanied at least locally by volcanism. These rocks are now recognized only in the southwest part of Grenville Province. Temporal equivalents of the Grenville Group may once have been widespread but subsequently removed by uplift and deep erosion. During or after Paleohelikian deposition and prior to significant deformation, large quantities of basic magma were intruded into the lower part of the sequence and underlying basement, resulting in formation of widespread anorthosite–mangerite plutons. Smaller intrusions of gabbro, diorite, and granitic and syenitic rocks may also have been emplaced at about this time. The culmination of regional metamorphism and the major deformation of the Grenvillian Orogeny followed. In some regions of high-grade metamorphism gneiss domes rose from the underlying granitic basement into the sedimentary sequence, perhaps accompanied by the emplacement of magmatic granites at higher levels. Structural trends in the Grenville Group are northeasterly as are those close to the Grenville Front. Elsewhere, complex fold patterns record deformation that predates the Grenvillian Orogeny. The present moderate to high grade of regional metamorphism throughout much of Grenville Province together with the characteristic complex structural style is evidence that strong uplift and deep erosion have exposed rocks whose environment of formation was the catazone. Following the period of intense orogenic activity some small granitic and syenitic plutons were emplaced.

Zones of cataclasis and mylonitization such as those along the Grenville Front are believed to have developed during the later stages of deformation and probably after the main metamorphic episode.

After the close of the Grenvillian Orogeny small-scale intrusive activity is represented by the Chatham–Grenville stock, alkaline complexes, and diabase dyke swarms. The Oka alkaline complex was intruded in the early Cretaceous.

Archean and Aphebian

Along the northwestern margin of Grenville Province highly metamorphosed Archean and Aphebian rocks have deformational histories that predate the Grenvillian Orogeny. Elsewhere in Grenville Province complex structural trends also suggest multiple deformation. Combination of these observations has led to speculation that the typically complex fold patterns are the result of superpositions of two or more orogenies and that rocks formed during orogenies older than the Grenvillian might be widespread. In the Surprise Lake area (Déland, 1956; Déland and Grenier, 1959) progressive metamorphism of Archean metasedimentary and metavolcanic rocks occurs at the Grenville Front btween Superior and Grenville Provinces (Fig. IV-23). The northwestern part, in Superior Province, is underlain by Archean rocks comprising pillowed mafic and intermediate lavas intruded by sills of meta-gabbro, silicic lavas, quartzo-feldspathic and slaty metasedimentary rocks, and small amounts of pyroclastics. Low greenschist facies mineral assemblages are present in these rocks. The sequence has been tightly folded about easterly trending axes. The southeastern part, in Grenville Province, is underlain by gneissic granite, biotite and hornblende paragneiss, hornblende gneiss, and amphibolite. Foliation and gneissosity strike northeasterly. The metasedimentary rocks are progressively metamorphosed into mica schists, biotite, and hornblende paragneiss. The mafic volcanic rocks are transformed into amphibolite (Fig. IV-24). The width of the zone of transformation averages two to three miles and mineral assem-

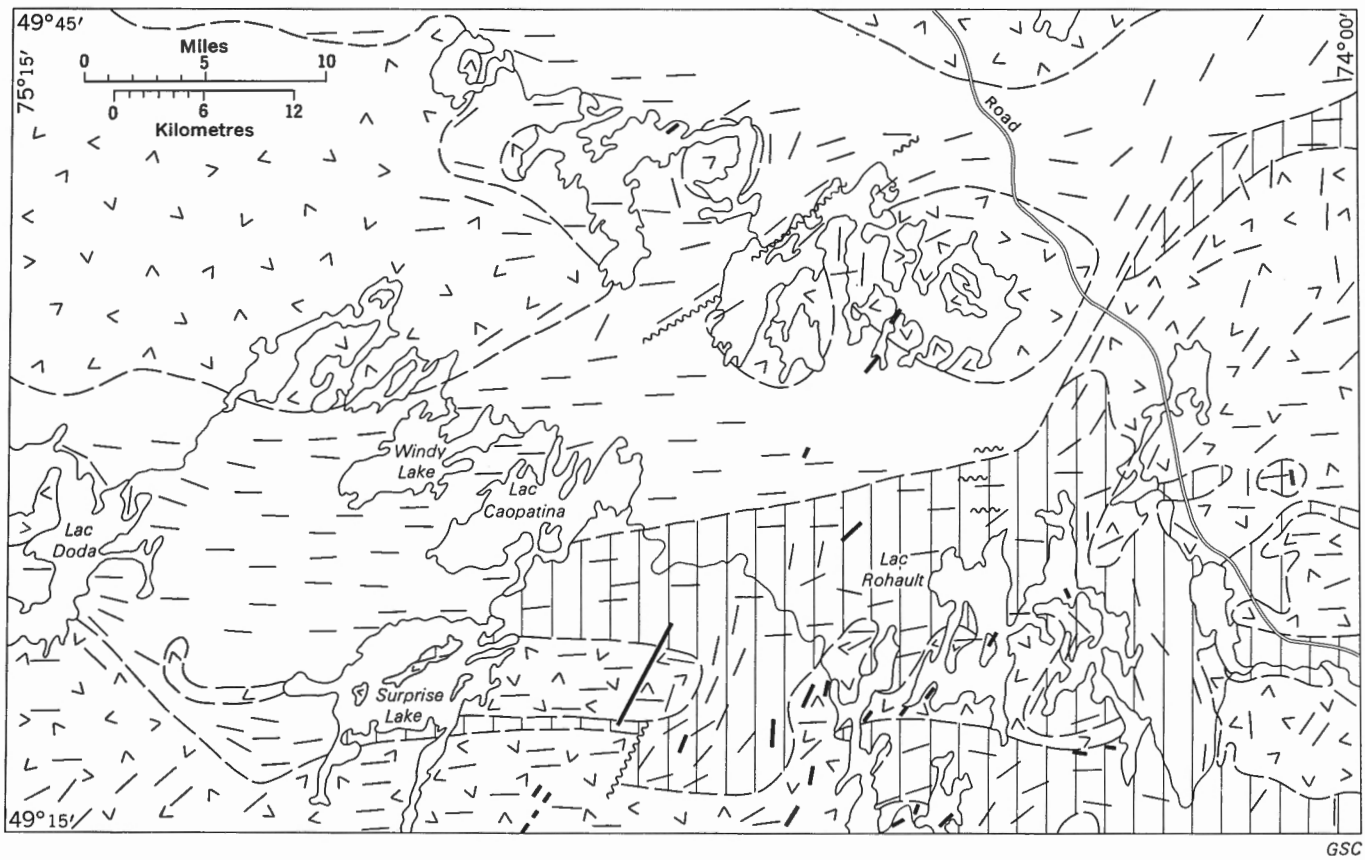


FIGURE IV-23. Geology of Suprise Lake region, Quebec (Déland and Grenier, 1959).

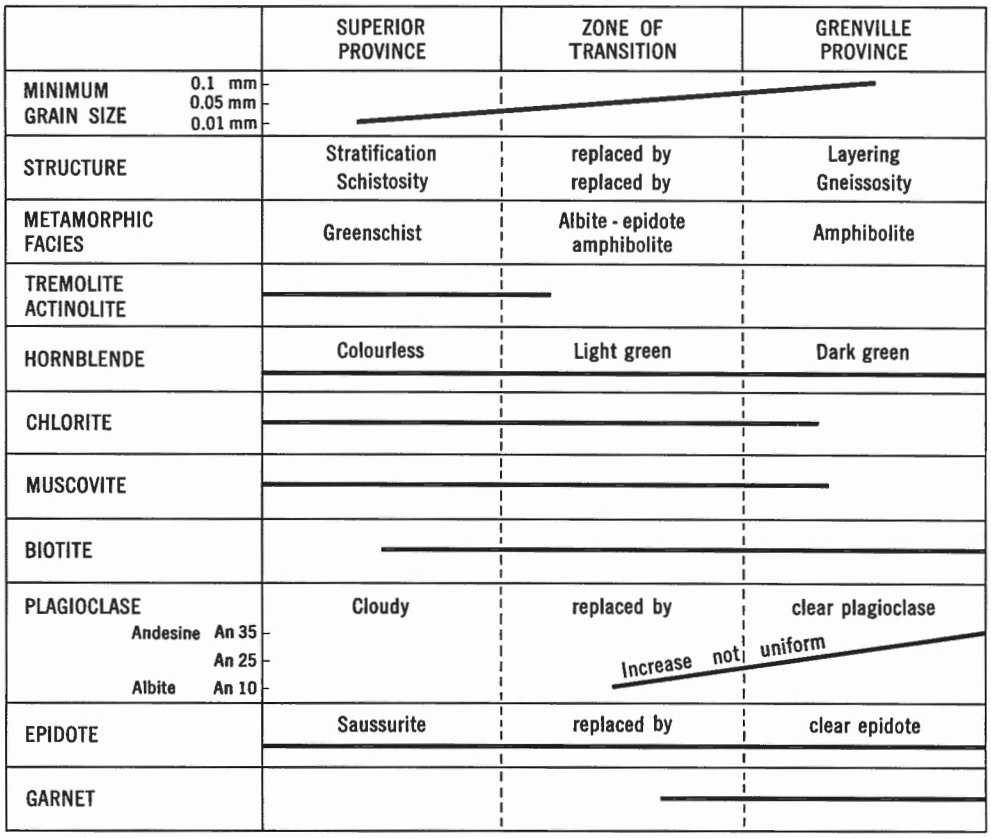


FIGURE IV-24
Mineralogical and textural changes in Archean rocks across Grenville Front, Suprise Lake area, Quebec (Déland, 1956).

blages of the upper greenschist facies are characteristic. Accompanying the increase in metamorphic grade, primary structures such as pillows and amygdules are almost completely obliterated in the metavolcanics and stratiform foliation replaces bedding in the metasediments. Passing beyond this zone to the east and south, biotite and hornblende paragneiss and amphibolite become coarser grained. The presence of deep green hornblende and oligoclase-andesine in the mafic rocks is characteristic of the almandine–amphibolite facies. There is some faulting but no major dislocations are apparent. The boundary between Superior and Grenville Provinces is chosen by Déland (1956) as the low side of the transition zone between the greenschist and almandine–amphibolite facies.

In the Wabush–Mount Wright district, the distinctive lithologies of iron-formation quartzite and carbonate of the Aphebian Kaniapiskau Supergroup have been recognized in Grenville Province (Duffell and Roach, 1959; Fahrig, 1960; Clarke, 1961). North-northwest striking unmetamorphosed rocks of the Labrador Fold Belt can be traced into high-grade schists and gneisses. There is also a rapid change in metamorphic grade and structural style at the Grenville Front. North of the Grenville Front (Fahrig, 1960; Wynne-Edwards, 1961) granulite facies gneiss forms a basement to the Kaniapiskau rocks, and the Sims Formation, largely quartzite, unconformably overlies it. The biotite isograd approximately indicates the southern limit of essentially unmetamorphosed rocks. Abundant evidence of faulting and cataclasis is found in the vicinity of the biotite isograd. Northwest and northeast directions of folding are recognized south of the Grenville Front whereas only northwest fold axes occur to the north. South of the front there are high-grade gneisses with mylonite zones and evidence of thrusting from the south. In the Archean granitoid gneisses of the granulite facies retrograde effects become increasingly apparent and almandine–amphibolite facies mineral assemblages predominate. Accompanying this metamorphic change is a structural change from gently dipping foliations and gently plunging lineations in the north to steep foliations and lineations in the south. Folding south of the Grenville Front is considerably more complex than to the north. At least two fold directions are recognized in the Aphebian rocks, northwest and northeast; the latter is generally considered to be younger. Gastil and Knowles (1960) interpret numerous structural discontinuities in the Wabush area as low angle thrusts. Folds, asymmetrical and overturned to the northwest also suggest thrusting from the southeast. In the Wapussakatoo Mountains (Gill, *et al.*, 1937) tight folds overturned to the northwest are attributed to thrust faulting. Quirke and Collins (1930) recognized remnants of Aphebian sediments of the Huronian Supergroup southeast of the Grenville Front in the Lake Huron–Lake Panache district of Ontario. They considered that vertical displacement of the Grenville Province side by as much as 6 miles was necessary to account for the abrupt disappearance of the thick Huronian formations.

Apart from the localities described above there are no other places in Grenville Province where Archean and Aphebian rocks have been demonstrated to exist. However, in recent years evidence bearing on the recognition of basement and cover rocks in Grenville Province has been discussed by numerous authors. Hewitt (1962) interprets granite gneiss domes in the Hastings–Haliburton Highlands of Ontario as autochthonous. He suggests that under catazonal conditions granitic rocks became mobile and rose as domes into the overlying paragneisses. North of Ottawa, Pollock (1962) has concluded that rocks beneath the Grenville Group have been remobilized and intruded into the Grenville Group. Pollock includes within the basement complex, rocks of the anorthosite–mangerite association which are now believed to have been intruded during the Elsonian Orogeny. In the Adirondack Highlands of New York State, Walton and DeWaard (1963) suggest that most of the igneous rocks including those of the anorthosite–mangerite form a basement to Grenville sediments. Their hypothesis of evolution of the region involves at least two major orogenic cycles.

Wynne-Edwards (1964) suggests that supracrustal rocks within Grenville Province are largely limited to the Grenville Group in the southwestern part of the province and that rocks elsewhere are interpreted as having formed a basement complex to the once widespread, thick, Grenville Group sedimentary sequence. Wynne-Edwards, *et al.* (1966), on the basis of work in western Quebec, have modified the previous interpretation to include the anorthosite–mangerite series as a post-Grenville Group igneous event, and in addition they propose that structural effects of orogenies predating the Grenvillian Orogeny can be recognized (Fig. IV-25).

Helikian

Grenville Group. The term Grenville series was first applied to the sequence of marble, quartzite, and paragneiss outcropping near the village of Grenville, Quebec, by Logan in 1863. Although positive correlation is not possible, most workers have accepted correlation of the marble-rich sequences in eastern Ontario, western Quebec, and the northwest Adirondack region with the type area. Osborne (1936) suggested that the thickness of the Grenville Group in the type area was between 5,000 and 10,000 feet and in the Haliburton–Bancroft area, somewhat less than 20,000 feet. In the Shawinigan Falls district of Quebec, he estimated that 3,000 to 5,000 feet of quartzite, garnet–sillimanite gneiss and marble overlies about 2,000 feet of amphibolite. Engel and Engel (1953) estimated about 16,000 feet of Grenville Group rocks in the northwest Adirondacks. Due to folding and flowage

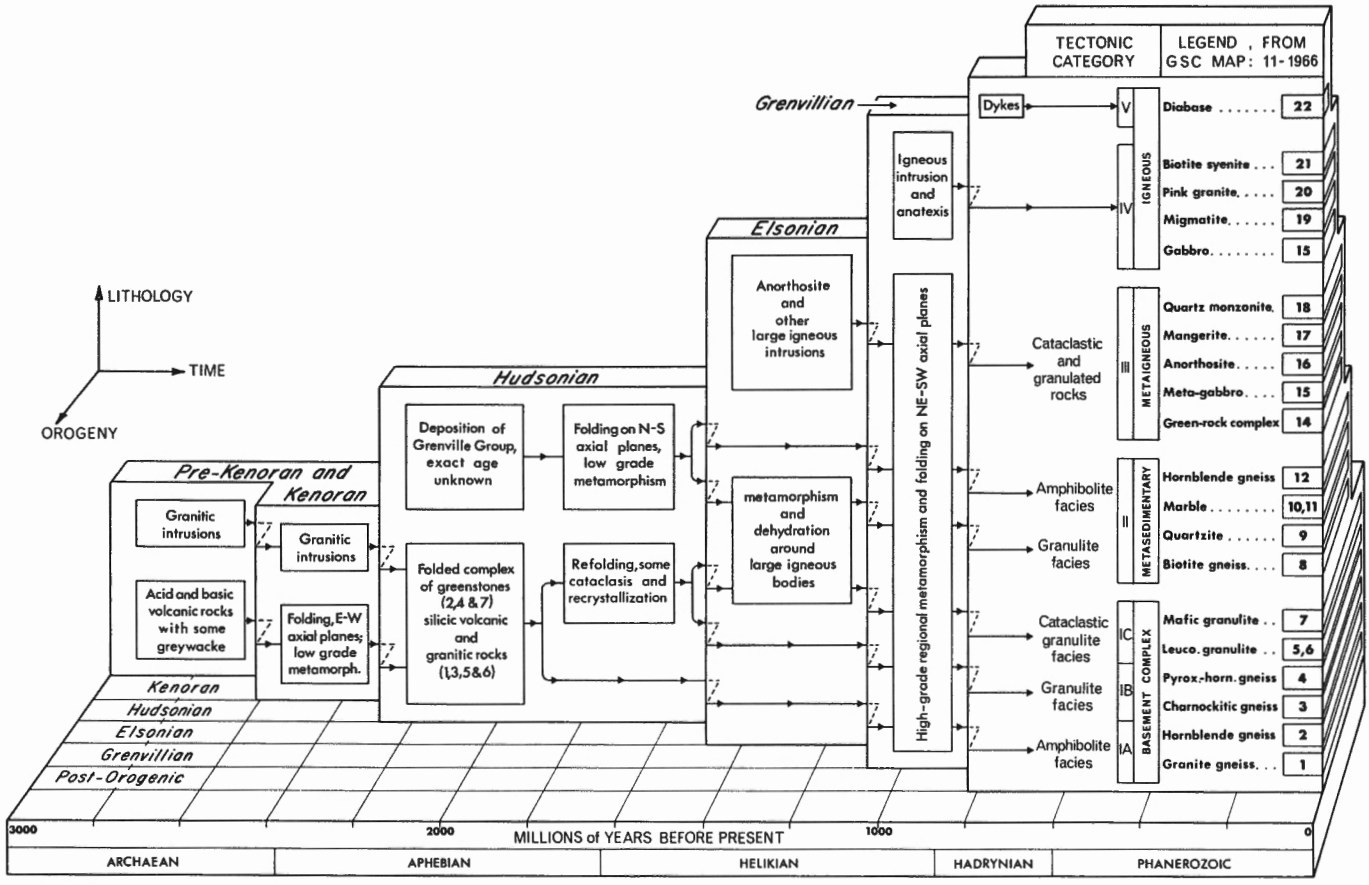


FIGURE IV-25. Tectonic steps in the evolution of Grenville Province, Mont-Laurier–Kempt Lake map-areas, Quebec (by H. R. Wynne-Edwards).

deformation these thicknesses are rather uncertain. Neither the top nor base of the Grenville Group has been defined. In eastern Ontario, basic and intermediate metavolcanic rocks occur mainly in the lower part of the exposed Grenville section, and metavolcanics are also found intercalated with metasedimentary rocks (Lumbers, 1964).

The thick metasedimentary sequences of marble, quartzite, and paragneiss typical of the Grenville Group occur only in the southwestern part of Grenville Province. Elsewhere, as for example, east of Georgian Bay, some marble occurs in amphibolite and feldspathic paragneiss but the sequence seems sufficiently dissimilar from the Grenville Group that correlation is doubtful. In the French River area clean quartzite is present but may be equivalent to the Aphebian Huronian formations northwest of the Grenville Front (Hewitt, 1960). Northeast of the type region of the group quartzitic rocks occur but marbles are rare and amphibolite and paragneiss predominate. In the Gagnon area of Quebec the appearance of marble, quartzite, and iron-formation marks the southwestern limit of rocks recognizable as metamorphic equivalents of the Aphebian Kaniapiskau Supergroup.

The K–Ar dates of about 950 m.y. associated with the Grenvillian Orogeny are a minimum age for the Grenville Group. Unequivocal evidence of the maximum age of deposition is, however, not available but a post-Archean age can be strongly supported. Hewitt (1957) concluded that the available evidence at that time favoured a late Precambrian age for the Grenville Group. Wynne-Edwards (1964) proposed a Helikian age as being most likely. Stockwell (1964) indicated that the distribution of marble and quartzite remnants across Grenville Province suggested a correlation with Huronian rocks on the southwest and with the Kaniapiskau Supergroup of the Labrador Trough to the northeast, and he adopted an Aphebian age for the Grenville Group. Wynne-Edwards, *et al.* (1966) also conclude that the Grenville Group is Aphebian. The lithological assemblage of the Grenville Group in the type region is sufficiently distinctive that arguments supporting correlation with known Aphebian rocks on lithological grounds alone are not compelling. Aphebian rocks in both the Penokean and Labrador Fold Belts have been affected by the Hudsonian Orogeny. Wynne-Edwards, *et al.* (1966) suggest that tight north-south folding of Grenville Group rocks in southwestern Quebec formed during the Hudsonian Orogeny. Northerly trending folds and accompanying intense cataclasis in part of the Morin anorthositic intrusion and the adjacent area to the east must have post-dated consolidation of the anorthosite, and therefore at least part of the north-south folding in this region is probably Neohelikian. If all the north-trending folds are of this age then the necessity for the existence of the Grenville Group at the time of Hudsonian folding is removed. Assignment of the Grenville Group to the Aphebian leaves no sedimentary sequence clearly related to the Grenvillian orogenic cycle. A Paleohelikian age is believed to be more likely and this does not seriously conflict with Rb–Sr whole rock isochron (Krogh and Hurley, 1965) and U–Pb zircon (Silver and Lumbers, 1965) ages from eastern Ontario.

Hastings Group. The Hastings Group is recognized only in southeastern Ontario. It overlies the Grenville Group but the relationship between the two groups is not certain everywhere. Lithologically, the Grenville and Hastings sequences are similar in that they contain limestone, quartzite, volcanics, and amphibolite. Conglomerate at the base of the Hastings sequence contains pebbles of quartz, quartzite, limestone, argillite, and granite and has been cited as evidence of an unconformity between the two groups. Ambrose and Burns (1956) later demonstrated the presence of two and possibly three conglomerate horizons thus casting doubt on the existence of a regional unconformity. In Barrie township, Moore (in press) reports evidence for an angular unconformity evident in the outcrop patterns, structural trends, and the presence of a basal conglomerate between Hastings Group metasedimentary rocks and Grenville Group metavolcanic and metasedimentary rocks.

Wakeham Group. Rocks of the Wakeham Group outcrop in an area of about 1,500 square miles on the north shore of the St. Lawrence River in Quebec. Estimates of about 20,000 feet for the maximum thickness of the sequence have been suggested by Claveau (1949) and Grenier (1957). Injection of numerous thick gabbro sills has added to the total thickness of the section. The group consists of pure and impure (including calcareous) varieties of quartzite with some pelitic schists and gneisses and a little conglomerate and marble. The base and top of the sequence are undefined. Grenier divided the Wakeham Group into an upper unit of calcareous quartzite with interbeds of phyllite and white quartzite, a middle unit of fine-grained white quartzite, and a lower unit of impure quartzite with minor quartz–mica schist, biotite gneiss and hematite, and rutile-bearing quartzite. Cross-bedding and ripple-marks have been found. Although there is no direct evidence of an unconformity at the base of the Wakeham Group, the granitoid gneisses east of the Caron Lake fault may represent the basement on which the Wakeham Group was deposited, because the fold pattern in the gneiss is discordant with the folds in the Wakeham Group.

The major structures in the Wakeham are upright, north-northwest trending folds that plunge southerly at moderate angles. The grade of metamorphism is upper greenschist facies over much of the area (Grenier, 1957), but may reach amphibolite facies in garnet–staurolite schist adjacent to a faulted contact with altered gabbro. In addition to the gabbro sills, younger biotite granite also cuts the Wakeham Group. K–Ar biotite dates of 845 m.y. from a staurolite schist and of 870 m.y. from the presumed basement gneiss are considered to be minimum ages for the Wakeham Group. Claveau and Grenier consider possible correlation with the Aphebian rocks of

Labrador Fold Belt. Stockwell (1964) suggests a Neohelikian age for the Wakeham Group chiefly because of Grenier's proposal that the hematite–rutile-bearing quartzites were derived from erosion of the titaniferous Allard Lake anorthosite complex. However, east of Allard Lake, Wakeham strata are intruded by syenites similar to those associated with the Allard Lake anorthosite (Retty, 1944) which suggests a Paleohelikian age or older. However, until better evidence is available the group is considered Neohelikian and correlated with the Seal Lake Group.

Southeastern Labrador. The oldest rocks in the Seal Lake area of Labrador (Fig. IV-26) are granitoids containing remnants of schist and paragneiss. These are intruded by the huge Harp Lake anorthositic pluton. On this basement, at different localities, lie the Croteau Lake, Letitia Lake, and Seal Lake Groups. The Croteau Lake Group outcrops east of the Seal Lake Group and is separated from it by a fault. The lower strata consist of black shale, minor quartzite, greywacke, dolomite, and metabasalt overlain by boulder conglomerate and arkose. The thicker upper part of the group is composed mainly of intermediate and silicic volcanic rocks that contain feldspar and quartz phenocrysts. Amygdaloidal and pyroclastic layers are common. The rocks strike northeast and dip gently southeast.

The Letitia Lake Group (Brummer and Mann, 1961) appears to correspond to the upper volcanic part of the Croteau Lake Group as described by Fahrig (1961). The lower part of the Letitia Lake Group consists of porphyries with phenocrysts of quartz and feldspar. The upper part of the group contains rhyolites, fine to coarse pyroclastics, argillites, and quartz–sericite schists. The total thickness of the group is estimated to be 8,500 feet.

The Seal Lake Group unconformably overlies the Letitia Lake Group. It is at least 34,200 feet thick. The basal, Bessie Lake Formation, 4,200 feet thick, is composed of blue, white, and pink quartzite, interbedded basalt, and basal conglomerate. It is overlain by the Wuchusk Lake Formation, 20,000 feet thick, of interbedded chert, variegated shale, phyllite, argillite, quartzite, and calcareous beds with thick diabase sills. The Whiskey Lake Formation comprises 3,000 feet of varicoloured argillaceous rocks with minor red quartzite. The overlying Salmon Lake Formation is also 3,000 feet thick. It is composed of varicoloured shale with amygdaloidal basalt and diabase sills succeeded by the Adeline Island Formation, 1,400 feet of varicoloured slate, shale, and pink and white quartzite. The Upper Red Quartzite Formation is 2,600 feet of red quartzite with pebble bands.

The Seal Lake Group has been folded into an arcuate synclinorium 75 miles long and 28 miles wide, with the folds overturned to the north. A number of subsidiary folds are superimposed on the major structure. To the northwest, relatively flat lying strata of the Seal Lake Group underlie Shipiskan Plateau. Most of the Seal Lake rocks show little effects of regional metamorphism, but shearing and schistosity become evident near the thrust zone bounding the granite in the south. The zone of major thrusting is marked by mylonite 100 yards wide.

K–Ar dates on biotite and hornblende from granitic gneiss that is unconformably overlain by the Seal Lake Group gives ages of 1,430 m.y. and 1,350 m.y., respectively. Muscovite from quartzite collected 3 miles south of the thrust zone and considered to be a metamorphic equivalent of the Seal Lake Group gave a K–Ar age of 975 m.y. A 960 m.y. whole rock K–Ar date was obtained from amygdaloidal basalt, and an age of 865 m.y. from a diabase

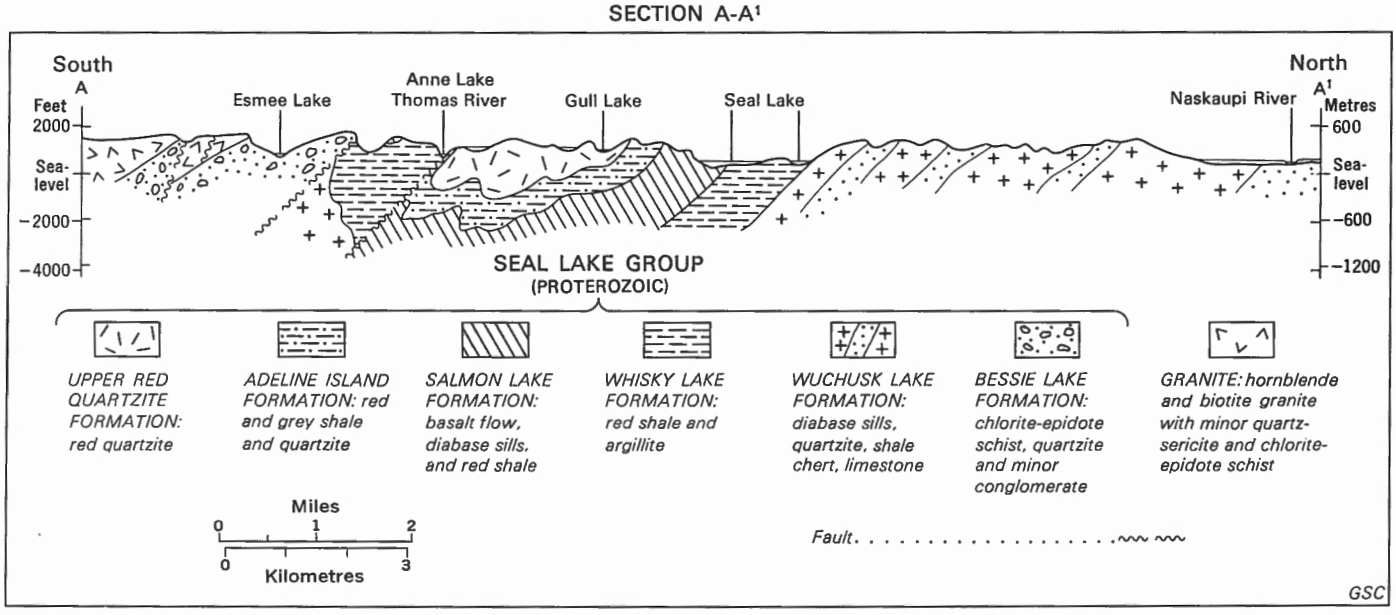


FIGURE IV-26. Structure-section through Naskaupi (Seal Lake) Fold Belt, Grenville Province, Labrador (Brummer and Mann, 1961).

sill intruding the Seal Lake Group. These dates provide an approximate minimum age for the group.

Near Aillik, Labrador, rocks of the Aillik Group consist of quartzite with interbedded carbonates, slate, and conglomerate. They may correlate with the Seal Lake Group. The rocks have been invaded by granite and partly granitized. Biotite samples from granite gneiss in southeastern Labrador yield K–Ar ages of 960 m.y. and 1,095 m.y. A biotite from a granite that invades the Aillik Group gives an age of 1,645 m.y. This latter age is from a sample very close to the Grenville Front and may be anomalous. If, however, it is valid it provides a minimum age for the Aillik Group and would rule out correlation with the Seal Lake Group.

Hadrynian

The Double Mer arkosic sandstone outcrops north of Lake Melville, Labrador. It is relatively undisturbed and is believed to be post-Grenvillian Orogeny. Kindle (1924) estimates a minimum thickness of 500 feet for the unit and describes it as well-cemented, dull red, coarse arkosic sandstone with pebble bands and local crossbedding. The contact with underlying rocks has not been described. The beds are relatively flat lying except where tilted by faulting.

Intrusive Igneous Rocks

By far the most abundant and distinctive intrusive rocks in Grenville Province are members of the Elsonian anorthosite–mangerite series. The origin of these rocks is controversial, mostly because of structural complexities and metamorphism during the Grenvillian Orogeny. They are believed to be genetically related but the nature of the relationship is not clear (Philpotts, 1966). Evidence of at least some differentiation *in situ* is often present but it is not known whether this is a major factor or if differentiation at depth or assimilation of crustal rocks have played a role in development of the diverse rock types. There is usually geological evidence to indicate that the anorthositic rocks are early members of the series, and textures and structures are commonly present that suggest that accumulation of plagioclase crystals has taken place. Evidence from Nain Province strongly suggests that basic magma has played a prominent role. Heath (1966) found that initial Sr^{87}/Sr^{86} ratios for fifteen anorthosite bodies in North America and Norway fell in the narrow range between 0.703 and 0.706 and this supports the theory of an origin from basic magma derived from the mantle or lower crust. The presence of layered structures and coarse unzoned crystals in the anorthositic rocks suggests very slow cooling in a relatively quiescent, non-tectonic environment. In southwest Grenville Province rocks of the anorthosite–mangerite series intrude the Grenville Group. Buddington (1962) has shown that the anorthositic complex in the Adirondacks was emplaced before strong deformation of the Grenville Group and that it behaved as a rigid mass during the deformation. In the Morin anorthosite–mangerite complex of southwestern Quebec the form of the rock units and the relationships among them suggest a similar conclusion. Intense cataclasis of a broad zone in the eastern part of the intrusion is consistent with failure of a rigid body.

In northern New York and southwestern Quebec the large Adirondack and Morin anorthositic plutons are marginal to the thickest sections of the Grenville Group. Although small intrusive masses of anorthositic gabbro are found within the group, large bodies are absent. For both massifs the roofs are considered to be more or less domal. A gravity survey over the Adirondack anorthosite suggests layer-like or lopolithic form. Structural data on the Michikamau anorthositic intrusion in Labrador (Emslie, 1965) also indicate a lopolithic or funnel-like form. These forms are not uncommon for large basic intrusions and imply that the magma spread along a pre-existing permissive horizon. They also suggest that the basic control on the structural position of large anorthositic plutons may have been the unconformity between the basement and the overlying, thick, relatively undisturbed Grenville sediments. Other intrusive rocks with a wide variety of petrographic characteristics, size, and form occur in Grenville Province. Some are truly post-orogenic granitic intrusions but these are probably not common (Pl. IV-20). Much of Grenville Province is believed to

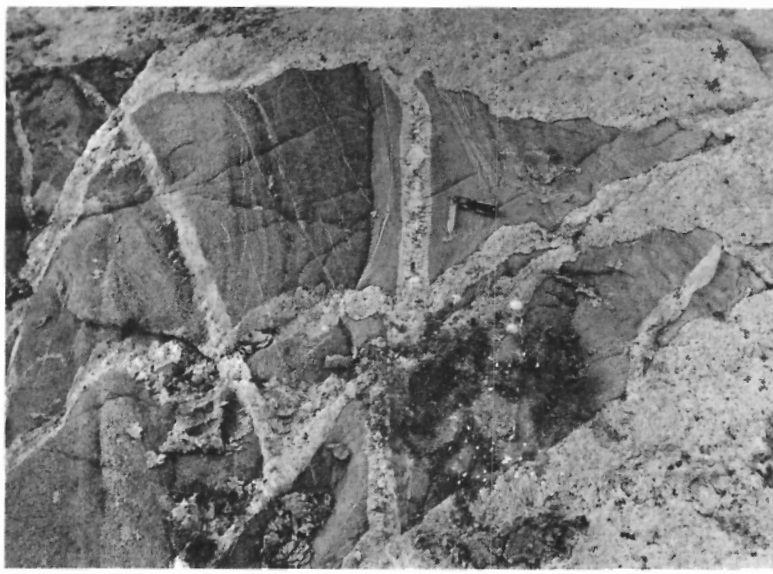


PLATE IV-20
Leucocratic coarse-grained Grenvillian monzonite of Wolfe Lake pluton intrusive into pyroxene gneiss, Grenville Province, Westport, Ontario.

represent the catazone environment and, therefore, it is difficult to distinguish synorogenic intrusions from those that predate the Grenvillian Orogeny.

Alkaline rocks occur in southwestern Grenville Province. The best-studied are the nepheline syenites of eastern Ontario at Blue Mountain, Haliburton–Bancroft, and French River (Hewitt, 1960). All have similar lithological and textural characteristics and field relations. In general, the nepheline syenites are gneissic and for the most part conformable with the paragneisses in which they occur. Pegmatitic varieties commonly show cross-cutting relations. In the Haliburton–Bancroft district nepheline-bearing rocks occur in a discontinuous band more than 80 miles long. Individual bodies rarely exceed a few hundred feet in width and two to three miles in length. Evidence for nephelinization of wall-rocks is abundant. Alkalic mafic rocks are associated with the nepheline syenite in Glamorgan and Monmouth townships. In western Quebec, a stock of coarse-grained alkaline syenite includes some nepheline syenite, and several small subcircular alkali syenite and alkali gabbro plutons also occur.

Small ultramafic bodies occur in a few areas. Most are partly altered to serpentine, tremolite, and talc but considerable amounts of fresh olivine are present. In the Gagnon–Mount Wright district several small ultramafic bodies occur with peridotitic rocks and a large gabbro complex. In the Bristol–Masham area a small peridotite body contains as much as 60 per cent olivine and enstatite with some serpentine and a little magnetite and tremolite. In the Gouin Reservoir area two ultrabasic masses with olivine, augite, tremolite, and carbonate are altered to some degree.

After the close of the Grenvillian Orogeny a number of localized igneous events took place in Grenville Province at different times. In the Chatham–Grenville stock near Grenville, Quebec (Osborne, 1936), a coarse syenite facies occurs in the western part and a granite facies to the east.

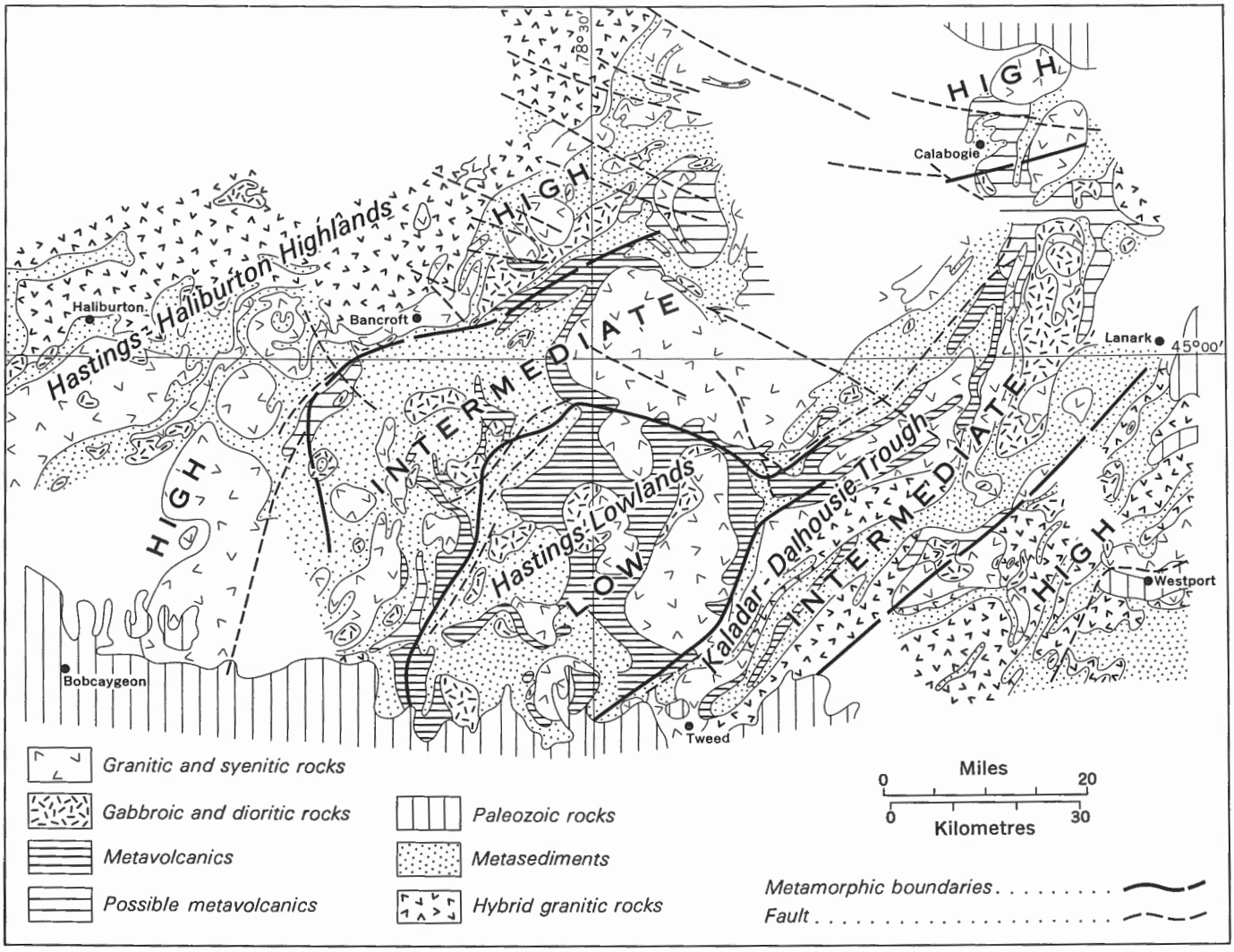


FIGURE IV-27. Geology and metamorphic zones of part of Grenville Province in southeastern Ontario (Lumbers, 1964).

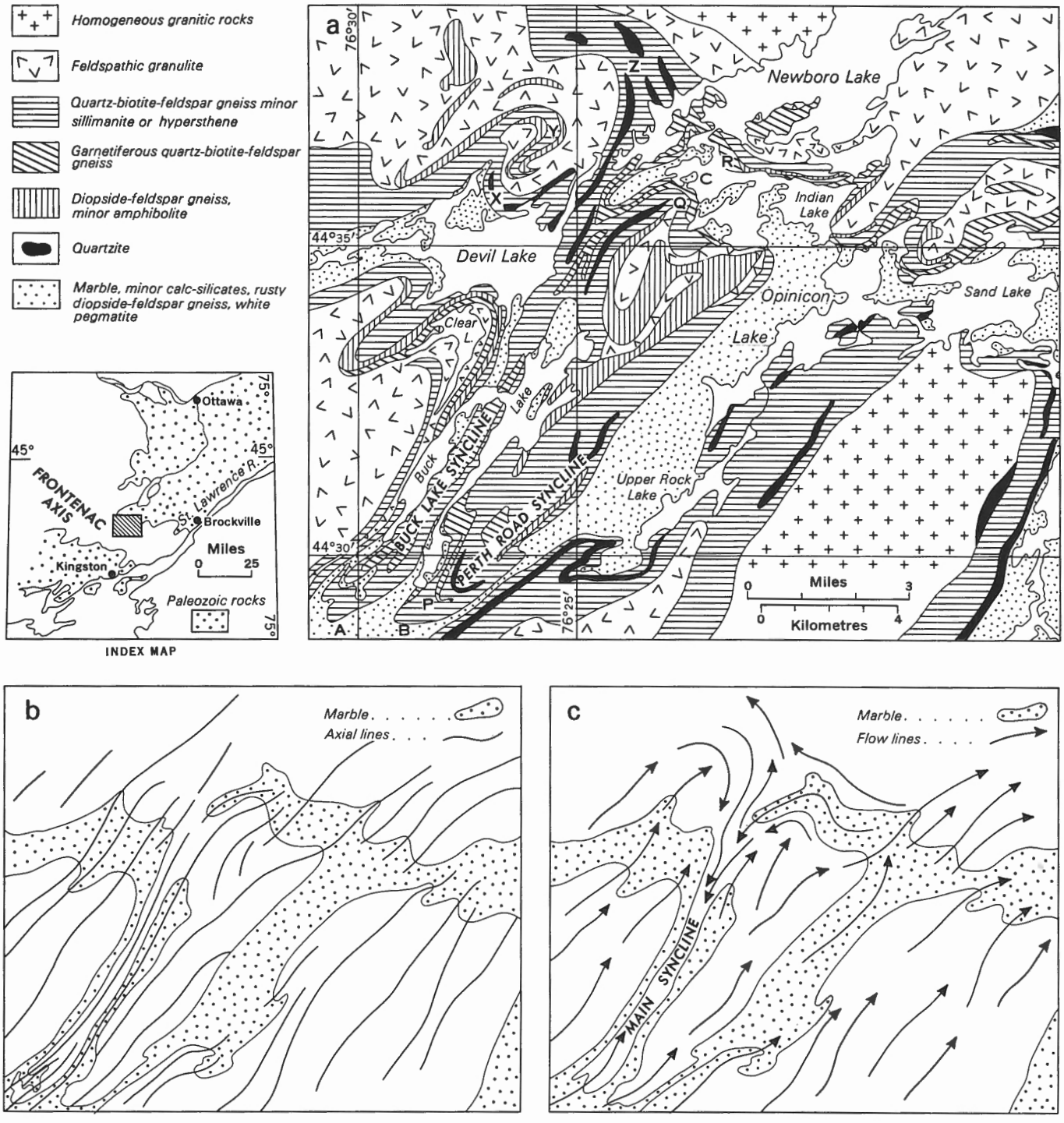


FIGURE IV-28. Geology of part of the Westport map-area, Ontario (Wynne-Edwards, 1963): (a) The folds plunge northeast at an average of 35°, so that the map is an oblique section through the structure. Stratigraphic units are repeated at successive structural levels B, C (marble); X, Y, Z (gneiss); and P, Q, R (gneiss) by refolding about the same axis. (b) Axial lines. (c) Flow pattern.

Both facies contain sodic pyroxene and amphibole. The margins are syenite porphyry. Cataclasis of the wall-rock has taken place and dykes and zones of microbreccia are considered to have accompanied intrusion. The hornblende has an average K–Ar age of 642 m.y. that is Hadrynian. An intrusion at nearby Rigaud Mountain is similar. Four small alkalic intrusive complexes occur in and around Lake Nipissing. A potassium–argon biotite date from the one on Newman Island gave an age of 560 m.y. A large diabase dyke swarm strikes east-west across eastern Ontario and western Quebec, being concentrated north of the Ottawa River. A whole rock K–Ar date from

this swarm gave an age 790 m.y. This age agrees with the date from the Chatham–Grenville stock which is known from geological evidence to be younger. Biotite ages from three samples of a lamprophyre dyke in the vicinity of Aillik in Labrador gave a mean age of 570 m.y.

Metamorphism

In northwestern Grenville Province the grade of regional metamorphism is the almandine–amphibolite facies. Kyanite occurs in rocks of appropriate composition in areas near the Grenville Front. Rocks of granulite facies are irregularly distributed, but occur mainly in the southwest, the approximate isograd between the amphibolite and granulite facies extending from near Lake Albanel southwesterly to the Ottawa River west of Ottawa (Osborne and Morin, 1962). In southeastern Ontario, rocks of the Paleohelikian Grenville Group have been raised to granulite facies during the Grenvillian Orogeny. In the northeast in the Mount Wright district, Archean granulite facies rocks have been retrograded to amphibolite facies. It is apparent therefore that high-grade regional metamorphic rocks of more than one age are present in Grenville Province, but it is difficult to distinguish them because of the lack of generally applicable criteria in recognizing and resolving the effects of polymetamorphism.

In parts of the Hastings Lowlands (Fig. IV-27), greenschist facies mineral assemblages are preserved and other criteria such as the structural character and mode of granite emplacement suggest a shallow mesozone environment. Bordering this area are higher grade rocks indicative of progressive metamorphism accompanied by a change in structural style and the character of granitic plutons that suggest a gradual transition to a catazone environment (Hewitt, 1962). High-grade gneisses with mineral assemblages of the almandine–amphibolite and granulite facies are characteristic of the Hastings–Haliburton Highlands area. The granitic plutons tend to be concordant masses. There is evidence of metasomatism in the formation of hybrid gneisses, nephelinized gneisses, certain amphibolites, and metamorphic pyroxenites. Deformation by plastic flow is characteristic. Along the southern edge of the highlands, a series of granite and hybrid granite gneiss bodies occurs which Hewitt considers is mobilized granitic material that rose by plastic flow to form domes under conditions of catazone metamorphism.

The boundary between the highlands and lowlands is not clearly defined (Best, 1966), but there is some evidence of faulting that has produced southeast-dipping zones of mylonite. Much of Hastings Lowlands is underlain by rocks of low and intermediate metamorphic grade. These rocks include schist, argillite, fine-grained "blue" limestone, marble, amphibolite, and basic to silicic metavolcanics and pyroclastics. Primary structures such as crossbedding, graded bedding, and pillows are commonly preserved. The folded stratified rocks are intruded by crosscutting syenite, gabbro, and granite plutons. Migmatites are rare. Flowage features are seen only in marble and are not common. Hewitt (1962) considers that the Hastings Lowlands area represents a mesozonal environment.

Along the Frontenac Arch, the grade of metamorphism increases to upper amphibolite and granulite facies. In the Westport area, the complex structure is interpreted by Wynne-Edwards (1963) as due to continuous non-uniform flow (Fig. IV-28). He postulates synchronous refolding as the more rapidly advancing anticlinal parts flow into the troughs of the adjacent, retarded, synclinal zones. The pattern of apparently refolded folds he interprets as having formed during a single period of deformation, as the flowage had taken place parallel with the axial planes. The Westport concordant quartz monzonite pluton is believed to have been emplaced into a vertically plunging fold or vortex formed by flowage of marble (Wynne-Edwards, 1957). The body is considered to be late or post tectonic and is cylindrical or funnel-shaped.

Isotopic Dates

It has become clear in recent years, particularly in Grenville Province, that the dating methods in common use (K–Ar, Rb–Sr, and U–Pb) and the materials dated (various minerals and whole rocks) do not necessarily date the same event. The mean of 950 m.y. K–Ar dates is commonly considered to be the time of the Grenvillian Orogeny, the time of the last major regional metamorphism causing widespread recrystallization. It is probably more correctly referred to the time at which the minerals

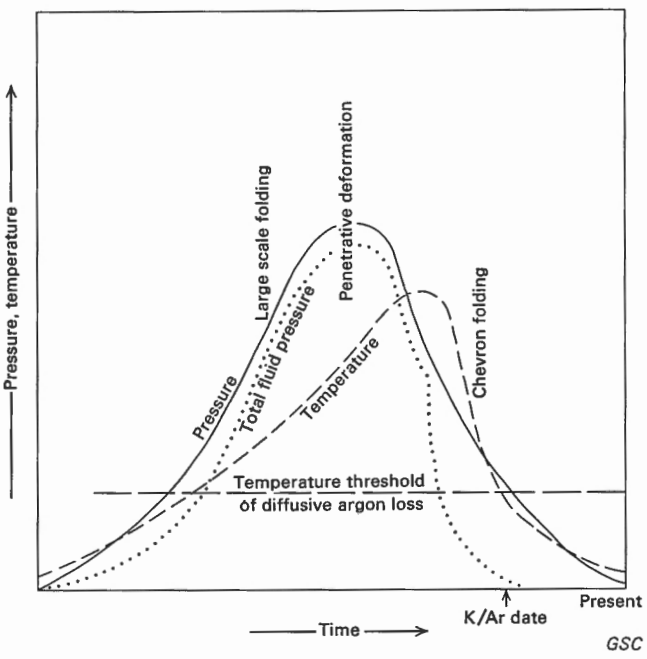


FIGURE IV-29. Inferred relationships between time, temperature, pressure, and deformation in the metamorphic interior of an orogenic belt (Armstrong, 1966). The point in time given by a K–Ar date is indicated.

or rocks were cooled below some critical temperature thus isolating the isotopic system. K–Ar dates in Grenville Province may therefore be more closely related to the rate of uplift and erosion than to the culmination of regional metamorphism (Armstrong, 1966). If other conditions are comparable, K–Ar biotite dates for example may be expected to approach more closely the time of culmination of metamorphism in the terrane of low-grade regional metamorphism than in a high-grade regional metamorphic terrane as typified by much of Grenville Province. The widespread 950 m.y. K–Ar biotite dates, although clearly referable to the Grenvillian Orogeny, probably do not reflect the culmination of regional metamorphism that likely occurred some 100 m.y. earlier as suggested by Rb–Sr and U–Pb zircon age determinations. Armstrong stresses that there is no exact correspondence between metamorphism and structural events and that metamorphism spans a period rather than having an exact age (Fig. IV-29).

Rb–Sr whole rock isochrons and U–Pb zircon ages are available from only a few areas in Grenville Province. Grant (1964) has obtained a Rb–Sr whole rock isochron from granitic rocks that straddle the Grenville Front southwest of Lake Timagami. Sampling extended 5 miles into Grenville Province and yielded an isochron age of 2,350 m.y. Rb–Sr whole rock isochrons have been determined by Krogh and Hurley (1965) for several rocks in southeastern Ontario. The Burleigh gneiss yields an isochron age of 1,103 ± 39 m.y., interpreted as a time of extensive metasomatism accompanying formation of the pluton. An isochron age of 1,285 ± 41 m.y. was found for the Blue Mountain nepheline syenite in Methuen township. The Kaladar gneissic granite adjacent to the Kaladar–Dalhousie synclinorium gave an isochron age of 1,035 ± 42 m.y. An isochron age of 1,016 ± 39 m.y. for the Westport pluton is in agreement with the geological interpretation of late tectonic emplacement. The Gananoque syenite gave an isochron age of 1,096 ± 50 m.y. Garnet–sillimanite–cordierite paragneiss from the Westport area gave an isochron age of 1,230 ± 72 m.y. Silver and Lumbers (1965) report U–Pb zircon ages from eastern Ontario. Low-grade metarhyolite from the Hastings Lowlands gave an age of 1,310 ± 15 m.y. Zircon ages from plutons throughout the region yielded two principal age groups: 1,125 ± 25 m.y. and 1,250 ± 25 m.y. Plutons of both groups are found in the Hastings–Haliburton Highlands and in the Hastings Lowlands. From northwestern Grenville Province, Davis, *et al.* (1967) obtained Rb–Sr whole rock isochron ages of 1,730 ± 75 m.y. for the French River granite, 1,500 ± 75 m.y. for granite in the Lake Muskoka area, and 1,330 ± 70 m.y. for granite south of North Bay, Ontario.

DIABASE DYKE SWARMS

The Precambrian diabase dykes and genetically related rocks are described and related to the regional geology in the preceding sections. The purpose of this section is to develop a more coherent view of these rocks in time and space. In the past any attempt to study the dyke rocks systematically was severely limited by lack of knowledge of their regional distribution and age. Recently, geological mapping and aeromagnetic surveys have established the regional distribution of virtually all the great dyke swarms, and it is now evident that many of the major dyke swarms transected the entire craton as it existed at the time of their intrusions. Several K–Ar age determinations provided the approximate ages of most of the swarms (Fig. IV-30). The average ages are based on approximately 100 determinations (Fahrig and Wanless, 1963; Burwash, *et al.*, 1963; Leech, 1966). Three types of material provide reasonably concordant K–Ar ages. These are chilled marginal dyke material, biotite concentrated from the dykes, and micas from country rocks occurring within a centimetre or so of the contact. Correlation of diabase dykes and related rocks has been aided by determining the character of their remnant magnetism (Fahrig, *et al.*, 1965). Similar paleomagnetic pole positions are evidence for correlation whereas different positions are evidence of different ages.

Diabase dykes are customarily considered to be the intrusive equivalents of tholeiitic flood basalts. In tholeiites, any olivine present generally shows reaction with orthopyroxene or pigeonite. The predominant pyroxene is Ca-poor augite and interstitial quartz may be present. They are hypersthene normative. The other great basalt group, the alkali basalts, contains olivine showing growth parallel with that of Ca-rich augite. Pigeonite and hypersthene are rare or absent. These basalts are nepheline normative. It has been shown that different dyke swarms of the District of Mackenzie have different K_2O contents that are characteristic of the swarms (Burwash, *et al.*, 1963). Leech (1966) indicated that the increase in K_2O content is related to the decreasing age of the swarms with the possibility of the existence of more complex relationships. For example, the increase in alkalinity may not be a simple time function but may be influenced by the tectonic history of the areas cut by the dykes, in which case each orogenic region may exhibit a sequence of basaltic swarms whose alkalinity increases with decreasing age. Both tholeiitic and alkalic basalts form diabase dyke swarms in the Canadian Shield (Fahrig, *et al.*, 1965). The average alkali–silica ratios of thirty-one swarms (Fig. IV-31) have been divided into two groups: Paleohelikian and older, and Neohelikian and younger.

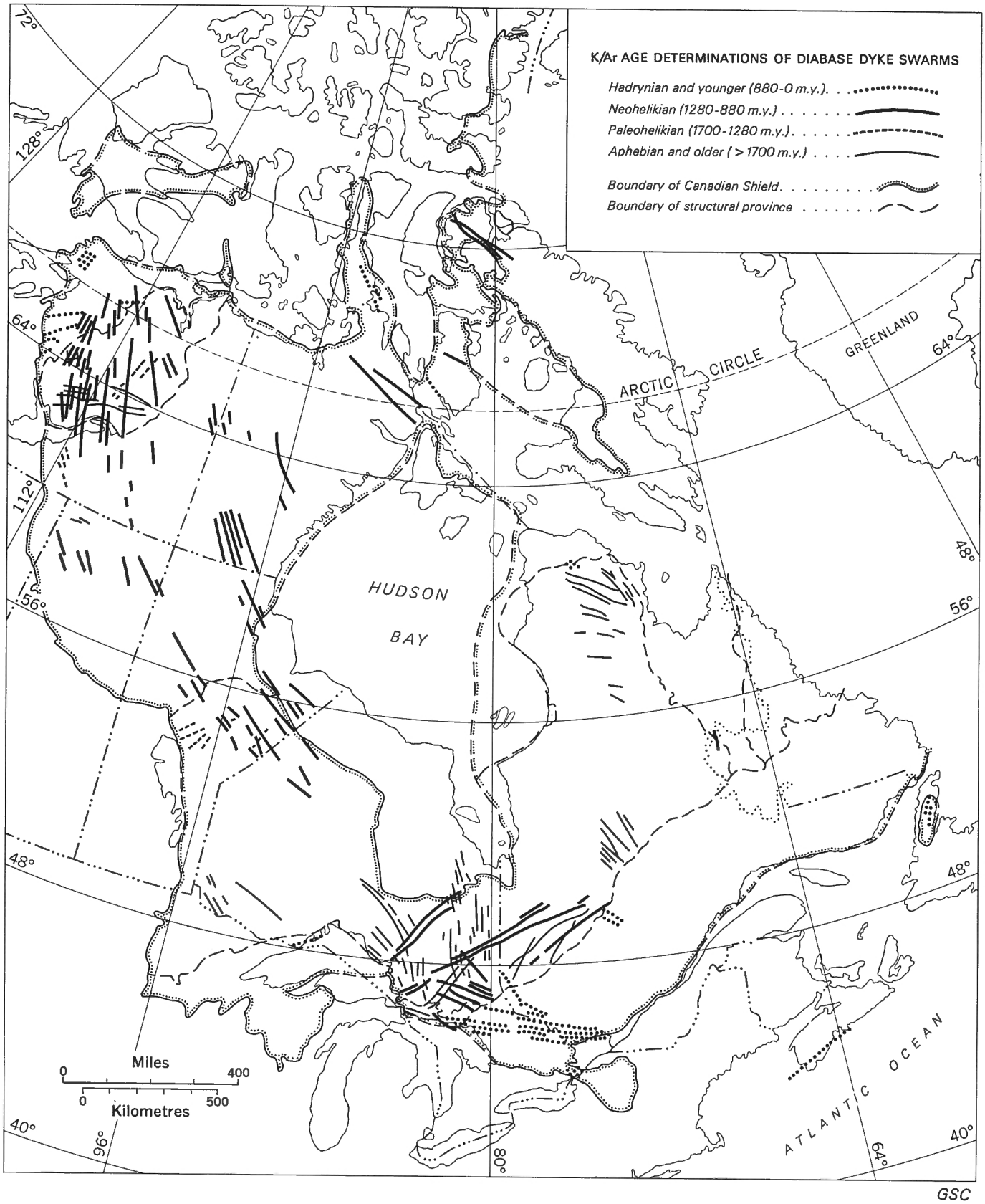


FIGURE IV-30. Diabase dyke swarms of the Canadian Shield (by W. F. Fahrig).

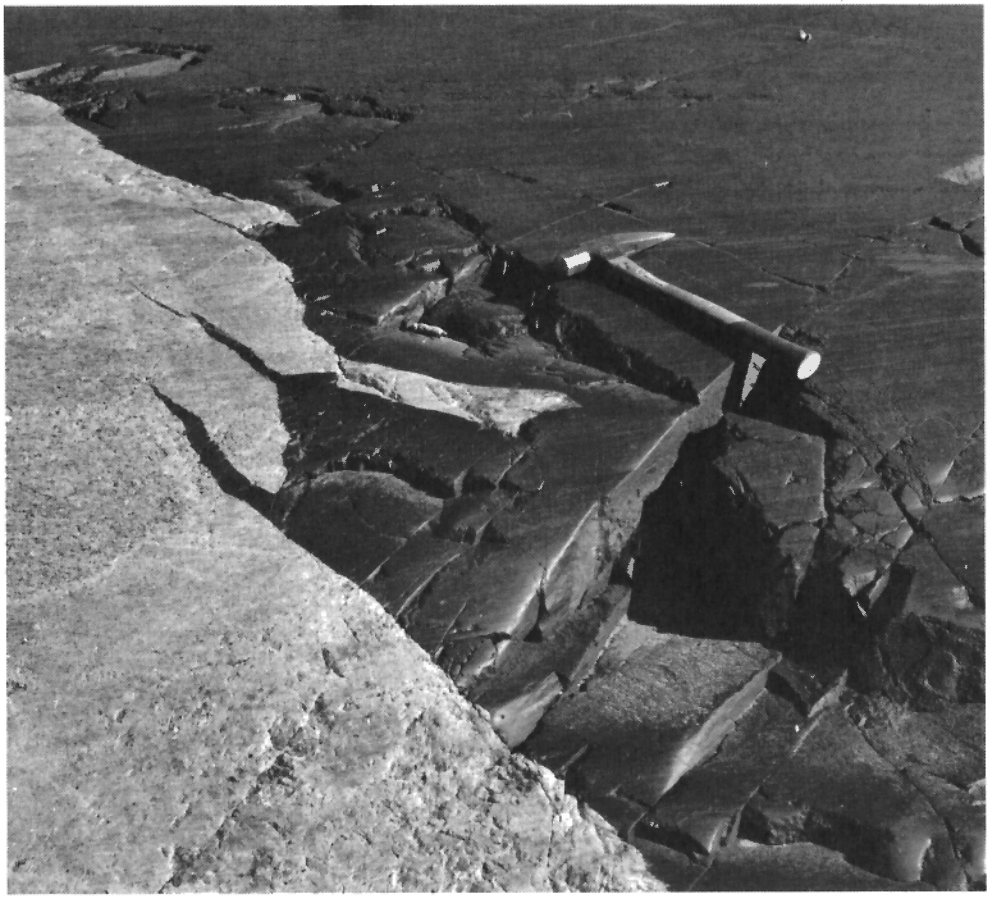


PLATE IV-21
Contact between diabase dyke and granite near Povungnituk, east coast of Hudson Bay, Superior Province, Quebec.

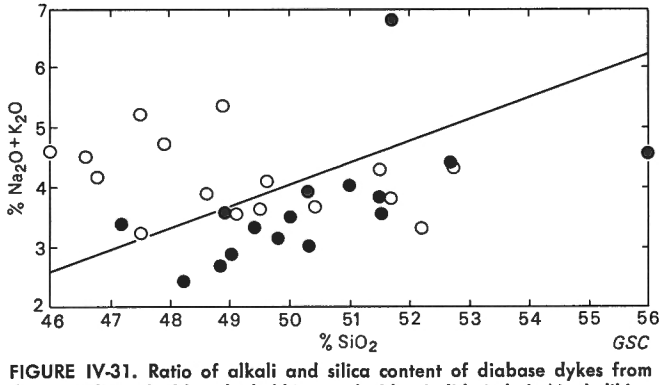


FIGURE IV-31. Ratio of alkali and silica content of diabase dykes from the Canadian Shield: Paleohelikian and older (solid circles); Neohelikian and younger (open circles). The diagonal line separates rocks with tholeiitic mineral composition (lower right field) from rocks with alkalic mineral compositions (according to G. A. MacDonald and T. Katsura).

There is a tendency towards increasing alkalinity with decreasing age. This is not a sharp division, as there is at least one known pre-Neohelikian alkali basalt swarm, and there are several Neohelikian and younger tholeiitic swarms. In addition, some of the swarms whose data are plotted on the figure may be duplicates as some samples although widely separated may represent the same swarm.

It is apparent that alkali basalt dykes are intrusive into the craton and are chiefly Neohelikian or younger in age. The change in chemistry of dyke-fed basaltic material may reflect fundamental differentiation taking place in the mantle. However, it has yet to be established whether the increase in alkalinity was gradual, or whether a rather abrupt change occurred at some stage, perhaps at the end of the Paleohelikian. Poldervaart's formula has also been used where suitable chemical data were available together with the alkali silica ratios to illustrate the relationship

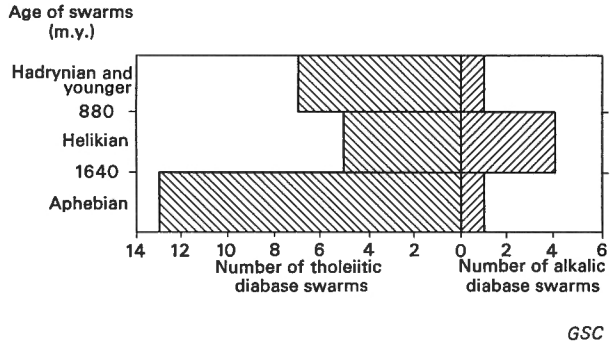


FIGURE IV-32. Classification of basaltic dyke swarms according to Poldervaart's formula.

between the number of dyke swarms, their ages, and their classification (Fig. IV-32). As basaltic rocks have contributed significant amounts of detritus to Precambrian sedimentary basins, the change in their chemistry should be reflected in a progressive change in the chemistry of the sediments and in the gneisses and other crystalline rocks that have resulted from the ultra-metamorphism of the sediments.

The presence of large numbers of diabase dykes of various ages indicates that large volumes of subcrustal material were added to the continental crust throughout the geological past. This material provides the best sample of upper mantle derived-material that is available from within continental areas and provides valuable data on the variation with geological time of the abundances of major and minor elements supplied from below the crust. The

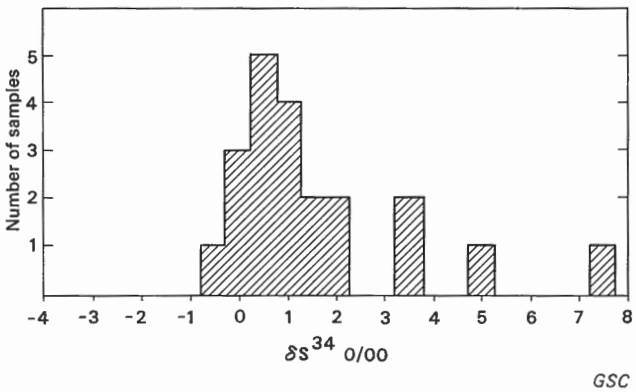


FIGURE IV-33. Sulphur isotope ratios of sulphides from diabase dykes of the Canadian Shield (by Akira Sasaki).

abundance of heat-producing elements, K, U, Th, and the isotope ratios of elements such as S and Pb are of special interest. On Figure IV-33 the sulphur isotope ratios of sulphides from twenty-one Canadian Shield diabase dykes are shown, whose ages range from Aphebian to early Paleozoic. The $\delta^{34}0/00$ is an expression that relates the S^{32}/S^{34} ratios of the samples to that of a standard sample, in this instance, to sulphur in troilite of the Canon Diablo meteorite. The grouping of the $\delta^{34}0/00$ values near the zero point indicates that the sulphides of these dykes have S^{32}/S^{34} ratios similar to the meteorite value. This value represents the ratio of sulphur in basalt generated in the upper mantle.

Diabase dykes are probably indicative of tensional conditions in the crust, some of continent-wide dimension which have resulted in continental stretching (Pl. IV-9, -21). The mechanism that caused this tension is likely to have acted in a more extreme fashion at various times and to have actually resulted in the breakup of continental masses. Diabase dyke swarms can be considered as direct evidence of continental drift. In addition, they are features of such continuity that the reassembling of continental masses into hypothetical proto-continents requires that these linear features pass from one segment to another. Payne, *et al.* (1965) have shown that, if Greenland and Scotland are moved along paths determined by physical outline and paleomagnetic studies, ancient dyke swarms more than 2,000 m.y. old in Greenland, Scotland, and Canada fall on a great circle (Fig. IV-34). They suggest that this continuous line of intrusion of more than 2,500 miles presents independent evidence of continental displacement.

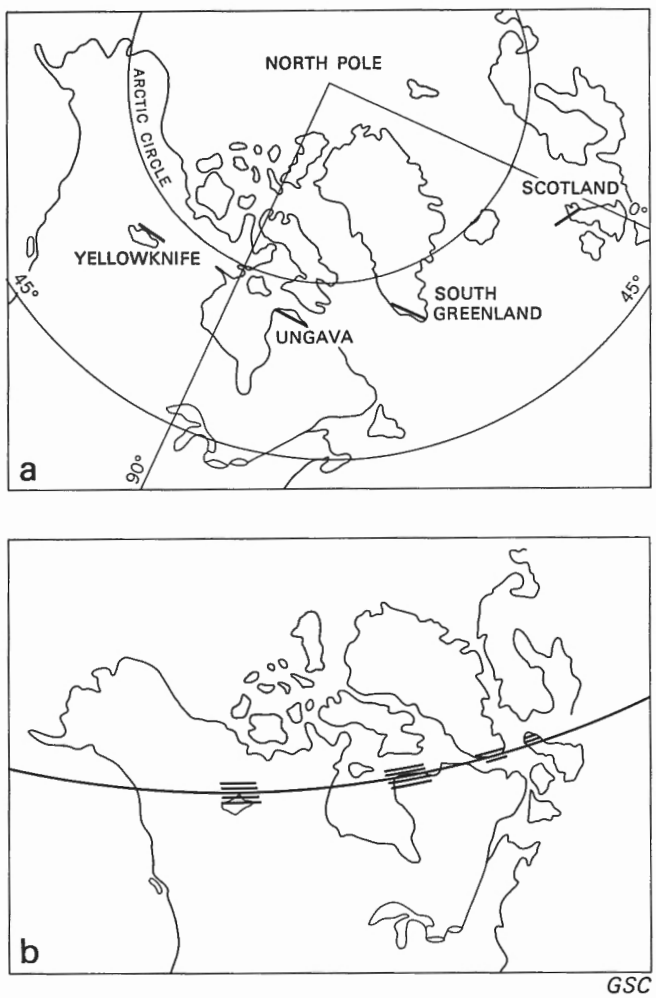


FIGURE IV-34. Diabase dyke swarms, 1,900 to 2,200 m.y. old, of Canada, Greenland, and Scotland: (a) present position; (b) hypothetical restoration as landmass of Laurasia (Payne, et al., 1968).

SHOCK METAMORPHIC STRUCTURES

Some subcircular structures in the Canadian Shield are characterized by the occurrence of shock metamorphic effects evident in breccias, rocks of volcanic appearance, and abnormal glassy or porcelain-like appearance of the country rocks. In shape they are either simple bowl-shaped depressions with a raised bedrock rim, or shallow depressions with little or no rim, but with a prominent mound in the centre that may be higher than the rim. The diameters range from 6,500 feet to 38 miles. In general the smaller structures are the simple depressions and the larger ones are the central peak depressions, but there are exceptions. About sixteen structures are known (Fig. IV-35). The ages of most structures, about half of which are associated with Paleozoic sediments, fall in the range 200 to 450 m.y. Some of the Canadian shock metamorphic structures may be the result of meteorite impact. Others are the result of geological processes related to the intrusion of alkaline igneous rocks.

The breccia is polymict with a vast range in size of fragments. Glass may be present as fine splinters in the matrix, or as irregular balls and flaps. Different types of glass and rapid variation in the properties of a single glass fragment occur. The breccia matrix in some cases may be partly welded and show flow structure. Fragments of non-glassy material often show shock metamorphism. The breccias are termed suevite. Several shock metamorphic features commonly occur together, either on breccia fragments or in the country rocks. Planar features are fine cleavage and slip lines, commonly seen in quartz and feldspar. Occasionally they may be seen in hand specimen of quartz as a very fine, regularly spaced cleavage. Under the microscope they appear as closely spaced, fine, dark lines. Orientations in quartz parallel the basal prism (0001) and the rhombohedron $(01\bar{1}3)$ are particularly diagnostic of shock metamorphism. Thetomorphic glass partly or entirely preserving the form of felsic minerals is common. Mafic minerals are little affected. Plagioclase glass (maskelynite) is more common, but quartz glass is also found. The refractive index and density are higher than that of the fused minerals. Melt glass with vesicles and streaky flow structure are less commonly found. Kink bands occur on biotite and occasionally hornblende. Shatter cones with parasitic radiating striae (horsetailing) on the surface are present. The cones occur as both positive and negative casts.

Fracturing of country rocks of unusual style is commonly found in and near shock metamorphic sites. The joints have rough surfaces and sometimes a white coating. The number of joint sets is abnormally high, and their regularity of attitude abnormally low. The regional joint sets in the vicinity are commonly deflected. Small scale normal faults occur in the rim of the structures.

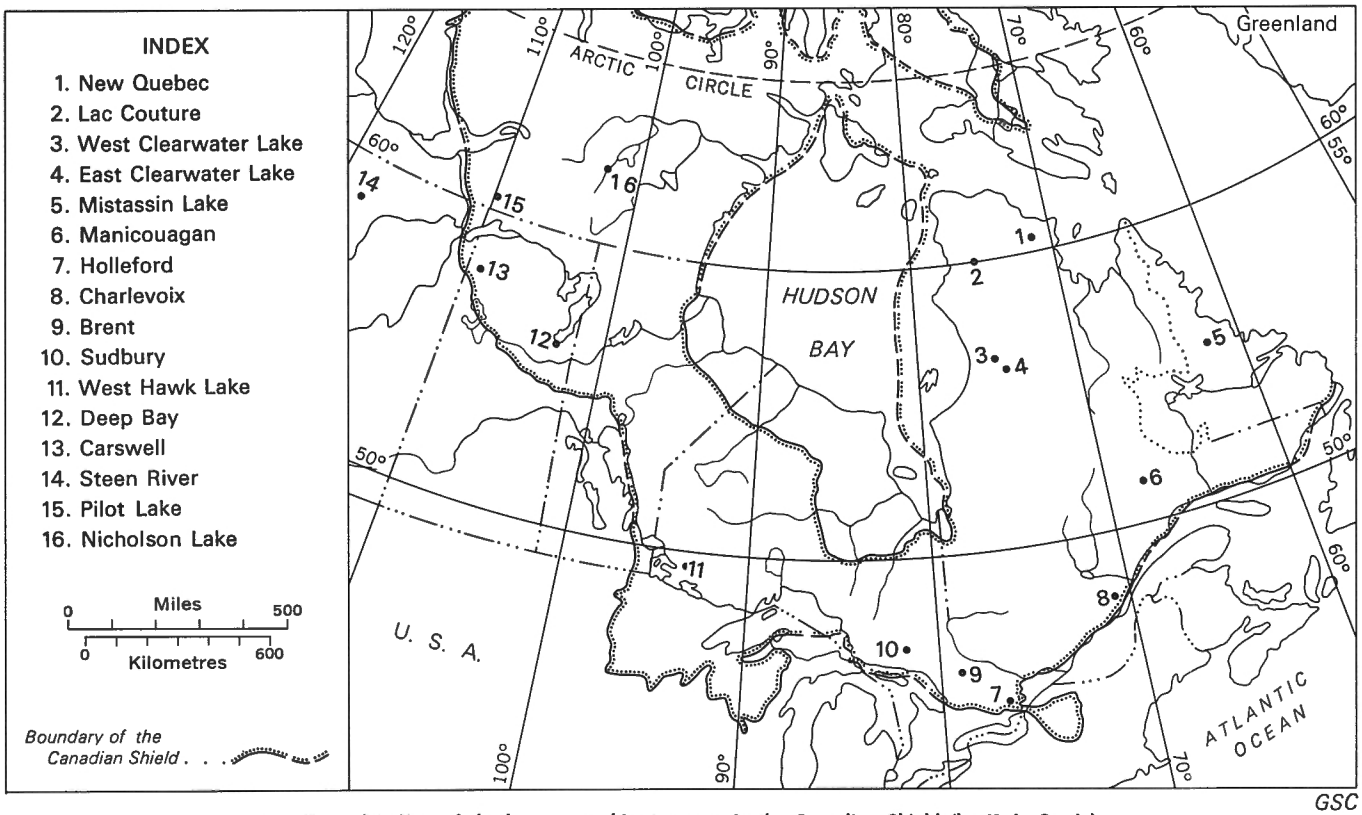


FIGURE IV-35. Sites of shock metamorphic structures in the Canadian Shield (by K. L. Currie).

Rocks of igneous appearance, that is with textures of normal igneous rocks, are aphanitic to fine grained with few or no inclusions. In some samples the contacts with the country rocks are sharp; in others they grade through an inclusion-rich zone into breccia. Dykes are common but small and short. Those analyzed are andesitic or dacitic in composition, moderately to strongly alkaline.

Some shock metamorphic structures seem to be funnel-like depressions underlain by a mass of breccia that narrows downward. Large scale depression or upheaval of the bedrock does not occur in their vicinity. The others, with central uplifts, are associated with large scale down-faulting at their margins that, together with the large uplift at the centre, has the effect of preserving some older sedimentary rocks, generally of Paleozoic age. Shock metamorphic effects are generally intense in the central uplift. The volcanic rocks appear to have been fed from fissures near the outside of the structure.

The New Quebec crater is a slightly glaciated, simple crater of late Pleistocene age, 10,400 feet in diameter, 825 feet deep (Currie, 1965). Granitic gneiss in the vein is hydrothermally altered to epidote and calcite. There is a marked bending of the regional joints near the crater. Two boulders bearing thetomorphic glass in a matrix of volcanic material were recovered southwest of the crater. A subcircular negative gravity anomaly of 6 milligals suggests the presence of breccia beneath the structure.

The West Clearwater Lake crater, Quebec (Bostock, 1968) is a nearly circular depression 20 miles in diameter, bounded by series of curving linears (Pl. IV-22). In the centre is a ring of islands about 8 miles in outside diameter and half a mile wide. The stratigraphic succession on these islands is fractured and altered country rocks with remnants of Ordovician limestone, glass-bearing breccia cut by slightly different breccias, inclusion-rich dacite, and inclusion-poor dacite. The dacite is markedly richer in potash and magnesia, and poorer in soda than the country rocks. Two K–Ar dates average 290 m.y. Drilling has shown dykes of dacite to persist at least to 1,300 feet. Complex hydrothermal mineralization of gypsum, tetrahedrite, and millerite is associated with unusual alkaline ultrabasic veinlets. An irregularly shaped negative Bouguer anomaly of 8 milligals occurs over the crater. Intensely shock-metamorphosed country rocks form shoals in the centre of the lake. The East Clearwater Lake crater is a quadrate basin about 14 miles on each side separated from West Clearwater Lake by a screen of islands (Dence, 1968). Much of the lake is more than 300 feet deep. The central uplift is composed of fractured but almost unmetamorphosed basement; its size is uncertain. It is surrounded by at least 300 feet of massive and brecciated to massive, dark rocks of igneous appearance. A simple, subcircular, negative Bouguer gravity anomaly of about 10 milligals is over the crater.

Manicouagan is the largest and most complex crater in Canada; it is octagonal and is 38 miles across. The central peak is rectangular, about 6 by 12 miles, and towers 1,700 feet above its surroundings. All types of shock metamorphic features noted above are present in the region of the central uplift. Three distinct varieties of igneous rocks are present. Pipes and small flows of meimechite and alkali basalt are the older, while vast volumes of trachyandesite and larvikite are the younger. The stratigraphic sequence is similar to that at Clearwater

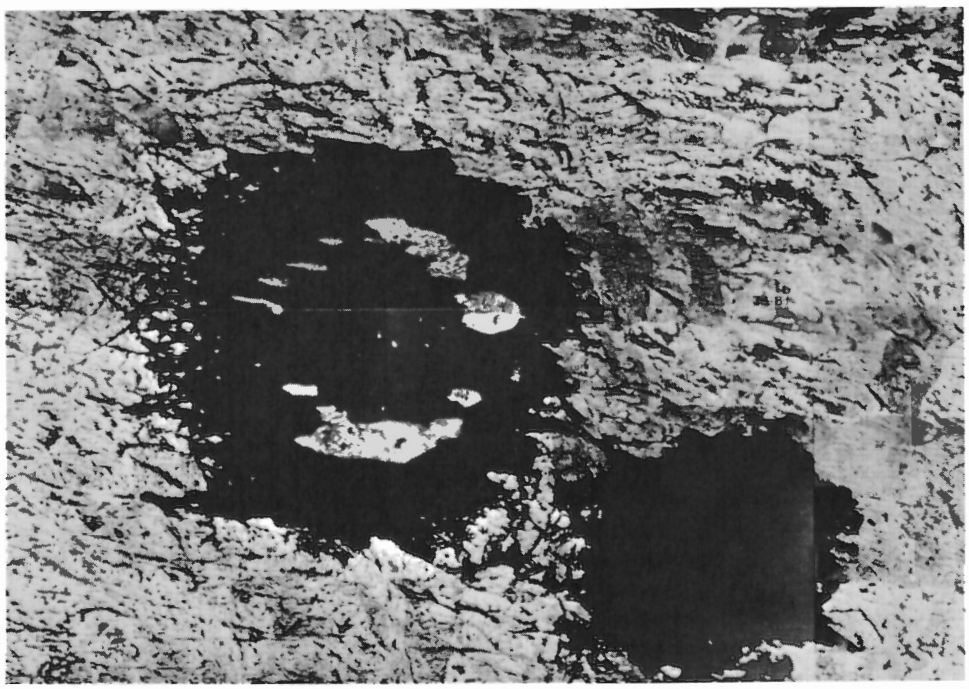


PLATE IV-22

Vertical air photograph mosaic of Clearwater Lake shock metamorphic structure, Clearwater Lake, Quebec.

but breccia is almost absent. A large number of K–Ar ages average 210 m.y.

The Brent crater, Ontario, is a simple structure without a rim, about 11,000 feet in diameter, filled with flat-lying Ordovician sedimentary rocks 800 feet thick (Dence, 1968). Beneath them is 2,000 feet of breccia displaying shock metamorphic effects cut by alnoite dykelets. Carbonate nodules in the dykelets have oxygen isotope ratios characterisitic of carbonatite. A mass of hyper-potassic trachyte is at a depth of 2,900 feet, below which brecciation rapidly disappears. An age determination on the alnoite gave 590 m.y. and three dates from the trachyte average 330 m.y. Lamprophyre dykes radial to the crater are present in the country rocks.

The Carswell structure, Saskatchewan, is 24 miles in diameter. It comprises an outer ring of complexly folded Carswell dolomite downfaulted into the Paleohelikian Athabasca Formation, and an inner core of Archean or Aphebian crystalline rocks. Relative displacements on the faults are thought to be of the order of 4,000 feet. Trachyandesite is present as dykes. They have a K–Ar age of 475 m.y. Poorly developed shatter cones occur in the basement rocks. Shock metamorphism is not found in the sedimentary rocks. Clear-cut evidence of the action of ultrahigh pressures has not been found in Canadian occurrences of shock metamorphism (with the dubious exception of one coesite deposit). The impact theory does not explain the presence of coherent blocks of rock raised in the centre of eight of the structures. The presence of alkaline igneous rocks in at least four of the craters, in particular alkaline rocks usually associated with explosive activity, strongly suggests an endogenetic origin for at least some of the craters.

HUDSON PLATFORM

The Hudson Platform lies in the central part of the Canadian Shield and comprises the remnants of the Moose River and Hudson Bay sedimentary basins. The smaller Moose River Basin borders and extends beneath James Bay. The larger Hudson Bay Basin to the north is mainly covered by Hudson Bay. Only parts are present on land in northern Hudson Bay Lowland and on the islands of Southampton, Coats, and Mansel. Separating the two basins is the northeast-trending Cape Henrietta Maria Arch (Fig. IV-36). Two structural provinces of the Canadian Shield, the Superior and the Churchill, border and extend beneath Hudson Platform. Their boundary extends from the vicinity of Nelson River, Manitoba, eastward and southeastward beneath the Paleozoic cover of Hudson Bay Basin to reappear in the Sutton Inlier on Cape Henrietta Maria Arch; from there it extends beneath the Paleozoic and Mesozoic rocks of Moose River Basin beneath James Bay to the east side of Hudson Bay. Within Superior Province, plutonic rocks of Archean age form most of the Precambrian basement. Rocks of Proterozoic age dominate Churchill Province; some are plutonic crystalline rocks and others, as in the Sutton Inlier, are slightly altered and little deformed Aphebian sedimentary rocks.

Phanerozoic strata of Hudson Platform consist of nearly flat lying to gently dipping sedimentary rocks (Fig. IV-37). In Moose River Basin, rocks of Ordovician, Silurian, and Devonian ages are represented by a variety of shallow marine facies composed of sandstone, shale, limestone, dolomite, and evaporite deposits that are succeeded by non-marine sediments of Lower Cretaceous age.

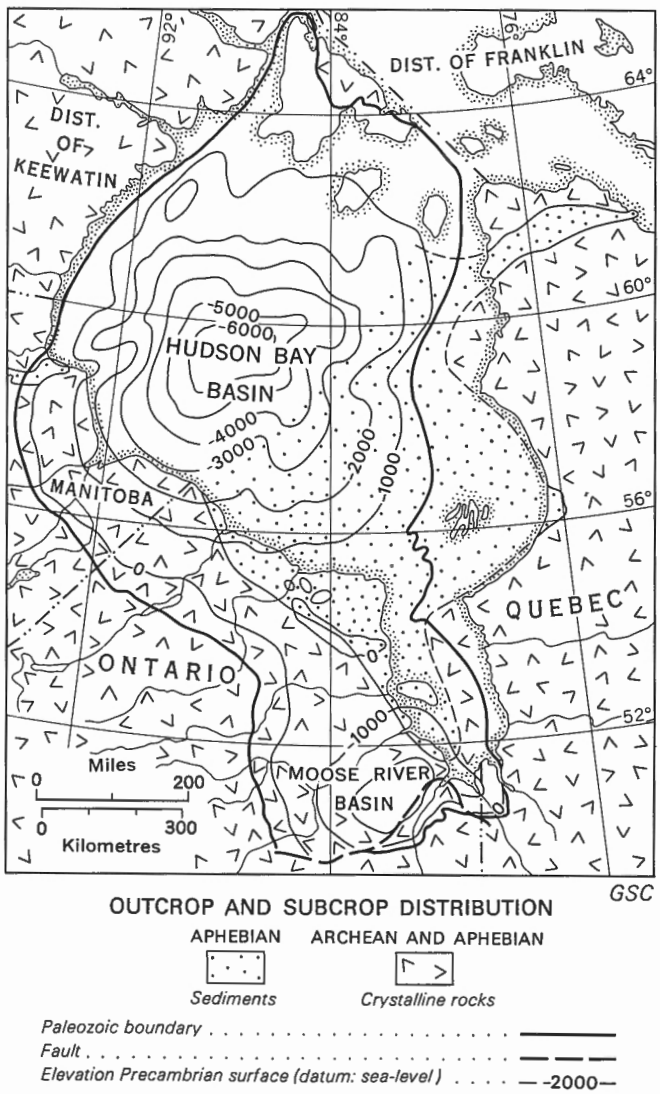


FIGURE IV-36. Configuration of Precambrian rocks beneath Paleozoic cover of Hudson Platform (modified from Hobson, 1967).

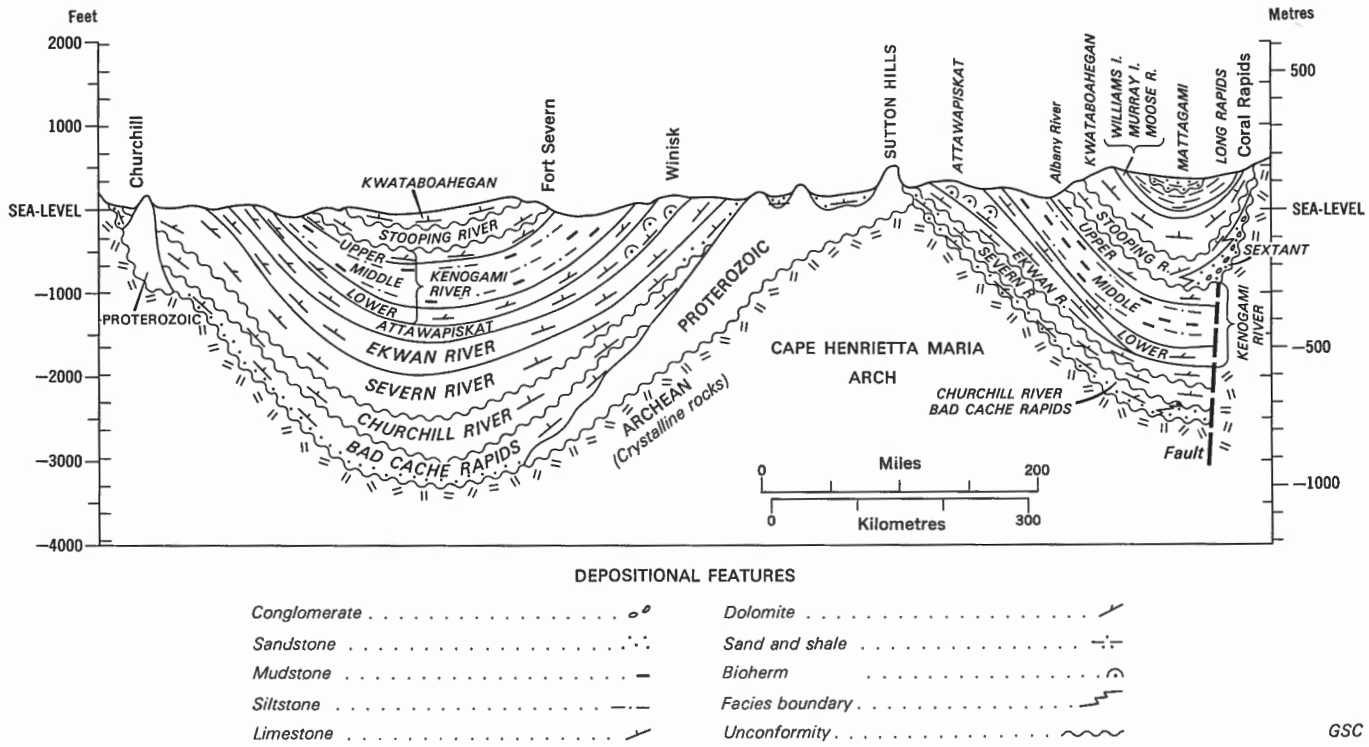


FIGURE IV-37
Cross-section of Phanerozoic rocks of southern Hudson Platform (by B. V. Sanford and A. W. Norris).

Their combined thickness is about 2,500 feet in the southern part of the basin. In Hudson Bay Basin, similar rocks of Ordovician, Silurian, and Lower and early Middle Devonian ages are represented on the mainland where they have a combined thickness of about 3,000 feet in Manitoba. In the northern part of the basin, only Ordovician and Silurian rocks are exposed on the islands of Southampton, Coats, and Mansel. A thicker Phanerozoic sequence, 6,000 feet as determined by geophysical surveys (Hobson, 1967), is presumably present offshore in the central part of the basin beneath Hudson Bay. Paleozoic outliers are present on the Canadian Shield at Clearwater Lake, Waswanipi Lake, Lake St. John, Lake Nipissing, Lake Timiskaming, Manicouagan Lake, and Mattawa. The Hudson Bay and Moose River Basins are now separated by parts of the Canadian Shield from Williston Basin in the southwest and from the Michigan and Quebec Basins to the south. The northern boundary of Hudson Bay Basin is Bell Arch, trending northwestward through Southampton Island and bordering Foxe Basin of the southeastern Arctic Platform.

PALEOZOIC

Ordovician

Tectonic Summary

Although the first widespread Paleozoic submergence of the southern Canadian Shield was during the Middle Ordovician (Wilderness), it was possibly not until the Late Ordovician (Edenian) that the seas finally transgressed the central part of the Canadian Shield to initiate the Hudson platformal sequence (Fig. IV-38). In the Edenian, arkose, orthoquartzitic sandstone, and shale were deposited as a thin veneer over the irregular Precambrian surface, succeeded by marine fossiliferous limestones and minor dolomites (Pl. IV-23). The Maysvillian was presumably a time of uplift of parts of the Canadian Shield, particularly Severn and Fraserdale Arches, during which the Edenian on the southern margin of Hudson Bay Basin was bevelled by erosion and, if formerly present, was removed entirely from Moose River Basin south of Cape Henrietta Maria Arch. During the Richmondian, a widespread transgression again connected Hudson, St. Lawrence, Interior, and Arctic Platforms. Fossiliferous limestones were deposited along the present margins of Hudson Platform during this stage, giving place to dolomitic limestones and dolomites with interbeds of gypsum or anhydrite in central Moose River Basin and possibly also in the central Hudson Bay Basin. The Fraserdale Arch south of Moose River Basin formed a highland from which coarse detritus was derived, represented by sandstone along the southern margin of the basin.

Upper Ordovician

Rocks of early Late Ordovician (Edenian) age in Hudson Bay Basin form the Bad Cache Rapids Group, and may be present also in Moose River Basin. The group is divisible into two formations (Nelson, 1964). The basal Portage Chute Formation consists of arkose, orthoquart-

PLATE IV-23. Upper Ordovician Bad Cache Rapids Group unconformably on Precambrian granitic gneiss, Churchill River, Manitoba.

zitic sandstone, and argillaceous or calcareous sandstone and shale, 4 to 13 feet thick, succeeded by 71 feet of light grey, microcrystalline, dolomitic, locally bioclastic, and nodular limestone. It is overlain by the Surprise Creek Formation composed of 64 feet of light yellowish tan and grey, mottled, finely crystalline, cherty, dolomitic limestone. A similar lithological and faunal assemblage overlies Precambrian crystalline rocks on Southampton Island (Nelson and Johnson, 1966), which suggests a wide distribution of the Bad Cache Rapids Group beneath Hudson Bay. In addition, outliers of rocks in part equivalent to the Bad Cache Rapids are present at Clearwater Lake, east of Hudson Bay, and in two isolated localities west of the bay. The Bad Cache Rapids Group is faunally and lithologically similar to the Red River Formation of the Lake Winnipeg area of southern Manitoba (Nelson, 1964).

The Churchill River Group of late Late Ordovician (Richmondian) age disconformably succeeds the Bad Cache Rapids Group in Hudson Bay Basin. Churchill River strata rise to surface in the western Hudson Bay Lowland, but are in fault contact with Precambrian rocks along the southwestern margin of Moose River Basin. They again rise to surface immediately south of James Bay, and on Southampton Island in northern Hudson Bay. The Churchill River Group in the southern Hudson Bay Basin is divisible into the Caution Creek Formation that consists of bioclastic, grey to yellowish grey and tan, mottled, cryptocrystalline dolomitic limestone, 42 feet thick, and into the overlying Chasm Creek Formation of massive to rubbly-bedded, light yellowish grey to buff, locally fucoidal, microcrystalline limestone, 190 feet thick (Nelson, 1964). A similar lithological and faunal succession occurs on Southampton Island except that the uppermost light brownish grey, finely crystalline limestones locally contain dark brown oil shale interbeds (Nelson and Johnson, 1966). In central Moose River Basin rocks possibly equivalent to the Churchill River Group consist of about 300 feet of grey-tan, microsucrosic dolomite containing interbeds of gypsum and anhydrite. Towards the southern margin of the basin, the dolomite becomes increasingly arenaceous, and eventually grades into 70 feet of arkose, granite pebble-conglomerate, minor shale, yellowish dolomitic sandstone, and sandy dolomite bordering the Canadian Shield (Remick, Gillain, and Durden, 1963).

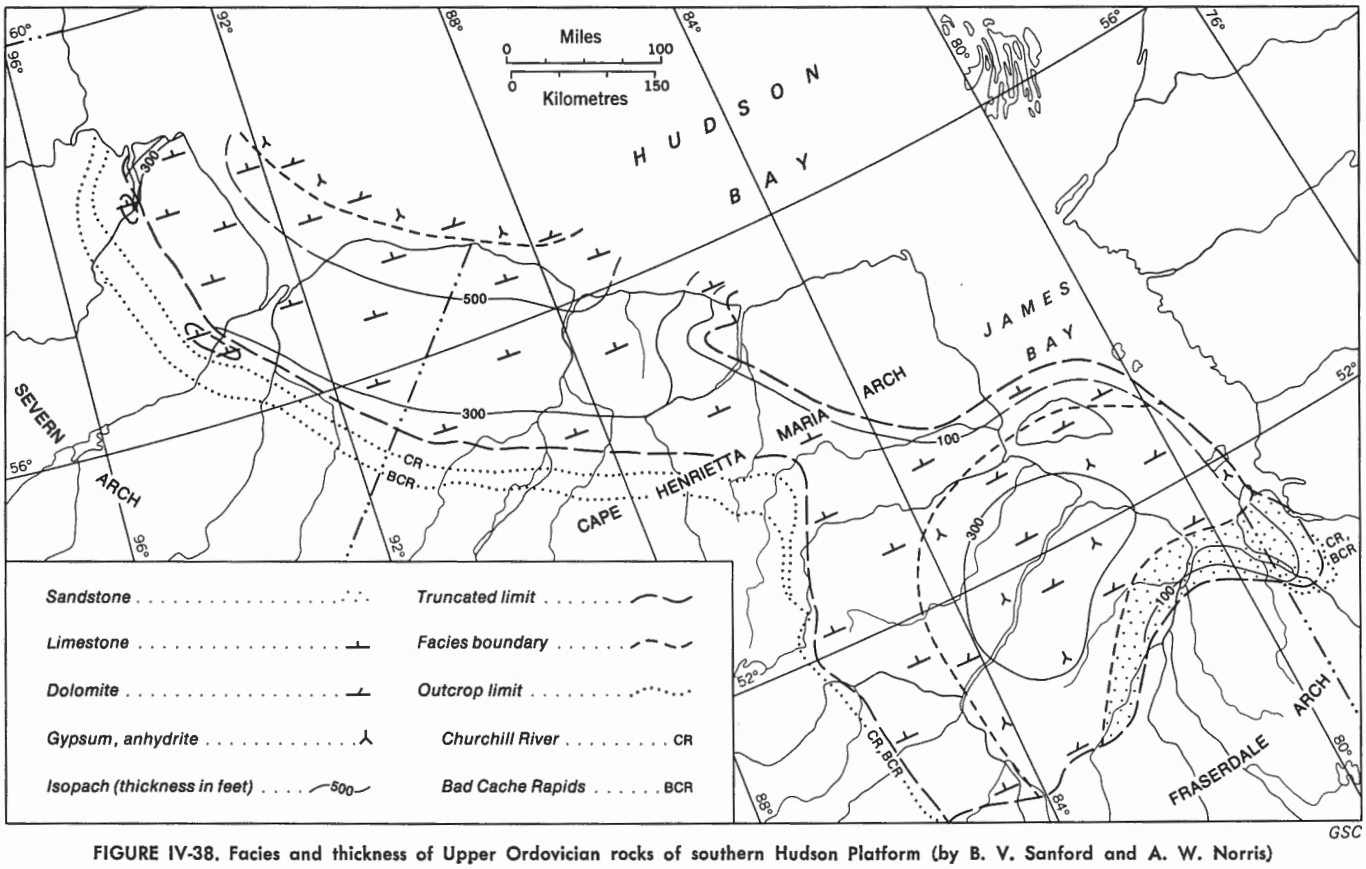


FIGURE IV-38. Facies and thickness of Upper Ordovician rocks of southern Hudson Platform (by B. V. Sanford and A. W. Norris)

The Churchill River Group is correlated with the Stony Mountain Formation of southern Manitoba (Nelson, 1964), and is coeval with the Queenston–Kagawong–Meaford Formations of southern Ontario. Equivalent strata are present at Lake St. John outlier, but are not represented in the Lake Timiskaming outlier. The latter region, accordingly, may have been land.

Silurian

Tectonic Summary

Although much of the southern Canadian Shield was inundated during the Alexandrian, Hudson Platform was presumably emergent. In the early Niagaran the sea transgressed into Williston Basin and onto Arctic and Hudson Platforms leaving thick limestone deposits (Fig. IV-39). Late Niagaran sedimentation on Hudson Platform was characterized by major reef development comparable to that of the Great Lakes region of Canada and the United States (Fig. IV-40). A fringing reef facies developed on the flanks of Hudson Bay and Moose River Basins, giving place to inter-reef facies in the more rapidly subsiding central parts of the basins. During the Late Silurian, Cayugan, Severn and Fraserdale Arches again became emergent, providing clastic detritus for the Moose River and Hudson Bay Basins to the north (Fig. IV-41). The normal marine environments that prevailed during the preceding Niagaran presumably became restricted, resulting in the deposition of primary dolomites, gypsum, and anhydrite in association with sandstone, mudstone, and siltstone, the latter forming the dominant facies.

Niagaran

Of the Niagaran formations the Severn River is a relatively uniform rock unit throughout Hudson Bay and Moose River Basins, whereas the succeeding Ekwan River and Attawapiskat Formations are closely related lithologically and form separate map units only on the margins of the basins. The Severn River Formation disconformably overlies the Upper Ordovician Churchill River Group, except in the vicinity of Churchill, Manitoba, and on Cape Henrietta Maria Arch, where it overlaps the Ordovician to rest directly upon the Precambrian. The formation rises to the surface along the western margin of the Hudson Bay Lowland and forms the youngest Paleozoic rocks over the Cape Henrietta Maria Arch (Fig. IV-38). It is in fault contact with the Precambrian on the southern margin of the Moose River Basin, and outcrops on Coats and Southampton Islands in the Hudson Bay. Maximum thickness of the formation in Moose River Basin is 150 to 200 feet, and 700 feet along the southern margin of Hudson Bay Basin. The Severn River is composed of

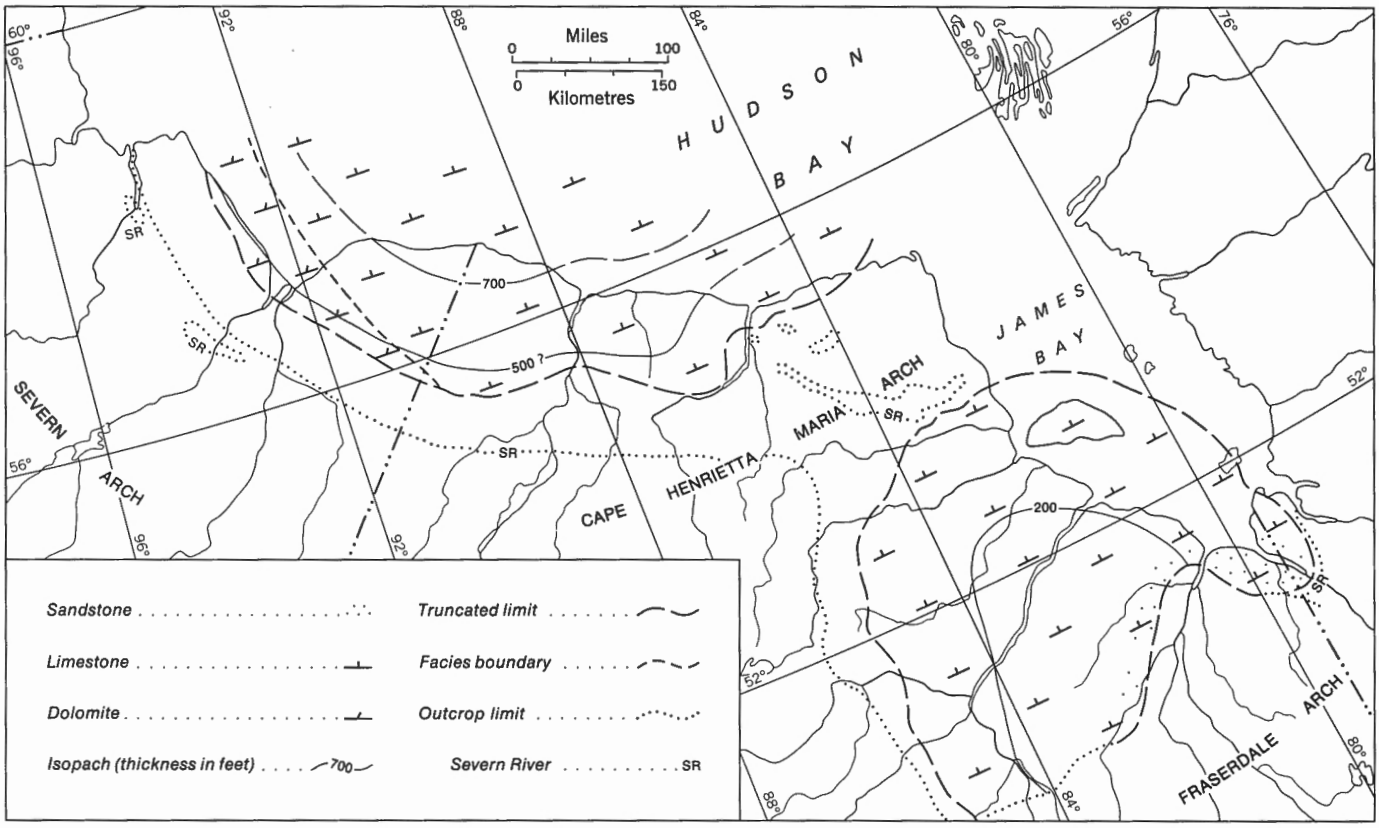


FIGURE IV-39. Facies and thickness of Silurian (early Niagaran) rocks of southern Hudson Platform (by B. V. Sanford and A. W. Norris).

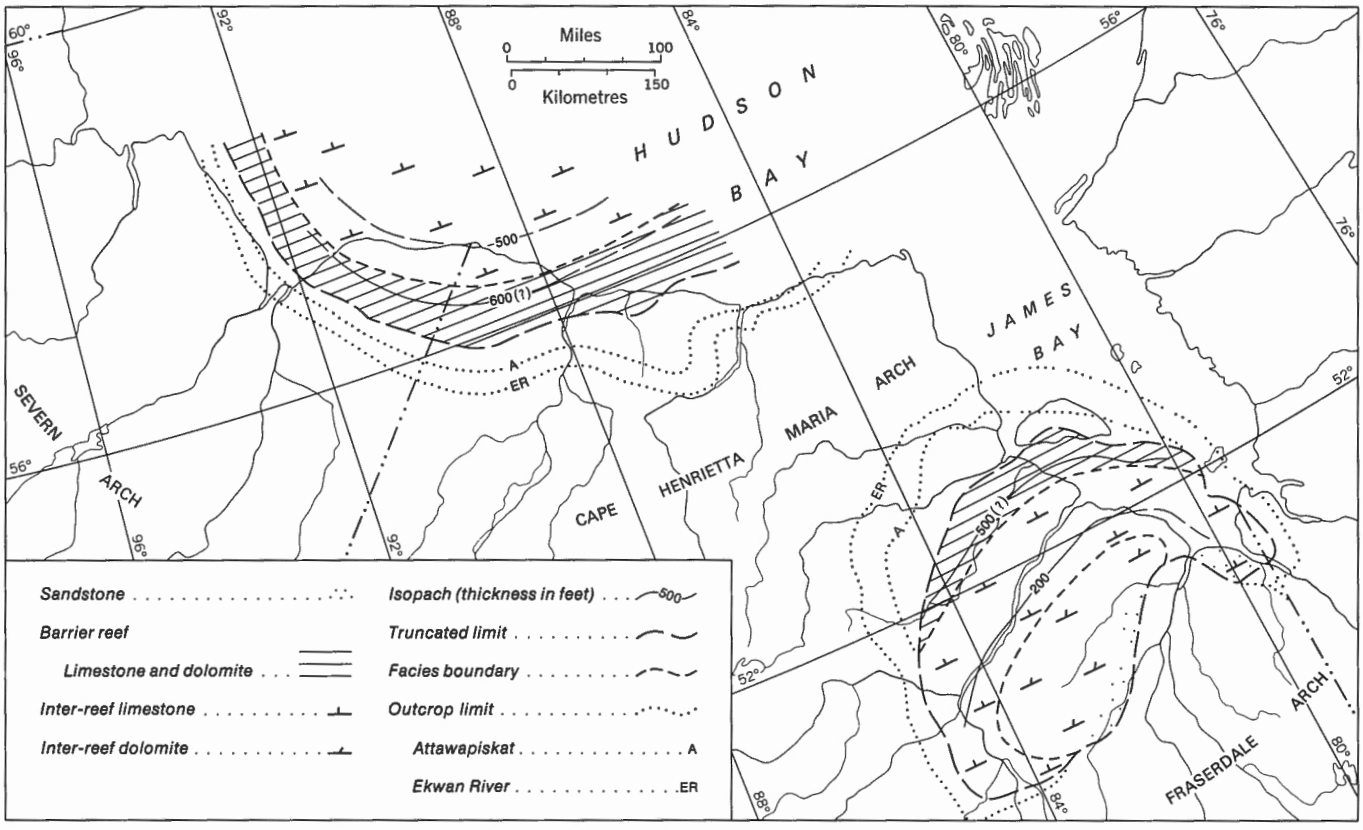


FIGURE IV-40. Facies and thickness of Silurian (late Niagaran (?)) rocks of southern Hudson Platform (by B. V. Sanford and A. W. Norris).

brown and tan, finely crystalline to aphanitic limestone and dolomite and mottled limestone with coarse, bioclastic, and fragmental limestone, and flat pebble-conglomerate locally present. Although generally thin bedded, the formation may be massive, swelling into thick biostromal lenses. The Severn River Formation correlates approximately with the upper part of the Wabi and Cataract Groups of Lake Timiskaming outlier and southwestern Ontario, respectively, and the lower part of the Interlake Group of southern Manitoba.

The Ekwan River Formation overlies the Severn probably disconformably, and, where combined with the succeeding and, in part, laterally equivalent Attawapiskat fringing reef facies, probably reaches thicknesses of 500 to 700 feet along the margins of the Hudson Bay and Moose River Basins (Fig. IV-40). Because of the rapid change to inter-reef facies the Ekwan River–Attawapiskat interval thins to 200 feet or less in central Moose River Basin, and perhaps to a comparable thickness in Hudson Bay Basin. The Ekwan River Formation is composed of light grey, tan, and brown, locally bituminous, fine- to medium-crystalline limestone and dolomite. It is thin to thick bedded and locally biostromal. The formation contains varying amounts of bioclastic, mainly crinoidal detritus and fragmental limestone, and in southern Moose River Basin, particularly in Quebec, sandstone interbeds and lenses. The Ekwan River Formation is tentatively correlated with the Thornloe Formation of Lake Timiskaming outlier, the Fossil Hill and Amabel Formations of southwestern Ontario, and part of the Interlake Group of southern Manitoba.

The Attawapiskat Formation conformably succeeds the Ekwan River, reaches its maximum development bordering the Cape Henrietta Maria Arch, and changes basinwards to inter-reefal carbonate rocks. The Attawapiskat is a reef complex composed of small bioherms that consist of thick structureless masses of yellowish tan and brown, vuggy, cavernous limestone, weathering ash grey. Flanking the bioherms are thick beds of carbonate and bioclastic detritus that dip at steep angles away from the reef cores. These beds become finer and thinly bedded where they grade into the inter-reef facies. Succeeding the biohermal facies and forming a dominant part of the Attawapiskat are thick biostromal beds of light grey or tan and brown, massive, vuggy limestones and dolomites. At numerous localities these strata form domes, apparently draped over buried bioherm reefs lower in the Attawapiskat. The bioherms and associated carbonate rocks of the Attawapiskat are closely similar in lithological character to the barrier reef facies of the late Middle Silurian Guelph

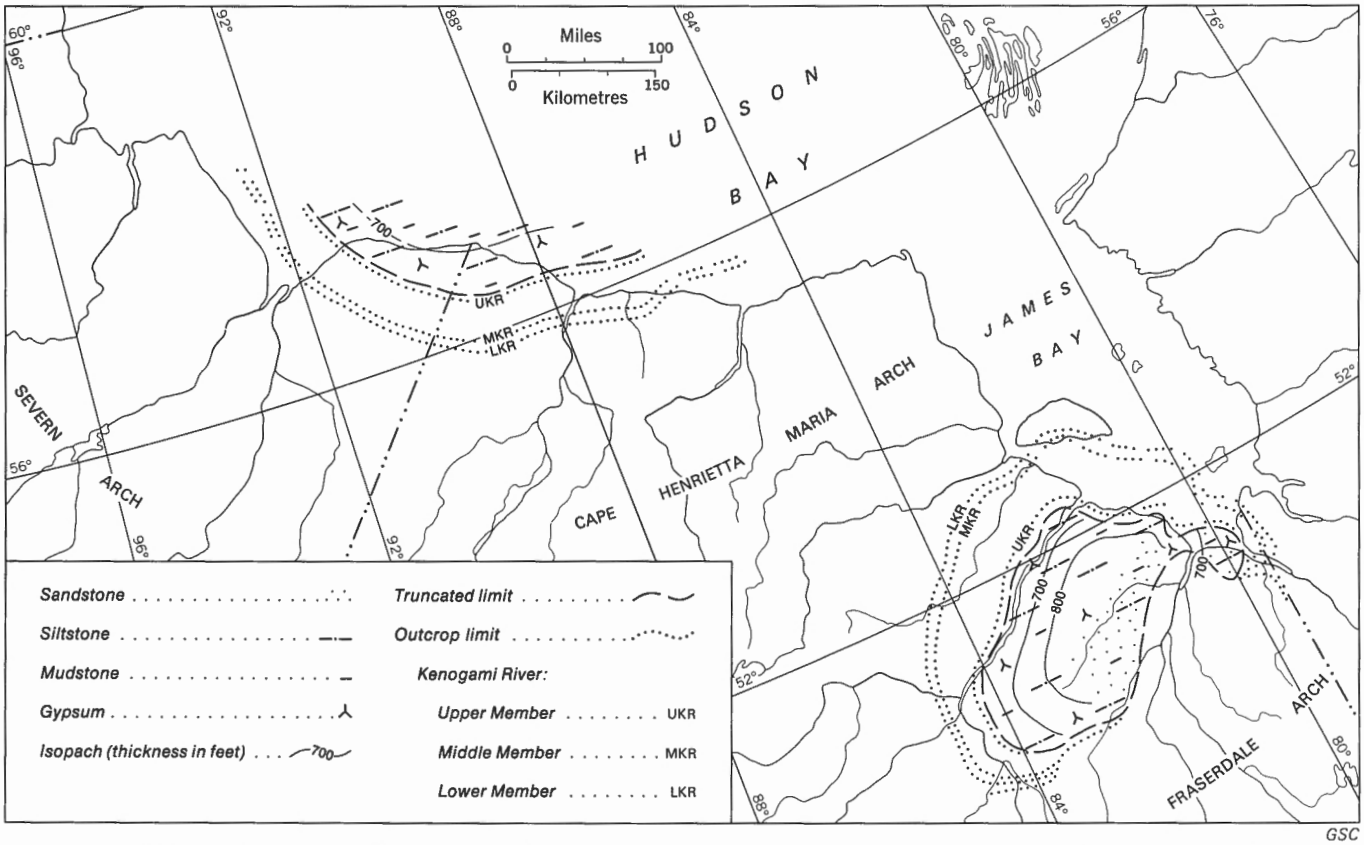


FIGURE IV-41. Facies and thickness of Upper Silurian rocks of southern Hudson Platform (by B. V. Sanford and A. W. Norris).

Formation of southwestern Ontario, and are tentatively correlated with that formation. The Attawapiskat is also probably equivalent to the Chemahawin Member of the Cedar Lake Formation of southern Manitoba.

Cayugan

The Kenogami River Formation conformably succeeds the Attawapiskat Formation, or the partly equivalent Ekwan River. The formation has a known thickness of 835 feet in eastern Moose River Basin, and its thickness in Hudson Bay Basin is presumably comparable (Fig. IV-41). It is divisible into three members. The lower member is a uniform sequence, 74 to 174 feet thick, of thin- to thick-bedded, brown, finely crystalline dolomite, containing thin interbeds of white gypsum or anhydrite. The middle member consists of gypsiferous, red and green siltstone, mudstone, sandstone, minor argillaceous dolomite, and honeycomb limestone, 475 to 552 feet thick. The upper member is a uniform succession of brown, tan, and cream coloured, microsucrosic oölitic dolomite, and dolomite breccia, 37 to 109 feet thick. The Kenogami River Formation is considered coeval with the lithologically similar Salina and Bass Islands Formations of southwestern Ontario, and the Ashern Formation of southern Manitoba.

Devonian

Tectonic Summary

During the early Early Devonian (Gedinnian–Siegenian), Fraserdale Arch was epeirogenically uplifted (Fig. IV-42). Uplift of the Precambrian basement took place on a fault along the southern margin of the Moose River Basin to bring Archean plutonic rocks into juxtaposition with Ordovician and Silurian strata. Thus a highland area extended along the southern margin of the basin as the initial late Early Devonian sea trangressed onto Hudson Platform. Rocks of Emsian age deposited at the foot of the fault scarp consist of non-marine sandstone, siltstone, shale, and conglomerate. These give place laterally to normal marine limestones and dolomites in the central part of Moose River Basin, and marine carbonate rocks form the entire sequence in the Hudson Bay Basin. The local terrigenous sequence was succeeded and overlapped by marine limestones, the latter presumably forming a continuous deposit across the Canadian Shield extending to Michigan and Allegheny Basins in the south. At the close of Early Devonian time, the sea retreated from Hudson Platform, initiating a brief interval of erosion.

The Middle Devonian is represented by normal marine limestone, evaporites, and minor shale. The faunas are

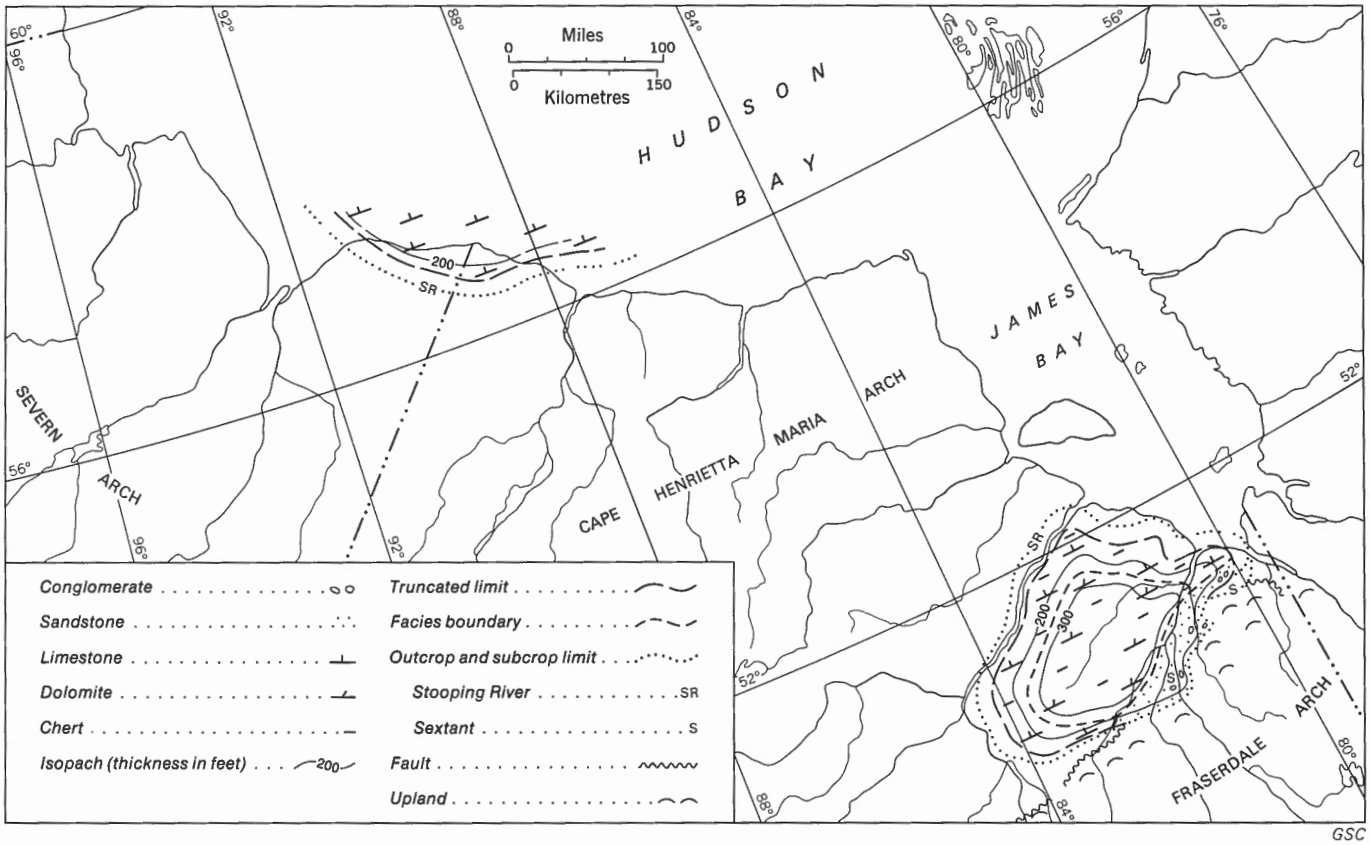


FIGURE IV-42. Facies and thickness of Lower Devonian rocks of southern Hudson Platform (by B. V. Sanford and A. W. Norris).

similar to those of the Allegheny and Michigan Basins and indicate three intervals of submergence and interconnection: early Eifelian, late Eifelian, and mid-Givetian. The latter intervals show some faunal similarity to parts of the Middle Devonian of Williston Basin in southern Manitoba. During the early Givetian hiatus evaporite deposits were removed by solution along the southern margin of Moose River Basin resulting in collapse and brecciation of interbedded and overlying carbonates. This interval also corresponds with the development of the Mackinac Straits breccia of northern Michigan, which suggests that widespread regional epeirogenic uplift of the eastern craton took place.

Upper Devonian rocks of Hudson Platform are composed of black shales similar to those in the Allegheny and Michigan Basins. They were presumably derived from the same provenance to the southeast in the Appalachian Geosyncline uplifted during the Acadian Orogeny and transported far across the southern Canadian Shield.

Lower Devonian

Two formations of Early Devonian age are recognized in the Hudson Platform: the non-marine Sextant Formation, confined to the southern part of Moose River Basin, and its marine equivalent, the Stooping River Formation. Where it overlies Archean rocks of the basement, the Sextant consists of as much as 175 feet of reddish pink and grey, mottled, quartz feldspar conglomerate, coarse feldspathic sandstone, and red or grey, locally carbonaceous, siltstone and shale. In Quebec, two outliers of the Sextant rest unconformably upon undivided Upper Ordovician strata, and the Middle Silurian Ekwan River Formation. The Sextant Formation grades basinward to thin-bedded, nodular, cream, tan and grey, finely crystalline cherty limestone and dolomite of the Stooping River Formation, about 300 feet in thickness. In central Moose River Basin and in Hudson Bay Basin, the Stooping River disconformably succeeds the upper member of the Kenogami River Formation. In southern Moose River Basin the Stooping River Formation transgressively overlaps the Sextant to rest directly upon the Precambrian. Plant remains are locally abundant in the Sextant and indicate a continental environment of deposition. The spores have been dated as late Lower Devonian (Emsian). The marine shelly fauna in the Stooping River Formation indicates a correlation with the Bois Blanc Formation of southwestern Ontario and Michigan, and is also dated as Emsian.

Middle Devonian

The Middle Devonian Kwataboahegan, Moose River, Murray Island, and Williams Island Formations have a combined thickness of about 700 feet and are composed predominantly of marine limestones with minor shale and evaporites. Although these formations are well developed in Moose River Basin, only the Kwataboahegan is present on the mainland part of Hudson Bay Basin. A more complete Middle Devonian sequence is presumably present offshore, beneath Hudson Bay. The Kwataboahegan Formation disconformably succeeds the Stooping River. It consists of tan and light to dark chocolate brown, bituminous, coral limestone. The beds are commonly thin to medium bedded but became thick bedded to massive and locally biostromal along the extreme southern margin of Moose River Basin. On the basis of its rich coral fauna the Kwataboahegan is correlated with the Amherstburg Formation and the Edgecliff Member of the Onondaga Formation of southwestern Ontario.

Succeeding the Kwataboahegan with fairly abrupt but conformable contact are the carbonate and evaporite deposits of the Moose River Formation. In central Moose River Basin these are composed of light to medium brown and tan, aphanitic to microsucrosic limestones and dolomites containing thick beds of white gypsum, with a combined thickness of more than 100 feet. Along the southern margin of the basin, gypsum is sporadic, having been removed in large part by solution, which left the limestones and dolomites contorted and brecciated. Although relict bedding can be observed here and there in the breccia, the formation is largely a jumbled mass of carbonate fragments as much as several feet in diameter in a calcisiltite and micrite matrix.

The Murray Island Formation overlies the Moose River disconformably. It consists of about 20 feet of thick-bedded, light brown, crinoidal limestone grading upward to thin-bedded, finely crystalline to aphanitic limestone. The formation has a fracture pattern that apparently formed from slight subsidence as a result of leaching or compaction of the underlying evaporites. The Murray Island contains a brachiopod fauna that suggests correlation with the Elm Point Formation of southern Manitoba. It is also tentatively correlated with the lithologically similar Dundee and Rogers City Formations of Michigan Basin considered late Eifelian and early Givetian.

The Williams Island Formation, 150 to 200 feet in thickness, succeeds the Murray Island Formation, possibly with a disconformable contact. The lower strata are blue-grey and red shales locally containing thin interbeds of gypsum and coarse brown crinoidal limestone. These grade upward to tan or light brown and light grey, finely crystalline to granular, high calcium limestone, containing traces of gypsum and minor limestone breccia. The coral and brachiopod fauna of the Williams Island Formation in Moose River Basin indicates correlation with the Hamilton Formation of Givetian age of southwestern Ontario. Fossils characteristic of the Dawson Bay Formation of Manitoba, mixed with Williams Island forms, occur in rubble near the mouths of several rivers flowing into Hudson Bay near the Manitoba–Ontario boundary, and were apparently scoured by glacial action from rock outcrops located offshore.

Upper Devonian

The Long Rapids Formation, 285 feet thick, forms the youngest Paleozoic strata of Hudson Platform. They

rest with an abrupt and possibly disconformable contact upon the Williams Island Formation and are composed of sparsely fossiliferous, dark brown and black, carbonaceous, fissile shales with thin interbeds of soft greyish green shale and hard grey-green dolomite. It is tentatively correlated with the lithologically similar Upper Devonian Kettle Point Formation of southwestern Ontario.

MESOZOIC

Tectonic Summary

After the widespread submergence of Hudson Platform and the Canadian Shield during the early and middle Paleozoic, the Shield was uplifted and stripped of most of its sedimentary cover. This epeiorogeny may have occurred mainly during the late Paleozoic and early Mesozoic as non-marine clastic sequences of late Jurassic and early Cretaceous ages occur in the Williston, Michigan, and Moose River Basins, and on the Atlantic Continental Shelf. In addition, alkalic magmatic activity, the Monteregian Intrusions, occurred in western Quebec Basin. They are dated as late Jurassic to early Lower Cretaceous and may be associated with faulting. Lamprophyre and kimberlitic dykes and sills were intruded into Devonian rocks on Abitibi River at Sextant and Coral Rapids near the southern margin of Moose River Basin.

Lower Cretaceous

The Mattagami Formation is recognized only in the Moose River Basin where it unconformably overlies bevelled edges of various formations from Upper Silurian to Upper Devonian age and rests locally on the Precambrian. It is about 170 feet thick. The lower part consists of dark grey to black fire clays, and brownish to yellowish micaceous sands with fragments of carbonized plant stems and thick seams of lignite, succeeded by a sequence of varicoloured plastic clay, and white quartz sand and clay. Fossil plants and spores have been dated as Upper Jurassic or Lower Cretaceous, with a preference for the latter age. Drilling has delineated about 10 million tons of coal at or close to surface and substantial reserves beneath greater thicknesses of overburden.

SELECTED REFERENCES

GENERAL

Davies, J. F., Bannatyne, B. B., Barry, G. S. and McCabe, H. R.
1962: Geology and mineral resources of Manitoba; *Man. Dept. Mines Natl. Res.*

Dresser, J. A. and Denis, T. C.
1944: Geology of Quebec; *Que. Dept. Mines,* Geol. Rept 20, vol. 11.

Geological Survey of Canada:
Age determinations and geological studies; annual paper on K–Ar age determination, Papers 60-17 to 67-17 and 68-2, et seq.
Report of activities, Papers 63-1 to 67-1.

Ontario Dept. of Mines:
Summary of field work; annual papers in the Prel. Rept. Series, 1960–1967.

Quebec Dept. of Mines:
Summary of field work; annual papers in S series, 1962–1967.

Saskatchewan Dept. of Mineral Resources:
Summary of geological surveys conducted in the Precambrian area; annual papers, 1960–1968.

SPECIFIC

Alcock, F. J.
1934: Report of the National Committee on stratigraphic nomenclature; *Trans. Roy. Soc. Can.,* vol. 28, sec. 4, pp. 113–121.

Ambrose, J. W. and Burns, C. A.
1956: Structures in the Clare River Syncline: a demonstration of granitization; *Roy. Soc. Can.,* Sp. Publ. No. 1, pp. 42–53.

Armstrong, R. L.
1966: K–Ar dating of plutonic and volcanic rocks in orogenic belts; *in* Potassium argon dating, New York, Springer-Verlag, pp. 117–133.

Baragar, W. R. A.
1960: Petrology of basaltic rocks in part of the Labrador Trough; *Bull. Geol. Soc. Am.,* vol. 71, pp. 1598–1644.
1966: Geochemistry of the Yellowknife volcanic rocks; *Can. J. Earth Sci.,* vol. 3, p. 26.
1967: Volcanic studies; Coppermine River basaltic flows; *in* Report of activities, *Geol. Surv. Can.,* Paper 67-1, pp. 26–29.

Beall, G. H., Hurley, P. M., Fairbairn, H. W. and Pinson, W. H., Jr.
1963: Comparison of K–Ar and whole rock Rb–Sr dating in New Quebec and Labrador; *Am. J. Sci.,* vol. 261, pp. 571–580.

Béland, Rene and Auger, P. E.
1958: Structural features of the northern part of the Labrador Trough; *Trans. Roy. Soc. Can.,* sec. 4, vol. 52, pp. 5–15.

Bell, C. K.
1966: Churchill-Superior province boundary in northeastern Manitoba; *in* Report of activities, *Geol. Surv. Can.,* Paper 66-1, pp. 133–137.

Bennet, G., Brown, D. D. and George, P. T.
1966: Operation Kapuskasing, District of Cochrane; *in* Summary of field work, 1966, *Ont. Dept. Mines,* Prel. Rept. 1966–1, pp. 42–47.

Bergeron, R.
1957a: Proterozoic rocks of the northern part of the Labrador geosyncline, the Cape Smith belt and the Richmond Gulf area; *Roy. Soc. Can.*, Spec. Publ. 2, pp. 101–111.
1957b: Late Precambrian rocks of the north shore of the St. Lawrence River and of the Mistassini and Otish Mountains areas, Quebec; *in* The Proterozoic of Canada, *Roy. Soc. Can.*, Spec. Publ., No. 2, pp. 101–111.
1959: Povungnituk Range area, New Quebec; *Que. Dept. Mines*, Prel. Rept. 392.

Best, M. G.
1966: Structural geology of Precambrian rocks south of Bancroft, Ontario; *Can. J. Earth Sci.*, vol. 3, pp. 441–455.

Blackadar, R. G.
1965: Geological reconnaissance of the Precambrians of northwestern Baffin Island, Northwest Territories; *Geol. Surv. Can.*, Paper 64-42.

Blackadar, R. G. and Christie, R. L.
1963: Geological reconnaissance, Boothia Peninsula, and Somerset, King William, and Prince of Wales Islands, District of Franklin; *Geol. Surv. Can.*, Paper 63-19.

Blais, R. A.
1959: L'origine des minerais crétacés du gisement de fer Redmond, Labrador; *Le Naturaliste Canadien*, vol. 86, pp. 265–299.

Bostock, H. H.
1968: The Clearwater complex, New Quebec; *Geol. Surv. Can.*, Bull. 178.

Brummer, J. J. and Mann, E. L.
1961: Geology of the Seal Lake area, Labrador; *Bull. Geol. Soc. Am.*, vol. 72, pp. 1361–1382.

Buddington, A. F.
1962: Regional geology of the St. Lawrence county magnetite district; northwest Adirondacks, New York; *U.S. Geol. Surv.*, Prof. Paper 376.

Burwash, R. A., Baadsgaard, H., Campbell, F. A., Cumming, G. L. and Folinsbee, R. E.
1963: Potassium-argon dates of diabase dyke systems, District of Mackenzie, N.W.T.; *Trans. Can. Inst. Min. Met.*, vol. 66, pp. 303–307.

Byers, A. R. and Dahlstrom, C. D. A.
1954: Geology and mineral deposits of the Amisk-Wildnest Lakes area, Saskatchewan; *Sask. Dept. Min. Res.*, Rept. 14.

Card, K. D.
1965a: Hyman and Drury townships; *Ont. Dept. Mines*, Geol. Rept. 34.
1965b: The Croker Island Complex; *Ont. Dept. Mines.*, Geol. Circ. 14.

Clarke, P. J.
1961: Geology of the Gras Lake area, Saguenay county; *Que. Dept. Natl. Res.*, Prel. Rept. 453.

Claveau, J.
1949: Wakeham Lake area, Saguenay county; *Que. Dept. Mines*, Geol. Rept. 37.

Coleman, A. P.
1914: Precambrian rocks north of Lake Huron; *Ont. Bur. Mines*, vol. 23, pt. 1.

Collins, W. H.
1925: North shore of Lake Huron; *Geol. Surv. Can.*, Mem. 143.

Cooke, H. C.
1923: Opasatika map-area, Timiskaming county, Quebec; *Geol. Surv. Can.*, Summ. Rept. 1922, pt. D., pp. 19–74.
1946: Problems of Sudbury geology; *Geol. Surv. Can.*, Bull. 3.

Currie, K. L.
1965: Geology of the New Quebec Crater; *Geol. Surv. Can.*, Bull. 150.

Davies, J. F., Bannatyne, B. B., Barry, G. S. and McCabe, H. R.
1962: Geology and mineral resources of Manitoba; *Man. Dept. Mines Natl. Res.*

Davis, G. L., Hart, S. R., Aldrich, L. T., Krogh, T. E. and Munizaga, F.
1967: Geochronology of the Grenville Province in Ontario, Canada; *in* Ann. Rept. of the Director, Geophysical Laboratory, *Carnegie Inst. Wash.*, pp. 379–386.

Davison, W. L.
1966: Caribou River map-area, Manitoba; *Geol. Surv. Can.*, Paper 65-25.

Déland, A. N.
1956: The boundary between the Timiskaming and Grenville Subprovinces in the Surprise Lake area, Quebec; *Proc. Geol. Assoc. Can.*, vol. 8, pp. 127–141.

Déland, A. N. and Grenier, P. E.
1959: Hazeur-Druillettes area, Abitibi-East Electoral District; *Que. Dept. Mines*, Geol. Rept. 87.

Dence, M. R.
1968: Shock zoning at Canadian craters; *in* Shock metamorphism of natural materials, *Mono Books*, Baltimore.

Dietz, R. S.
1964: Sudbury structure as an astrobleme; *J. Geol.*, vol. 72, pp. 412–434.

Donaldson, J. A.
1965: The Dubawnt Group, Districts of Keewatin and Mackenzie; *Geol. Surv. Can.*, Paper 64-20.

Donaldson, J. A. and Jackson, G. P.
1965: Archean sedimentary rocks of North Spirit Lake area, northwestern Ontario; *Can. J. Earth Sci.*, vol. 2, pp. 622–647.

Duffell, S. and Roach, R. A.
1959: Mount Wright, Quebec-Newfoundland; *Geol. Surv. Can.*, Map 6-1959.

Dyer, W. S.
1934: Geology of the Pashkokogan Lake-Eastern Lake St. Joseph area; *Ont. Dept. Mines*, Geol. Rept. 42.

Eade, K. E.
1966a: Fort George River and Kaniapiskau River (West Half) map-areas, New Quebec; *Geol. Surv. Can.*, Mem. 339.
1966b: Kognak River (West Half), District of Keewatin; *Geol. Surv. Can.*, Paper 65-8.

Eade, K. E., Fahrig, W. F. and Maxwell, J. A.
1966: Composition of crystalline shield rocks and fractionating effects of regional metamorphism; *Nature*, vol. 211, pp. 1245–1249.

Emslie, R. F.
1965: The Michikamau anorthositic intrusion, Labrador; *Can. J. Earth Sci.*, vol. 2, pp. 385–399.

Engel, A. E. J. and Engel, C. G.
1953: Grenville Series in the northwest Adirondack Mountains; Part I: General features of the Grenville Series; *Bull. Geol. Soc. Am.*, vol. 64, pp. 1013–1097.

Fahrig, W. F.
1957: Geology of certain Proterozoic rocks in Quebec and Labrador; *Roy. Soc. Can.*, Spec. Publ. No. 2, pp. 112–123.
1960: Shabogamo Lake, Newfoundland and Quebec; *Geol. Surv. Can.*, Paper 60-9.
1961: The geology of the Athabasca Formation; *Geol. Surv. Can.*, Bull. 68.

Fahrig, W. F. and Wanless, R. K.
1963: Age and significance of diabase dyke swarms of the Canadian Shield; *Nature*, vol. 200, pp. 934–937.

Fahrig, W. F., Gaucher, E. H. and Larochelle, A.
1965: Palaeomagnetism of diabase dykes of the Canadian Shield; *Can. J. Earth Sci.*, vol. 2, pp. 278–298.

Fairbairn, H. W., Hurley, P. M. and Pinson, W. H.
1965: Re-examination of Rb–Sr whole-rock ages at Sudbury, Ontario; *Proc. Geol. Assoc. Can.*, vol. 16, pp. 95–102.

Farquhar, R. M. and Russell, R. D.
1957: Dating the Proterozoic in Canada; *in* The Proterozoic in Canada; *Roy. Soc. Can.*, Spec. Publ. No. 2, pp. 28–32.

Feniak, M.
1952: MacAlpine Channel, Northwest Territories; *Geol. Surv. Can.*, Map 1011A.

Ferguson, S. A.
1966: The relationship of mineralization to stratigraphy in the Porcupine and Red Lake areas, Ontario; *Geol. Assoc. Can.*, Spec. Paper No. 3, pp. 99–121.

Frarey, M. J.
1967: Three new Huronian formational names; *Geol. Surv. Can.*, Paper 67-6.

Frarey, M. J. and Duffell, S.
1964: Revised stratigraphic nomenclature for the central part of Labrador Trough; *Geol. Surv. Can.*, Paper 64-26.

Fraser, J. A.
1960: North-central District of Mackenzie, Northwest Territories; *Geol. Surv. Can.*, Map 18-1960.
1964: Geological notes on northeastern District of Mackenzie, Northwest Territories; *Geol. Surv. Can.*, Paper 63-40.
1966: Study of the Epworth Group; *in* Report of activities, *Geol. Surv. Can.*, Paper 66-1, p. 29.

Gastil, G. and Knowles, D. M.
1960: Geology of the Wabush Lake area, southwestern Labrador and eastern Quebec, Canada; *Geol. Soc. Am.*, vol. 71, pp. 1243–1254.

Gaucher, E. H.
1966: Elsas-Kapuskasing-Moosonee magnetic and gravity highs; *in* Report of activities, *Geol. Surv. Can.*, Paper 66-1, pp. 189–191.

Gill, J. E., Bannerman, H. M. and Tolman, C.
1937: Wapussakatoo Mountains, Labrador; *Bull. Geol. Soc. Am.*, vol. 48, pp. 567–586.
1948: Mountain building in the Canadian Shield; *18th Internatl. Geol. Congr.*, pt. 13, pp. 97–104.
1949: Natural divisions of the Canadian Shield; *Roy. Soc. Can.*, sec. 4, ser. 3, vol. 43, pp. 61–69.

Ginn, R. M.
1965: Nairn and Lorne townships; *Ont. Dept. Mines*, Geol. Rept. 35.

Gittins, J., MacIntyre, R. M. and York, D.
1967: The ages of carbonatite complexes in eastern Canada; *Can. J. Earth Sci.*, vol. 4, pp. 651–655.

Goldich, S. S., Nier, A. O., Baadsgaard, H., Hoffman, J. H. and Krueger, H. W.
1961: The Precambrian geology and geochronology of Minnesota; *Minn. Geol. Surv.*, Bull. 41.

Goodwin, A. M.
1960: Gunflint iron formation of the Whitefish Lake area, district of Thunder Bay; *Ont. Dept. Mines*, vol. 69, pt. 7.
1964: Preliminary report on volcanism and mineralization in the Birch-Uchi Lakes area, district of Kenora; *Ont. Dept. Mines*, Prel. Rept. 1964-1.
1965: Mineralized volcanic complexes in the Porcupine-Kirkland Lake-Noranda region; *Econ. Geol.*, vol. 60, pp. 955–971.

Grant, A. C.
1966: A continuous seismic profile on the continental shelf off NE. Labrador; *Can. J. Earth Sci.*, vol. 3, pp. 725–730.

Grant, J. A.
1964: Rubidium–strontium isochron study of the Grenville Front near Lake Timagami, Ontario; *Science*, vol. 146, pp. 1049–1053.

Grenier, P. E.
1957: Beetz Lake area, Electoral District of Saguenay; *Que. Dept. Mines*, Geol. Rept. 73.

Gross, G. A.
1961: Iron-formations and the Labrador geosyncline; *Geol. Surv. Can.*, Paper 60-30.

Gunning, H. C. and Ambrose, J. W.
1939: The Temiskaming-Keewatin problem in the Rouyn-Harricanaw region, northwestern Quebec; *Trans., Roy. Soc. Can.*, vol. 33, sec. IV, pp. 19–47.

Hall, D. H. and Brisbin, W. C.
1965: Crustal structure from converted head waves in central western Manitoba; *Geophysics*, vol. 30, pp. 1053–1067.

Harrison, J. M.
1951: Precambrian correlation and nomenclature, and problems of the Kisseynew gneisses, in Manitoba; *Geol. Surv. Can.*, Bull. 20.

Hart, S. R., Aldrich, L. T., Darco, G. L., Tilton, G. R., Baadsgaard, H., Kouvo, O., and Steiger, R. H.
1963: Ages from Early Precambrian near Rainy Lake, Ontario; *Carnegie Inst. Wash.*, Year Book 625, p. 265.

Hawley, J. E.
1930: Geology of the Sapawe Lake area; *Ont. Dept. Mines*, vol. 38, pt. 6.

Heath, S. A.
1966: Sr ^{87}/Sr ^{86} ratios in anorthosites and some associated rocks; *in* Variations in isotopic abundances of strontium, calcium, argon and related topics; *Mass. Inst. Technol.*, 14th Ann. Progr. Rept., pp. 151–155.

Henderson, J. F.
1941: Gordon Lake south, District of Mackenzie, Northwest Territories; *Geol. Surv. Can.*, Map 645A.

Henderson, J. R. and Brown, I. C.
1966: Geology and structure of the Yellowknife greenstone belt, District of Mackenzie; *Geol. Surv. Can.*, Bull. 141.

Hewitt, D. F.
1957: The Grenville Province; *Roy. Soc. Can.*, Spec. Publ. No. 2, pp. 132–140.
1960: Nepheline syenite deposits of southern Ontario; *Ont. Dept. Mines*, vol. 69, pt. 8.
1962: Some tectonic features of the Grenville Province of Ontario; *Roy. Soc. Can.*, Spec. Publ. No. 4, pp. 102–117.
1963: The Temiskaming Series of the Kirkland Lake area; *Can. Mineralogist*, vol. 7, pt. 3, pp. 497–523.

Heywood, W. W.
1961: Geological notes, northern District of Keewatin; *Geol. Surv. Can.*, Paper 61-18.
1966: Geological notes on Operation Wager, Northwest Territories; *Geol. Surv. Can.*, Paper 66-10.

Hobson, G. D.
1967: A reconnaissance seismic refraction survey in Hudson Bay, Canada; *Proc. Seventh World Petrol. Congr.*, pp. 813–826.

Hoffman, P. F.
1967: Stratigraphy, sedimentology and palaeocurrents in the east arm of Great Slave Lake; *in* Report of activities, Pt. A, *Geol. Surv. Can.*, Paper 67-1, pp. 36–39.

Innes, M. J. S.
1960: Gravity and isostasy in Manitoba and northern Ontario; *Pub. Dom. Observ.*, vol. 21, No. 6.

Jackson, G. D.
1960: Belcher Islands, Northwest Territories; *Geol. Surv. Can.*, Paper 60-20.

Jolliffe, A. W.
1966: Stratigraphy of the Steeprock Group, Steep Rock, Ontario; *Geol. Assoc. Can.*, Spec. Paper, No. 3, pp. 75–99.

Kalliokoski, J.
1953: Interpretation of the structural geology of the Sherridon-Flin Flon region, Manitoba; *Geol. Surv. Can.*, Bull. 25.

Kindle, E. M.
1924: Geography and geology of the Lake Melville district, Labrador Peninsula; *Geol. Surv. Can.*, Mem. 141.

Kornik, L. J. and MacLaren, A. S.
1966: Aeromagnetic study of the Churchill-Superior boundary in northern Manitoba; *Can. J. Earth Sci.*, vol. 3, pp. 547–557.

Kranck, E. H.
1951: On the geology of the east coast of Hudson Bay and James Bay; *Acta Geographica*, vol. 11, pp. 1–71.

Krogh, T. E. and Hurley, P. M.
1965: Strontium isotopic variation and whole rock isochron studies in the Grenville Province of Ontario; 13th Ann. Progr. Rept. U.S. Atomic Energy Comm., *Mass. Inst. Technol.*, 1381-13, pp. 89–105.

Latulippe, Maurice
1966: The relationship of mineralization to Precambrian stratigraphy in the Matagami Lake and Val d'Or districts of Quebec; *Geol. Assoc. Can.*, Spec. Paper No. 3, pp. 21–42.

Leech, Alice Payne
1966: Potash-argon dates of basic intrusive rocks of the District of Mackenzie, N.W.T.; *Can. J. Earth Sci.*, vol. 3, pp. 389–412.

Lemon, R. R. H. and Blackadar, R. G.
1963: Admiralty Inlet area, Baffin Island, District of Franklin; *Geol. Surv. Can.*, Mem. 328.

Leslie, R. J. and Pelletier, B. R.
1965: Bedrock geology beneath Hudson Bay as interpreted by submarine physiography; *Bedford Inst. Oceanography*, Report 65–12.

Lord, C. S.
1942: Snare River and Ingray Lake map-areas, Northwest Territories; *Geol. Surv. Can.*, Mem. 235.

Lumbers, S. B.
1964: Preliminary report on the relationship of mineral deposits to intrusive rocks and metamorphism in part of the Grenville Province of southeastern Ontario; *Ont. Dept. Mines*, Prel. Rept. 1964-4.

Macdonald, R. D.
1941: Geology of the Hutchison Lake area; *Ont. Dept. Mines*, vol. 50, pt. 3.

Martison, N. W.
1953: Petroleum possibilities of the James Bay Lowland area; *Ont. Dept. Mines*, vol. 61, pt. 6.

McGlynn, J. C.
1957: Tumi Lake, District of Mackenzie, Northwest Territories; *Geol. Surv. Can.*, Paper 56-4.
1959: Elbow-Heming Lakes area, Manitoba; *Geol. Surv. Can.*, Mem. 305.
1966: Thekulthuli Lake area; *in* Report of activities, *Geol. Surv. Can.*, Paper 66-1, pp. 32–33.

Moore, J. M., Jr.
in press Angular unconformity within the Grenville Group in southeastern Ontario; *Proc. Geol. Assoc. Can.*

Moorhouse, W. W.
1957: The Proterozoic of the Port Arthur and Lake Nipigon regions, Ontario; *in* The Proterozoic in Canada, *Roy. Soc. Can.*, Spec. Publ. No. 2, pp. 67–76.
1965: Stratigraphic position of sulphides in the Archaean; *Trans. Can. Inst. Mining Met.*, vol. 58, pp. 947–950.

Nelson, S. J.
1964: Ordovician stratigraphy of northern Hudson Bay Lowland; *Geol. Surv. Can.*, Bull. 108.

Nelson, S. J. and Johnson, R. D.
1966: Geology of Hudson Bay Basin; *Bull. Can. Petrol. Geol.*, vol. 14, pp. 520–578.

Osborne, F. F.
1936: Lachute map-area; *Que. Bur. Mines,* Ann. Rept., pt. C, pp. 1–40.

Osborne, F. F. and Morin, M.
1962: Tectonics of part of the Grenville subprovince in Quebec; *Roy. Soc. Can.,* Spec. Publ. No. 4, pp. 118–143.

Parsons, G. E.
1961: Niobium-bearing complexes east of Lake Superior; *Ont. Dept. Mines,* Geol. Rept. No. 3.

Patterson, J. M.
1963: Geology of the Thompson-Moak Lake area; *Man. Dept. Mines Natl. Res.,* Publ. 60-4.

Payne, A. V., Baadsgaard, H., Burwash, R. A., Cumming, G. L., Evans, C. R. and Folinsbee, R. E.
1965: A line of evidence supporting continental drift; *Intern. Union Geol. Sci.,* Upper Mantle Symp., New Delhi, 1964, p. 83.

Pettijohn, F. J.
1937: Early Precambrian geology and correlation problems of the northern subprovince of the Lake Superior region; *Bull. Geol. Soc. Am.,* vol. 48, pp. 153–202.
1943: Archaean sedimentation; *Bull. Geol. Soc. Am.,* vol. 54, pp. 925–972.
1962: Dimensional fabric and ice flow, Precambrian (Huronian) glaciation; *Science,* vol. 135, p. 442.

Philpotts, A. R.
1966: Origin of the anorthosite-mangerite rocks in southern Quebec; *J. Petrol.,* vol. 7, pp. 1–64.

Pienaar, P. J.
1963: Stratigraphy, petrology and genesis of the Elliot Group, Blind River, Ontario, including the uraniferous conglomerate; *Geol. Surv. Can.,* Bull. 83.

Pollock, D. W.
1962: Some petrogenic-structural relationships in an area of Grenville rocks; *Trans. Roy. Soc. Can.,* sec. III, vol. 56, pp. 127–142.

Quirke, T. T. and Collins, W. H.
1930: The disappearance of the Huronian; *Geol. Surv. Can.,* Mem. 160.

Remick, J. H., Gillain, P. R. and Durden, C. J.
1963: Geology of Rupert Bay-Missisicobi River area, Abitibi and Mistassini Territories; *Que. Dept. Natl. Res.,* Prel. Rept. No. 498.

Retty, J. A.
1944: Lower Romaine River area, Saguenay county; *Que. Bur. Mines,* Geol. Rept. 19.

Robertson, D. S.
1951: The Kisseynew lineament, northern Manitoba; *Precambrian,* vol. 24, No. 5, pp. 8–18.
1953: Batty Lake map-area, Manitoba; *Geol. Surv. Can.,* Mem. 271.

Robertson, J. A.
1963: Geology of the Iron Bridge area; *Ont. Dept. Mines,* Geol. Rept. No. 17.
1967: Recent geological investigations in the Elliot Lake-Blind River uranium area, Ontario; *Ont. Dept. Mines,* Miscell. Paper 9.

Robertson, W. A.
1964: Palaeomagnetic results from northern Canada suggesting a tropical Proterozoic climate; *Nature,* vol. 204, pp. 66–67.

Roscoe, S. M.
1957: Geology and uranium deposits, Quirke Lake-Elliot Lake, Blind River area, Ontario; *Geol. Surv. Can.,* Paper 56-7.
1965: Geochemical and isotopic studies, Noranda and Metagami areas; *Trans. Can. Inst. Mining Met.,* vol. 58, pp. 965–971.

Ross, J. V.
1959: Mesa Lake map-area, Northwest Territories; *Geol. Surv. Can.,* Map 30-1959.

Ross, J. V. and McGlynn, J. C.
1965: Snare-Yellowknife relations, District of Mackenzie, N.W.T., Canada; *Can. J. Earth Sci.,* vol. 2, pp. 118–130.

Rousell, D. H.
1965: Geology of the Cross Lake area; *Man. Dept. Mines Natl. Res.,* Publ. 62-4.

Sanford, B. V., Norris, A. W. and Bostock, H. H.
1968: Geology of the Hudson Bay Lowlands; *Geol. Surv. Can.,* Paper 67-60.

Schenk, P. E.
1965: Depositional environment of the Gauganda Formation (Precambrian) at the south end of Lake Temagami, Ontario; *J. Sed. Petrol.,* vol. 35, pp. 309–318.

Shaw, D. M., Reilly, G. A., Muysson, J. R., Pattenden, G. E. and Campbell, F. E.
1967: An estimate of the chemical composition of the Canadian Precambrian Shield; *Can. J. Earth Sci.,* vol. 4, pp. 829–853.

Shklanka, R.
1965: Steep Rock iron area, district of Rainy River; *in* Summary of field work, *Ont. Dept. Mines,* Prel. Rept. 1965–3, pp. 12–14.

Silver, L. T. and Lumbers, S. B.
1965: Geochronologic studies in the Bancroft-Madoc area of the Grenville Province, Ontario, Canada; (abs.) *Geol. Soc. Am.,* 1965 Ann. Meeting.

Smith, C. H.
1962: Notes on the Muskox intrusion, Coppermine River area, District of Mackenzie; *Geol. Surv. Can.,* Paper 61-25.

Sopher, S. R.
1963: Palaeomagnetism in the Sudbury Irruptive; *Geol. Surv. Can.,* Bull. 90.

Stevenson, I. M.
1963: Leaf River map-area, New Quebec; *Geol. Surv. Can.,* Paper 62-24.
1965: Leaf River map-area, Quebec and District of Keewatin; *Geol. Surv. Can.,* Paper 64-28.

Stockwell, C. H.
1936: Great Slave Lake, District of Mackenzie, Northwest Territories; *Geol. Surv. Can.,* Map 378A, 377A.
1945a: Beresford Lake area; *Geol. Surv. Can.,* Map 809A.
1945b: Rice Lake area; *Geol. Surv. Can.,* Map 810A.
1945c: Gem Lake area; *Geol. Surv. Can.,* Map 811A.

Stockwell, C. H. (*cont.*)
1960: Flin Flon-Mandy, Manitoba and Saskatchewan; *Geol. Surv. Can.*, Map 1078A.
1961: Structural provinces, orogenies, and time-classification of rocks of the Canadian Precambrian Shield; *Geol. Surv. Can.*, Paper 61-17.
1964: Fourth report on structural provinces, orogenies and time-classification of rocks of the Canadian Precambrian Shield; *Geol. Surv. Can.*, Paper 64-17.

Taylor, F. C.
1963: Snowbird Lake map-area, District of Mackenzie; *Geol. Surv. Can.*, Mem. 333.
1968: Operation Torngat, Quebec, Newfoundland-Labrador; *in* Report of activities, *Geol. Surv. Can.*, pt. A, Paper 68-1, pp. 149–150.

Taylor, S. R.
1964: Abundance of chemical elements in the continental crust: a new table; *Geochim. Cosmochim. Acta*, vol. 28, p. 1273.

Thomson, J. E.
1953: Geology of the Mamainse Point copper area; *Ont. Dept. Mines*, vol. 62, pt. 4.
1956: Geology of the Sudbury basin; *Ont. Dept. Mines*, vol. 65, pt. 3.
1962: Extent of the Huronian system between Lake Temagami and Blind River, Ontario; *in* Tectonics of the Canadian Shield, *Roy. Soc. Can.*, Spec. Publ. No. 4, pp. 76–89.

Thomson, J. E. and Card, K. D.
1963: Geology of Kelley and Davis townships; *Ont. Dept. Mines*, Geol. Rept. 15.

Thomson, R.
1957: The Proterozoic of the Cobalt area; *in* The Proterozoic in Canada, *Roy. Soc. Can.*, Spec. Publ. No. 2, pp. 40–45.

Thorsteinsson, R. and Tozer, E. T.
1962: Banks, Victoria, and Stefansson Islands, Arctic Archipelago; *Geol. Surv. Can.*, Mem. 330.

Tremblay, L. P.
1957: Ore deposits around Uranium City; *in* Structural geology of Canadian ore deposits, *Trans. Can. Inst. Mining Met.*, vol. 11, pp. 211–220.

Tuke, M. F., Dineley, D. L. and Rust, B. R.
1966: The basal sedimentary rocks in Somerset Island, N.W.T.; *Can. J. Earth Sci.*, vol. 3, pp. 697–711.

Van Schmus, W. R.
1965: The geochronology of the Blind River-Bruce mines area, Ontario, Canada; *J. Geol.*, vol. 73, pp. 755–780.

Walton, M. S. and DeWaard, D.
1963: Orogenic evolution of the Precambrian in the Adirondack Highlands, a new synthesis; *Proc. Koninkl. Ned. Akad. Wetenschap.*, Amsterdam, ser. B, pp. 98–106.

Wetherell, G. W., Davis, G. L. and Tilton, G. R.
1960: Age measurements on minerals from the Cutler batholyth, Cutler, Ontario; *J. Geophys. Res.*, vol. 65, pp. 2461–2466.

Wheeler, E. P.
1960: Anorthosite-adamellite complex of Nain, Labrador; *Bull. Geol. Soc. Am.*, vol. 71, pp. 1755–1762.

Williams, Howel
1956: Glowing avalanche deposits of the Sudbury basin; *Ont. Dept. Mines*, vol. 65, pt. 3.

Wilson, H. D. B.
1956: Structure of lopoliths; *Bull. Geol. Soc.*, vol. 67, pp. 289–300.

Wilson, H. D. B. and Brisbin, W. C.
1961: Regional structure of the Thompson-Moak Lake nickel belt; *Bull. Can. Inst. Mining Met.*, vol. 54, pp. 815–822.

Wilson, H. D. B., Andrews, Peter, Moxham, R. L. and Ramlal, K.
1965: Archaean volcanism in the Canadian Shield; *Can. J. Earth Sci.*, vol. 2, pp. 161–175.

Wilson, J. T.
1949: Some major structures in the Canadian Shield; *Trans. Can. Inst. Min. Met.*, vol. 52, pp. 231–242.

Wilson, M. E.
1933: The Clare River syncline; *Trans. Roy. Soc. Can.*, vol. 27, sec. 4, pp. 7–11.
1939: The Canadian Shield; *Geologie der Erde*, Geology of North America, I, p. 232.
1943: Early Precambrian succession in western Quebec; *Trans. Roy. Soc. Can.*, vol. 37, sec. 4, pp, 119–138.
1962: Rouyn-Beauchastel map-area, Quebec; *Geol. Surv. Can.*, Mem. 315.
1965: The Canadian Shield; *in* the Geologic systems, Intersciences Publishers, vol. 2, pp. 263–415.

Woodcock, J. R.
1960: Geology of the Richmond Gulf area, New Quebec; *Proc. Geol. Assoc. Can.*, vol. 12, pp. 21–39.

Wright, G. M.
1955: Geological notes in central District of Keewatin, Northwest Territories; *Geol. Surv. Can.*, Paper 55–17.

Wynne-Edwards, H. R.
1957: Structure of the Westport concordant pluton in the Grenville, Ontario; *J. Geol.*, vol. 65, pp. 639–649.
1961: Ossokmanuan Lake, west half, Newfoundland; *Geol. Surv. Can.*, Map 17-1961.
1963: Flow folding; *Am. J. Sci.*, vol. 261, pp. 793–814.
1964: The Grenville Province and its tectonic significance; *Proc. Geol. Assoc. Can.*, vol. 15, pp. 53–67.

Wynne-Edwards, H. R., Gregory, A. F., Hay, P. W., Giovanella, C. A. and Reinhardt, E. W.
1966: Mount Laurier and Kempt Lake map-areas, Quebec; *Geol. Surv. Can.*, Paper 66-32.

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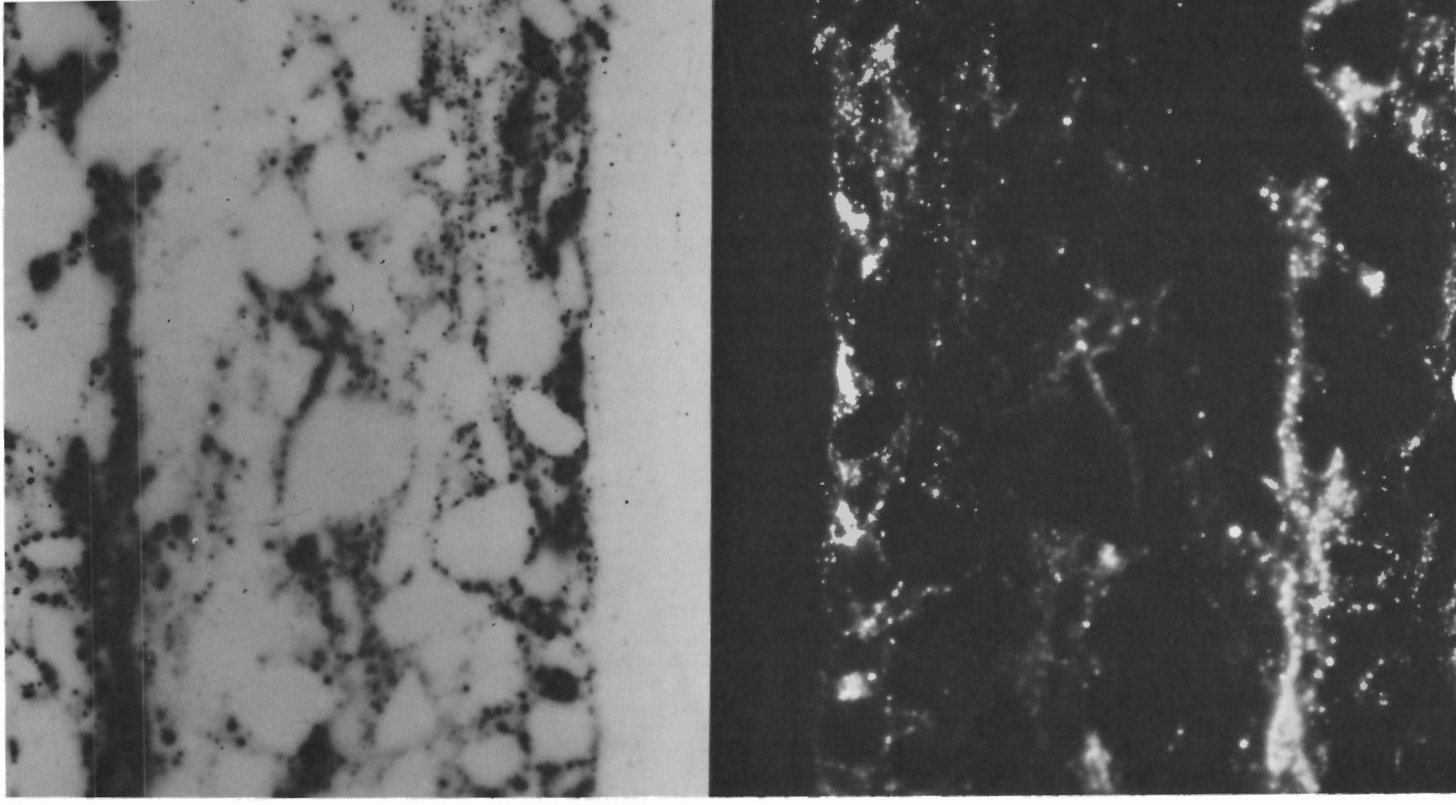

INTRODUCTION

A wide range of mineral commodities is produced from the Canadian Shield including precious metals, base metals, ferrous and ferro-alloy metals, nuclear metals, and some non-metals, notably insulants, and chemical and metallurgical minerals (Table V-1). The ten most valuable mineral commodities produced in the Canadian Shield in 1966 in order of decreasing value were: iron ore, nickel, copper, zinc, gold, uranium, platinum group metals, silver, magnesium, and lead. These ten commodities account for 42 per cent of the total mineral production including mineral fuels in Canada in 1966.

Iron ore is produced from banded iron-formations in Quebec and Labrador and also northern Ontario. Nickel production is from large nickel–copper deposits at Sudbury, Ontario, and the Thompson–Moak Lake and Lynn Lake areas of Manitoba. Formerly, other production came from Rankin Inlet on the west shore of Hudson Bay. Copper is derived from the nickel–copper deposits at Sudbury and Lynn Lake, from large stratiform copper–zinc deposits in northern Quebec, Ontario, and Manitoba. Gold is obtained both as a byproduct of the base metal operations and from lode deposits in Ontario, Quebec, Manitoba, and the Northwest Territories. Uranium production is from large uraniferous quartz–pebble conglomerates in the Elliot Lake area of Ontario. Formerly, other production came from vein and pegmatitic deposits

TABLE V-1 *Production of the ten main mineral commodities from the Canadian Shield in 1966*

	Quantity ($\times 10^6$)	Value ($\times 10^6$ Dollars)	Percentage of Total Canadian Production (by quantity)
Iron ore	38 (ton)	406	94.0
Nickel	445 (lb)	375	99.5
Copper	738.7 (lb)	331.4	73.0
Zinc	877.2 (lb)	132.4	45.5
Gold	3.3 (troy oz)	119.1	95.1
Uranium (U_3O_8)	7.9 (lb)	54.3	100.0
Platinum group metals	0.4 (troy oz)	32.3	100.0
Silver	21.4 (troy oz)	29.9	64.0
Magnesium	13.4 (lb)	4.2	100.0
Lead	9.6 (lb)	1.4	1.6
Total value: $1,486,000,000 (42% of total Canadian production)			

1 The Introduction and sections on Metallogenic Associations and Metallogenic Evolution were prepared by A. M. Goodwin; Copper–Zinc, Lead, and Uranium by A. H. Lang; Nickel, Platinum, and Chromium by J. A. Chamberlain; Iron by G. A. Gross; Gold by D. R. E. Whitmore; Silver and Cobalt by R. W. Boyle and A. G. Johnston; Titanium by E. R. Rose; Beryllium, Cesium, Lithium, Molybdenum, Niobium, Tantalum, Tin, and Tungsten by R. Mulligan. The remaining parts are from previous editions with revisions by the staff of the Mineral Deposits Section. When acknowledging, reference should be made to individual author and page number.

*See Page 793

V

Economic Minerals of the Canadian Shield

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Uraniferous conglomerate, Blind River, Ontario. Section on right under natural light shows rounded quartzite pebbles with grains of pyrite in matrix. Autoradiograph negative print forms centre section and a positive print the left section.

in southeastern Ontario, Saskatchewan, and the Northwest Territories. Silver is produced from silver–cobalt deposits in the Cobalt area, Ontario, as a byproduct of copper–zinc operations in northern Quebec, Ontario, and Manitoba, and from gold–silver deposits in Quebec, Ontario, Manitoba, and the Northwest Territories. Lead is a byproduct of copper–zinc production in Quebec, Ontario, and Manitoba. Titanium oxide comes from titaniferous magnetite deposits in Quebec.

Certain belts of rocks are particularly rich in mineral deposits. The most productive belt, which lies in Quebec and Ontario, contains the great copper–zinc, uranium, gold, nickel, and iron deposits of the Chibougamau, Matagami, Noranda, Timmins, Blind River, Michipicoten, Manitouwadge, and Steeprock Lake areas. Additional productive belts, the source of copper, zinc, nickel, uranium, gold, and silver, occur at Flin Flon, Lynn Lake, Lake Athabasca, Great Slave Lake, and Great Bear Lake. Major iron-bearing belts cross Ungava and Baffin Island.

The rates of production of mineral commodities from the Canadian Shield, and their individual value, fluctuate over the years with changing market demands and technology and the impact of new discoveries. Gold production has been in steady decline for 30 years in response to the fixed market price of gold bullion. Production of nickel and iron have increased steadily in response to strong demand. Uranium production, directly related to its use as a fuel, has fluctuated drastically in recent years. Silver production is destined to increase substantially due to the recent discovery of a single, unusually large copper–zinc–silver deposit at Kidd Creek, Ontario. Mineral production has come principally from the margins of the Shield (Map 1252A), particularly the southern parts, mainly as a matter of accessibility and transportation. The northern and central parts of the Shield, far removed from habitation, difficult to reach, and expensive to supply, have received correspondingly less exploration attention. Despite this, a substantial number of gold, nickel, and iron occurrences have been found, sufficient to suggest that many others await discovery. However, the paucity of significant copper–zinc and uranium discoveries to date in the northern parts of the Shield raises the possibility of a regional deficiency in these and other metals.

History of Exploration

Geological studies and mineral exploration have been inextricably linked in the Canadian Shield. In the early stages exploration travel across the Shield was by canoe and other shallow-draft boats on the navigable streams and lakes. Since the advent of air transportation, float-equipped planes have habitually used lakes and streams for landing and recently helicopters have been used to reach still less accessible terrain. Systematic searches for minerals may be said to have begun with the founder of the Geological Survey of Canada, Sir William Logan. Appointed "Provincial Geologist" in 1842, Logan's assignment was to make a geological survey of Canada and to organize ". . . a plan of investigation as may promise to

lead to the most speedy and economic development of the mineral resources of the country." Logan's early reports of progress and annual reports culminating in his classic "Geology of Canada, 1863" are storehouses of information on mineral occurrences in eastern Canada; included is reference to copper occurrences on the north shore of Lake Huron destined to become the Bruce mine, the first copper mine in Canada.

In 1852, Sterry Hunt identified ilmenite in the "titanic iron ore" at St. Urbain, Quebec. Alexander Murray, in 1846, first reported nickel at the Wallace mine near Whitefish Falls, Ontario, and, in 1856, described nickel in "magnetic trap" on Salter's meridian near the present site of the International Nickel Company Creighton mine. In 1866, H. G. Vennor reported the first occurrence of gold in Ontario at the Richardson mine north of Madoc. Between 1877 and 1895 Robert Bell and A. P. Low reported large iron deposits on the Belcher Islands of Hudson Bay and along the Koksoak River in northern Quebec and Labrador. G. C. Hoffman first reported niobium in Canada in 1882 in Maissoneuve township, Quebec. In 1900, J. M. Bell reported the copper–cobalt occurrences later found by Gilbert Labine to contain pitchblende at Great Bear Lake, Northwest Territories. In 1903, W. G. Miller identified silver in ore discovered by Fred LaRose at Cobalt, Ontario. In 1904, W. A. Parks reported gold in quartz veins at Kirkland Lake and Larder Lake, Ontario. E. H. Horne, in 1917, located mineralized rock at the Horne orebody, Noranda, Quebec. In 1934, H. V. Ellsworth identified pitchblende in vein material from Beaverlodge, Saskatchewan. J. E. Thomson, in 1931, reported the occurrence of sulphide minerals near Lake Manitouwadge, Ontario. Franc Joubin located large uranium deposits by drilling at Elliot Lake, Ontario in 1953. In 1962–65 high-grade hematite iron ore was explored in Baffin Island by Murray Watts and associates.

Exploration Techniques

The traditional methods of mineral exploration involving geological mapping and conventional prospecting with or without the aid of simple instruments such as dip-needle and gold pan have gradually evolved. Modern, airborne, geophysical surveys employ magnetic, electromagnetic, radioactive, and remote sensing devices. Ground geophysical surveys produce electrical, magnetic, radioactive, and seismic data. Equally sophisticated geochemical programs comprising stream, soil, and bedrock sampling, and wall-rock alteration studies are based on complex instruments and analytical procedures.

Present exploration practices include intensive searches for mineral deposits in large areas selected on the basis of known geological relationships. Increasingly, mineral deposits are viewed as integral parts of complex geological environments and geological theory is, therefore, an essential guide to successful exploration. Dramatic evidence of the impact of technology upon exploration is provided by a comparative summary of discovery methods in recent decades (Lang, 1967). In the decade 1946–55, of the seventy-seven mines brought into production, fifty-three (69 per cent) are attributed to conventional prospecting; seventeen (22 per cent) to geological methods; and seven (9 per cent) to geophysical prospecting. In the succeeding decade, 1955–65, of the 175 new mines brought into production, eighty-seven (50 per cent) are attributed to conventional prospecting; forty-nine (28 per cent) to geological methods; twenty-eight (16 per cent) to geophysical methods; and eleven (6 per cent) to other methods. Geochemical prospecting was a supporting method in some of the discoveries in the 1955–65 decade. Lang concludes that conventional prospecting is still important, that geological and geophysical methods are about equally important, that geochemical prospecting is increasing in value, and that combined programs of mineral exploration are increasingly effective.

STRUCTURAL PROVINCES AND METALLOGENIC ASSOCIATIONS

The imprint of the main Precambrian orogenies that divide the Shield into the seven structural provinces also gives rise to distinctive metallogenic associations. The oldest orogeny, the Kenoran, dated at about 2,500 m.y., is the last important interval of folding, metamorphism, and intrusion in Superior and Slave Provinces. The Hudsonian Orogeny, dated at about 1,700 m.y. occurred throughout Churchill, Bear, and Southern Provinces. The Nain Province was affected by the Elsonian Orogeny. The Grenvillian Orogeny, dated at about 950 m.y., affected Grenville Province. The Canadian Shield contains many distinctive lithic communities of which the mineral occurrences themselves are a very important part. Most mineral deposits are considered to express the geological environments prevailing during the periods of host rock accumulation, consolidation, and deformation. Accordingly, an understanding of the original geological environment commonly provides metallogenic insight and contributes substantially to mineral exploration.

Archean lithic assemblages contain great thicknesses of volcanic rocks, predominantly basalt–andesite–rhyolite associations typical of orogenically active continental margins including island arcs and of flysch-type greywacke–conglomerate–breccia–shale assemblages also produced in orogenically unstable environments. Archean granitic rocks include a high proportion of layered migmatite and gneiss attributed in large part to metasomatic alteration of pre-existing sedimentary rocks. Archean mineral deposits are likewise products of orogenic environments. They include stratiform polymetallic sulphide,

gold–silver, and nickel sulphide deposits together with sedimentary iron-formations. The mineral deposits are associated preferentially with igneous rocks, especially volcanic rocks.

Proterozoic lithic assemblages of the Shield feature platformal or miogeosynclinal deposits including great thicknesses of mature sandstone–quartzite, dolomite and limestone, shale, granular iron-formation, and tholeiitic flood basalts. In some belts, geosynclinal-type basalt and associated greywacke and shale occur together with large mafic and ultramafic intrusions, the latter commonly flat lying and occasionally layered. Alkalic intrusions, including carbonatites, are widely though sparsely distributed. Proterozoic mineral deposits are, accordingly, mainly products of comparatively stable, platformal crustal environments. Included are extensive placer uranium deposits, granular iron-formations, carbonate-enclosed lead–zinc deposits, complex silver–cobalt and nickel–copper sulphide and sulpharsenide deposits in the mafic intrusions, titaniferous magnetite deposits, and niobium-bearing carbonatites.

Superior Province

Superior Province is characterized by easterly trending belts of Archean supracrustal rocks separated by large areas of granitic rocks. The supracrustal rocks in many of the belts are of low metamorphic grade. Mafic intrusions and rare post-orogenic alkalic intrusions are present locally.

Numerous stratiform polymetallic sulphide deposits such as the copper–zinc–silver–gold affiliation are associated with the volcanic rocks. The deposits occur either in the volcanic rocks and associated mafic intrusions or in nearby sediments. Notable examples are the deposits at Chibougamau, Matagami, and Noranda in Quebec, and at Timmins, Timagami, and Manitouwadge in Ontario.

Banded iron-formation of the Algoma type is common in the volcanic-sedimentary belts. The larger, richer parts may constitute orebodies. Large reserves of low-grade concentrating-type, magnetite–hematite ores are present at Kirkland Lake, Timagami, Bruce Lake, North Spirit Lake, and Lake St. Joseph, all in northern Ontario. Siderite and pyrite deposits are present locally as are secondary hematite–limonite deposits.

Gold lode deposits are common in the volcanic-rich belts, many at the contact with small granitic stocks or in shear zones. The typical quartz–carbonate veins contain sulphide minerals, tellurides, and free gold. Native silver is also generally present. Some gold deposits occur in banded iron-formation. At Kirkland Lake the gold deposits are associated with syenite stocks. In addition, much gold is found in the large polymetallic sulphide deposits. Large native silver orebodies are associated with mafic sills of Proterozoic age in Cobalt Subprovince and with the large volcanic-associated polymetallic sulphide deposits in Ontario and Quebec. Molybdenum-, lithium- and beryllium-bearing deposits occur in pegmatitic and granitic rocks in Quebec and Ontario.

Slave Province

Slave Province contains belts of Archean volcanic and sedimentary rocks that generally trend north and are separated by extensive areas of granitic rocks. The most common metal in Slave Province is gold. It is widely distributed in a variety of rocks; more than a thousand occurrences have been reported (Lang, 1962). The larger, producing deposits are associated with volcanic rocks and intrusions in the southern part of the province. A few occurrences of copper, lead, cobalt, nickel, and native silver have been found also in the south. Pegmatites with small amounts of lithium, tungsten, beryllium, niobium, tantalum, and tin are known in the eastern part of the province. As known, significant deposits of the base metals, uranium and iron, are rare to absent.

Bear Province

This province is underlain by Proterozoic sedimentary and volcanic rocks, in part deformed by the Hudsonian Orogeny, and in part later and flat lying. The characteristic metal of Bear Province is uranium. Hundreds of occurrences of pitchblende, mainly in veins, are known over a large part of the province. East of Great Bear Lake small deposits contain native silver, cobalt, nickel, copper, and gold. In the northern part of the province basaltic lava flows are mineralized with copper.

Churchill Province

Churchill Province, the largest in the Canadian Shield, contains a great variety of rocks of both Archean and Proterozoic ages. Archean volcanic-rich belts contain mineral associations similar to those of Superior Province. Polymetallic sulphide deposits and occurrences of the copper–zinc–gold–silver affiliation occur in the Flin Flon belt of Manitoba and Saskatchewan and the Ennadai belt of the Northwest Territories. Nickel–copper sulphide ores are associated with mafic to ultramafic intrusions in the Lynn Lake and Thompson areas of Manitoba and at Rankin Inlet and Ferguson Lake in the Northwest Territories. Numerous gold lode occurrences are present in the Flin Flon belt in Manitoba, in the area north of LaRonge, Saskatchewan, and in the eastern part of the Ennadai belt. Most occurrences consist of gold-bearing quartz veins in sheared volcanic and sedimentary rocks in the vicinity of porphyry granite intrusions.

Major iron deposits are present in the iron-formations of the Labrador Geosyncline. The iron ores take the form of direct-shipping hematite ores in the central part of the belt and of concentrating-type magnetite–hematite ores in the southern part. Low-grade iron deposits are present in the sedimentary sequences on Belcher Islands and those adjacent to the mainland of Hudson Bay. Large high-grade hematite iron deposits lie in metasedi-

mentary strata on Baffin Island. Magnetite-bearing iron-formations of possible commercial grade and size are present in the Ennadai belt. Smaller bands of iron-formation, including iron sulphide concentrations, are present in some narrow belts of metamorphosed volcanic and sedimentary rocks in northern District of Keewatin and on southern Baffin Island.

Uranium deposits occur in sedimentary and granitic rocks in the Beaverlodge area bordering Lake Athabasca, Saskatchewan. Pitchblende is present in brecciated granitized material and as calcitic vein-filling. At the Gunnar mine carbonatized albite syenite contains disseminated pitchblende and uranophane. Uranium mineralization also occurs in Aphebian sediments near Lake Mistassini in northern Quebec.

Asbestos occurrences are associated with mafic to ultramafic bodies in the Cape Smith belt in northern Quebec. Crocidolite showings have been found in Aphebian iron-bearing rocks near Knob Lake, Quebec.

Grenville Province

Grenville Province includes a great mixture of rocks of the various Precambrian eras. The Grenvillian Orogeny is the youngest of the major Precambrian orogenies that affected them. The mineral associations are correspondingly varied. Large magnetite–hematite deposits occur in highly metamorphosed iron-formation that forms the southern extension of the Aphebian rocks of Labrador Geosyncline. Smaller titaniferous magnetite skarn deposits border mafic intrusions in the southern part of the province. Small, titanium-free magnetite deposits occur in limestone in southeast Ontario and Quebec. Large deposits of ilmenite, the principal ore of titanium, occur as magmatic segregations in the Elsonian anorthosites of southern Quebec as at Allard Lake and St. Urbain. Niobium-bearing deposits are found in carbonatites near Lake Nipissing, Ontario, and Oka, Quebec. Uraniferous pegmatites occur in metamorphosed gneiss at Bancroft, Ontario. Small deposits of gold, lead–zinc, and molybdenum as well as the non-metallic nepheline syenite and the magnesium ores dolomite and brucite are present locally.

Southern Province

Although one of the smaller structural provinces of the Shield, Southern Province of Ontario has yielded great mineral wealth. The Sudbury nickel deposits occur in a thick sill of norite, quartz diorite, and micropegmatite emplaced at the unconformity between the Aphebian strata and Archean crystalline rocks. In addition to nickel, large quantities of copper and smaller amounts of gold, silver, and platinum group metals are present. Huge tonnages of uranium ore are contained in the quartz–pebble conglomerates of the lower part of the Aphebian Bruce Group in the Blind River area. The ore minerals, brannerite, uraninite, pitchblende, and monazite, are considered to represent placer deposits filling erosional depressions in the basement rocks. In the Port Arthur area, silver deposits lie in Animikie sediments at the contact with Helikian mafic sills and dykes. Small lead–zinc deposits occur in Helikian red beds. The Gunflint iron-formation in the Thunder Bay district contains large submarginal iron deposits.

METALLOGENIC EVOLUTION OF THE CANADIAN SHIELD

Studies of geological and metallogenic relations in the Canadian Shield have led to the concept of crustal evolution by growth of protocontinents (Goodwin, 1968). According to this concept, the main facets of Precambrian crustal evolution were from thin unstable protocontinents to a thick stable continental mass, representing pre-geosynclinal and early geosynclinal stages, respectively. The sites of supracrustal accumulation progressed from basins and trenches with random to sublinear distribution in Archean time, to stable platforms, broad basins, and comparatively long linear primitive geosynclines in Proterozoic time. Preferred easterly and northerly tectonic directions of the Archean changed to preferred northeasterly and northwesterly directions of the Proterozoic. Orogenic, flysch-type Archean sedimentation changed to stable and mature, shelf-type Proterozoic sedimentation. Volcanic activity changed from compositionally simple and sequential in Archean time to compositionally varied and non-sequential in Proterozoic time. Correspondingly, the pattern of mineralization changed from comparatively simple native gold and silver—simple base metal sulphide–iron–nickel assemblages of Archean time to the complex polymetallic sulphide and sulpharsenide–uraniferous–lead–iron–nickel mineral assemblages characteristic of the Proterozoic.

Archean Crust

Archean protocontinents are considered to be primary crustal units, comprising granitic nuclei or cratonic elements and linear, supracrustal orogenic elements. Incipient protocontinents feature a random to sublinear distribution of small cratons and orogens. Mature protocontinents feature a peripheral distribution of longer linear orogens about larger central cratons. The proto-

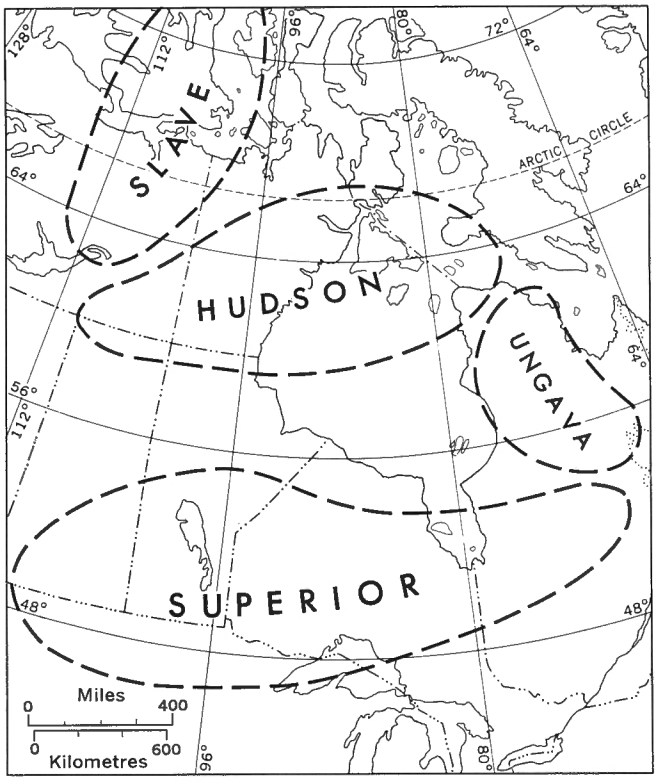


FIGURE V-1. Postulated Archean protocontinents (by A. M. Goodwin).

continents grew by surficial accretion of orogenic elements and by subcrustal addition of new, mantle-derived crustal material. With continued growth, the protocontinents, at various stages of development, merged to form a large stable continental mass. In the Canadian Shield, the remnants of at least four protocontinents in different stages of growth and development are evident: the Superior, Hudson, Slave, and Ungava Protocontinents (Fig. V-1).

Superior Protocontinent. This protocontinent contains a number of alternating volcanic- and sedimentary-rich orogenic belts together with irregular granitic masses. The southern part of the protocontinent contains three main east-trending volcanic-rich belts: the Uchi, Wabigoon, and Abitibi–Wawa belts (Fig. V-2). The northwestern part also contains three, though less well defined, volcanic-rich belts: the Windigo, Amisk, and LaRonge belts. The orogenic belts are distributed about a main granitic nucleus or craton that is partly exposed in northwestern Ontario and the adjacent part of Manitoba. The volcanic-rich belts in the southern part of the Superior Protocontinent, viewed from north to south, exhibit the following general progressions: 1) the belts increase in width; 2) individual areas of volcanic rocks within the belts increase in size; 3) the quantity of felsic volcanic rock increases; and 4) the volcanic assemblages as known increase in chemical diversity. The northwestern belts, though less well known, in part exhibit similar progressions to the north. These core-to-periphery progressions may also correspond to younger ages. Accordingly, a long and complex orogenic history involving many episodes of granite emplacement is postulated; however many local divergencies from these generalizations are undoubtedly present.

Hudson and Slave Protocontinents. Random to sublinear distribution of comparatively short discontinuous volcanic and sedimentary-rich belts is characteristic of the central and northern parts of the Canadian Shield. East to east-northeastern trends predominate in the Hudson Protocontinent and northern trends in the Slave Protocontinent. In the Hudson Protocontinent, on the basis of regional trends and location of predominantly granitic masses, cratonic elements are postulated for the areas immediately northwest of Hudson Bay and possibly northeast of Lake Athabasca. In the Slave Protocontinent, the northerly trend of the belts and distribution of granitic masses suggest the presence of a cratonic mass in the northern part, now mainly covered by post-Archean rocks.

Ungava Protocontinent. Very little is known about Archean volcanic and sedimentary rocks in the highly metamorphosed, structurally obscure part of the Shield east of Hudson Bay. Long linear belts of Proterozoic rocks girdle all but the southwestern part of a large area of predominantly granitic rocks in northern Quebec. On this basis the northerly trending Ungava Protocontinent is postulated. Other remnants of Archean protocontinents may be present in northeastern parts of the Shield such as Baffin Island and eastern Ungava.

Archean Mineralization

Nearly all known mineral occurrences in Archean rocks are located in the volcanic-rich or greenstone belts and most occurrences, whether they consist of sulphide masses, gold-bearing quartz veins, nickeliferous mafic intrusions, or iron sediments, are closely associated with the volcanic rocks themselves. Many mineral occurrences are associated with concentrations of felsic volcanic rocks, the sites of ancient volcanic centres. These closely associated metals and volcanic rocks are viewed as consanguineous igneous products (Goodwin, 1965). Base metal deposits occur preferentially in the outer, presumably younger parts of the Superior Protocontinent, whereas gold, iron, and nickel mineralization is more uniformly distributed in direct proportion to the quantity of volcanic rocks. Established mineral patterns in the Slave and Hudson Protocontinents resemble those in the inner or base-metal deficient part of the Superior Protocontinent. The metallogenic patterns of the Canadian Shield illustrated on Figures V-2 to V-5, are based on the present stage of exploration and hence are influenced by many variables (Goodwin, 1968b). In preparing these figures a balanced representation of occurrences rather than a demonstration of all occurrences and types of mineral deposits has been sought for each part of the Shield.

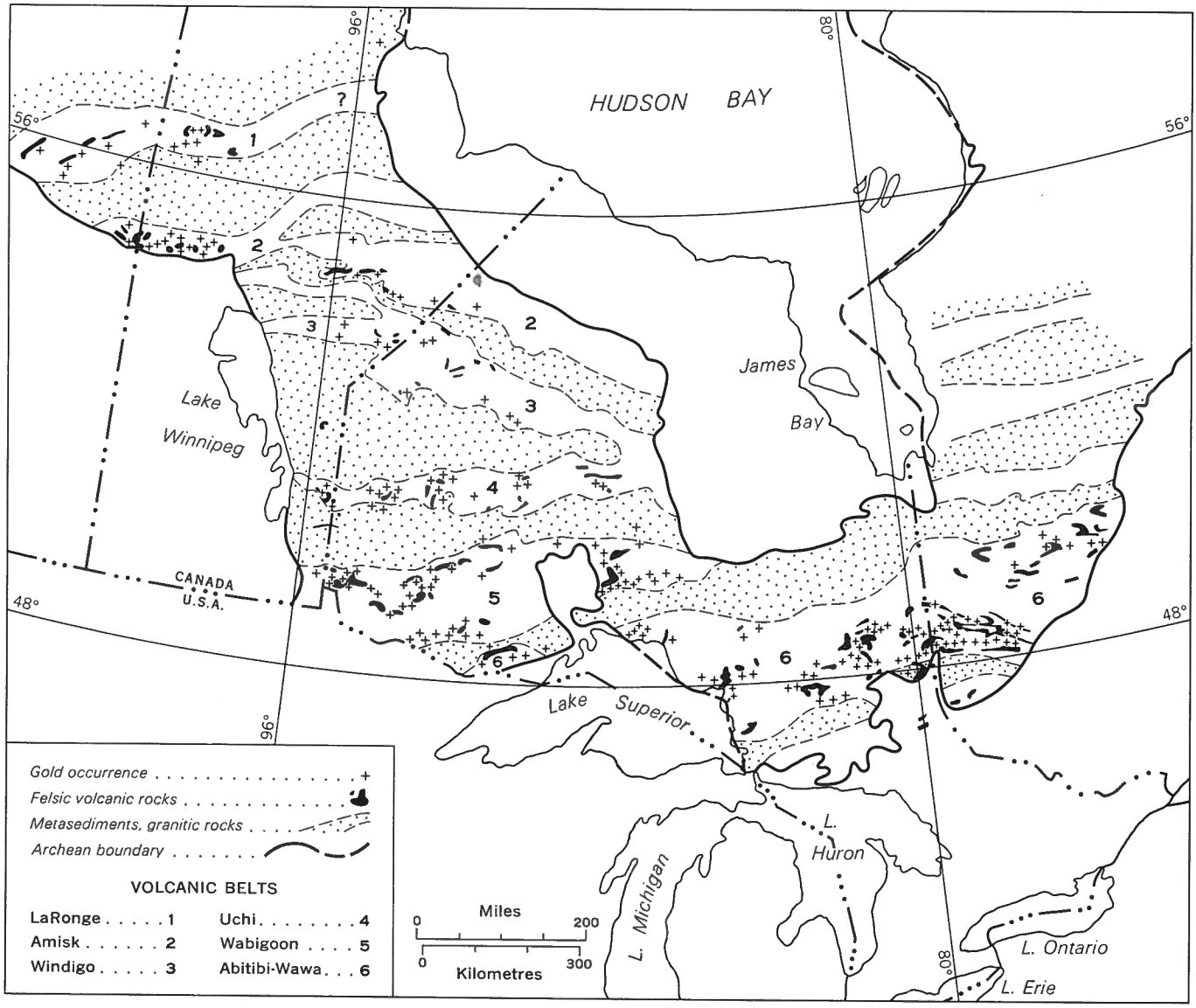


FIGURE V-2. Representative gold occurrences in the Superior Protocontinent (by A. M. Goodwin).

The distribution of one hundred and ninety-seven representative gold occurrences in the Superior Protocontinent is shown on Figure V-2. With few exceptions the occurrences lie in volcanic-rich belts and are preferentially associated with the felsic volcanic rocks. In general, the numbers of representative gold occurrences (Table V-2) in the six volcanic-rich belts are in direct proportion to the quantity of volcanic rocks in the belts indicating therefore that gold mineralization is fairly evenly distributed within the volcanic rocks of the protocontinent.

Of the thirty-three representative nickel and seventy-one representative iron occurrences (Fig. V-3) most occur in or near the volcanic-rich belts. Nickel distribution shows no preference for felsic volcanic rocks, but, on the contrary, is associated with mafic and ultramafic rocks. The ratios of nickel occurrences are in proportion to the relative sizes of the belts with the exception of the apparently nickel-deficient LaRonge belt. Most iron is in pyroclastic volcanic phases or nearby sediments. The ratios of iron occurrences are generally proportionate to the sizes of the three southern belts; however recognized iron occurrences are rare in the Amisk belt and absent in the LaRonge belt.

Most of the one hundred and eighty-three representative copper–zinc and seventeen representative zinc–lead occurrences (Fig. V-4) are associated with felsic volcanic rocks. A pronounced core-to-periphery increase within the protocontinent in the ratios of copper–zinc occurrences is apparent, an increase out of proportion to the relative sizes of the belts. Lead-bearing sulphide occurrences are almost restricted to the Abitibi–Wawa belt, the largest and presumably youngest volcanic-rich belt in the Superior Protocontinent. The inner part of the Superior Proto-

TABLE V-2 *Representative mineral occurrences and relative sizes of volcanic belts in Superior Protocontinent*

Volcanic Belt	Relative Size	Gold	Copper–Zinc	Zinc–Lead	Nickel	Iron	Total
a) Total Number, Superior Protocontinent							
LaRonge[1]	1.5	14	19	3	2	0	38
Amisk	2	20	30	1	7	3	61
Windigo	1	10	2	0	3	5	20
Uchi	1	21	5	0	4	13	43
Wabigoon	2	50	17	2	7	20	96
Abitibi–Wawa[2]	4	82	110	11	10	30	243
Total		197	183	17	33	71	501
Per cent		39	36	4	7	14	100
b) Total Number, Nucleus (Uchi and Windigo Belts)							
Windigo	1	10	2	0	3	5	20
Uchi	1	21	5	0	4	13	43
Total		31	7	0	7	18	63
Per cent		49	11	0	11	29	100
c) Total Number, Annulus (LaRonge, Amisk, Wabigoon and Abitibi–Wawa Belts)							
LaRonge	1.5	14	19	3	2	0	38
Amisk	2	20	30	1	7	3	61
Wabigoon	2	50	17	2	7	20	96
Abitibi–Wawa	4	82	110	11	10	30	243
Total		166	176	17	26	53	438
Per cent		38	40	4	6	12	100

1 Including Meades Lake area to the north
2 Including Ville Marie area to the south

continent, comprising the Uchi and Windigo belts, contains proportionately more gold, iron, and nickel and far less copper–zinc–lead sulphide than the outer and presumably younger part comprising the Abitibi–Wawa, Wabigoon, Amisk, and LaRonge belts (Table V-2).

Representative mineral occurrences in Archean rocks of the Hudson and Slave Protocontinents are shown on Figure V-5. The mineral occurrences are preferentially associated with the volcanic-rich belts. The gold, which occurs mainly in the volcanic belts of the Slave Protocontinent and in the Ennadai belt of the Hudson Protocontinent, is commonly associated with felsic rocks. Iron occurrences, both as magnetite iron-formation and iron sulphide, are present in eastern Hudson Protocontinent. Some iron and nickel lie in sedimentary rocks some distance from known volcanic rocks. Compared with the Superior Protocontinent the number of known mineral occurrences in the Slave and Hudson Protocontinents is much less, a metallogenic relationship in keeping with the smaller number and size of volcanic-rich belts. In addition, copper–zinc sulphide occurrences are scarce (Table V-3).

Thus, the geological and metallogenic relations in the Slave and Hudson Protocontinents appear to be similar to those prevailing in the inner part of the Superior Protocontinent and to represent gold–iron–nickel mineral provinces (Table V-4). The outer part of the Superior Protocontinent represents a more diversified and richly endowed base metal sulphide–gold–iron–nickel mineral province. The trend to metallogenic diversity in the outer, presumably younger parts of the protocontinent may be matched by increasing chemical diversity, particularly the alkalinity of igneous suites including the volcanic rocks.

Proterozoic Crust

The distribution of Proterozoic supracrustal rocks is dominated by comparatively long linear and broad basinal elements (Map 1250A). Northeasterly and, to a lesser degree, northwesterly trends predominate. Flat-lying to gently dipping strata are common. The main Proterozoic belts extend intermittently from Lake Superior to Lake Mistassini, across northern Quebec and Labrador, the northern tip of Ungava, and along the east shore of Hudson Bay. Proterozoic rocks underlie large areas south and east of Lake Athabasca, south and east of Great Slave Lake, 200 miles farther east at Dubawnt and Baker Lakes, and in the vicinity of Great Bear Lake and Bathurst Inlet. Additional Proterozoic belts lie in the Arctic Islands to the north and on Baffin Island to the east.

Proterozoic sedimentary assemblages include mature quartzite and sandstone, limestone and dolomite, carbonaceous shale, Superior-type iron-formation, and red beds. Because of distinctive lithology, substantial thickness, broad stratigraphic continuity, and abundant diagnostic criteria such as crossbedding, ripple-marks, raindrop impressions, mudcracks, intraformational conglomerates and breccia, and stromatolites, many Proterozoic assemblages are attributed to shallow-water, stable platformal, or miogeosynclinal environments of accumulation.

Proterozoic volcanic assemblages of the Shield are represented mainly by thick, tholeiitic basalts in the Lake Superior area, at Coppermine River in the Northwest Territories, and at Seal Lake in eastern Ungava. They resemble younger continental flood basalts characteristic

of stable continental sites. In addition, geosynclinal-type tholeiitic basalts characterized by high iron content (Baragar, 1960) are present in the eastern part of the Labrador Geosyncline, and trachytic volcanic rocks in the Dubawnt Lake area of the Northwest Territories (Donaldson, 1965). Other felsic volcanic rocks are present locally.

Granitic rocks of Proterozoic age are widespread in the Shield. Many Proterozoic intrusions and complexes have been indentified in the Northwest Territories in the southern and eastern parts of Churchill Province, in Grenville and Nain Provinces, and in certain parts of Superior Province. A reconnaissance geochemical study of Proterozoic granitic terrains has established an average composition (Fahrig and Eade, 1968; Shaw, *et al.*, 1967) that is close to that of common granodiorite. A comparison of average K_2O, U, and Th contents in Proterozoic and Archean crystalline rocks indicates a significant

TABLE V-3 *Representative mineral occurrences in the Slave and Hudson Protocontinents*

Protocontinent	Gold	Copper–Zinc	Nickel	Iron	Total
Hudson	16	7	8	15	46
Slave	30	7	3	5	45
Total	46	14	11	20	91
Per cent	51	15	12	22	100

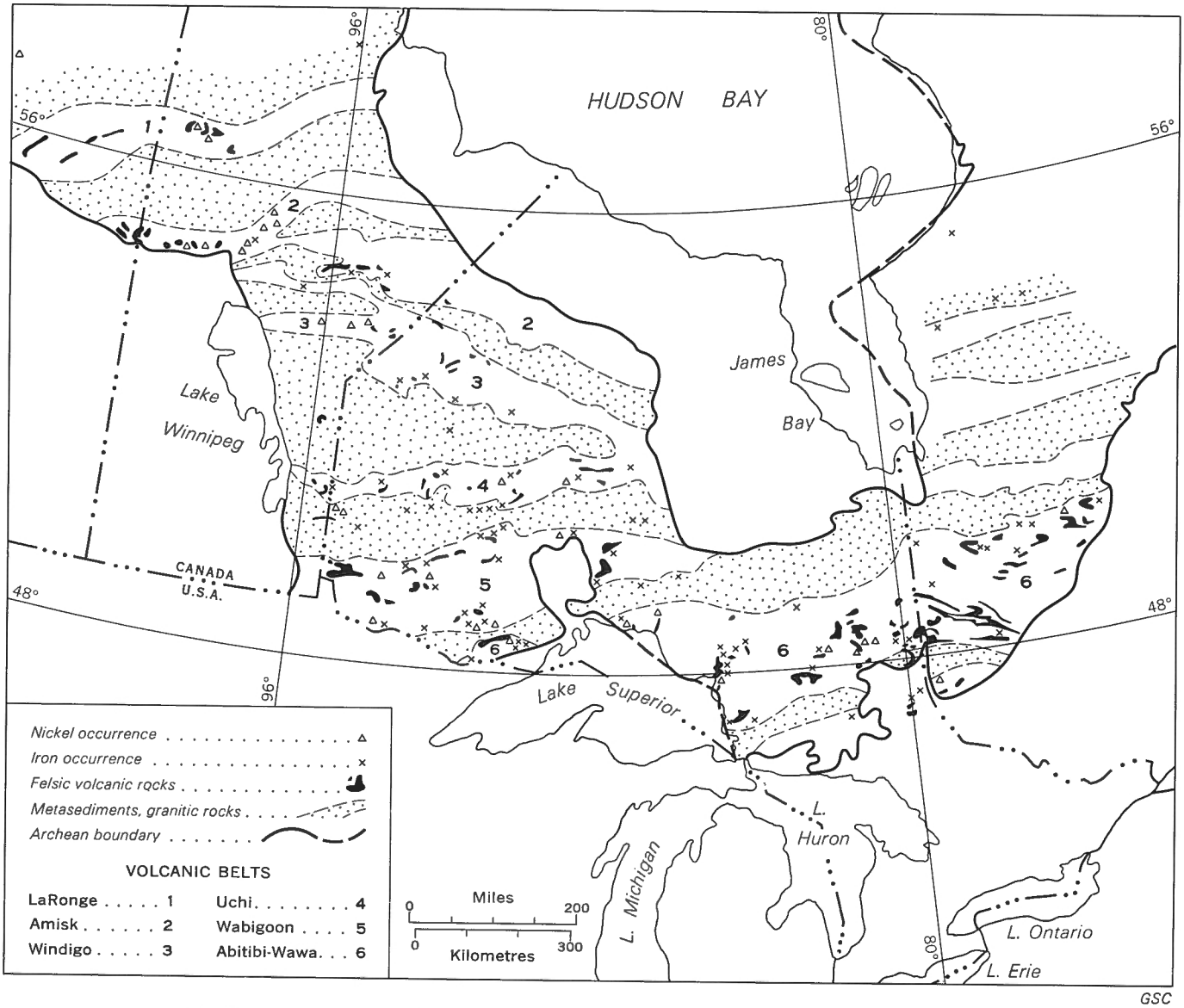


FIGURE V-3. Representative nickel and iron occurrences in the Superior Protocontinent (by A. M. Goodwin).

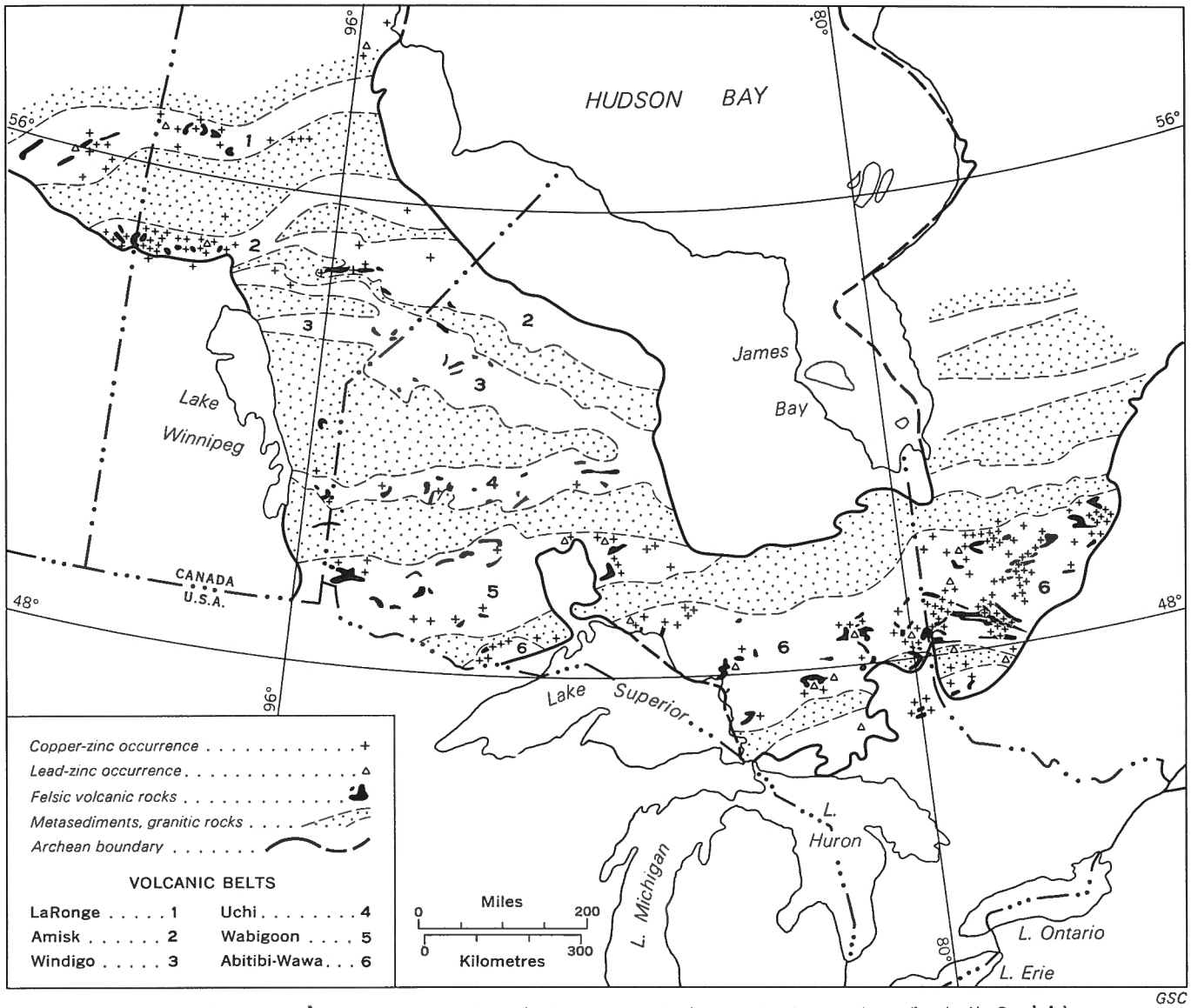


FIGURE V-4. Representative copper–zinc and zinc–lead occurrences in the Superior Protocontinent (by A. M. Goodwin).

increase of 1.8 times in radioactive level in the Proterozoic granitic rocks, notably in uranium.

Proterozoic Mineralization

Proterozoic rocks of the Canadian Shield contain a distinctive suite of mineral deposits: 1) uranium deposits of three main types: the quartz-pebble conglomerate type of Blind River, Ontario, and the northwestern Shield, the pegmatitic type of Grenville Province, and the vein type of the northwestern Shield (Lang, *et al.*, 1962); 2) granular iron-formation of the Superior type (Gross, 1965) in the Lake Superior, Labrador, Belcher Islands, and Lake Mistassini regions; 3) complex nickel–platinum ores associated with a mafic intrusion at Sudbury; 4) complex silver sulpharsenides associated with mafic intrusions at Cobalt and in the Thunder Bay area of the Lake Superior region; 5) copper deposits in Proterozoic volcanic and sedimentary rocks in the Lake Superior region and Coppermine River area of the Northwest Territories; and 6) minor lead sulphide occurrences in several regions.

Proterozoic mineral occurrences or groups of related occurrences are generally large and extensive corresponding in form and habit to the Proterozoic host rocks. The lithological character and distribution of Proterozoic rocks point to the presence of stable platforms, basins, and primitive geosynclines. These features imply substantial crustal stability and continuity of linear elements, hence the presence of a comparatively thick stable crust. Development of a thick Proterozoic crust is attributed mainly to growth and aggregation of Archean protocontinents and sub-crustal accretion of new, mantle-derived crustal material (Goodwin, 1968). In large

measure, Proterozoic tectonic history of the Canadian Shield reflects progressive crustal thickening and stabilization. Proterozoic mineral deposits, whether placer uranium concentrations in quartz-pebble conglomerates, granular iron-formations, lead–zinc deposits in reef carbonates, or complex sulpharsenides in mafic intrusions, are products of a comparatively thick, stable crustal regime.

In lithological character, tectonic pattern, and mineral habit Proterozoic rocks more closely resemble Phanerozoic rocks than Archean rocks. This is viewed within the context of a unidirectional evolving crust, the metallogenic associations constituting one important facet of this evolution.

TABLE V-4 *Percentages of representative mineral occurrences in Archean protocontinents*

	Superior Protocontinent			Hudson and Slave Protocontinents
	Total (%)	Annulus (%)	Nucleus (%)	(%)
Gold	39	38	49	51
Copper–zinc–lead	40	44	11	15
Iron	14	12	29	22
Nickel	7	6.	11	12

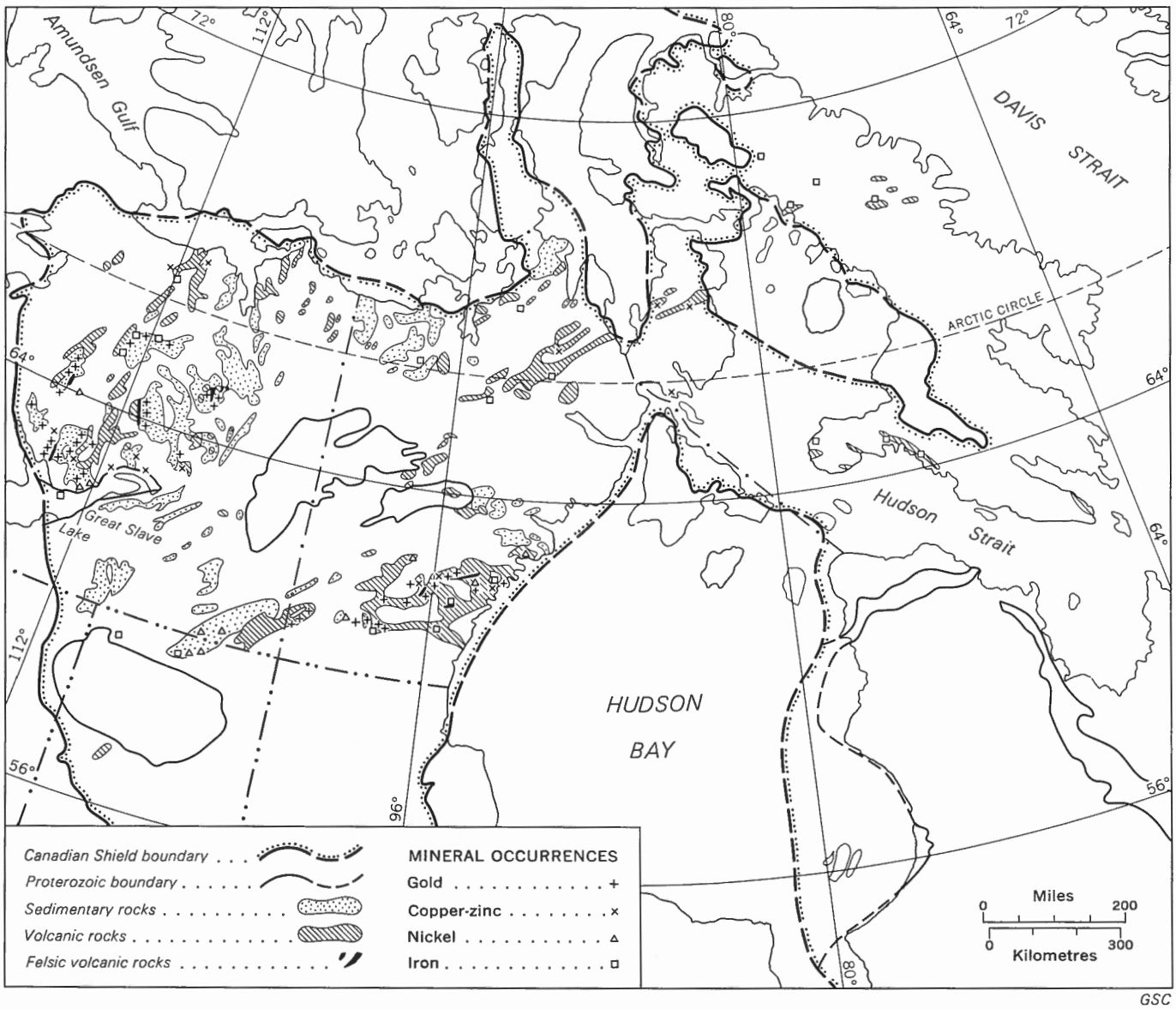


FIGURE V-5. Representative mineral occurrences in relation to Archean sedimentary and volcanic rocks in northern Canadian Shield (by A. M. Goodwin).

Uranium

Canada is one of the world's leading producers of uranium and has the largest known reserves of ore (Fig. V-6). All production has been from the Canadian Shield (Table V-1), and began in 1942 at the Eldorado mine on Great Bear Lake. Larger deposits were found in northern Saskatchewan at Beaverlodge in 1946 and in Ontario at Blind River in 1949. Uranium was actively sought from 1948 to 1955 and thousands of occurrences were found in various parts of the Shield. Expiry of contracts forced closure of several mines after 1960 and others closed as ore was exhausted. In recent years demand has been increasing again. Uranium is fairly common among the metals of the earth's crust, being more abundant than gold or silver but less so than copper, nickel, or zinc. Uranium has a strong tendency to form oxides rather than sulphides and to be dispersed rather than concentrated in high-grade deposits. In Canada, a content of 0.05 per cent uranium oxide (U_3O_8) or its equivalent has been chosen as the lower limit for substances to be classed as radioactive under the Atomic Energy Control Regulations. This limit has been followed in defining occurrences of uranium and thorium; smaller quantities are present at many places but are not considered occurrences. Prospecting and mining for uranium are governed by regulations of the Atomic Energy Control Board which require that discoveries be reported to the Director, Geological Survey of Canada, Ottawa and that permits for advanced exploration and mining be obtained from the Secretary, Atomic Energy Control Board, Ottawa. Export permits are required for shipments abroad.

Canadian reserves of ore were estimated in 1967 to contain 490,000 tons of U_3O_8. Most Canadian reserves are at Elliot Lake, Ontario. Other reserves are mainly in the Athabasca area. Many other areas contain partly tested prospects and generally favourable conditions (Roscoe, 1966). Non-producing areas that attracted most attention in 1966 and early 1967 were the Agnew Lake area between Blind River and Sudbury, Ontario, the Havre St. Pierre district in Quebec, the Makkovik district in Labrador, and Bancroft, Ontario.

Other common radioactive elements are thorium and radium. Demand for thorium is not large at present but it may become supplementary to uranium in the future. The ores of Elliot Lake average about half as much thorium oxide as U_3O_8, mainly because monazite is present. The Bancroft ores carry thorium, mainly in uranothorite. The high price of radium is mainly due to the long, careful processes required to separate it from uranium. Artificially produced radioactive isotopes such as cobalt-60 are cheaper and more effective for many purposes, causing such a decline in demand for radium that the plants at most uranium mines were not designed to save the radium, and the value of contained radium is not considered in estimating ore. Limited amounts of thorium and certain rare-earth elements are recovered as byproducts from some of the Elliot Lake ores.

Types of Deposits

About fifty mineral species or varieties containing uranium have been found in Canada. The number of ore minerals from which uranium has been obtained commercially is much smaller, consisting essentially of: uraninite (uranium oxide) and its variety pitchblende; 'brannerite'; monazite; uranothorite (silicate of thorium and uranium); and uranophane (hydrated silicate of calcium and uranium). Some ores contain a little uranium-bearing hydrocarbon called 'thucholite'. The distinction between uraninite and pitchblende has proven useful in Canada as the crystalline uraninite and the cryptocrystalline or botryoidal pitchblende occur in different types of deposits. Also, crystalline uraninite contains appreciable amounts of thorium and rare earths, whereas pitchblende carries less than 0.1 per cent of these elements. About half the uranium minerals are supergene but of these only uranophane has been found in commercial quantities in Canada. Almost all the supergene minerals have an earthy appearance and a distinctive canary-yellow colour and occur in small amounts at or near the surface of many primary occurrences. They are referred to as 'uranium stain' and serve as a useful guide in prospecting although they are difficult to identify individually except by laboratory methods.

In order of productivity, Canadian uranium ores are: 1) quartz–pebble conglomerates containing "brannerite", uraninite, and uraniferous monazite; 2) disseminations, stringer-systems, and veins of pitchblende; and 3) 'dykes' of syenite and granite, with pegmatitic facies, containing uraninite and uranothorite (Fig. V-6). The conglomeratic ores, which first became productive in 1955, are in the Elliot Lake area of Ontario and lie near the unconformity at the base of the Huronian strata. They contain about 0.1 per cent U_3O_8 and are mined successfully at this relatively low content because of the accessibility of the district and because they form extensive, thick, and uniform bodies that are more amenable to underground mining than deposits of the pitchblende type.

Pitchblende-bearing veins at Great Bear Lake were mined at first for radium as early as 1933. Copper, silver, and cobalt were also produced, along with a little uranium. The deposit was relatively small but of exceptionally high grade, as was necessary in that remote region. Larger but lower grade pitchblende deposits are those of the Lake Athabasca district, Saskatchewan, where production began at the Ace mine in 1953 and the Gunnar mine in 1955. The Gunnar ore was virtually unique in that it contained, along with pitchblende, much

supergene uranophane. The granitic type ores were mined near Bancroft, Ontario, where the Bicroft, Faraday, and Dyno mines and the Greyhawk were operated between 1956 and 1964. Uranium has also been found in several other kinds of deposits. Pegmatitic and granitic rocks occasionally contain accessory grains of radioactive minerals. Uranium has also been found in metasomatic and related deposits, quartzites, sandstones, and dolomites.

Elliot Lake district, Ontario (72–75)[1]. The leading

[1] Number assigned to the deposit on Mineral Deposits of Canada, Map 1252A.

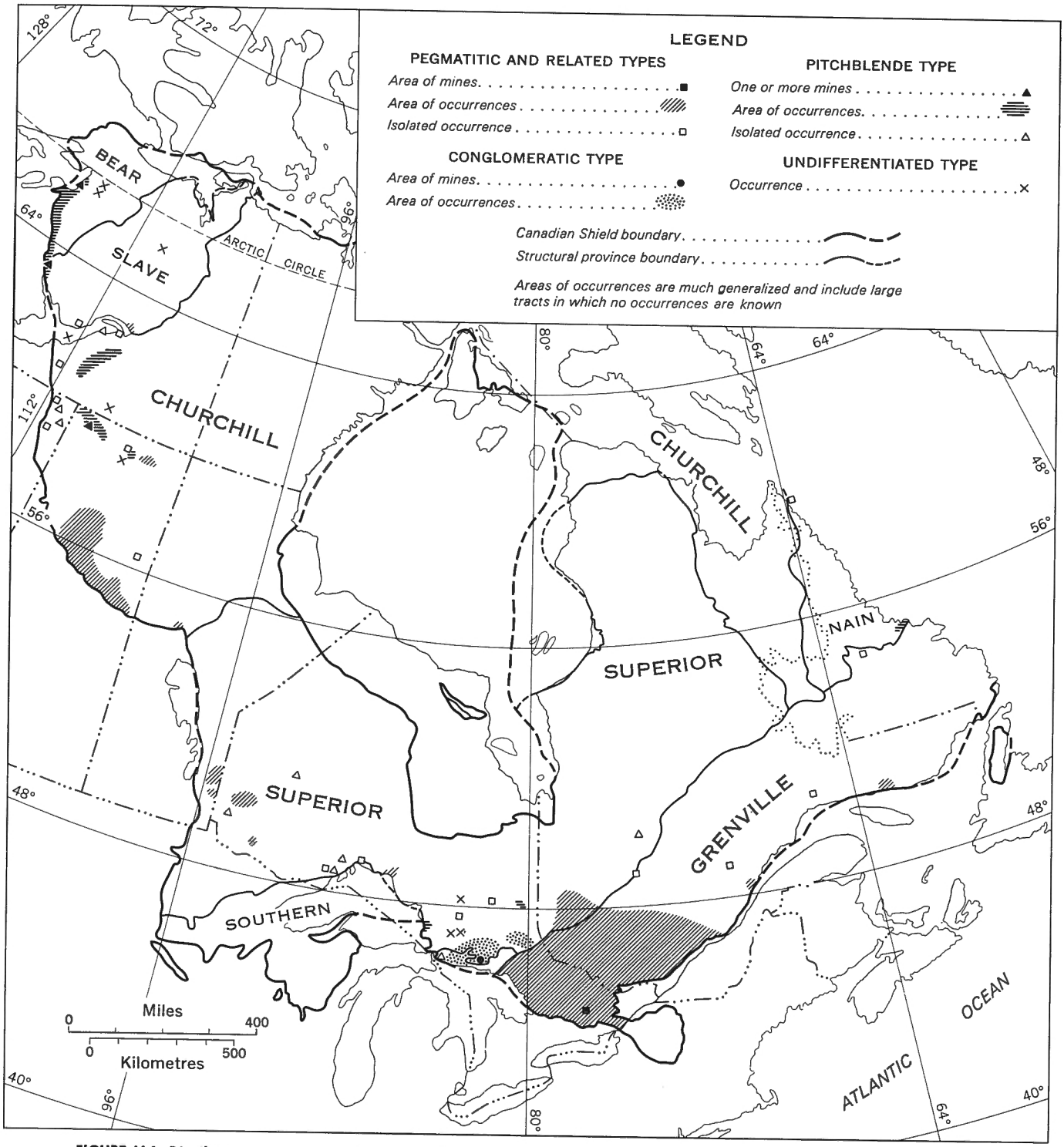


FIGURE V-6. Distribution of present and former uranium mines and known occurrences in the Canadian Shield (by A. H. Lang).

Canadian uranium-producing district is about 25 miles northeast of Blind River, Ontario. Huronian conglomerate outcropping near the north shore of Lake Huron, 11 miles east of Blind River, was found to be radioactive in 1949 and subsequently the Pronto mine was developed there in 1955. This discovery led to the finding of two large belts of deposits of the same general type as the Pronto in the vicinity of Elliot Lake some 15 to 20 miles to the north. These were discovered by diamond drilling to be structurally and stratigraphically favourable zones based on the general mode of occurrence of the Pronto ore. Eleven mines were developed from these two deposits, the largest being the Denison. The deposits are so nearly similar, except in size, that they are not described separately. The matrix of the conglomerate contains grains of pyrite 'brannerite', uraninite, monazite, hematite, magnetite, zircon, and other minerals. Some monazite is unusually high in uranium, possibly because of admixed uranothorite. Grains are commonly rounded but some grains of pyrite and uraninite are only slightly so. The material classed as brannerite presents a problem not yet fully solved. Hand-picked samples containing as much as 41 per cent U_3O_8 and 6 per cent ThO_2 are metamict and before heating yield X-ray patterns comparable to those of anatase and rutile, but after prolonged heating at high temperature they yield patterns characteristic of brannerite. Microscopically, many grains are seen to be mixtures, possibly of uraniferous anatase and rutile that were partly converted to synthetic brannerite by heating.

The beds of ore-bearing conglomerate of the Matinenda (lower Mississagi) Formation are composed of closely packed, subrounded quartz pebbles and cobbles. Most pebbles are a quarter inch to 2 inches in diameter. Those of the Elliot Lake sector (Fig. V-7) are in the Quirke Lake syncline which strikes easterly, plunges westerly, and contains Huronian strata over a width of nearly 10 miles. The syncline comprises as much as

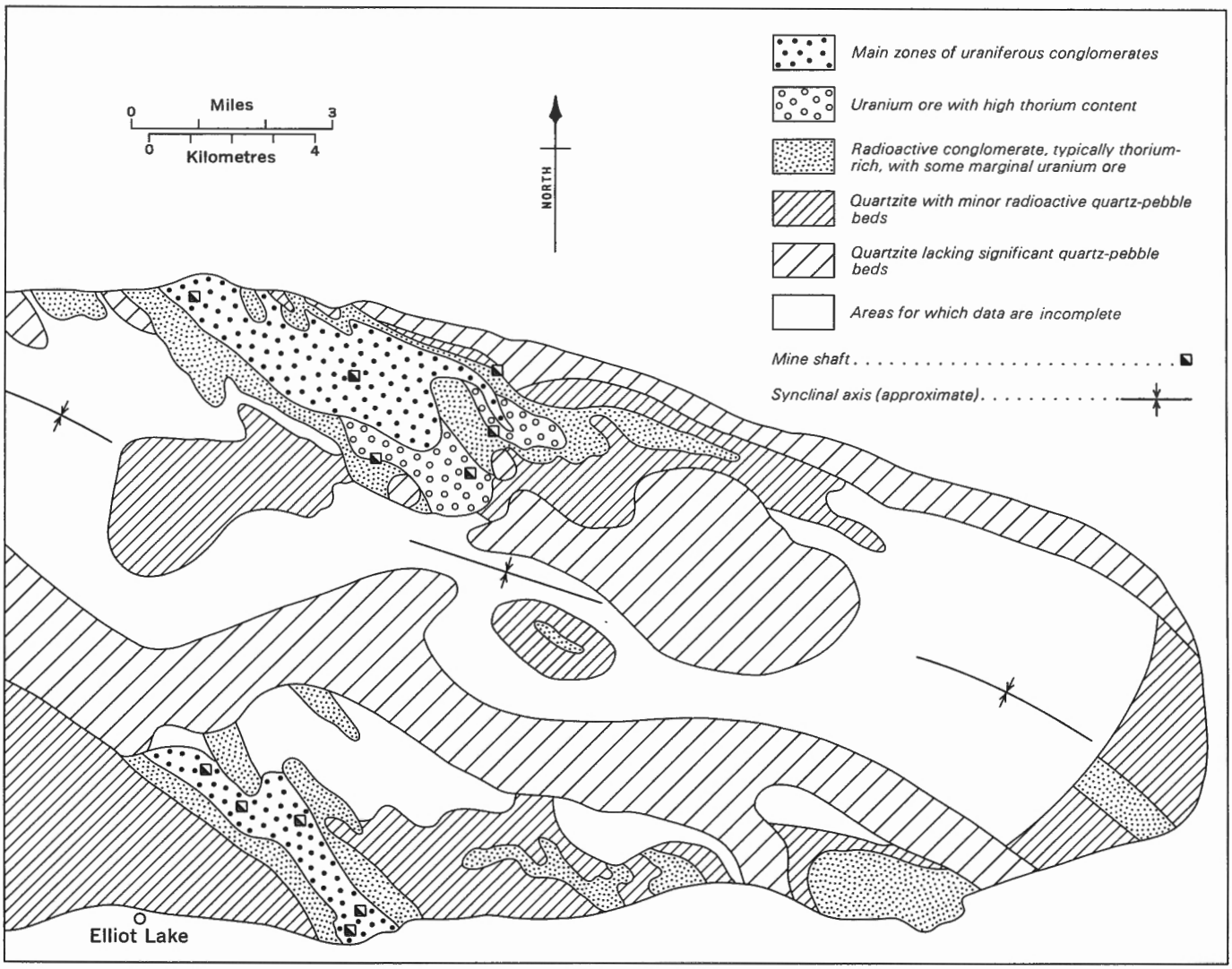


FIGURE V-7. Distribution of uranium ore, other radioactive conglomerates, and other strata in the Matinenda Formation, Quirke Lake syncline, Elliot Lake, Ontario (by S. M. Roscoe).

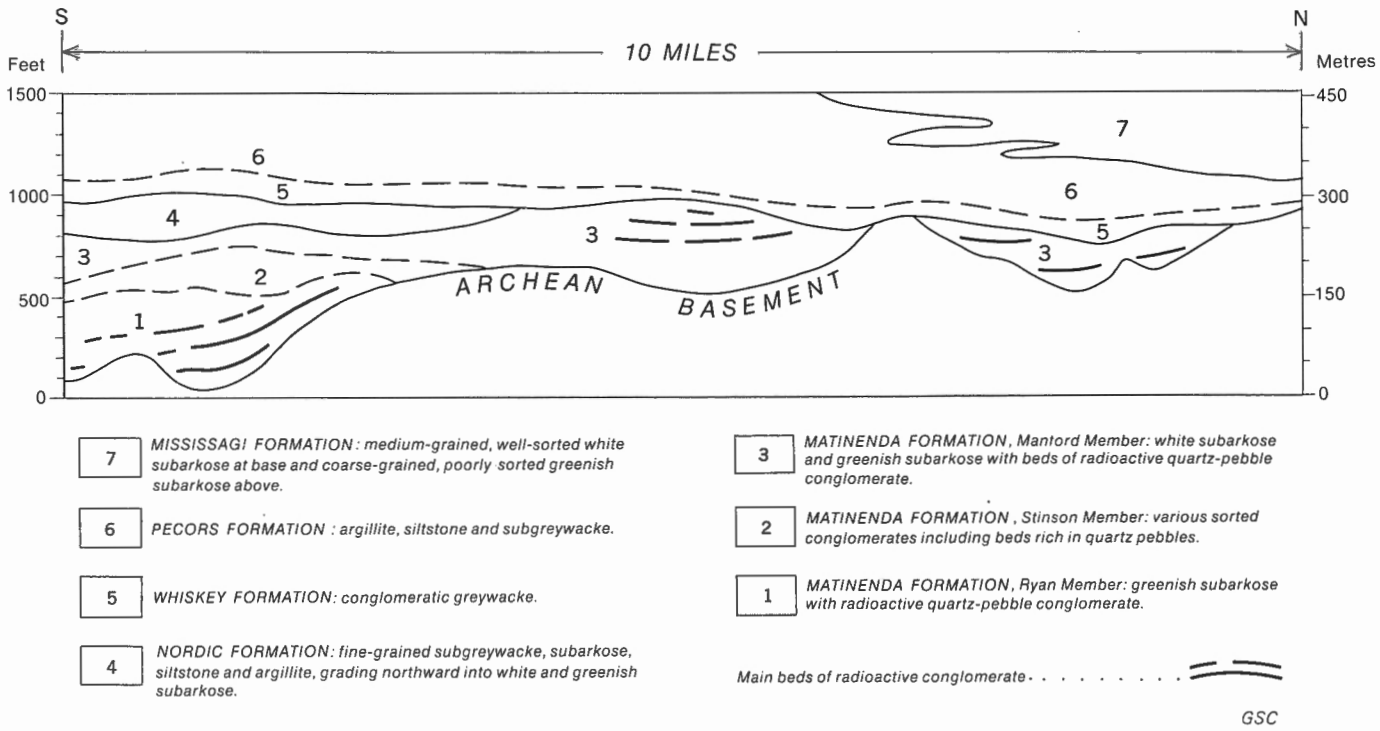


FIGURE V-8. Restored stratigraphic section through main uranium-bearing part of Quirke Lake syncline before Hudsonian folding (by S. M. Roscoe).

4,000 feet of strata, including up to 1,000 feet of Matinenda beds lying on the Archean basement (Fig. V-8). South of an anticline in basement rocks are southerly dipping Huronian rocks broken by the Murray fault, near which is the *Pronto* (72) mine. Most of the Pronto ore and some ore in the Quirke Lake syncline lie at the contact with the basement rocks, but most of the ore in the Quirke Lake syncline occurs in beds as much as 150 feet above the basement that vary from a single bed of conglomerate or grit to fairly intricate lenses of conglomerate and lean quartzite.

The average uranium content of the ores of the area as a whole is about 2.4 pounds of U_3O_8 a ton. The lowest grade material that is mined has about 0.06 per cent U_3O_8. The Elliot Lake ore-bearing conglomerates occur as accumulations in shallow valleys in the basement. Production has been confined to the southeasterly striking Quirke and Nordic belts. The Quirke belt contains six present or former producers: the Denison, Quirke, Spanish American, Panel, Can-Met, and Stanrock. The Denison mine, with a daily capacity of 6,000 tons of ore, is the largest in the entire district. The Nordic belt contains five present or past producers: the Nordic, Stanleigh, Milliken Lake, Lacnor, and Buckles. The belts end because of the interfingering of the conglomerate with other strata, the presence of ridges in the basement, and disconformable relationships with overyling strata. Studies of crossbedding and other features indicate that the sediments were derived from the northwest (Pienaar, 1963).

Explanations for the origin of the Elliot Lake deposits range from purely alluvial to purely hydrothermal. Most features of the deposits are consistent with a placer origin, whereas they are difficult to explain as a result of introduction of uranium-bearing fluids with resultant permeability-controlled deposition or replacement into the rocks. Roscoe and Steacy (1958) and others have shown that the deposits are restricted to a specific host rock, namely quartz-pebble conglomerate. Sharp, vertical and lateral variations in uranium content and mineralogy occur within the conglomeratic zones. The ore minerals are high-temperature types unlikely to have been formed in situ in the little-altered Huronian sediments and, moreover, occur in discrete, commonly rounded grains that resemble undoubted detrital minerals such as zircon, and are invariably associated with them. The high pyrite and uraninite content, the low magnetite content, and the low thorium to uranium ratio are features uncommon to placers. They could be explained by postulating special sources and depositional conditions during sedimentation or post-depositional modifications of the ores, including the introduction of hydrogen sulphide of biogenic or other origin to convert magnetite to pyrite. Little evidence has been presented for such special processes, however, and some geologists, therefore, consider hypotheses involving an epigenetic origin for the uranium more credible. Davidson (1957) suggested that the ores were deposited from uranium-bearing solutions derived from a deep-seated source but later proposed connate waters containing uranium dissolved from Huronian sediments as the source.

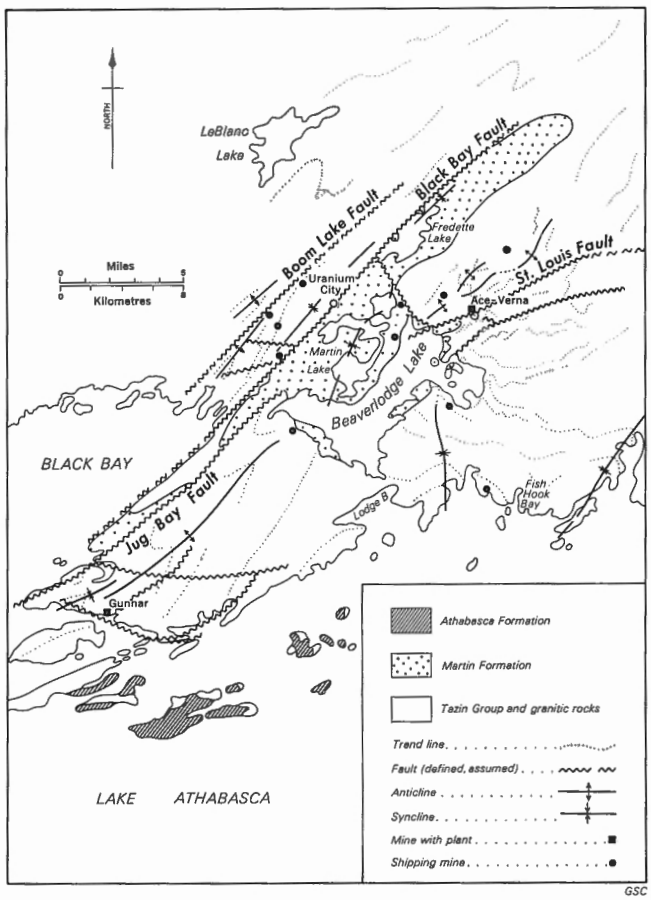


FIGURE V-9. Generalized geology and location of uranium mines, Lake Athabasca, Saskatchewan (by L. P. Tremblay and C. K. Bell).

Derry (1960) believed that the uranium was dissolved from weathered Archean rocks during deposition of the Huronian sediments and deposited biochemically from groundwater percolating through the unindurated gravels.

Athabasca district, Saskatchewan (1–4). The Athabasca or Beaverlodge district (Fig. V-9) on the north side of Lake Athabasca is underlain by highly metamorphosed sedimentary and volcanic rocks of the Archean or Aphebian Tazin Group, granitic gneiss and granite, and the Helikian Martin and Athabasca Formations. The distribution of uranium deposits in the area is controlled by regional and local structures and by lithology. The mineralized area is in a belt of folded and faulted rocks with a prevailing northeasterly trend. Faults are of two main ages, one group having originated after granitization of the Tazin rocks and the other just before and after deposition of the Martin strata. Zones of fracturing, brecciation, and mylonitization are commonly associated with the earlier faults. Some of the later faults may have followed the earlier fault traces.

The pitchblende deposits lie along the northeasterly trending faults, particularly at intersections with southeasterly trending faults and anticlines. They rake or plunge southwesterly, apparently partly because of the angles of intersection between the fault and fracture systems. Many show preference for rocks easily brecciated and mylonitized, and for argillites and mafic rocks. Most deposits are mineralogically simple—pitchblende with hematite as an alteration product. Some veins at the Nicholson property are more complex, having a mineralogical resemblance to those of the Port Radium, District of Keewatin. A vanadium mineral, nolanite, is fairly common in parts of the Ace orebodies and at the Fish Hook Bay prospect. The Gunnar ore contains much uranophane, also common at Fish Hook Bay. Bodies of migmatite and pegmatite in areas bordering the pitchblende occurrences carry uraninite and other radioactive minerals. The uraninite appears to have crystallized during the period of granitization in Tazin rocks and to have been followed by an early period of pitchblende mineralization. Younger pitchblende occurrences, some in the Martin Formation, probably represent redeposition of earlier material.

Production of the *Ace-Verna* (2) mine was begun in 1953 at the Ace orebody after an intensive prospecting program and diamond drilling of several of the better discoveries. The workings were connected underground with the Verna orebodies found nearby, mining being done at intervals for a distance of 14,000 feet and a maximum depth of 4,000 feet. The treatment plant has a daily capacity of 2,000 tons of ore that have averaged about 3 to 4 pounds of U_3O_8 per ton. The orebodies are in Tazin rocks along the St. Louis fault, which here strikes N60–70°E and dips 50° south. The Ace ore zones are in the footwall and those of the Verna are in the hanging-wall. The Ace ore is in brecciated feldspathic rock cemented by pitchblende, quartz, calcite, and chlorite, or in groups of narrow veins that occur as much as 300 feet from the fault. The Verna ores are groups of veins and veinlets in a mass of argillite 350 feet from the fault. Much of the Ace ore is sharply limited by the fault gouge on one side but is based on arbitrary grade limits on the other. Ore reserves in 1966 were reported to be 2 million tons grading 0.21 per cent U_3O_8.

The *Gunnar* (4) mine produced at a daily rate of 1,650 to 2,000 tons of ore from 1955 to 1964. The shape of the orebody permitted open-pit mining to a depth of 380 feet, below which underground operations were carried to a total depth of about 1,200 feet, mainly below lake-level. The ore was in brecciated porous albite–calcite–chlorite rock close to the intersection of two faults, the Zeemel which strikes northeast and the St. Mary's which strikes southeast along the shoreline. The general orebody plunged southward at 45° and comprised a group of small bodies elongated along the plunge, each with a clearly marked footwall and hanging-wall but irregularly limited in other directions. The ore consisted of disseminated pitchblende and uranophane in a gangue of albite, hematite, calcite, chlorite, and quartz.

Uranophane was unusually abundant even at low levels, probably because of circulation of groundwater through the porous rock. The grade of ore was fairly consistent at about 3.4 pounds of U_3O_8 a ton.

Bancroft district, Ontario (107, 108). The four productive mines of the Bancroft district are in the southwestern part of Grenville Province (Fig. V-6). The district has long been famous for rare minerals, mainly those of pegmatites and related deposits. Many radioactive minerals had been found and studied before uranium became important and an attempt to mine radium was made in 1929. After 1948 many more deposits were found, but not until 1952 were deposits of consistently higher uranium content discovered at *Bicroft* (108a), *Faraday* (107a), and *Canadian Dyno* (108b). Ore was shipped to the Faraday plant from the *Greyhawk* (107b) mine from 1957 to 1959. All mines were closed by 1964. The Bancroft area is underlain by three fairly circular masses, called the Cheddar granite, Cardiff complex, and Faraday granite; each is about 6 miles in diameter, and is composed of granite, syenite, gneisses, and related rocks. They are separated by metamorphic rocks of various kinds that exhibit a concentric structure. These are mainly marble, paragneiss, para-amphibolite, and meta-gabbro. The principal uranium deposits are in bodies of granite and syenite with pegmatitic and metasomatic phases that either cut the wall-rocks or replace them. The most favourable rocks were pegmatitic pyroxene granite or syenite, leucogranite, and cataclastic quartz-rich granite–pegmatite. All are commonly high in sodium. Many ore shoots were associated with concentrations of mafic minerals and magnetite.

The Bicroft mine is in paragneiss and amphibolite on the east flank of the Cardiff complex. Its ores were in an *en echelon* swarm of lenticular dykes in a zone half a mile wide and 3½ miles long. The ore minerals were uranothorite and uraninite, the ore averaging about 0.1 per cent U_3O_8. The Faraday mine is in a belt of meta-gabbro and amphibolite on the south flank of the Faraday granite. The ores were parts of a zone of irregular pegmatitic granite dykes, with metasomatic phases, extending at intervals over about 6,000 feet. The ore minerals were uraninite and uranothorite, with minor uranophane; ore averaged about 0.1 per cent U_3O_8. The Canadian Dyno mine is in a belt of paragneiss and other rocks on the east flank of the Cheddar granite. The property contains a series of pegmatitic granite dykes only some of which were of ore grade. The ore minerals were uraninite and uranothorite. The Greyhawk mine is in meta-gabbro on the south flank of the Faraday granite. Its ores were in dykes of pegmatitic granite containing uraninite and uranothorite.

Great Bear Lake area, District of Keewatin. The *Eldorado* (3) mine at Port Radium on the east shore of Great Bear Lake produced from 1933 to 1940 and 1942 to 1960. Although almost on the Arctic Circle the richness of the veins and the high price of radium permitted mining, and throughout its life the mine had the distinction of being the most northerly metal mine in Canada. Radium was the significant commodity during the earlier years, but silver, copper, and cobalt were produced as well. For several years the mine was one of the two main sources of radium in the world and the principal one on this continent. Although the pitchblende contained far more uranium than radium there was virtually no demand for uranium until 1942. Output was then increased to 300 tons of ore daily.

The deposits were in Bear Province; the host rocks were metamorphosed tuffs and coarse fragmental material interbedded with cherty sedimentary strata, all part of the Echo Bay Group of Aphebian age (Fig. V-35). Masses of feldspar porphyry are interbanded and are at least partly intrusive. These rocks are invaded by granite encountered in the lower levels. Diabase dykes are younger than the granite and are transected by structures associated with the ore. The youngest rocks are flat-lying sheets of diabase, apophyses of which cut ore. The Eldorado orebodies were in an area roughly 2,000 feet wide and a mile long, mined in places to 1,650 feet below the surface. The rocks are traversed by a series of steep northeasterly trending faults, some coalescing and some branching. The orebodies were veins and breccia-fillings in the faults, individual ore shoots being a few inches to 15 feet wide and 50 to 700 feet long; one was worked for a depth of 1,100 feet. The ore shoots were confined almost entirely to the stratified rocks or to places where the fault-zones followed contacts between them and diabase. They extended only a little way into parts of the fault-zones that crossed porphyry, granite, or massive tuff. Ore shoots appeared to be grouped around 'noses' of porphyry.

Forty metallic minerals were present including cobalt or nickel arsenides and sulpharsenides. Gangue consisted of altered rock, quartz, and carbonate minerals. The nickel minerals, native silver, botryoidal pitchblende, the supergene minerals, and red hematitic alteration occurred only in the upper levels. Mineralization took place in four stages, the pitchblende apparently being deposited first and at fairly low temperatures and pressures. All evidence indicated that the mineralization was related to the granite. Some veins extend into it, suggesting that the mineralization was a late stage of the intrusion itself rather than redistribution, by metamorphism or granitization, of metals contained in the invaded rocks.

In southern Bear Province, the *Rayrock* (5) mine was operated for two years with a 150-ton plant. Pitchblende occurs in shoots in a northeasterly trending large quartz stockwork. These are locally called 'giant quartz veins' and are fairly abundant in southern Bear Province.

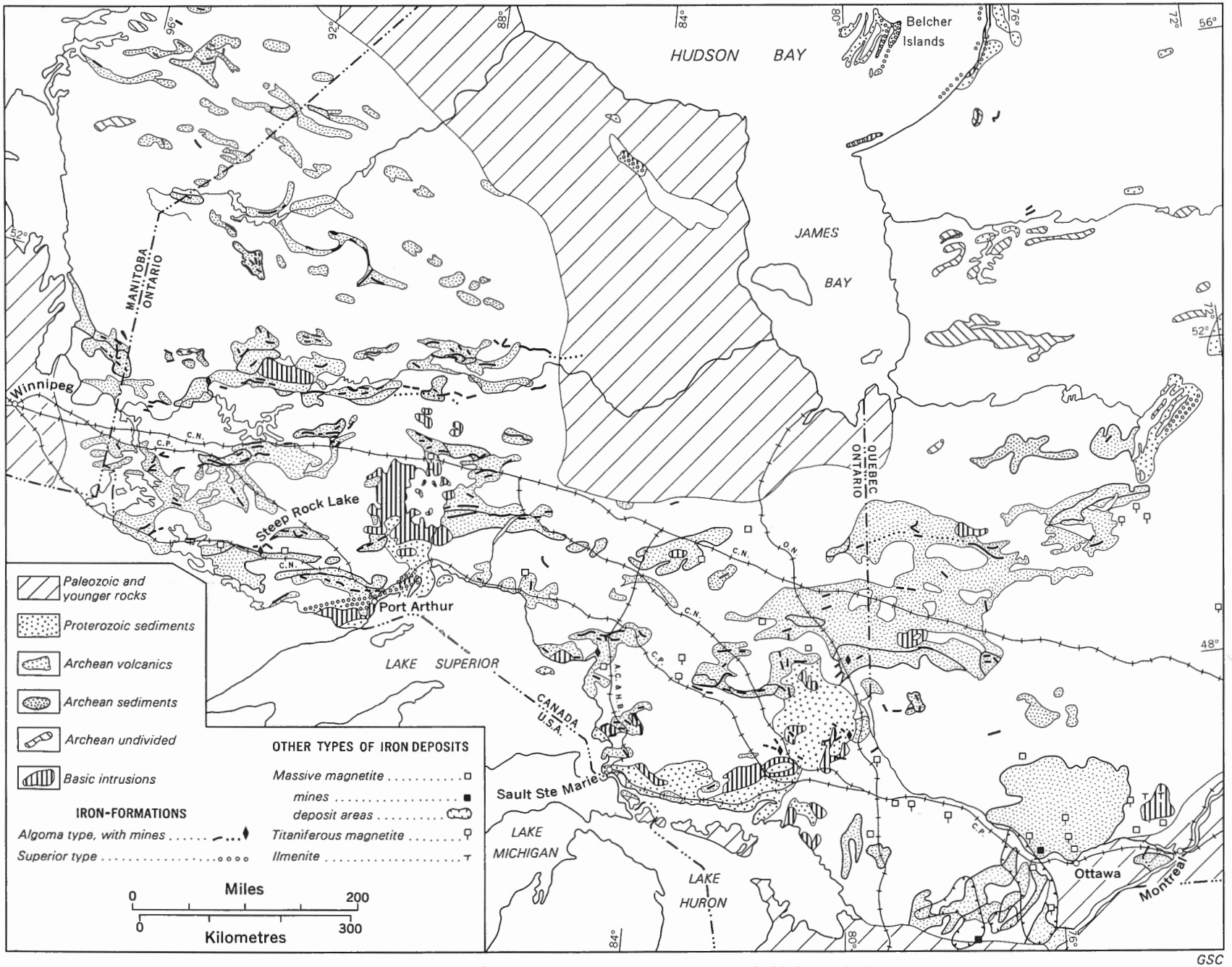


FIGURE V-10. Iron deposits and mines of the southern Canadian Shield (by G. A. Gross).

Iron

Canada produced 36 million long tons of iron ore in 1966, valued at $420 million, and was the fourth largest producer in the world after France, the United States, and the Soviet Union. Iron ore exceeds nickel in value, and was surpassed only by copper as the most valuable metallic commodity produced in Canada in 1966. More than 94 per cent of the iron produced was derived from the Precambrian rocks of the Canadian Shield (Table V-1). The opening of the Helen mine in the Michipicoten district of Ontario in 1939 marked the beginning of a new period of development and rapid growth in the Canadian iron ore industry after a non-productive stage of nearly 20 years. The Steep Rock iron range was developed during World War II to help offset increased continental market needs. In the decade after 1950 as a result of a phenomenal expansion in exploration and growth in the industry, ore production rose from 3.5 million tons to 22 million tons. The first ore was shipped from the Labrador–Quebec ranges in 1954 and since then production from that area has increased greatly.

A profound change has taken place during the past 10 years, especially in North America, in the grade and structural specifications for iron ore and hence in the processing required. Direct-shipping quality ore is no longer considered to be premium material, and pelletized high-grade concentrates, beneficiated and sintered ores are now in greatest demand. Research is being done on methods for direct reduction and partial reduction on ore concentrates with the aim of providing even higher grade furnace burdens. These revolutionary changes in processing technology and in market specifications are of major significance to Canada as it has become economical to concentrate and pelletize the widely distributed low-grade siliceous iron-formations that comprise the huge reserves of potential iron ore in the Canadian Shield. Iron is also recovered as a byproduct in the treatment of nickel and copper sulphide ores. More than one million tons of pellets and iron oxide calcine were produced in 1965 in the Sudbury area.

Types of Iron-formation

There are many types of iron deposits in Precambrian rocks in addition to the low-grade iron-formations. The classification of deposits as shown in Table V-5 is based on empirical and descriptive data (Gross, 1965). The general distribution of iron-formations and iron-producing areas in the southern part of the Shield is shown on Figure V-10. Some of the features of these siliceous iron-formations are summarized on Figure V-11 and are compared to other types of iron-bearing sediments that occur in Canada in rocks younger than Precambrian. The composition of four different types of iron-bearing sediments are compared in Table V-6 and general features

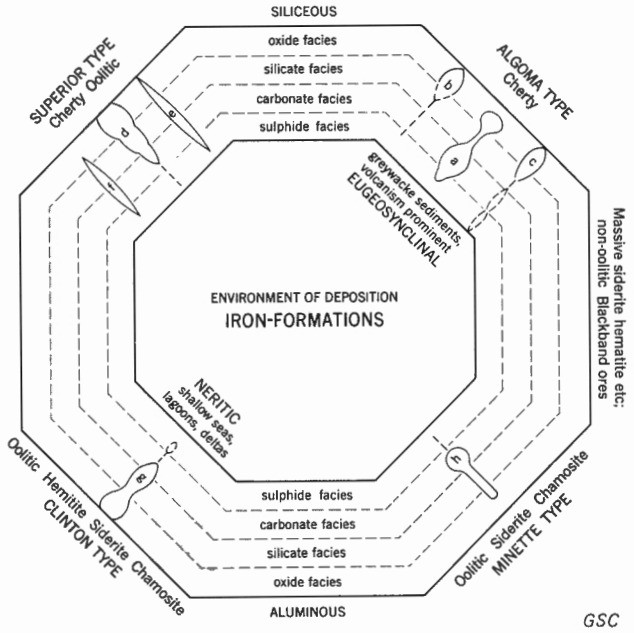


FIGURE V-11. Diagram showing major types of chemically precipitated iron-formation with their sedimentary facies and depositional environment. Examples are from: a, Michipicoten, Ontario; b, Moose Mountain, Ontario; c, Timagami, Ontario; d, Knob Lake, Labrador and Quebec; e, Iron River, Michigan; f, Gunflint and Biwabik iron-formation, Ontario and Minnesota; g, Wabana, Newfoundland; h, Clear Hills, Alberta (Gross, 1967).

are noted for the two prominent types found in the Canadian Shield. The geology of iron-formations and other ferruginous sedimentary rocks has become increasingly important during the last two decades. It is the basis for guiding prospecting, evaluating deposits of higher grade ore within the iron-formations formed by natural enrichment processes, and for selecting, exploring, and developing low-grade formations for production of high-grade concentrates. Almost every belt of volcanic and sedimentary rock in Superior and Churchill Provinces contains some iron-formation of the Algoma type. Younger Aphebian rocks, such as those of the Labrador Geosyncline or those near Mistassini Lake and west of Lake Superior, contain iron-formations of the Superior type. They were deposited in continental shelf environments.

The Algoma type of iron-formation was deposited with volcanic and sedimentary rocks characteristic of eugeosynclinal environments (Goodwin, 1965). Typical beds are composed of grey or red jasper chert interlayered with magnetite and hematite-rich layers (Pl. V-1), but other mineral facies, such as massive siderite and pyrite–pyrrhotite beds, occasionally form part of the formation. Algoma type iron-formations range in thickness from a few inches to more than 100 feet and are usually less than a few miles long. They were commonly deposited during a volcanic cycle near the close of a rhyolitic stage and before andesitic or basic extrusion. Carbon-bearing

PLATE V-1. Algoma-type, Archean, iron-formation of magnetite, siderite, and chert. Helen mine, Michipicoten district, Ontario.

schists containing iron sulphide minerals are closely associated with the cherty iron-formations in this environment. Algoma type beds are abundant in Precambrian volcanic belts, and similar beds also occur in the Appalachian and Cordilleran Geosynclines.

Iron-formations of the Superior type are typically thin-banded cherty rocks with granular to oölitic textures, and contain little or no clastic material. Lithological facies, either cherty magnetite and hematite or the cherty iron silicate and carbonate varieties, are prominent and usually separated in well-defined stratigraphic units. The beds show abundant evidence of deposition in shallow water and many were deformed when the sediment was in a hydroplastic state. Superior type beds are commonly associated with quartzite, dolomite, black ferruginous slate, argillite, chert, and various volcanic rocks, including tuffs and lava flows and the sedimentary rocks derived from them. They were deposited on continental shelves or in miogeosynclinal basins or troughs occurring within narrow belts of sediments bounded by ancient cratonic areas on the one side and by volcanic belts on the other. These iron-formations are hundreds of feet thick and may extend continuously along the margin of the geosyncline for hundreds of miles. Superior type formations are the protore throughout the world for most of the large, naturally enriched, hematite–goethite ore deposits.

Iron Deposits in Superior Type Iron-formation

Superior type iron-formations in the Labrador Geosyncline extend more than 700 miles from west of Ungava Bay southeast beyond *Schefferville* (75), Quebec, and *Wabush Lake* (1), Labrador, and thence southwest for an additional 200 miles within Grenville Province (Fig. V-12). In the central and northern part of the belt they were folded and deformed during the Hudsonian Orogeny. Rocks of the southern part of the geosyncline within Grenville Province have been redeformed by the Grenvillian Orogeny and possibly also by the Elsonian Orogeny. The iron deposits differ in the northern, central, and southern parts of this belt. In the northern part of the geosyncline, west of Ungava Bay, rocks are highly metamorphosed and the recrystallized medium- to coarse-grained iron-formations form extensive metataconite deposits (Type IIE) suitable for beneficiation.

Iron-formations in the central part of the Labrador Geosyncline are not highly metamorphosed and form the host rock for hematite–goethite ore deposits (Type IA). The unoxidized iron beds constitute a vast reserve of

potential taconite ore (Type IID). The iron-formations are composed mainly of iron oxide and silicate–carbonate and because of their fine-grained cherty character were especially amenable to natural enrichment processes that produced pockets and masses of direct-shipping hematite–goethite ore of Type IA (Fig. V-13). During Mesozoic time groundwater is believed to have penetrated the iron-formations along permeable zones connected with deeply weathered erosion surfaces. It leached silica, and oxidized and remobilized some of the iron causing secondary enrichment and formation of ore. Existing ore deposits are the roots of larger deposits that were partly eroded during

TABLE V-5 *Classification of iron deposits (Gross, 1967)*

GROUP

I HEMATITE–GOETHITE DEPOSITS IN IRON-FORMATION. Direct-shipping ores and wash ores formed in iron-formation by leaching of silica and concentration of iron by natural processes.

Type A: i) Lake Superior type in Minnesota, and Knob Lake type in Quebec and Labrador. Concentrations of hematite, goethite, and other iron minerals in cherty iron-formation. Cherty iron silicate, carbonate, and cherty iron oxide iron-formations are the common kinds of protore for this type.

ii) Semitaconites, partly leached iron-formations associated with Type Ai) that provide "wash ore". These are considered as a special subtype in this group.

Type B: The Old Helen mine deposit, Michipicoten district, Ontario. Concentrations of hematite and goethite of direct shipping quality in siderite beds.

II IRON-FORMATIONS. Various kinds or types of iron-formation that may be utilized without concentration or beneficiation, or that are suitable for beneficiation.

Type A: Clinton type of iron-formation, Wabana deposits, Newfoundland. Hematite–siderite–chamosite beds with distinctive oölitic texture.

Type B: Minette or Lorraine oölitic siderite–chamosite iron-formations, mined in the Northampton district of England.

Type C: Helen mine and Sir James mine, Michipicoten district, Ontario. Siderite iron-formation consisting of stratigraphic units of fairly massive siderite.

Type D: Taconite iron-formation, Moose Mountain mine, Ontario, and Mesabi Range taconites in Minnesota. Included here are all iron-formations that must be ground finer than 100 mesh to be concentrated. Common types include iron oxide, iron-silicate, iron-carbonate, and iron silicate-iron oxide types with a banded cherty matrix.

Type E: Metataconite iron-formation, Wabush Lake, Labrador, Newfoundland, and Lac Jeannine, Quebec, or the itabirite deposits in Minas Gerais, Brazil. Included here are metamorphosed iron-formations that have undergone extensive recrystallization and can be concentrated without grinding finer than 100 mesh.

Type F: Pyrite-rich iron-formations of potential ore value.

Type G: Other types of iron-formation of distinctive character found in local areas.

III RESIDUAL DEPOSITS, AND CHEMICALLY AND MECHANICALLY TRANSPORTED SURFACE DEPOSITS

Type A: Steep Rock Lake type, Steep Rock Range, Ontario. Buried residual accumulations of iron minerals on regoliths, with subsequent alteration of iron minerals and redistribution of iron. Mainly massive to crudely banded red and brown hard rubbly hematite and goethite ores of direct-shipping quality.

Type B: Residual deposits, Londonderry area, Nova Scotia; Bilbao, Spain.

Type C: Laterite deposits developed by surficial oxidation and supergene enrichment of rocks other than iron-formation, Conakry, French Guinea.

Type D: Bog Iron deposits, St. Maurice, Quebec. Iron is transported chemically and precipitated near or on the surface.

Type E: Placer deposits and deposits formed by mechanical concentration of iron minerals. Iron sands of the North Shore of the St. Lawrence River, or the Charleson hematite gravel deposit south of Steep Rock Lake.

IV DEPOSITS DIRECTLY ASSOCIATED WITH PLUTONIC ROCKS

Type A: The St. Charles deposit, Bourget township, Quebec; or Chaffey mine at Newboro Lake, Ontario. Layered, disseminated, interstitial, and injected magnetite with minor hematite and ilmenite in basic and ultrabasic rocks.

Type B: Allard Lake deposits, Quebec; or Taberg type of deposit in Sweden. Layered, disseminated, interstitial, and injected ilmenite with magnetite and hematite in anorthosite rocks.

Type C: Stephenville, Newfoundland. Deposits in acid intermediate rocks or in alkalic rocks. Massive and disseminated ores in these rock types. Further subdivision may be based on types of host rock.

V SKARN, CONTACT METASOMATIC, VEIN, AND STRUCTURALLY CONTROLLED EMPLACEMENTS OF IRON MINERALS

Type A: Texada Island, British Columbia; Marmora deposit, Ontario. Skarn, contact metasomatic deposits or high temperature replacement deposits.

Type B: Forsyth deposit, near Hull, Quebec. Veins with minor replacement, deposited under structural control.

Type C: Disseminated magnetite, iron oxides, and iron minerals that are probably of replacement origin and deposited under structural control in shear zones and other structural features.

Type D: Noranda deposits, Quebec. Massive and disseminated iron sulphide bodies, may contain base metals and other ore minerals.

VI OTHER TYPES OF DEPOSITS

Pleistocene glaciation. More than 45 deposits of this kind, some of which contain as much as 50 million tons of ore, are present at Schefferville near the border of Quebec and Labrador (Pl. V-2). Conditions are favourable for the occurrence of this type of ore throughout most of the central part of the belt. These ores are composed of porous, friable to rubbly, red, blue-black, or brownish yellow masses of hematite and goethite formed within bands of cherty oxide and silicate–carbonate iron-formation. Ore of direct-shipping quality usually contains from 51.5 to 65% iron, as much as 12% silica, 0.045% phosphorus, 1.5% alumina, and small amounts of lime and magnesia. Manganese content varies, averaging less than 3%.

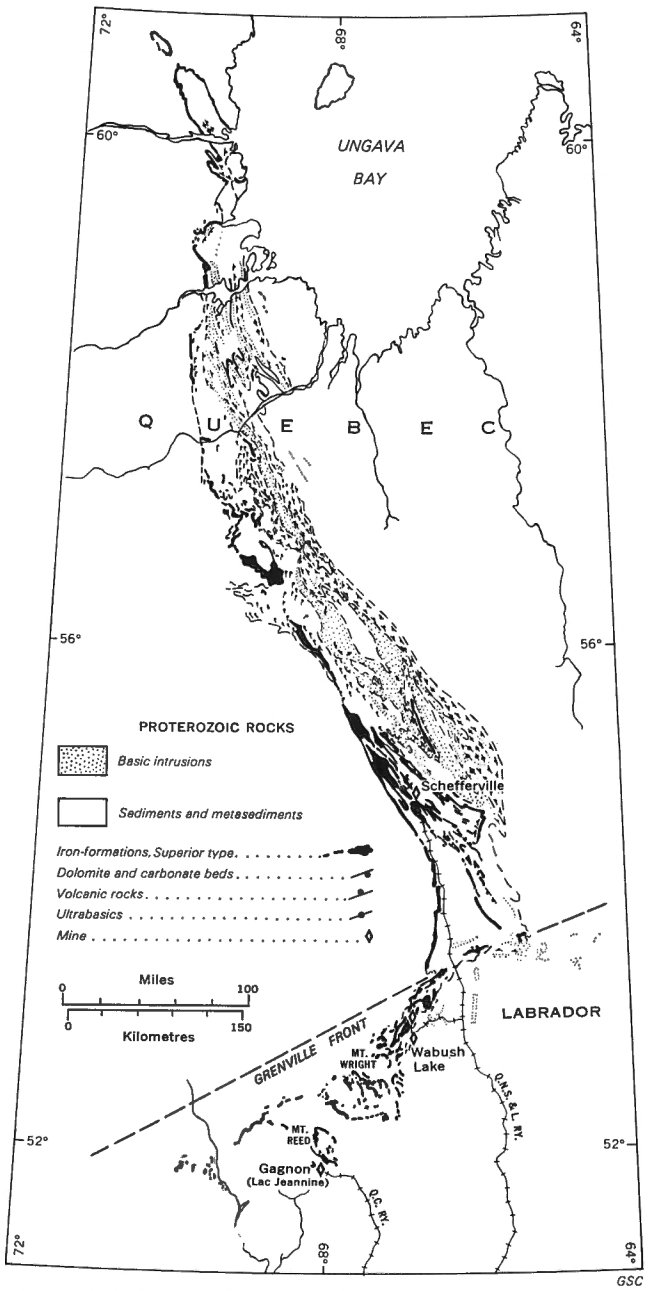


FIGURE V-12. Iron-formations of the Labrador Geosyncline (by G. A. Gross).

TABLE V-6 *Compositions of iron-formation types*

Type	Algoma	Superior		Clinton	Minette
Facies	Oxide (1)	Oxide (2)	Silicate carbonate (3)	(4)	(5)
Fe	33.52	33.97	30.23	51.79	30.97
SiO_2	47.9	48.35	49.41	11.42	28.06
Al_2O_3	0.9	0.48	0.68	5.07	5.79
Fe_2O_3	31.7	45.98	16.34	61.83	29.81
FeO	14.6	2.33	24.19	11.00	13.08
CaO	1.45	0.1	0.1	3.32	1.92
MgO	1.8	.32	2.95	0.63	1.54
Na_2O	0.2	.33	0.03	ND	0.33
K_2O	.32	.01	.07	ND	.53
H_2O^+	.47	2.0	5.2	1.94	13.10
H_2O^-	.1	0.04	0.38		
TiO_2	.05	.01	.01	0.015	0.18
P_2O_5	.1	.04	.08	1.96	1.59
MnO	.3	.025	.65	0.17	0.16
CO_2	ND	.03	.22	2.15	2.89
S	ND	.013	.05	0.023	ND
C	ND	.08	.15	ND	ND
Location	Timagami	Knob Lake		Wabana	Peace River

(1) Average of four analyses for 50 feet of section sampled systematically; Algoma type, mainly oxide facies, magnetite–quartz iron-formation; Timagami Lake area, Ont. (Analyses, Geol. Surv. Can. Laboratories.)
(2) Average of six analyses for 335 feet of section sampled systematically; Superior type, oxide facies, hematite–magnetite–quartz iron-formation; Knob Lake iron ranges, Quebec and Labrador. (Analyses, Geol. Surv. Can. Laboratories.)
(3) Analysis of 50 feet of section sampled systematically; Superior type, silicate–carbonate–chert facies; Knob Lake iron ranges, Quebec and Labrador. (Analysis, Geol. Surv. Can. Laboratories.)
(4) Analysis of large composite sample; Clinton-type iron-formation; Wabana, Newfoundland. (Courtesy, Wabana Mines.)
(5) Average of eleven analyses representing 15 feet of section; Minette type, oolitic siderite–chamosite–limonite iron-formation; Peace River District, Alberta. (Mellon, 1962.)

The iron-formations in the southern part of the Labrador Geosyncline (Fig. V-12), from the Wabush Lake area through Mount Wright and southwest to Matonipi Lake, are deposits of metataconite (Type IIE). Exceedingly complex structures are developed in this area as a result of deformation during both the Hudsonian and Grenvillian Orogenies. The coarse-grained texture in the highly metamorphosed iron-formations and the thickening and repetition of the iron beds by folding and faulting are controlling factors in the formation of large masses of easily concentrated metataconite ore.

The metamorphosed hematite and magnetite–quartz iron-formations derived from the sedimentary oxide facies supply good ore but the iron in beds rich in iron–silicate minerals and iron carbonates is difficult to concentrate. The oxide formations contain 30 to 40 per cent iron and pelletized concentrates produced from them contain 64

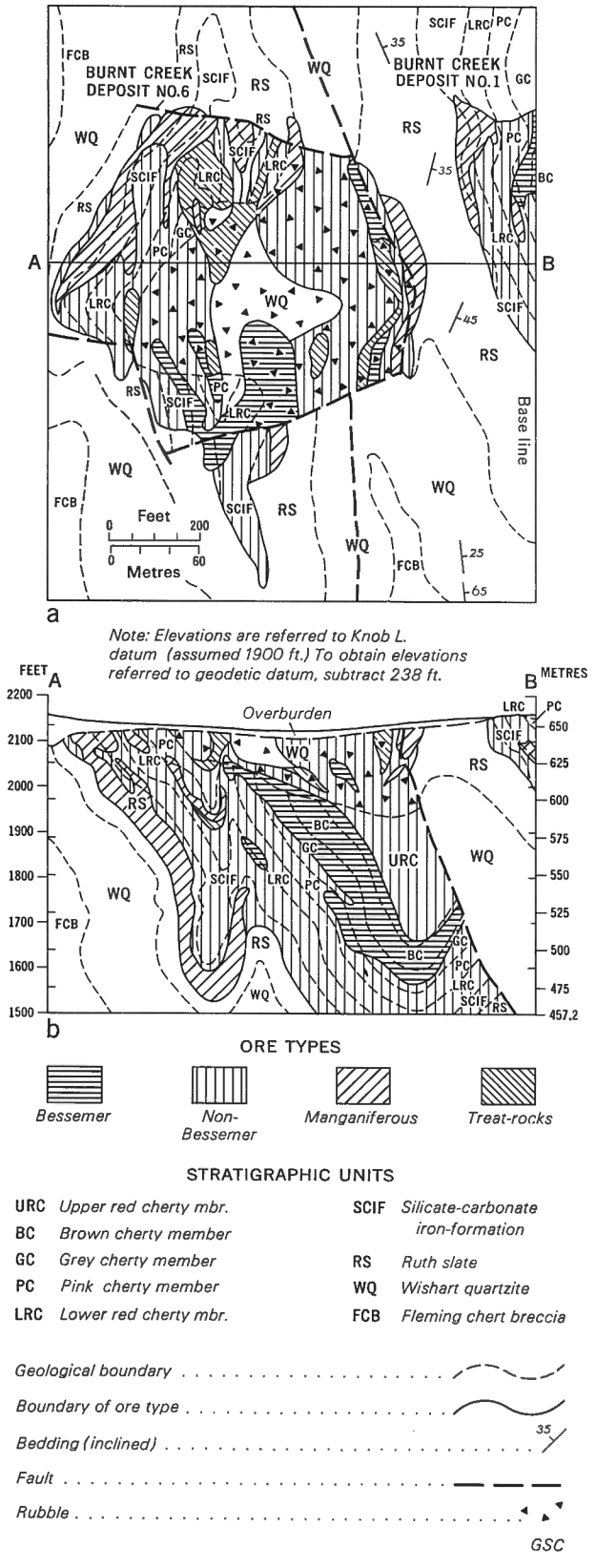


FIGURE V-13. French mine, Schefferville–Knob Lake area, Quebec (by G. A. Gross): (a) plan, 4B section of Burnt Creek deposit; (b) section along line A–B.

to 65 per cent iron with 4 to 5 per cent silica. Iron-formation mined in the Wabush Lake area contains about 38 per cent iron in the form of specular hematite and magnetite with quartz. Deposits at Mount Wright and Fire Lake, not yet produced, and *Lac Jeannine* (74) are typical of a group composed of specular hematite and quartz. Those such as the one at Lac Jeannine that lie well within Grenville Province are the coarsest grained. Concentration is done exclusively in gravity spirals. Other iron-formations composed of magnetite, specular hematite, quartz, and intermixed iron–silicate minerals, such as one at Mount Reed, contain billions of tons of potential ore but they are fine grained and difficult to concentrate. Mines in the Wabush area produce ore concentrate for 15 million tons of pellets per year and the Lac Jeannine mine near Gagnonville annually produces 8 to 9 million tons of concentrate. Conservative estimates indicate that 4 to 5 billion tons of ore concentrate can be obtained from 10 billion tons of metataconite ore mineable by open-pit methods in the southern part of the Labrador Geosyncline.

Superior type iron-formations are also present in Proterozoic rocks in the Cape Smith belt, along the east side of Hudson Bay on the Nastapoka and Belcher Islands, and near Sutton Lake in Ontario. They are also exposed for 35 miles along strike in the iron ranges near Mistassini and Albanel Lakes in central Quebec. The Gunflint iron range extends along the west shore of Lake Superior and southwest to link up with the Mesabi iron range in Minnesota. These iron-formations are relatively unmetamorphosed and contain large reserves of potential taconite ore. Some have been prospected for direct-shipping ores, but no commercial deposits have been found.

Iron Deposits in Algoma Type Iron-formation

Algoma type iron-formations in Superior Province of Ontario are becoming increasingly important as taconite ore (Type IID). Siderite beds with minor pyrite and pyrrhotite (Type IIC) are mined in Michipicoten district and the geology of the *Helen* (37) mine is typical of many iron deposits in the area (Fig. V-14). The siderite–pyrite ore zones are considered to be sedimentary facies of the iron-formation. The stratigraphic succession at the Helen, George McLeod, and Sir James mines consists of basal altered rhyolite volcanics that grade upward into massive or crudely banded beds of buff or black siderite with pyrite and pyrrhotite in the upper part. These grade upward into thinly banded chert, carbonate, and magnetite iron-formation, capped by andesitic pillow lava. The carbonate member ranges in thickness from 50 to 250 feet at Helen mine and although disrupted by numerous faults has been traced for miles along strike. The siderite–pyrite ore as mined contains about 33% iron, but after beneficiation in the sink-float plant and sintering, it contains 50 to 51% iron, 2.9% manganese, 11.4% silica, 3.32% lime, 7.37% magnesia, 1.84% alumina, 0.01% phosphorus, and 0.10% sulphur.

Magnetite–quartz facies predominate in most of the other Algoma type iron-formations of Ontario. The iron-formation at *Moose Mountain* (84) north of Capreol, Ontario, was first mined between 1901 and 1920 where the magnetite concentrate was briquetted and roasted in an attempt to provide a suitable high-grade product. The enterprise was not successful economically but it anticipated modern beneficiation methods for iron ore by 40 years. Several open-pit mines have been worked since 1959 on various fault segments of the iron-formation which averages about 33% iron. The pelletized concentrate contains 63 to 64% iron with less than 8.75% silica.

The *Adams* (60a) mine near Kirkland Lake, Ontario, has produced pelletized ore concentrate since 1964. Thinly laminated magnetite–quartz iron-formation with an average of 22% iron is mined from two pits in a structurally complex belt of iron-formation that extends for 6 miles. The pellets contain 62 to 63% iron and the rail haul of 700 miles to Pittsburgh where they are used is probably the longest for iron ore anywhere in the world.

The iron-formation at *Sherman* (95) mine in the Timagami area of Ontario is probably the least metamorphosed of any of the Algoma type. The magnetite–quartz beds average 25 to 30% iron and 1,200,000 long tons of pellets containing about 65% iron are expected to be produced annually.

Very highly metamorphosed iron-formations occur in Superior Province between Lake of the Woods, Lake Nipigon, Red Lake, and the Paleozoic rocks of Hudson Bay Lowland (Fig. V-10). Magnetite–quartz beds occur in garnet–biotite–quartz schists which are derived from Archean sedimentary and volcanic rocks. The Griffith mine is being developed in one of these iron ranges along the west shore of Bruce Lake; production commenced in 1968. It is expected that about 1,500,000 long tons of pellets containing 65 per cent iron will be produced yearly from magnetic taconite containing 30 to 33 per cent iron. Some of the important ranges in this area are the Lake St. Joseph, Bending Lake, Kapico, and Kowash ranges north of Nakina.

PLATE V-2

Ruth Lake mine, Labrador, Newfoundland. Hematite–goethite orebody in Knob Lake iron range, extending in background into Burnt Creek mine, Quebec.

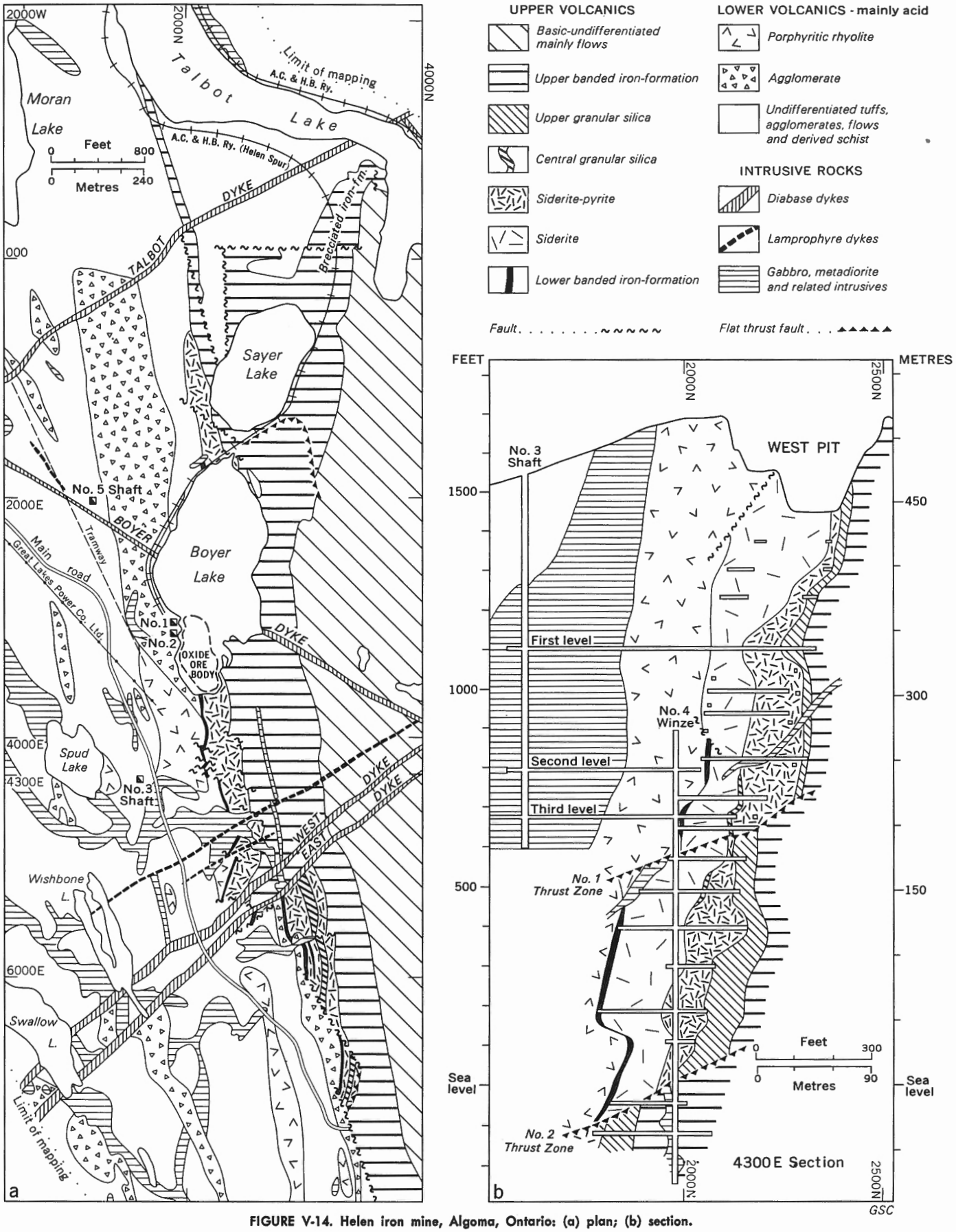


FIGURE V-14. Helen iron mine, Algoma, Ontario: (a) plan; (b) section.

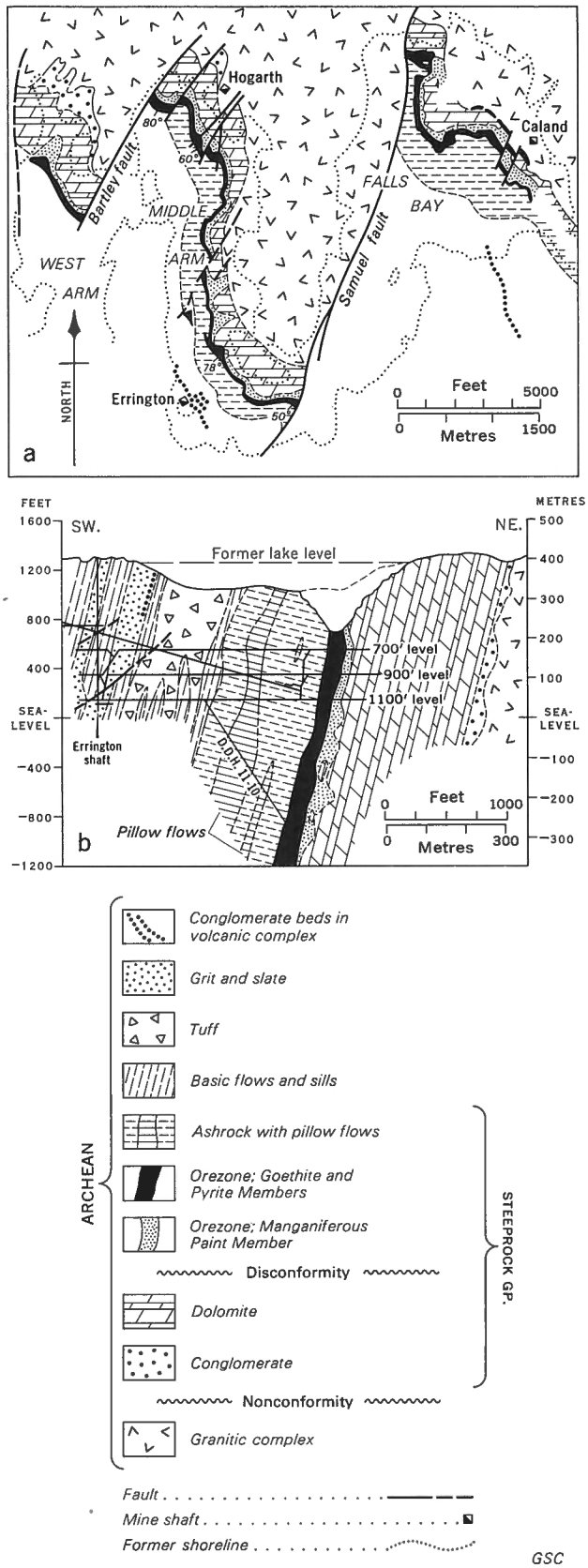


FIGURE V-15. Steeprock Lake area, Ontario (Jolliffe, 1966): (a) geological map; (b) section through Errington mine.

The hematite–goethite ore deposits of the *Steep Rock* (21) iron ranges are classified as Type IIIA. The tabular orebodies (Fig. V-15) are faulted segments of one stratigraphic zone. Jolliffe (1966) postulates that the interlayered goethite, minor pyrite lenses with graphite, and thinly banded chert were deposited on an old erosion surface where iron, in the form of colloidal oxide and hydroxide gels, accumulated in a manner akin to modern bog-iron deposits. The iron-rich bed was then covered by basic tuff, "ash rock". The rock succession was later folded and deformed in the Kenoran Orogeny. Oxidation and alteration took place in the ore zone during a late stage in its history, and part of the tuff and banded chert was leached and transformed to a clay or paint-rock that resembles many other altered iron-formations. This fact and other evidence suggest that the hematite and goethite were derived from siderite–pyrite and banded chert iron-formation similar to that at Michipicoten. The sediments were later transformed to ore by supergene enrichment processes. Neither hypothesis accounts fully for all the facts known, but new information from more extensive and deeper mine workings is helping to resolve the problem of ore genesis. Ore from the mines, before processing or pelletizing, contains about 55% iron, 5% silica, 1.5% alumina and lime combined, and 0.027% phosphorus. The dried ore contains about 60% iron.

Iron-formations in Churchill Province are of the Algoma type and most are highly metamorphosed. Very high-grade ore deposits have recently been discovered in northern Baffin Island near Milne Inlet. The deposits consist of zones of metamorphosed magnetite and hematite iron-formation, unusually rich in iron, that were further altered by secondary enrichment processes and then subjected to later metamorphism. Two kinds of ore are present: hard, dark grey to blue hematite and high-grade stratified bodies of massive or banded magnetite and specular hematite. Large reserves of potential ore containing 67 to 69% iron and less than 1% silica have been proven.

Iron Deposits of Southwest Grenville Province

Numerous deposits associated with anorthosite and gabbro (Types IVA and B) are present in Grenville Province. Some of these, like the famous large orebodies in anorthosite at *Lac Tio* (73), Quebec, are predominantly ilmenite and the ore is processed for titanium dioxide. More than one million tons of iron are produced each year as a byproduct. Numerous large low-grade bodies of titaniferous magnetite in gabbroic rocks are not mined because an economic metallurgical process for separating titanium from the iron minerals has yet to be developed.

Numerous contact metasomatic magnetite deposits (Type V) occur in the southern part of Grenville Province. These deposits are relatively small and many were worked during the 19th century. The *Marmora* (111b), Ontario, deposit was discovered beneath 125 feet of Paleozoic limestone by an aeromagnetic survey. The mass of

ore is 2,400 feet long and 400 feet wide and contains an average of 40% iron. It has been mined since 1955 and about half a million tons of pellets containing 65% iron are produced yearly. A similar orebody has been worked at *Hilton* (42) near Shawville, Quebec, since 1958. Nearly a million tons of pellets containing 66% iron are produced yearly from crude ore grading about 18% iron. Deposits of this type are related spatially to gabbro intrusions. The limestones and amphibolites are the most favourable host rocks.

Nickel

Canada has been a world leader in production of nickel since exploitation of the huge Sudbury deposits commenced in 1887. In 1966, Canada produced more than 70 per cent of the non-communist world's nickel with the year's production valued at $400 million. More than 99 per cent of the total Canadian production of 234,061 tons was derived from mines in the Canadian Shield. Since 1953, nickel discoveries have been made in other parts of the Shield, at Thompson, Manitoba, in Ontario, in Quebec, and at Rankin Inlet, District of Keewatin. Ore reserves in 1966 were in excess of 380 million tons, averaging 1.5 per cent nickel. Despite the large tonnages now mined, these reserves are being increased annually, a trend that is expected to continue for some time as new discoveries are made, and as technological improvements and increases in metal prices enable presently known reserves of marginal grade ore to be mined.

The orebodies in the Canadian Shield are all of the sulphide type. They may be considered primary, as they are little altered by surface weathering processes. The principal ore mineral is pentlandite, almost invariably associated with pyrrhotite. Other sulphides of nickel, copper, and iron are commonly present, their species and relative proportions being dependent both on the bulk composition and on the temperature-pressure environment within the orebody during its formation. All important nickel deposits in the Canadian Shield are located in or near magmatic rocks of mafic or ultramafic composition, which were the source of the nickel. Copper is generally present and the ratio of nickel to copper has been found to be relatively consistent for a given deposit. Also the nickel–copper ratios have shown a direct correlation with the magnesium content of the associated mafic or ultramafic rock. Thus, sulphide minerals associated with dunite and peridotite have higher nickel to copper ratios than those associated with gabbro and norite. In the descriptions that follow, the nickel deposits of the Canadian Shield are grouped on the basis of their mafic or ultramafic affiliation.

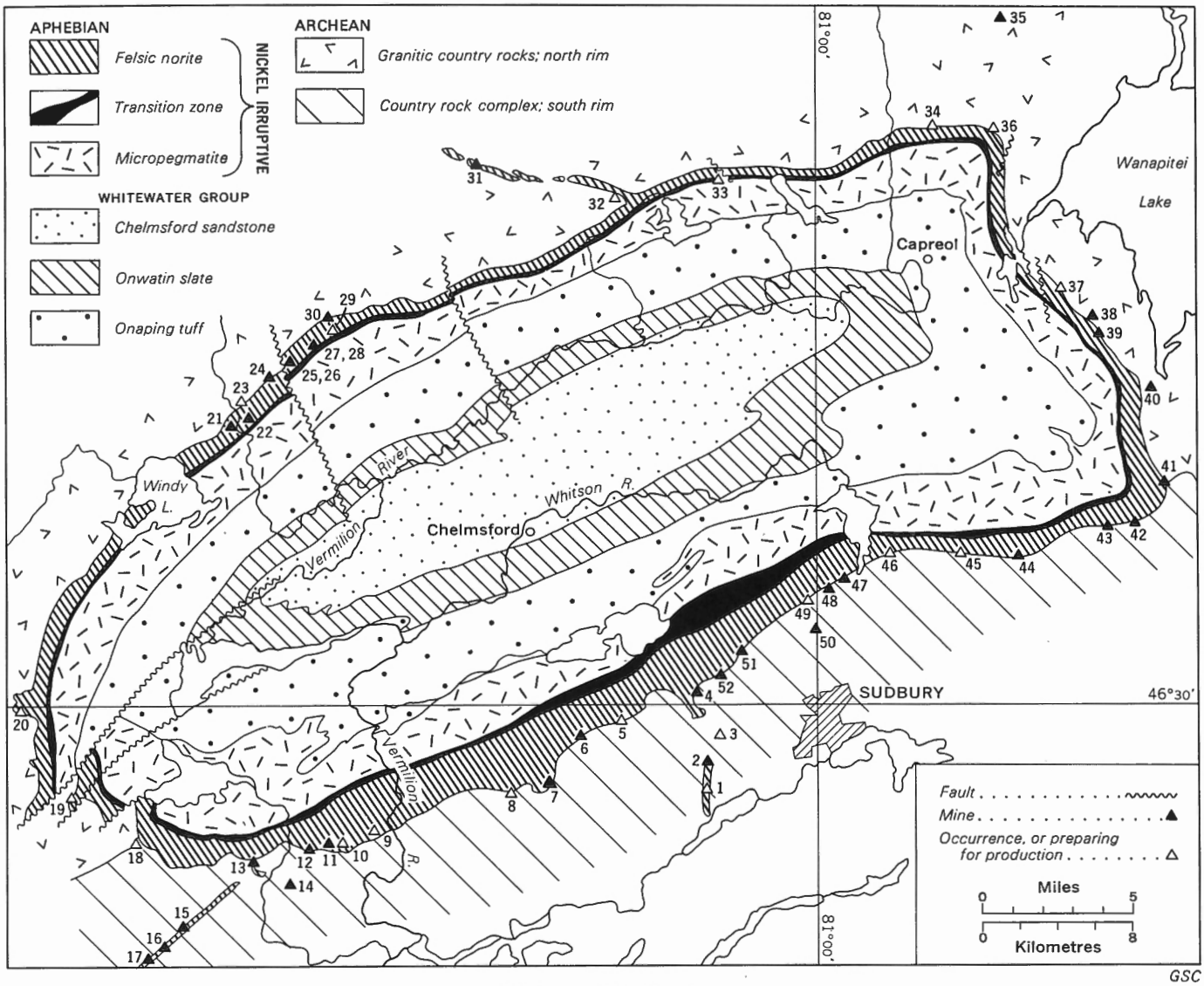
Deposits of Mafic Affiliation

Sudbury district, Ontario (78 to 90). Nickel ores affiliated with mafic rocks are typified by the deposits of the Sudbury district. About 185,000 tons, or more than 70 per cent of Canada's total annual nickel production, is derived from this district. A comparable tonnage of copper is also extracted, which makes Sudbury the largest copper producing area as well. The nickel sulphide orebodies occur at or near the outer margins of a body of igneous rock known as the Sudbury Irruptive. In plan, the irruptive forms an elliptical basin, 37 miles long and 17 miles wide (Fig. V-16). The outer part is composed of coarse-grained felsic norite and the inner part is a granophyre. The outer contact of the norite is marked by a zone of shearing and brecciation. The dip varies from 35 to 45 degrees south on the north side of the basin to vertical on the south (Fig. V-17). The rocks inside the irruptive, the Aphebian Whitewater Group, consist of tuffs, slate, and sandstone. They are generally synclinal but are broken by several east-west striking faults. Older rocks north of the irruptive are principally Archean granite. The southern contact of the irruptive is with the Sudbury Group, a sequence of metamorphosed and locally brecciated sediments and volcanics of Aphebian age intruded by granites and gabbros of various ages. The irruptive itself is metamorphosed, locally metasomatized, faulted, brecciated, and transected by diabase dykes. The origin of the Sudbury Irruptive and its associated ores is still a matter of conjecture. Cases can be made for the irruptive being a spoon-shaped sill, a lava lake remnant, a ring-dyke, a funnel-shaped intrusion, or even a structure produced by meteorite impact. The presence of abundant inclusions of ultramafic rock in many of the massive sulphide zones points to a deep-seated source. This and other less direct evidence suggest that some form of root or feeder exists beneath the Sudbury Irruptive.

The Sudbury ores consist of massive sulphides, breccia sulphides, and disseminated or stringer sulphides in silicates. The most abundant sulphide minerals are pyrrhotite, pentlandite, chalcopyrite, and cubanite. A host of less common sulphides and arsenides is the source of such byproduct metals as those of the platinum group, gold, silver, and cobalt. The overall ratio of nickel to copper is very close to 1:1, but in some orebodies there are significant departures, generally in the direction of increasing nickel.

The most commonly accepted theory on the origin of the sulphide minerals is that they were present in the main felsic norite magma and segregated as fluid droplets from the silicate fraction, settling toward the lower contact, to form pools of ore in depressions in the basement. In places, subsequent tectonic activity caused the sulphides to migrate into the adjacent country rocks, forming orebodies offset from the main irruptive bodies. Some recent observations (Souch and Podolsky, 1968; Naldrett and Kullerud, 1967) suggest that this theory needs revision. A complex group of intrusions and intrusive breccias occurs as a semi-continuous layer along the base of the main felsic norite and, in places, projects as dykes into

the footwall. These "sublayer" rocks, which vary in composition from quartz diorite to mafic norite, contain or lie adjacent to all known orebodies in the Sudbury district. They contain abundant inclusions and are intrusive into the felsic norite. Whole rock analyses indicate that the "sublayer" rocks contain about fifty times as much nickel and copper as the felsic norite. The implication is that the ores were deposited during a later intrusion of sulphide-rich silicate magma along the basal contact of the irruptive.



INDEX TO PROPERTIES

(Numbers in brackets according to Map 1252A)

1. Copper Cliff South
2. (89b) Copper Cliff No. 1
3. (89c) Copper Cliff North
4. (89a) Clarabelle
5. Tam O'Shanter
6. (90b) North Star
7. (90a) Creighton
8. Gertrude
9. McVittie Graham
10. Lockerby
11. (78b) Ellen
12. (78a) Crean Hill
13. (78c) Victoria
14. Vermilion
15. Kidd
16. (79c) Worthington
17. (79b) Totten
18. Chicago
19. Sultana
20. Trillabelle
21. (80a) Hardy
22. (80b) Onaping-Boundary
23. Levack West
24. (82b) Levack
25. (82a) Fecunis Lake
26. (82d) North
27. (82e) Strathcona
28. Coleman
29. Longvack South
30. (82c) Longvack
31. (83) Nickel Offset
32. W.D. 150, 155
33. North Range Shaft
34. New Dominion
35. (85) Milnet
36. Whistle
37. Capre Lake
38. Victor
39. (86) Nickel Rim
40. (87e) Maclennan
41. (87f) Norduna
42. East
43. (87a) Falconbridge
44. (87c) Garson
45. (87d) Kirkwood
46. Sheppard
47. (88a) Blezard
48. (88c) Mount Nickel
49. Little Stobie
50. (88b) Frood-Stobie
51. (89g) McKim
52. (89h) Murray

FIGURE V-16. Nickel deposits of the Sudbury district, Ontario (by J. A. Chamberlain).

Lynn Lake, Manitoba (1). The mines at Lynn Lake annually produce about 13,000 tons of nickel, or approximately 5 per cent of Canada's total. The orebodies, ten in all (of which three have been mined out), occur mainly in a variety of intrusive rocks of gabbroic character, but one orebody is in a more siliceous, fine-grained, variable quartz hornblende diorite. Peridotite is present in the vicinity of all orebodies, and sometimes close to them, and although some ore minerals are present in the peridotite at one locality, no orebodies have been developed. The sulphide minerals occur as massive or breccia type concentrations, disseminations, or stockworks. The main ore minerals are pyrrhotite, pentlandite, and chalcopyrite. Pyrite is minor. According to Ruttan (1955), the nickel–copper ratios range from 1:1 to 3.5:1 in the various orebodies, and average about 2:1. No significant change in ratio has been observed with depth. The orebodies are irregular to lenticular in plan, and pipe-like in section. They occur in zones that show a high incidence of fracturing and faulting. Some of the faulting is later than deposition of the ore. The sulphide minerals replace granite, pegmatite, feldspar porphyry, felsite, and quartz veins that cut the gabbros. A considerable time must have elapsed between emplacement of the mafic rocks and the period of mineralization. This is incompatible with formation of sulphides in situ by processes of magmatic segregation.

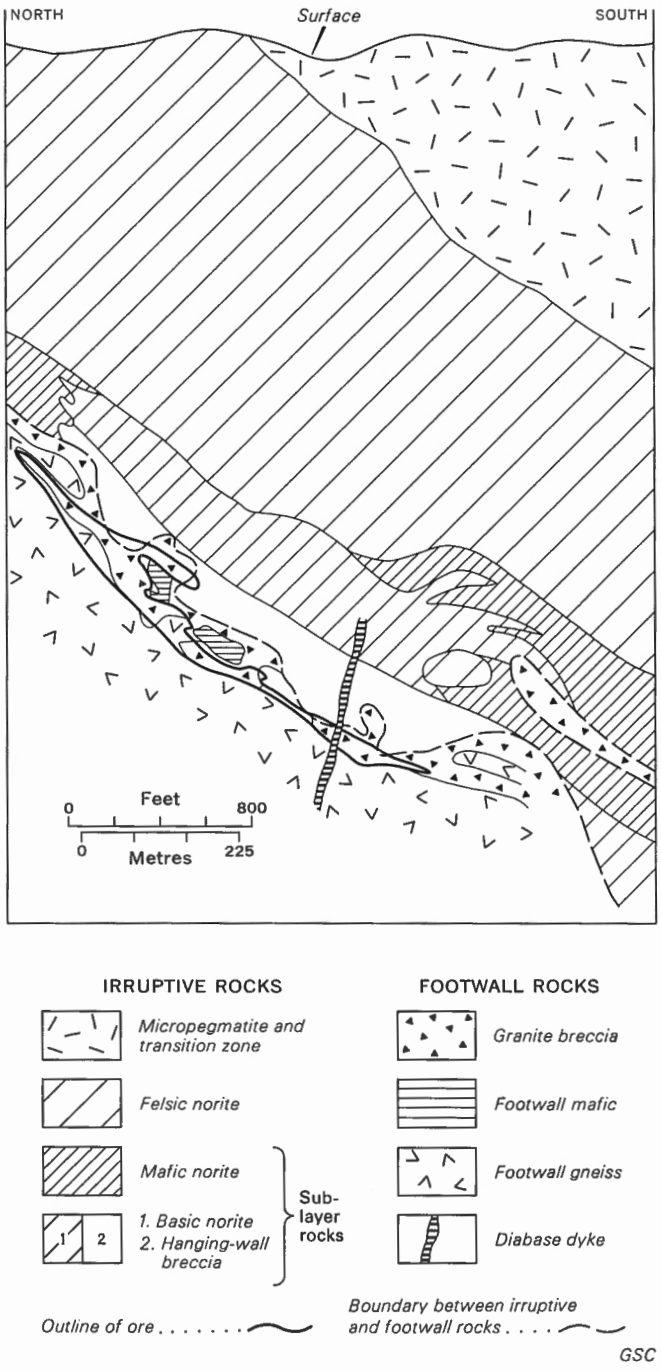


FIGURE V-17. Vertical section through the Strathcona deposit, north rim of the Sudbury basin, Ontario (Naldrett and Kullerud, 1967).

Other nickel deposits associated with mafic rocks are fairly common in the Canadian Shield, but few have proved to be economic. In 1965, the *Lorraine* (40) mine in the Belleterre area, Quebec, produced 900 tons of nickel and 2,200 tons of copper. The orebody is small, steeply dipping, and pipe-shaped and is present in Archean greenstones near a diorite intrusion. The ratio of nickel to copper in the sulphides is fairly consistent at 0.4:1. The *Kenbridge* deposit in the Kenora district, Ontario, occurs in a gabbro lens intrusive into greenstone. The sulphides occur in a series of flat sheets that have an average nickel to copper ratio of 2:1. In *Pardee Township,* south of Port Arthur, Ontario, pyrrhotite, chalcopyrite, and pentlandite occur along the lower margin of sill-like bodies of gabbro that intrude Aphebian sediments. Recent drilling has outlined large tonnages of low-grade sulphide ore occurring largely as disseminations and veinlets in coarse-grained gabbroic matrix. A uniform nickel–copper ratio of about 0.1:1 is indicated.

Deposits of Ultramafic Affiliation

Thompson district, Manitoba (12, 13). The largest nickel deposits associated with ultramafic rocks are those of the Thompson belt, in Manitoba, that were discovered in 1956 (Fig. V-18). The present annual nickel production from the Thompson mine of 50,000 tons accounts for nearly one fifth of Canada's total. Three other mines, the Pipe, the Soab, and the Birchtree, are currently being prepared for production. The orebodies of the Thompson belt are present for 90 miles along the boundary between Superior and Churchill Provinces. The deposits are very nearly colinear and occur in or near lenticular pods of Alpine-type peridotite within metasediments and gneisses. The peridotites are commonly intruded by dyke-like bodies of granite and pegmatite, and the sulphide minerals in places invade these younger intrusive rocks. The nickel ore is present in two principal forms: (1) as uniformly disseminated sulphides or sulphide veinlets in peridotite, and (2) as sharply defined zones of breccia sulphide in metasedi-

mentary rocks. Orebodies of the first type occur at Mystery Lake, Moak Lake, Pipe Lake, Grass Lake, Soab, and near Wabowden. They are relatively low grade and appear to be indigenous to the peridotites, being regarded by most geologists as magmatic in origin.

Orebodies of the second type occur at Birchtree Lake and Hambone Lake, and are best exemplified by the Thompson deposit (Fig. V-19). There, they occur in a continuous sheet that is grossly conformable to a large anticline and syncline in the metasediments and gneisses. The sulphides on the east limb of the anticline occur more or less continuously for more than 15,000 feet along strike within a narrow band of biotite–sillimanite schist. Although the schist thins and disappears on the nose and west limb of the anticline, the sulphides persist along the contact between quartzite and skarn rock. West of the main anticline the sulphides have been traced to a schist-encased peridotite lens (Zurbrigg, 1963). In places, the peridotite itself contains sufficient disseminated sulphide minerals to be considered as ore.

Conclusions concerning the origin of the Thompson ore are summarized as follows:

1. The continuity of the sulphide horizon suggests a strong structural control on the ore localization.
2. The close spatial relationship of nickel-rich peridotite to all ore zones in the Thompson belt suggests that the nickel is derived from these rocks. This is corroborated by the fact that the ores have high nickel–copper ratios, in excess of 15:1 regardless of whether they occur in peridotite or in the metasediments.
3. As the sulphide minerals clearly replace pegmatite which is intrusive into the peridotite, the formation of ore zones in the country rocks is considered to have taken place after emplacement of the peridotites.

The mechanism by which the nickel sulphide was transported away from the peridotite and deposited as a continuous sheet over many thousands of feet is not clear. As there is no evidence of wall-rock alteration, transportation via hydrothermal fluids is unlikely. On the basis of current knowledge, the most plausible explanation is that, as the temperature and pressure increased during a period of folding and regional metamorphism, a fluid consisting essentially of iron, nickel, and sulphur developed in the peridotite. This fluid seeped down a shear formed in the relatively incompetent schists or at the contact between the quartzite and skarn where it ultimately congealed to form the orebodies.

At the *Marbridge* (27) mine, Quebec, the ore is localized in massive, acidic tuff adjacent to a lens of altered ultramafic rock. Currently producing about 2,300 tons of nickel annually, this small but high-grade deposit is believed to have formed by multiple injections of a silicate–sulphide fluid derived from the peridotite (Clark, 1965). The nickel–copper ratio in these ores is about 30:1.

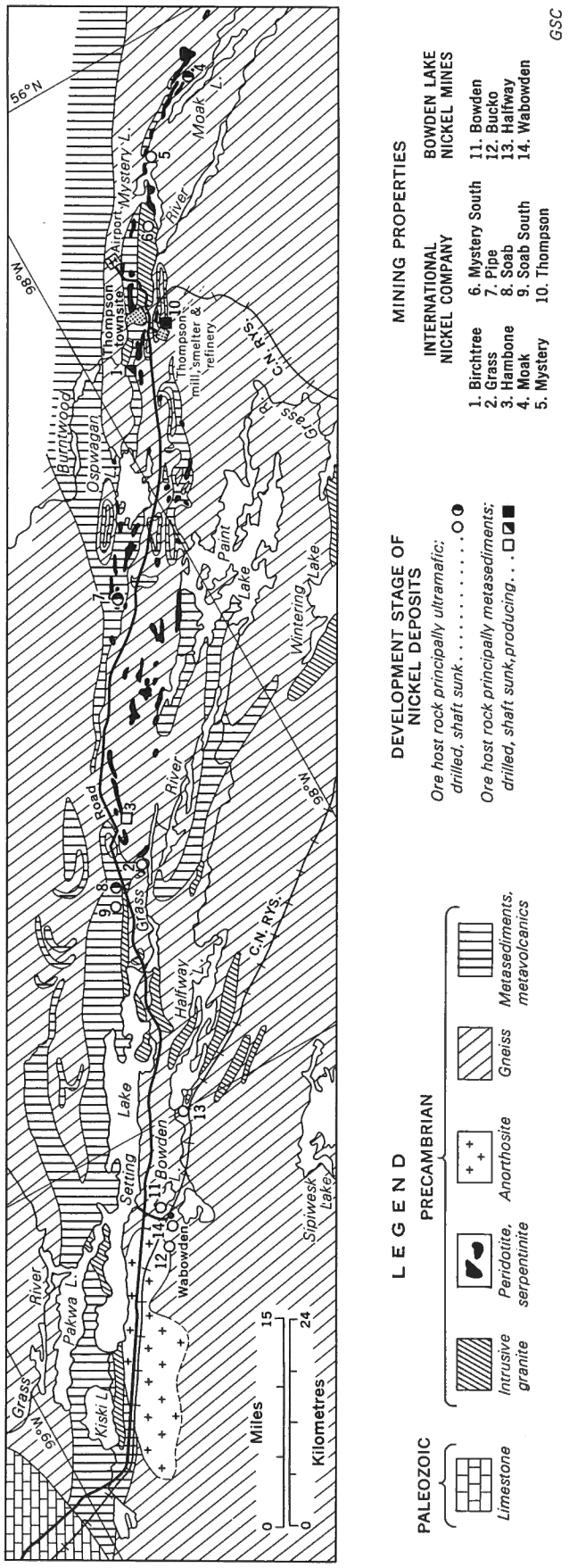


FIGURE V-18. Geology of the Thompson nickel belt, Manitoba (compiled by J. A. Chamberlain).

Gordon Lake, Ontario (13). The mine presently produces 2,800 tons of nickel annually. The sulphide minerals occur as disseminations, stringers, or flat-dipping tabular masses in or adjacent to peridotite in the footwall of a prominent fault. Lenticular or dyke-like pegmatitic intrusions transecting the peridotite are commonly mineralized. The sulphide assemblages in both the peridotite and pegmatite are much the same, indicating a common origin. The nickel–copper ratio in these ores is approximately 2:1.

The Cape Smith belt in northern Quebec contains several small, high-grade nickel–copper deposits. Although the remoteness of the region has hindered development, one orebody of 3.5 million tons is estimated to contain 3 per cent of combined nickel and copper at a ratio of 5:1. These sulphides occur as replacements at the base of sill-like bodies of altered peridotite (Philpotts, 1961). Between 1957 and 1962, a similar deposit at *Rankin Inlet* (11), District of Keewatin, produced more than 10,000 tons of nickel and 2,900 tons of copper. Other nickel deposits of ultramafic affiliation that attained production for short periods include the *Alexo* (54) and *Trebor* mines in the Timmins and Timagami areas of Ontario, respectively. The total production of nickel from these two properties was less than 200 tons.

Cobalt

All Canadian cobalt is obtained from the Shield, the greatest part as a byproduct of the nickel–copper ores at Sudbury, Ontario, and Lynn Lake, Manitoba. Pentlandite, the main source of cobalt in these ores, has an average cobalt content of about 1 per cent (Hawley, 1962). Minor amounts were produced during refining of silver ore from the Cobalt and Gowganda areas of Ontario. Total production since 1955 has remained constant at about 1,500 to

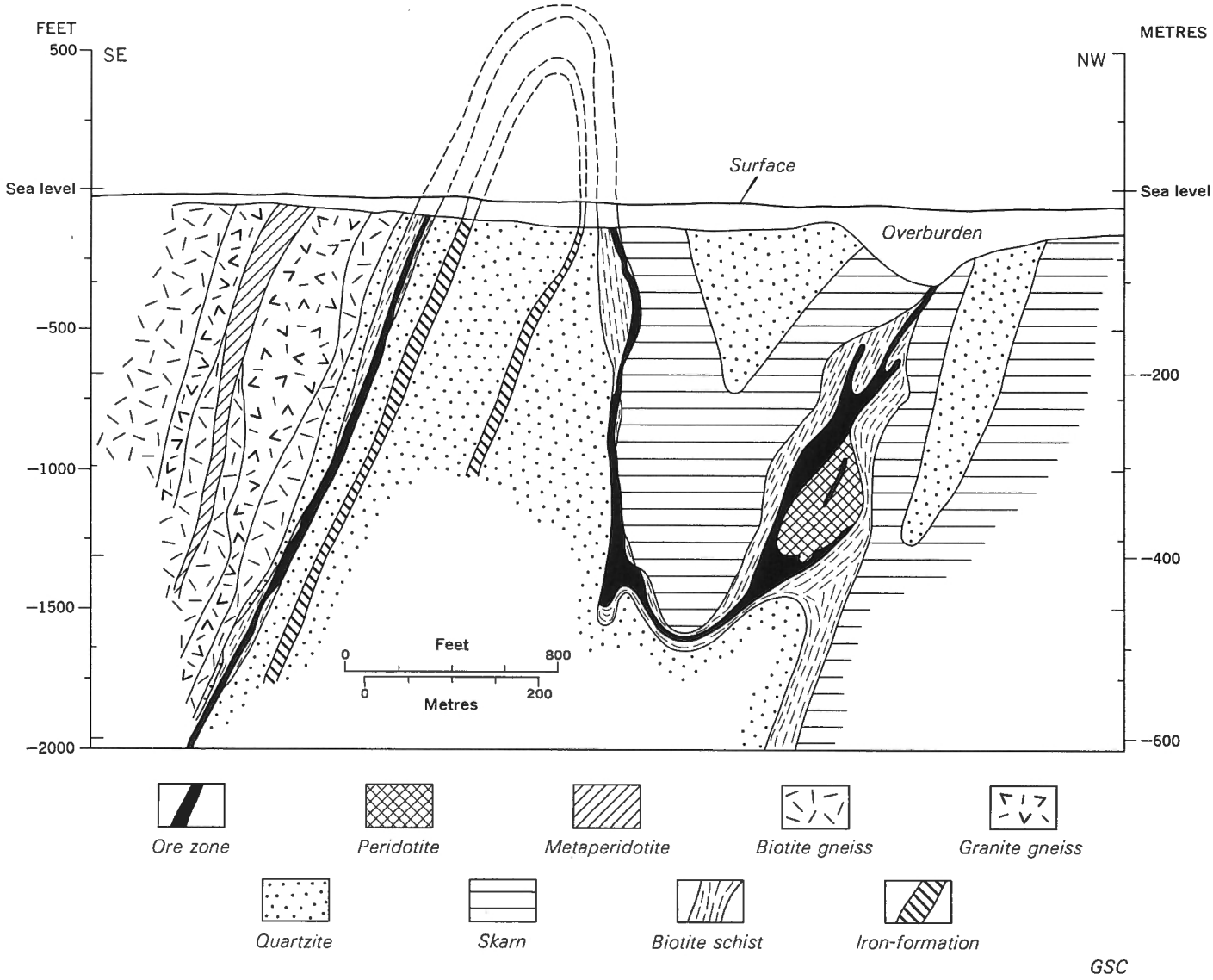


FIGURE V-19. Distribution of ore at the Thompson mine, Manitoba (Zurbrigg, 1963).

1,800 tons per year; 1966 production was 1,755 tons, about 7 per cent of which came from the Cobalt and Gowganda areas. Cobalt production in Canada has had a varied history, linked until recently with the fortunes of the Cobalt silver camp. Cobalt ores were mined from that area, and salvage operations were carried on during inactive periods. In 1951, the federal government raised the price for cobalt contained in cobalt ores or concentrates in order to stimulate exploration and production in the Cobalt and Gowganda areas. This premium price plan was terminated in 1956, the same year that the United States ended the price support in effect during the Korean war. No cobalt ores have been produced as such in Canada since then, although byproduct recovery from silver ores has continued. Shipping of byproduct cobalt from nickel mines began from Sudbury in 1954, and from Lynn Lake in 1955.

Chromium, Chromite

No chromite is being produced from the Shield. In the years 1934–37 a few thousand tons were mined from a deposit near Obonga Lake, Thunder Bay district of Ontario. There a mass of serpentinite composed of serpentine, chlorite, and talc in varying proportion underlies an area about 3 miles long and three-quarters mile wide. Vein-like bodies of chromite occur near the eastern end of the mass that carry an average of 27 to 34 per cent Cr_2O_3. The best concentrate that could be made of this material carried 42 per cent Cr_2O_3 and had a chrome–iron ratio of 1.3:1. In 1942 a large, low-grade chromite deposit was discovered north of Bird (Oiseau) River in southeastern Manitoba. The deposits have received intermittent attention but there has been no commercial production. A great sill-like mass of gabbro is intrusive into Archean rocks. It has been differentiated, presumably by gravity, into products ranging from augitite at the base to feldspathic quartz diorite at the top. Slightly below the middle of the sill small grains of chromite form a band that parallels the strike and dip. The chromiferous material occurs in alternate narrow bands of high- and low-grade material. The main band averages 7 feet wide, and has been traced several miles. The average grade is reported to be about 26 per cent Cr_2O_3, and the best chrome–iron ratio is 1.4:1.

Titanium

Titanium is the eighth most abundant metallic element on earth. It is estimated to average about 0.4 per cent by weight of rocks of the earth's crust, and it probably forms about 0.5 per cent of the rocks of the Canadian Shield, where it occurs mainly as the dark iron–titanium oxide minerals. It is about one-tenth as abundant as iron, and much more abundant than the common base metals, copper, nickel, lead, and zinc. Titanium is used on an increasing scale throughout the world in the white oxide form as a pigmenting material. Since 1950 Canada has become a leader in the production of ilmenite from the Lac Tio deposit near Allard Lake and TiO_2-rich slag is recovered at the smelter at Sorel, Quebec. In 1957 Canada became the world's leading ilmenite producer; by 1966 production reached more than a million tons per year. About 98 per cent of the titanium ore mined in Canada has gone into the production of TiO_2 pigment. Some is used as heavy aggregate in the concrete employed in laying natural gas pipelines and to form nuclear reactor shields. Only a small amount of titanium metal has been produced as yet; production may improve as use of metal increases, particularly in the construction of supersonic aircraft.

In the Canadian Shield, titanium occurs as an ilmenite–hematite mixture and as titaniferous magnetite (Pl. V-3). It is associated with large anorthositic and gabbroic intrusions that range in age from Archean in Superior Province, to Helikian in Grenville and Nain Provinces. This close association of ilmenite–hematite with anorthosite, and of titaniferous magnetite with gabbro, is also typical of many other parts of the world. Nowhere, however, is there a larger or more widespread development of anorthositic rocks, with associated gabbroic rocks and titaniferous deposits, than in Grenville and Nain Provinces.

Ilmenite Deposits

Ilmenite–hematite (titanic iron) deposits were first found in Canada by French colonists west of *St. Urbain* (70) in 1666. The first attempts to mine them were financially unsuccessful, but later attempts during World Wars I and II were more rewarding. Less than a million tons of ilmenite have been produced from the Furnace, General Electric, Coulombe, and Bignell deposits that contain about 22 million tons of ore averaging about 22 per cent titanium and 35 per cent iron. The deposits are dyke-like bodies composed almost entirely of massive, coarsely crystalline, blue-black intergrowths of ilmenite and exsolved hematite. The ore dykes, 10 to 100 feet wide and 100 to 1,000 feet long, are intrusive into the anorthosite on the hill west of St. Urbain. The deposits have been intersected by diamond drill at depths of more than 1,000 feet. Minor rutile pyrite, zeolites, calcite, and sapphirine occur sparingly, as well as inclusions of altered anorthosite. Some biotite is developed at the contacts of the ilmenite dykes with the anorthosite. Rutile is most abundant in the General Electric deposit where it is concentrated in a calcite segregation within the ilmenite–hematite lode. Many ilmenite deposits in the Morin anorthosite are similar to those at St. Urbain. The *Ivry* deposit has yielded about 52,000 tons of ilmenite since 1910. High-grade ore averages about 20 per cent titanium and 40 per cent iron. It consists predominantly of ilmenite with exsolved hematite, and minor pyrite, chalcopyrite,

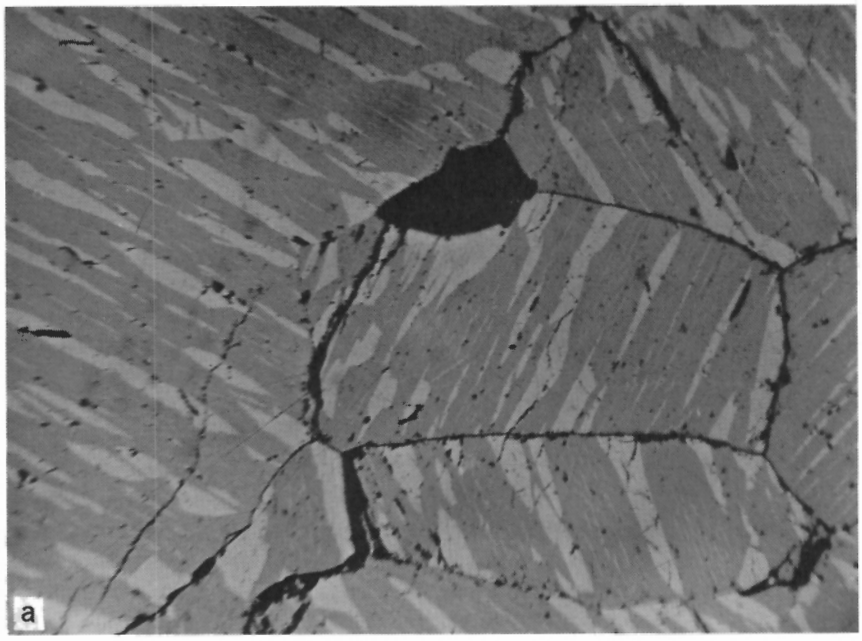
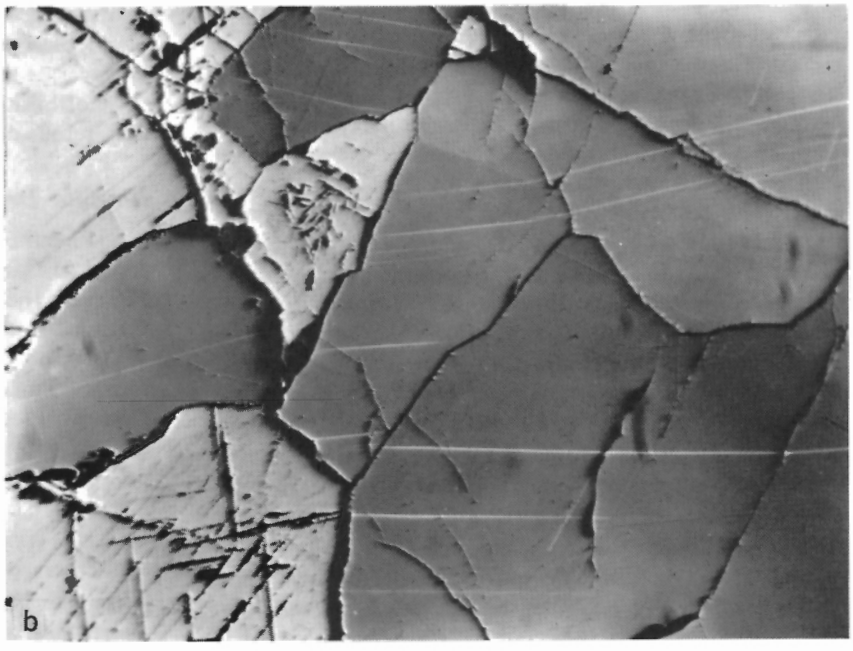


PLATE V-3
PHOTOMICROGRAPHS OF POLISHED SURFACES OF TITANIUM ORES.

(a) Lac Tio ilmenite–hematite deposit, Allard Lake, Quebec, showing hematite exsolution lamellae (light) in ilmenite (dark). Parallel nicols, low power.



(b) Titaniferous magnetite, south of Mattawa, Ontario, showing ilmenite grains (smooth, grey) with blades of exsolved hematite (white) and grains of titanomagnetite (rough, light grey) with exsolved ilmenite (dark). Crossed nicols, low power.

and magnetite. Mineralization is intermittent within a zone 100 feet wide and 1,000 feet long, and probably extends to depths of several hundred feet.

A large deposit of massive ilmenite–hematite was discovered in anorthosite west of Allard Lake, at *Lac Tio* (73). This deposit contains more than 125 million tons of ilmenite. The orebody forms a saddle and gently dipping sill-like mass, 25 feet to more than 200 feet thick, that intrudes anorthosite on the west, and is capped by gabbroic anorthosite on the east. The deposit has several dyke-like tongues and satellitic deposits associated with it. The ore consists almost entirely of massive, coarsely crystalline ilmenite with exsolved hematite (Pl. V-3a), averaging about 20.4 per cent titanium and 41 per cent iron. Inclusions of anorthosite, and crystals of plagioclase, pyroxene, pyrite, and chalcopyrite form the gangue or contaminate the orebody. About 10 million tons of ore have been mined up to 1967 in open-pit operations, from which about 5 million tons of TiO_2 slag and 3½ million tons of iron (Sorel metal) have been recovered.

Titaniferous Magnetite Deposits

Titaniferous magnetite deposits form a large undeveloped potential source of titanium and iron. More than

50 titaniferous magnetite deposits are known in the Grenville Province of Quebec alone, and many others are known elsewhere. Information is lacking regarding the full extent and grade of these occurrences, but they appear to range in size from several hundred thousand tons to more than a billion tons, and to average, conservatively, about 20 per cent iron, 5 per cent titanium, and 0.25 per cent vanadium. Representative of the better known titaniferous magnetite occurrences are the Seine Bay–Bad Vermilion Lake deposits in northwestern Ontario, the St. Charles and the Sept Iles Bay deposits of Quebec, and the Steel Mountain and Indian Head deposits of western Newfoundland. The Newfoundland deposits occur in Precambrian inliers within the Paleozoic rocks of the Appalachian Region. All deposits are associated with anorthositic and gabbroic rocks. This is also true of the less well known, recently discovered, titaniferous magnetite deposits around Lac Pin Rouge north of Montreal, at Magpie Mountain (Awater–Lapointe) north of Mingan, Quebec, and at Pipestone Lake near Cross Lake, Manitoba. Large tonnages of low-grade material are available in all these deposits, and many others undoubtedly remain to be discovered.

The main ore minerals, titanomagnetite, ferrian ilmenite, and titanhematite, commonly show exsolution textures characteristic of deposits formed at magmatic temperatures (Pl. V-3b). Because of the intimacy of the intergrowths it is commonly difficult, or impossible, to separate them satisfactorily by mechanical methods. Most deposits, even the low-grade ones may be readily concentrated magnetically, especially where the ilmenite and titanomagnetite occur as discrete grains. Most titaniferous magnetite deposits carry traces of vanadium, chromium, manganese, cobalt, and nickel. More than one per cent vanadium has been detected in the deposits at Pipestone Lake, Manitoba, at Millbridge and Mattawa, Ontario, and from Indian Head, Newfoundland.

Other potential ores of titanium in the Canadian Shield include occurrences of rutile, titanite (sphene), and perovskite, but none has yet been found in deposits of economic importance. Concentrations of heavy dark minerals in sands of Recent age may carry all these minerals and be potential ores of iron, titanium, or other rare metals, as they are in Australia, India, the United States, and Brazil. Notable concentrations of black magnetic sands have been found at localities along the north shore of the St. Lawrence River.

Locating Deposits

Aeromagnetic surveys have proved to be of value in locating concentrations of magnetic minerals, and also help to outline the gabbroic phases of anorthositic massifs. The gabbroic phases generally have a much higher magnetic intensity than the anorthosite proper, and the titaniferous magnetite concentrations within them are commonly associated with very strong positive aeromagnetic anomalies. On the other hand, the ilmenite–hematite occurrences that are commonly associated with the anorthositic phases are also generally represented by negative magnetic anomalies, as at Lac Tio in which the polarity of the deposit is reversed, with the north-seeking pole inclined upwards. However, the typical magnetic intensities may be muted by mixtures of the two types of minerals; furthermore, ilmenite–hematite occurrences are normally (positively) polarized and associated with positive aeromagnetic anomalies, as at St. Urbain, and titanomagnetite is in places reversely (negatively) polarized, as at Magpie Mountain. Ground magnetometer, gravimeter, and dip-needle surveys, are also used to advantage in outlining titaniferous deposits after they have been located or their presence suspected.

BASE METALS

Copper and Zinc

Copper produced from the Canadian Shield in 1966 was valued at $464 million, and formed 73 per cent of the total Canadian production of this metal; similarly, zinc was valued at $285 million and formed 45 per cent (Table V-7). About half the copper came from nickel–copper mines; these are described in the section on nickel. Most of the remaining copper and almost all the zinc (Tables V-8 and -9) came from lenticular, massive to disseminated, strata-bound deposits in metavolcanic and metasedimentary rocks. These deposits contain mixtures, in various proportions, of pyrite, pyrrhotite, sphalerite, chalcopyrite, and, in some instances, galena. They also contain significant amounts of gold and silver. Zinc is not recovered from some deposits, nor is copper recovered from others, even though the deposits are all essentially of the same type. Most production has been from the Abitibi belt in Superior Province, which extends from Timmins, Ontario, to Matagami and Chibougamau, Quebec (Fig. V-20). Important production from strata-bound deposits is also obtained in the Manitouwadge area of Ontario, and from the southern part of Churchill Province at Flin Flon, Manitoba, and within the surrounding district. Several copper–gold deposits in the Chibougamau region, Quebec, which is in Superior Province but east of Matagami, occur in basic plutonic rocks. A copper deposit mined in the northern part of Chibougamau region is in Aphebian dolomite.

Smaller amounts of either copper or zinc, or both, are produced from other deposits of various kinds includ-

TABLE V-7 *Estimated distribution of copper and zinc production in 1966 (based on preliminary figures for 1966, including some assumptions because of different ways of reporting)*

	COPPER			ZINC		
	Pounds (millions)	Per cent of Canadian Production	Per cent of Production from Shield	Pounds (millions)	Per cent of Canadian Production	Per cent of Production from Shield
Total Canadian production	1,033			1,889		
Production from Canadian Shield	751	73		862	45.5	
Production from nickel–copper mines	337	33	45			
Production from non-nickel mines	414	40	55			
Superior Province	322.5			709		
Timmins–Noranda–Matagami (by difference)	*129.5*	12	17	*571*	31	66.5
Manitouwadge	*60*	6	8	*125*	6.5	14.5
Chibougamau	*102*	10	13.5			
Other mines	*31*	3	4	*13*	0.5	1.5
Churchill Province	90	9	12	140	7	16
Grenville Province				13	0.5	1.5
Slave Province	1.5	<0.5	<0.5			

ing strata-bound ones in the Superior and other provinces of the Shield. These include a porphyry copper deposit at Timmins, Ontario, and a few chalcopyrite-bearing quartz veins near Kirkland Lake, Ontario, the Zenmac sphalerite-bearing lenses in gabbro north of Lake Superior, the North Coldstream copper deposits in basic volcanics near Port Arthur, the Copperfields deposits near a rhyolite–diorite contact at Timagami Lake, and chalcocite-bearing veins in Keweenawan strata near Sault Ste. Marie (Tables V-8 and -9). Although not at present mined, a large low-grade copper dissemination in a basic phase of an alkalic syenite complex occurs near Marathon, Ontario. Zinc is produced from a sphalerite deposit in metamorphosed impure limestone in Grenville Province northwest of Ottawa. Copper is obtained along with silver from veins at Great Bear Lake, in Bear Province, and much testing is being done on the copper occurrences in the basalts of the Coppermine River region.

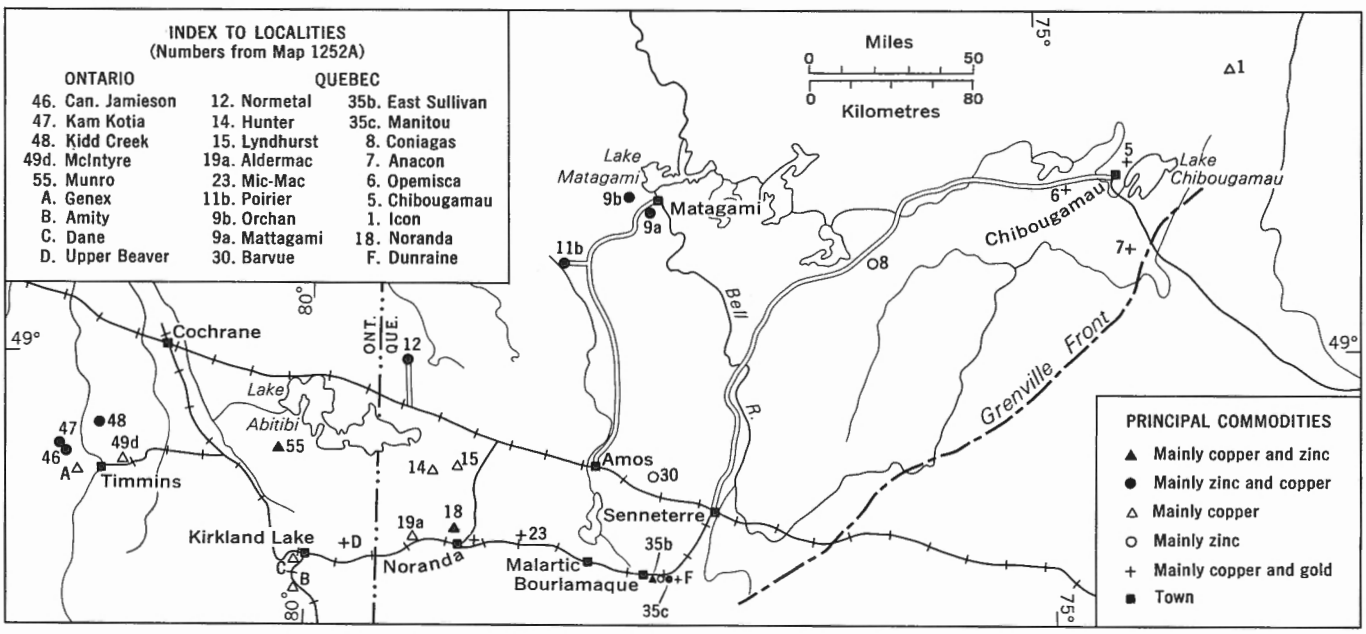


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FIGURE V-20. Copper and zinc mines of the Abitibi Belt, Ontario and Quebec (by A. H. Lang).

TABLE V-8 | *Copper and zinc mines in Superior Province*

Map No.[1]	Name	Production Began	Production Ended	Rate[2] (t.p.d.)	Main Tenor[3] % Cu	% Zn	Other	Type	Host Rock[4]	Remarks
ONTARIO										
	TIMMINS AREA									
48	Kidd Creek	1966		9,000	1.33	7.08	Ag	concordant massive	rhyolite	shipped to Kam-Kotia mill 1965-66
47	Kam-Kotia	1943, '61		1,700	1.73	2.94		shear zone	contact between basic and acid volcanics	
46	Can. Jamieson	1966		400	2.95	4.46			rhyolite	
49d	McIntyre (copper)	1963		1,800	0.88			porphyry copper	quartz–feldspar porphyry	contains molybdenite
	Genex[s]	1966	1967	200	1.95					
55	Munro	1967		700	2.09	1.69			greenstone near peridotite	
59b	Upper Beaver[s]	1965		150	1.19		Au	quartz veins	greenstone and syenite porphyry	shipped to Upper Canada mill
	Dane[s]	1911	1914	small				quartz vein	greenstone	Kirkland Lake
	Amity[s]	1928	1932	small					tuff, iron-formation	south of Kirkland Lake
QUEBEC										
	NORANDA AREA–MAIN									
18e	Horne	1927		3,500	2.2		Au	ellipsoidal bodies	rhyolite, etc.	
18f	Joliet				0.95		Au			operated by Noranda
19a	Aldermac	1932	1943	1,000	1.65			dissemi-nated masses	acid tuff and agg.	
18a	Amulet	1930	1962	1,000				domical masses	rhyolite	
	'A'				5.12	5.47		domical masses	rhyolite	
	'C'				2.2	8.5		domical masses	rhyolite	
	'F'				3.4	8.6		domical masses	rhyolite	
	'NW'				1.5			domical masses	rhyolite	
18c	D'Eldona		1952			7.7	Au	pyritic zone	volcanic	
18j	Quemont	1949			1.5		Au			
18k	West Macdonald[s]	1955	1959			3				zinc–pyrite shipper
17f	Waite, 'Old'	1928, '37	1961	700	4.7	2.98		lenses	rhyolite	
	Waite, 'East'	1952	1961		4.13	3.26				
17e	Vauze	1961	1965		5.2	3.7		tabular body in pipe	rhyolite	beneath diorite
18g	Lake Dufault	1964			3.3	6.6	Au			
	NORANDA AREA–OUTLYING									
40	Lorraine	1965		400	Cu		Ni			Belleterre area
23	Mic-Mac	1942	1944	600	Cu		Au	sheeted quartz stringers		Bonsquet tp.
35b	East Sullivan	1949	1966	2,800	0.51	0.51	Au	massive and dissemi-nated zones	tuff	Bourlamaque tp.

TABLE V-8 | *Copper and zinc mines in Superior Province (cont.)*

Map No.[1]	Name	Production Began	Production Ended	Rate[2] (t.p.d.)	Main Tenor[3] % Cu	% Zn	Other	Type	Host Rock[4]	Remarks
35c	Manitou	1942	1962	1,000	0.82	2.93		masses and disseminations	tuff	two distinct Cu and Zn zones
	Dunraine (Rainville)	1956	1958	500	1.22			at contact of diabase sill	tuff	two distinct Cu and Zn zones
14	Hunter[s]	1955	1957		1			disseminated lenses	rhyolite	Duparquet tp.
15	Lyndhurst[s]	1956	1957		1.93					Destor tp.
30	Barvue	1952	1957	5,300	0.82	2.93			tuff and agglomerate	Barraute area
12	Normetal	1937		900	1.07	7.1			fragmental volcanics	La Sarre area
MATAGAMI AREA										
9a	Mattagami Lake	1963		3,800	0.69	10.4		concordant lenses	rhyolitic	
9b	Orchan	1963		1,900	1.23	11.1		concordant lenses	rhyolitic	
10	New Hosco	1963		900	1.1	3.5		concordant lenses	rhyolitic	shipper to Orchan
11b	Poirier	1966		2,500	1.74	3.63		concordant lenses	rhyolitic	
11a	Joutel[s]	1967		2,358	2.35	9.5				shipper to Poirier; Zn ore has 0.25% Cu
8	Coniagas	1961	1967	350		4–7	Pb, Ag	lenses	agglomerate and tuff	at Bachelor Lake; contained considerable Pb
CHIBOUGAMAU REGION										
	Campbell-Chibougamau									
5b	Main Mine	1955		35% of total	2.06	0.03		shear zone	meta-anorthosite	3,000 t.p.d. concentrator includes Merrill Id. claims
5e	Kokko Creek[s]	1959	1966		2.24	0.01		shear zone	meta-anorthosite	
5c	Cedar Bay[s]	1958		24% of total	2.50	0.07		shear zone	meta-anorthosite	
2a	Henderson[s]	1960		39% of total	2.45	0.06		shear zone	meta-anorthosite	
	Grandroy[s]	1967		500 t.p.d.	1.2	0.03		stockwork	granite	15 miles to northwest
	Copper Rand									
3b	Main Mine	1960		46% of total	2.34	0.025		stockwork	meta-anorthosite	1,800 t.p.d. concentrator
3c	Jaculet[s]	1960		24% of total	2.05	0.025		stockwork	meta-anorthosite	
2b	Portage[s]	1960		21% of total	2.20	0.16		stockwork	meta-anorthosite	
5h	Que. Chib.[s]	1963	1967	3% of total	2.01	0.08		stockwork	meta-anorthosite	5 miles west of Main mine
3a	Bouzan[s]	1962		5% of total	3.22	0.25		stockwork	meta-anorthosite	eastern extension of main deposit
5a	Bruneau[s]	1966		135	1.60	0.02		stockwork	gabbro and pyroclastic volcanics	6 miles NW at Chibougamau
5g	Un. Obalski[s]	1964	1966	200				veins	granophyre	
6	Opemiska	1953		2,099	3.00	0.02		veins	gabbro	2,000 t.p.d. concentrator 20 miles SW of Chibougamau

TABLE V-8 | *Copper and zinc mines in Superior Province (conc.)*

Map No.[1]	Name	Production Began	Production Ended	Rate[2] (t.p.d.)	Main Tenor[3] % Cu	Main Tenor[3] % Zn	Main Tenor[3] Other	Type	Host Rock[4]	Remarks
1	Icon	1967		600	5.94 82.4				dolomitic	38 miles NE of Chibougamau; grades are for open-pit and underground ore
7	Anacon	1956	1960	500	0.39	0.21		shear zone and quartz veins	meta-volcanics	30 miles south of Chibougamau 500–750 t.p.d. concentrator
ONTARIO										
MANITOUWADGE AREA										
36	Geco	1957		3,300	1.95	4.15		concordant	meta-sediments	fairly high grade metamorphism
35	Willroy	1957		1,700	1.49	2.38		concordant	meta-sediments	fairly high grade metamorphism
34	Willecho[s]	1965		1,000	0.48	4.29		concordant	meta-sediments	fairly high grade metamorphism
OTHER MINES										
	Wendigo	1936	1943					quartz vein in shear zone	basalt	Lake of Woods
	Andowan	1903	1903					breccia zone	granite–pegmatite contact	Port Arthur area (Pb, Zn)
25	North Coldstream	1957	1967	1,000	1.95		Au, Ag	lenses	basic volcanics	Port Arthur area intermittent production 1903-17
	Zenmac	1966		100		23.3		lenses	meta-gabbro	Schreiber area
71	Bruce	1846	1876					quartz veins	diabase sills	Sault Ste. Marie area int. prod. 1908–1921
69	Jardun	1954	1957	300		3.52	Pb, Ag	veins	schist and sheared basic dykes	Sault Ste. Marie area int. prod. 1878–1904
70	Rock Lake	1899	1903		Cu			calcite quartz	sediments	Sault Ste. Marie area
68	Coppercorp	1965		500	2.1			veins	basalt and conglomerate	Sault Ste. Marie area[5]
67	Tribag	1967		400	2.2			stockwork		
	Cheney	1916	1916		4.65			vein		
76	Pater	1961		700	1.97			sulphide zone	metasediments and volcanics	Blind River area
	Parkway	1906	1906		Cu			veins	metasediments	Blind River area
81	Lake Geneva	1941	1944			9 to 13	Pb	concordant	metasediments and breccia	north of Sudbury
	Pax Intern'l	1950	1965	150	1.25		Mo	shear zones	peridotite	Matachewan area
63b	New Ryan	1948	1953		Cu		Au, Ag			Matachewan area
	Matarrow	1952	1953			1.59	Pb, Ag	lenses	iron-formation	Matachewan area
94	Temagami	1959		150	6.17		Au, Ag	zones near contact	rhyolite and diorite	Timagami area
	Trebor	1936	1936		0.84		Ni			Timagami area

[1] Number is that assigned to the deposit, according to Province, on Mineral Deposits of Canada, Map 1253A (in folio). Mines without a number are not shown on the map.

[2] Production rates per day, generally for latest producing year.

[3] Grades are derived from 1966 reserves or the latest producing year, and are intended to be a general indication only.

[4] Host rocks are the principal rock types immediately enclosing the main deposits.

[5] In Southern Province.

[s] Shipping mine.

Exclusive of nickel operations, 45 mines produced copper or zinc or both as main products in 1966. During that year there were 41 other mines classified as former producers. A few mines began to produce in 1967, but about the same number were closed. The Horne mine has produced for 40 years, the Flin Flon for 37, and the Normetal for 30. At the other extreme a few small shipping mines were operated for a year or less. Most periods of operation are about 10 to 20 years. The deposits, many of which comprise several orebodies within the compass of a single mine, range downwards from the huge Kidd Creek deposit being mined at a daily rate of 9,000 tons; most are in the range of 500 to 3,000 tons per day. Depths vary from 1,000 to 4,000 feet below surface; one mine, the Normetal, extends to 8,000 feet. The long axes of many deposits or clusters of deposits pitch steeply; thus the depths of some mines are two or three times the longest lateral dimensions of the deposit. The tenors of the strata-bound ores are about 0.5 to 5 per cent copper and 0.5 to 11 per cent zinc, but many mines have sections or separate bodies having different tenors.

Many of the mines are centred around the large concentrators and smelters at Noranda, Quebec, Flin Flon, Manitoba, and Sudbury, Ontario. In addition to treating ore from the company's mines, these plants also treat ore

TABLE V-9 *Copper and zinc mines in Churchill Province*

Map No.[1]	Name	Production Began	Production Ended	Rate[2] (t.p.d.)	Approx. Main Tenors[3] % Cu	% Zn	Other	Type	Host Rock[4]	Remarks
MANITOBA										
2	Sherridon	1931, 1937	1951	3,000	2.2	0.88		massive and disseminated bodies	quartzite–gneiss contact	
4b	Schist Lakes[s]	1954		300	4.76	9			andesite	
4a	Mandy[s]	1917	1920		7.3	12.9			schist and breccia	
5	Cuprus	1948	1954	300	3.25	6.4			andesite and tuff	
6b	North Star[s]	1955	1958						andesite and rhyolite	
6a	Don Jon[s]	1955	1958						andesite and rhyolite	
8	Chisel Lake[s]	1960		1,000	0.59	10.3	Pb		schist and gneiss	
10	Stall Lake[s]	1964			4.5	1.6				
	Waden Bay	1966		900	2.4			lenses	arkose–greywacke contact	Anglo-Rouyn Mines Ltd.
	Rottenstone Lake	1965		150	2	2			ultrabasic rock	
	Hanson Lake	1967		350	0.4	7.35	Pb	lenses	tuff	
SASKATCHEWAN										
8	Flin Flon	1930		6,300 (capacity)	2.23	4.57		massive and disseminated bodies	andesite and tuff	operated at 4,630 t.p.d. in 1966
9	Birch Lake[s]	1957	1960		6.2				intermediate lava flows	
10	Coronation[s]	1960	1965		4.25	0.2			basic flows and tuff	

[1] Number is that assigned to the deposit, according to Province, on Mineral Deposits of Canada, Map 1252A (in folio). Mines without a number are not shown on the map.
[2] Production rates per day, generally for last producing year.
[3] Grades are derived from 1966 reserves or the latest producing year, and are intended to be a general indication only.
[4] Host rocks are the principal rock types immediately enclosing the main deposits.
[s] Shipping mine.

or concentrates from smaller mines in their respective regions. Some concentrators also treat ore shipped from smaller nearby mines that are similar mineralogically. For example, three concentrators at Chibougamau are treating or have treated ore from 14 mines, and the concentrators at Matagami and Poirier treat ore from neighbouring mines. This system permits the mining of some deposits that otherwise could not have been economically worked, or could only have been worked at greater capital costs. The principal deposits are described briefly in the following sections. They are grouped together into regions of similar geology and according to the geological provinces of the Shield.

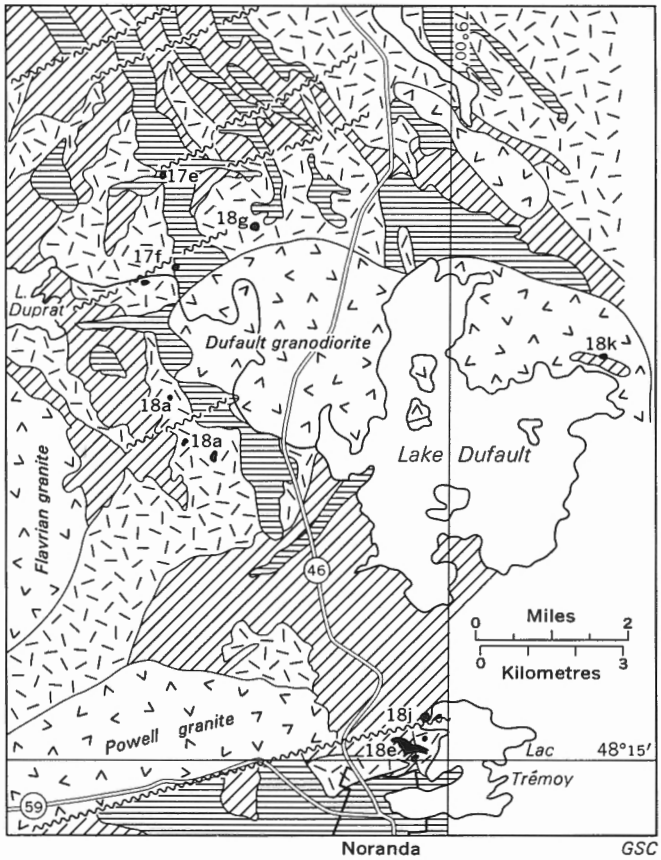
Copper–Zinc Deposits of Superior Province

Abitibi Belt, Ontario and Quebec

This region contains thick eugeosynclinal successions of metavolcanic and metasedimentary strata intruded by large and small masses of acidic, intermediate, and basic plutonic rocks. The belts of stratified rocks generally strike easterly but are internally complicated by local folds. The southern part of the belt extends eastward from Timmins, Ontario, through Noranda and Val d'Or to Bourlamaque, Quebec. This part contains the bulk of the mines. One hundred miles north the recently developed mines of the Poirier and Matagami areas are aligned with the Munro and Normetal mines.

Timmins, Ontario. In the Timmins area, but about 15 miles northwest of the main gold mines, are the *Kam-Kotia* (47), *Jamieson* (46), and *Genex* deposits of copper with some zinc and gold. They occur in Archean volcanic rocks on the flank of a large body of diorite and gabbro. Twelve miles northeast is the *Kidd Creek* (48) deposit, found in 1964 by geophysical prospecting in a terrain mainly covered by overburden. The deposit consists of massive sulphides concordant with enclosing steeply dipping rhyolite breccia that is overlain by andesite. An early estimate of open-pit ore indicated an orebody at least 400 feet wide and 2,000 feet long, with an exceptionally high content of zinc and silver and 1.33 per cent copper. At the *McIntyre* (49d) gold mine an important copper deposit was also found. It is of a type unusual in the Canadian Shield, being a dissemination of chalcopyrite with some tennantite and molybdenite in the Pearl Lake quartz–feldspar porphyry.

Noranda, Quebec. The sulphide deposits in the main part of Noranda area are in a thick pile of volcanic rocks containing much rhyolite, dacite, and related tuffs and breccias as well as andesite. Interbedded sediments are rare in comparison with the amount that occurs to the east and west. Most deposits are in acidic volcanics overlying a more widespread basic volcanic sequence; this leads to the speculation that the area had been one of abundant volcanism in an Archean eugeosynclinal belt,

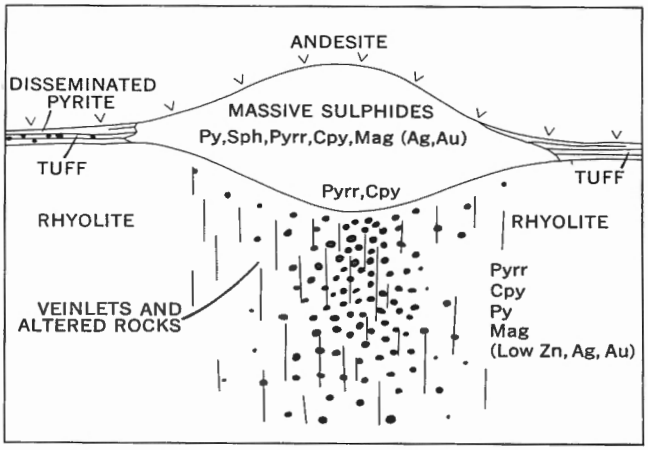


INDEX TO DEPOSITS
(Numbers from Map 1252A)

17e. Vauze	18g. Lake Dufault
17f. Waite	18j. Quemont
18a. Amulet	18k. West Macdonald
18e. Horne	

FIGURE V-21. Main copper and zinc producing part of Noranda area, Quebec. Some deep-seated deposits are in rocks other than shown on this surface map.

and that the volcanic host rocks of the deposits were laid down at the close of the main sequence of geosynclinal strata, or a little later. Many deposits occur peripheral to the Dufault Lake granodiorite body, those on the west side being in a remnant of volcanics bounded on the west by the Flavrian Lake granite (Fig. V-21). Most are lenticular, dome shaped, or ellipsoidal (Fig. V-22). All occur in acidic volcanics and most are at contacts of rhyolite with overlying andesite. Several are in rhyolite breccia beneath massive rhyolite. The *Waite* (17f), *East Waite*, and *Lake Dufault* (18g) orebodies are aligned and together



Pyrite	Py	Magnetite	Mag
Pyrrhotite	Pyrr	Zinc	Zn
Chalcopyrite	Cpy	Silver	Ag
Sphalerite	Sph	Gold	Au

GSC

FIGURE V-22. Features common to many sulphide deposits in Noranda area, Quebec (by S. M. Roscoe).

with that at *Amulet* (18a) appear to lie along northwesterly and northeasterly trending lineaments that form a rectilinear set. Several deposits north of the Horne mine are at the top of pipe-like zones of alteration to chlorite, sericite, and silica. Age determinations, geological settings, the fact that host rocks near deposits are deficient in the metals contained in the deposits, and other evidence cause several of the most recent students of the origin of the deposits (Gilmour, 1965; Roscoe, 1965) to conclude that the deposits are related genetically to the volcanism, but that they and their enclosing rocks are only slightly younger, and that subsequently in the Kenoran Orogeny the deposits and their host rocks were folded and tilted to their present attitudes.

The deposits are of two main mineralogical types: pyrrhotite–chalcopyrite–magnetite and pyrite–sphalerite. Both types carry minor amounts of gold and other metals. They commonly occur together as parts of a single orebody or as separate bodies at a single mine. In the latter case the pyrite–sphalerite bodies lie above the pyrrhotite–chalcopyrite bodies. This suggests that copper deposits might be encountered below known zinc orebodies in other areas.

The *Horne* (18e), the oldest and largest in the Noranda area, has yielded more than 50 million tons of ore containing more than one million tons of copper, 8 million ounces of gold, and large amounts of silver and pyrite. Reserves of the main orebodies at the end of 1966 were 3,831,600 tons carrying 2.47 per cent copper and 0.19 ounce of gold per ton. The orebodies are of irregular shapes, with long axes vertical or dipping steeply (Fig. V-23). They are in a fault block containing rhyolite and related tuff and agglomerate, and bodies of 'metadiabase' or 'older gabbro' that also may be related to the volcanism. Most ore is in the 'H' and Lower 'H' bodies. Some others contain siliceous flux ore. An alteration pipe has not been found beneath the Horne cluster of deposits. Some geologists suggest that the alteration found in places at the edges of deposits may be remnants of a faulted pipe. The largest body, the 'No. 5', contains pyrite, sphalerite, chalcopyrite, and gold and silver, but is low grade. It lies to the north, beyond the group shown on Figure V-23, and has been explored from surface to a depth of 8,000 feet. The feasibility of mining sections of it is being investigated. Gilmour (1965) suggests that it is concordant with the strata and stratigraphically above the copper-bearing bodies.

The *Poirier* (11b) mine, 60 miles north of Amos and 35 southwest of Matagami, is in a belt of volcanics

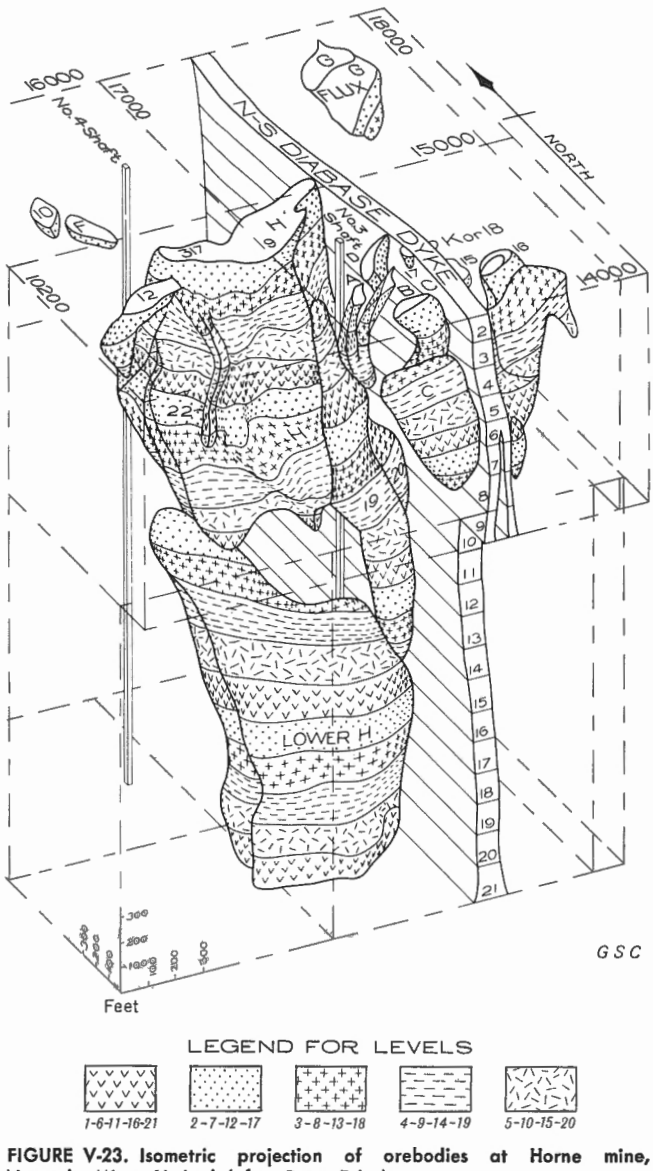


FIGURE V-23. Isometric projection of orebodies at Horne mine, Noranda Mines Limited (after Peter Price).

a mile from a granitic body. A zone 300 feet wide and 1,500 feet long lies in the steeply dipping contact between rhyolite and rhyolite tuff. It contains lenticular bodies in rock much altered to chlorite and talc. The lenses are of three kinds: predominantly pyrrhotite with sphalerite; chalcopyrite with some pyrrhotite; and chalcopyrite–sphalerite. The nearby *Joutel* (11a) deposit has a copper and zinc–copper section.

Matagami area, Quebec. The Matagami area is underlain by mafic and rhyolitic volcanics and the northwestern part of the Bell River complex of anorthosite, gabbro, and other rocks (Fig. V-24). Around the nose of the main part of the complex are sill-like bodies so intimately associated with the volcanics that a common origin has been suggested. The area contains three producing zinc–copper mines, the *Mattagami Lake* (9a), *Orchan* (9b), and *New Hosco* (10). These and several prospects are in a sequence of mainly rhyolitic rocks near some of the smaller bodies of the Bell River complex. The three mines and nine prospects have most of the following characteristics in common (Latulippe, 1966): they are in the contact zone of the Watson Lake group of rhyolitic rocks with the Wabassee group of dacite, andesite, and basalt; most host rocks are little metamorphosed; the sulphide masses are lensoid, some being deformed; the tops of the masses abut sharply against overlying strata but their basal parts grade into the host rocks; the deposits contain both massive and disseminated pyrite, pyrrhotite, sphalerite, chalcopyrite, and magnetite. The largest mine, the Mattagami, is at the nose of a minor drag-fold along the flank of the main anticline of the area. This property and the adjoining Orchan contain five orebodies as thick as 400 feet, over a total length of 6,700 feet. One of the Orchan bodies extends to a depth of 1,200 feet.

Manitouwadge area, Ontario. The *Geco* (36) discovery in Manitouwadge area, north of Lake Superior, was confirmed in 1953 by prospectors investigating an occurrence of sulphides noted on a map issued by the Ontario Department of Mines in 1932. Production was begun in 1957. Further prospecting and testing led to the discovery of the adjoining *Willroy* (35) and *Willecho* (34) orebodies farther northwest. In 1966 the Geco yielded 46,120 tons of zinc, 26,770 tons of copper, 840 tons of lead, 2,203,500 ounces of silver, and some gold. The combined Willroy and Willecho production was 10,696,766 pounds of zinc, 2,250,136 pounds of copper, 852,574 pounds of lead, 311,003 ounces of silver, and 429 ounces of gold.

The area is underlain by a synclinal roof-pendant of metavolcanic and metasedimentary strata of Keewatin type, surrounded by biotite–granodiorite gneiss and migmatite prevalent in the district. The development of the area is noteworthy because such small, strongly metamorphosed 'greenstone' belts were generally considered unfavourable for base metals. The syncline plunges northeast causing the strata to nose into the granitic rocks to the southwest and to assume a crescentic shape to the northeast, the two extremities being 6 miles apart where they taper into the granitic rocks. The older rocks, exposed in the western and southern parts of the area, are amphibolite and massive and laminated hornblende

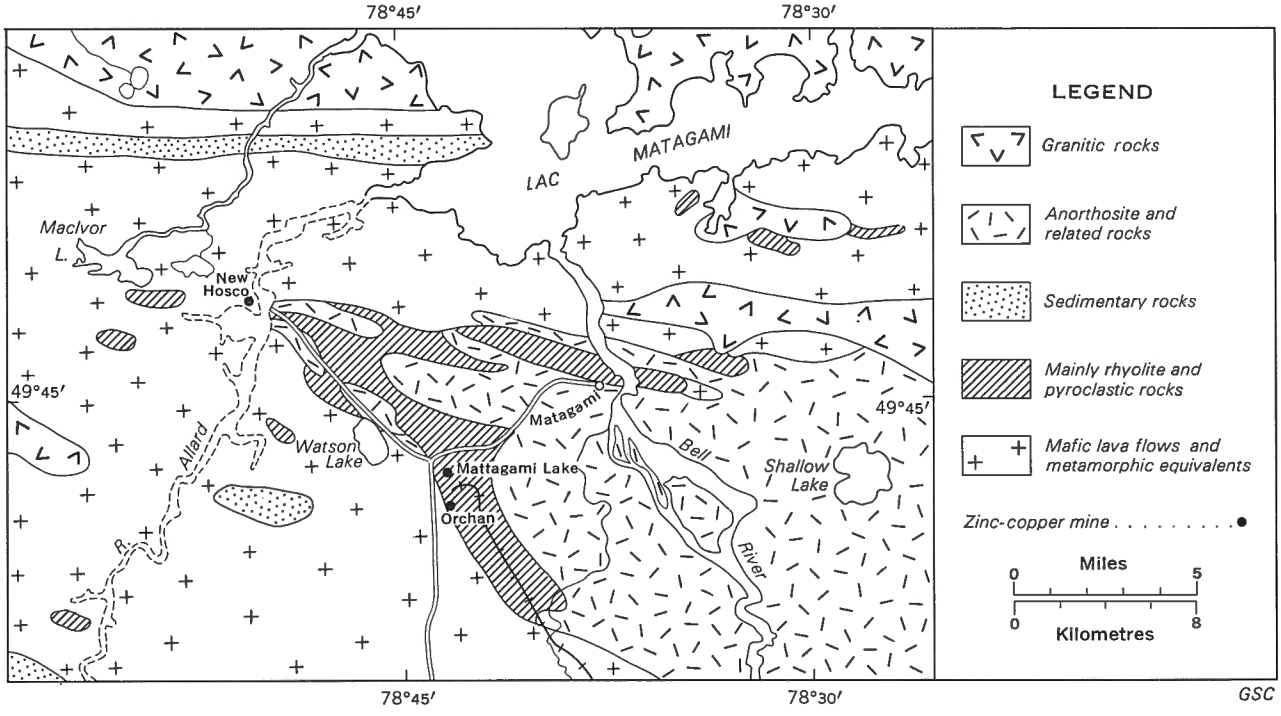


FIGURE V-24. Mines and prospects of Matagami area, Quebec (Latulippe, 1966).

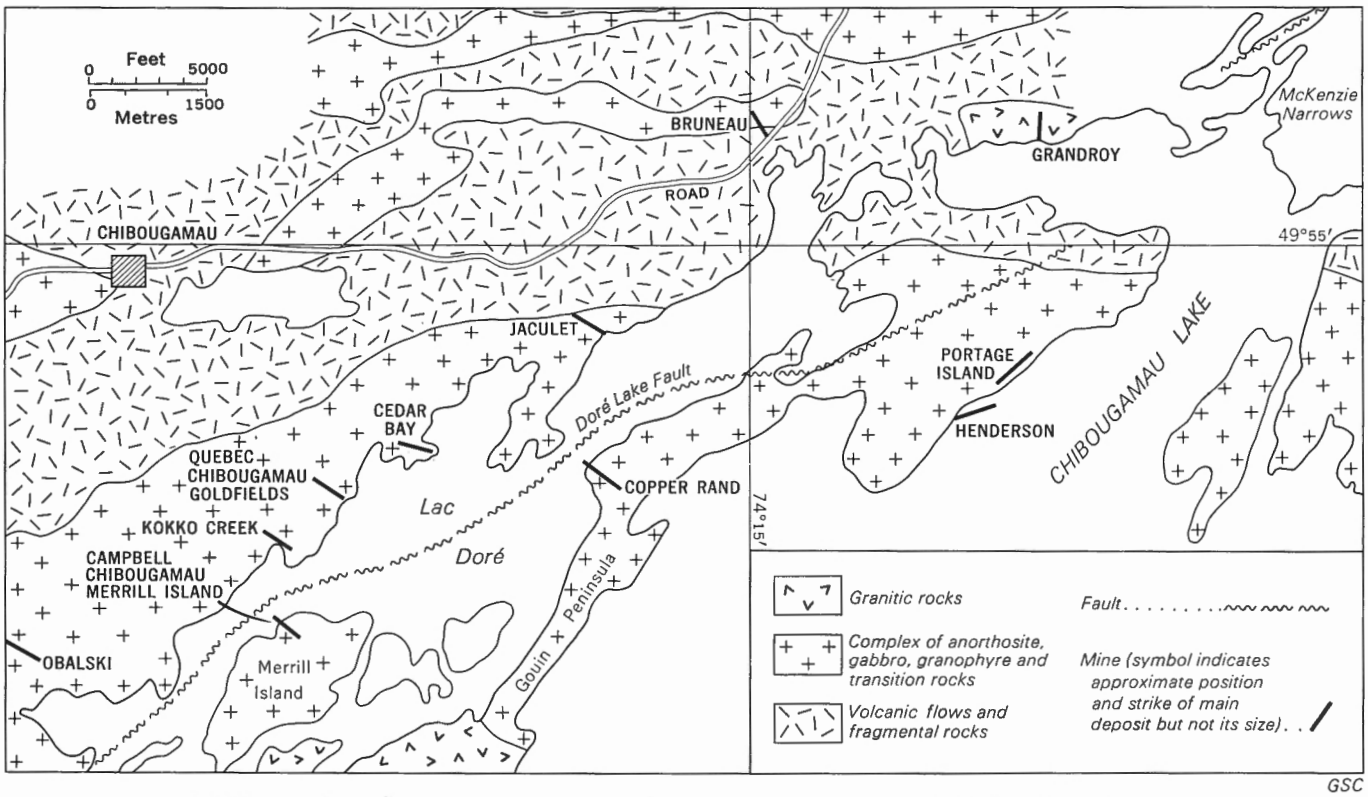


FIGURE V-25. Generalized geology and copper–gold mines of Chibougamau region, Quebec (by A. H. Lang).

schists. These are overlain by gneisses, schist, and iron-formation. A narrow belt of metavolcanics overlies the sedimentary rocks. Bodies of meta-gabbro intrude the volcanics but are not known to cut the sediments. Dykes and sills of microgranodiorite and dykes of pegmatite intrude the strata, and the youngest rocks of the area are diabase dykes. The area is crossed in various directions by faults; three northerly trending faults are near the orebodies but neither the emplacement nor the grade of ore seems related to them.

The orebodies are in foliated rocks, and conformable with them; all but one are in metasediments that are mainly iron-formation and associated garnet–amphibole schist. The orebodies are high-temperature types and of three kinds: disseminations, lode fissures containing cores of massive sulphides surrounded by disseminations, and a massive deposit. The most common minerals are pyrite, pyrrhotite, quartz, chalcopyrite, sphalerite, and galena. The relative amounts of sulphides and precious metals vary. Thus, some bodies are classed as copper–zinc–silver, some as copper–zinc–silver–lead, some as zinc–silver–lead, and one as copper–silver. The mineralization was later than the pegmatites and basic intrusive rocks and is probably older than the diabase dykes, and appears to have taken place during the later part of the period of granitic activity. Recent work has led to an explanation of the orebodies as being composed of series of generally coalescing lenses controlled by drag-folds later than the regional folding. Some lead isotope ratios have been interpreted as indicating that the age of the deposits is about 2,600 m.y. Others have suggested that early lead, about 3,250 m.y. old, was mixed with lead of about 2,250 m.y. to produce the intermediate age.

The main Geco orebody is divided by a north-striking fault and a diabase dyke 850 feet to the east. The west part is as much as 970 feet long and 50 feet wide, and extends to a depth of at least 1,000 feet. The central part is offset 200 feet to the north, and the east part extends an unknown distance beyond the dyke. The entire body rakes 35 degrees east. The west sector therefore represents the lowest part, and the east sector the highest. It has massive and disseminated phases. Massive ore is generally high in zinc, but copper and silver, as well as zinc, are common in the lower parts. Disseminated ore is mainly of value for copper and silver. One of the Willroy orebodies is in biotite–sillimanite–muscovite–quartz schist and the other three as well as the three Willecho bodies are in iron-formation.

Chibougamau Region, Quebec

Deposits of copper and gold were found and tested in Chibougamau region long ago because it was on a canoe route between Lake St. John and Hudson Bay; other deposits were found later, some by geophysical prospecting beneath lakes frozen in winter. After a road and later a railway were built production was begun at the Opemiska mine in 1953. The properties in the Chibougamau region (Fig. V-25) are now mostly operated by the Campbell

Chibougamau and the Copper Rand companies. Each has a concentrator at its main mine, to which it ships, or did ship, ore from outlying mines. Also, the Merrill Island company built a concentrator to treat ore mined from a part of its property not leased to Campbell Chibougamau; this plant has recently been used to treat custom ore from the Bruneau and Icon mines. Although much of the region is underlain by volcanic and granitic rocks the main feature is a differentiated sill complex of diorite, gabbro, and other rocks. The complex includes a large unit of altered anorthosite in which the principal deposits of the main Chibougamau camp are present. This unit is crossed by the Doré Lake fault, a northeasterly striking shear zone containing chlorite, sericite, quartz, and siderite. Duquette (1966) states that nine mines are within 4,000 feet of this fault and are mainly in shear zones striking west-northwest. They contain chlorite, sericite, carbonate, silica, sulphides, and gold. Siderite is common. The main economic mineral is chalcopyrite. The Portage and Henderson orebodies are in shear zones striking parallel with the apparent continuation of the Doré Lake fault.

The main *Campbell Chibougamau* (5b) property now contains a shear zone on the former Merrill Island claims and the underwater continuation to the Doré Lake fault (Fig. V-26). The zone contains porphyry dykes parallel with the shearing. The entire zone is 800 feet wide and 4,000 feet long. In it faulted sulphide bodies average 40 feet wide and are about 2,500 feet long. The main zone decreases below the 1,450-foot level and ends at the 2,000-foot level. Another body was found below the 2,700-foot level. The bodies contain about 33 per cent pyrrhotite, 10 per cent chalcopyrite, 5 per cent pyrite, 2 per cent sphalerite, 2 pounds of cobalt per ton, and free-milling gold. The lowest mine level is 3,750 feet below surface.

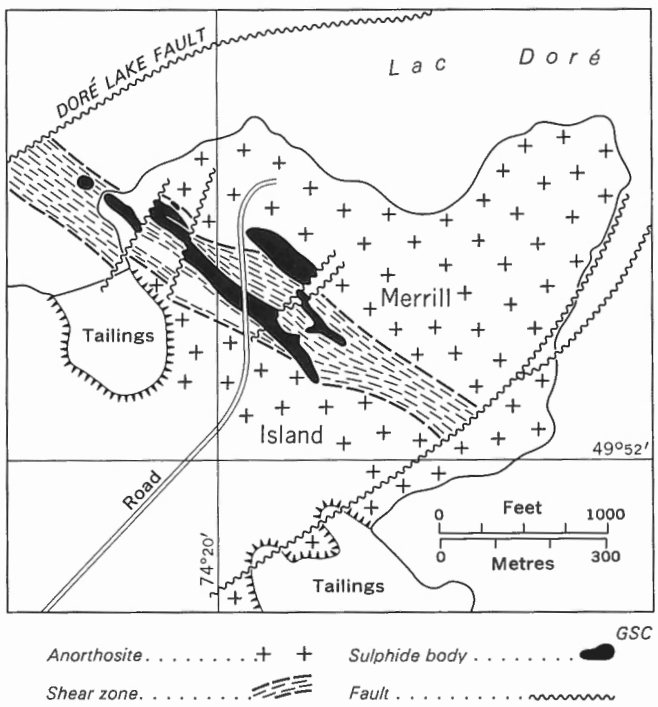


FIGURE V-26. Main Campbell Chibougamau–Merrill Island copper–gold deposit, Quebec (R. B. Graham).

The main *Copper Rand* (3b) mine lies in a northwesterly striking shear zone crossing Gouin Peninsula. The surface discovery at Machin Point is 1,000 feet from the probable position of the Doré Lake fault. The zone continues eastward into the *Bouzan* (3a) property. The zone of shearing and alteration is as wide as 2,000 feet and contains a zone of diorite and quartz porphyry dykes 400 feet in total width, parallel with the shearing. In the centre of the zone the orebodies are lenticular and occur at the sides of dykes. The lenses are 3 to 60 feet wide and have lengths of generally less than 500 feet. Most are within a total length of 2,500 feet. The mine is opened to a depth of 2,130 feet.

The *Icon* (1) mine, at the south end of Lake Mistassini, is a recent discovery in dolomitic strata of the Aphebian Mistassini Group. Diamond drilling showed three flat orebodies, all in the same stratigraphic horizon. The bodies are in a quartz–carbonate zone that may have been introduced along a fault parallel with the bedding. They are covered by 40 to 60 feet of overburden or a little rock. The bodies, 13 to 22 feet thick, contain disseminated and massive chalcopyrite, some recoverable silver, a little pyrite, and quartz and carbonate. They were stated in 1967 to contain 252,030 tons of open-pit ore averaging 5.94 per cent copper, and 504,370 tons averaging 2.4 per cent copper to be mined from an adit. In 1967, ore was trucked to the Merrill Island concentrator at a daily rate of 600 tons.

The *Opemiska* (6) deposits differ from typical Chibougamau ones in that they are mainly veins, occur in a gabbro sill rather than in anorthosite, and have quartz–calcite–chlorite gangue without reported siderite or sericite. The main veins are in shear zones in faults crossing the nose of an anticline in the sill. Parts of some deposits appear to be stockworks, and some wall-rock contains disseminations. The main orebodies are chalcopyrite, pyrite, and magnetite, with minor pyrrhotite, galena, sphalerite, molybdenite, and scheelite. Ore carries 5 per cent copper with about 0.05 ounce of gold and 0.5 ounce of silver per ton. The most important vein is a few inches to 25 feet wide. It was mined for a length of 2,500 feet, and to a depth of 2,400 feet; it is being deepened an additional 1,000 feet.

Other deposits in Superior Province. The *Zenmac (Zenith)* (33) mine, 10 miles northwest of Schreiber, Ontario, was worked in a small way from 1895 to 1901. Production with a 100-ton-per-day mill was begun in 1966. The main deposit is a fracture zone in gabbro that has irregular lenses 2 to 10 feet wide containing massive sphalerite with minor chalcopyrite and pyrrhotite. The zone has been traced 600 feet. In 1966, more than 13

million pounds of zinc, 126,000 pounds of copper, and 38,000 pounds of cadmium were produced. The nature of the deposit was reported to be such that an accurate estimate of ore reserves was not possible.

The *Temagami* (94) mine is on an island in Timagami Lake underlain by Archean basic to acidic volcanic rocks of Keewatin type intruded by a meta-diorite sill. Occurrences of sphalerite, chalcopyrite, and pyrite on the island had been known for some time but after diamond drilling and a geophysical survey two high-grade massive sulphide bodies were indicated. Open-pit mining was begun in 1955, the ore being shipped by barge to the railroad at Timagami. A shaft was sunk in 1956 and a 150-ton mill was built in 1958. The mine contains three types of ore: low-grade pyritic ore carrying copper, nickel, and cobalt; 'open-pit' high-grade massive chalcopyrite ore; and vein and replacement chalcopyrite ore. The orebodies lie in meta-diorite and rhyolite breccia and tuff, and are distributed near the south contact of the sill. They are surrounded by zones of chloritization or rock containing sericite, carbonate, and tourmaline. In 1966, ore reserves were estimated to consist of 97,884 tons averaging 6.73 per cent copper and 16,600 tons averaging 3.74 per cent copper. Production in 1966 totalled 6.8 million pounds of copper, 1,007 ounces of gold, and 17,438 ounces of silver.

Although deposits at *Mamainse Point,* 60 miles north of Sault Ste. Marie, Ontario, are not ranked with the main copper mines of the Canadian Shield they are of unusual interest because they contain chalcocite and native copper, have some of the characteristics of the Keweenawan deposits of Michigan, and were the object of some of the earliest Canadian attempts at mining. Experimental mining of copper was tried in 1770 by missionaries and an explorer near Sault Ste. Marie, probably at these deposits or near them. The orebodies are calcite–quartz veins carrying chalcocite and minor bornite, chalcopyrite, and native copper that occur in fault zones in interbedded Keweenawan basalt and conglomerate. In 1936, a piece of almost pure native copper weighing 147 pounds was found, but the native copper content of the deposits is generally minor. At the *Coppercorp* (68) property four main copper-bearing zones were located in 1949–52 and another was found later. Production was begun in 1965 and the mine is developed to a depth of 500 feet. The zone now providing most ore is reported to average 8 feet wide and 5,400 feet long. In 1965, reserves were reportedly 1,540,000 tons averaging 2.1 per cent copper.

The *North Coldstream* (25) mine, 65 miles west of Port Arthur, Ontario, produced from 1903 to 1917 and in 1957 to 1967. Sulphide orebodies lie in a lenticular chert-like body in basic and acidic schists. Whether the chert represents an original sediment or silicified schists is uncertain. The brittle chert appears to have fractured favourably for the introduction of pyrite, chalcopyrite, and a little pyrrhotite. These minerals are present in fracture fillings, or as masses and disseminations that form lenticular orebodies carrying an average of 1.95 per cent copper.

Copper Deposits of Southern Province

The *Bruce* (71) mine on the north shore of Lake Huron was the first copper mine in the Canadian Shield and one of the earliest producers in North America. Production was intermittent from 1846 to 1921, the ore being shipped to smelters in Wales, the United States, and finally Sudbury. Quartz–chalcopyrite veins in diabase sills in Aphebian Huronian sediments varied from stringers to 50-foot veins. The main vein, traced for at least 2,000 feet, had an average width of 5 feet and was worked to a depth of 450 feet. Early records were lost but the maximum tenor appears to have been about 3.5 per cent copper.

Copper–Zinc Deposits of Churchill Province

The Flin Flon and Snow Lake regions of Manitoba and Saskatchewan contain many zinc–copper deposits and in some copper predominates. With regard to the production of copper and zinc in recent years, this part of Churchill Province is second only to the Timmins–Chibougamau belt in Superior Province. Mining was begun in Saskatchewan at the Mandy mine in 1917. Its ore was taken by sled 40 miles and then by barge 130 miles to the railroad at The Pas, Manitoba, for shipment to the smelter at Trail, British Columbia. A larger deposit was discovered in 1915, a few miles away, at Flin Flon. It has been in continuous production since a smelter was completed in 1930 and is still the largest mine in the district. Ore and concentrates from mines in the Snow Lake district some 80 miles east of Flin Flon are shipped to the Flin Flon smelter. Four of the mines have been exhausted, four are still producing, and four others are being prepared. The large Sherritt–Gordon copper–zinc deposit at Sherridon, Manitoba, 40 miles northeast of Flin Flon, was found in 1922. Concentrates were shipped to the Flin Flon smelter in 1931–32 and from 1937 to 1951, when the ore was exhausted. The company acquired the Lynn Lake nickel–copper deposit and moved much of the Sherridon operation to it, production beginning in 1953.

Flin Flon–Snow Lake Region, Manitoba and Saskatchewan

This region is underlain largely by the Archean Amisk Group of volcanic and sedimentary strata, the unconformably overlying Missi sedimentary group, and the Kisseynew granitic gneisses that are derived from the Amisk and Missi Groups and developed extensively north of the mining district. The strata are intruded by granitic rocks, mainly contemporaneous with the Hudsonian folding and metamorphism. Some geologists believe that the rocks of this southern part of Churchill Province were

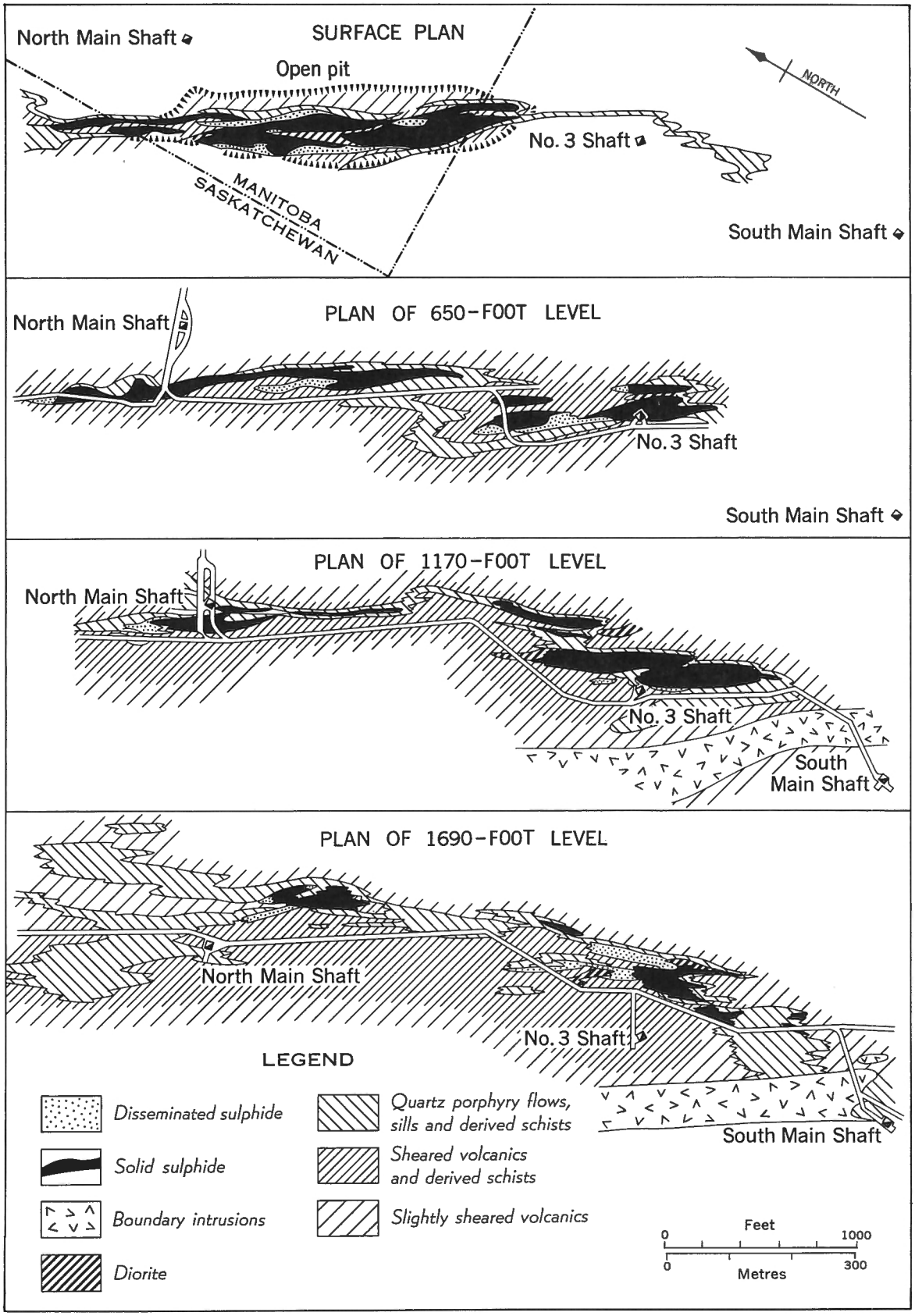


FIGURE V-27. Flin Flon mine, Manitoba (after the staff, Hudson Bay Mining and Smelting Company, Ltd.).

also subjected to the earlier Kenoran deformation related to the one in Superior Province. The orebodies are mainly in volcanic rocks of intermediate and basic composition or their metamorphosed equivalents. Most orebodies have both massive and disseminated zones, massive ore being the more abundant. Zoning is common in the massive deposits. Pyrite is the predominant sulphide mineral but sphalerite and chalcopyrite are the main ore minerals. Their ratios vary so that some deposits or parts of deposits are classed as zinc–copper ores and others as copper–zinc. Other sulphide minerals are present, and silver, gold, lead, cadmium, and selenium and tellurium are produced as byproducts. The orebodies are surrounded by narrow zones of alteration in which chloritization and carbonatization are characteristic of the more basic rocks whereas the more acidic ones are altered mainly by silicification, sericitization, and carbonatization. Ore deposits in the Flin Flon area have been found only in the Amisk rocks, which are cut by dykes and sills of feldspar porphyry that appear to be about the same age as the Boundary Intrusions. Lead isotopes indicate an age of 1,735 $\pm$ 160 m.y. for the galena in the orebodies.

The entire *Flin Flon* (3) deposit comprised six lenticular bodies in a shear zone having quartz porphyry as its hanging-wall (Fig. V-27). The porphyry lies along the contact between overlying competent flows and underlying less competent pyroclastic rocks and flow breccia. The general zone was 1,100 feet long by 200 feet wide, and is being worked to a depth of 3,700 feet. Complete production figures for this mine have not been published, but from 1930 to 1963 a total of about 53,200,000 tons of ore were mined. This averaged 4.57 per cent zinc, 2.23 per cent copper, and 1.30 ounces of silver and 0.074 ounce of gold per ton.

The nearby *Coronation* (10) deposit in Saskatchewan was mined from 1960 to 1965. During the life of the mine it yielded 1,412,861 tons of ore averaging 4.25 per cent copper, 0.20 per cent zinc, and 0.150 ounce of silver and 0.060 ounce of gold per ton. The deposit, 900 feet long and 120 feet wide, was mined to a depth of about 950 feet. It lay along a fault in basic lava flows and tuffs, recrystallized and altered to the staurolite–almandine grade of metamorphism. Although much smaller than the Flin Flon deposit it is of special interest and was selected for numerous research studies on ore genesis.

Other deposits in the Flin Flon region differ only in detail from the two described above. The *Birch Lake* (9), *Cuprus* (5), and *North Star* (6b) deposits have been mined out. The *Schist Lake* (4b) zinc–copper deposit is in production and the *Flexspar* copper deposit is being developed. In the Snow Lake area the *Chisel Lake* (8) zinc–lead–copper deposit and the *Stall Lake* (10) copper–zinc deposits are being mined. The *Osborne Lake* and *Anderson Lake* copper deposits and the *Dickstone* copper–zinc deposit are being prepared for production. These all occur in Amisk volcanic and sedimentary formations with the exception of the Osborne mine which is located in Kisseynew gneisses.

The *Sherritt–Gordon* (2) mine, at Sherridon, Manitoba, was operated in 1931–32 and from 1937 to 1951, concentrates being shipped to the Flin Flon smelter. During its life the mine produced 133,122 tons of copper, about 74,500 tons of zinc, 101,026 ounces of gold, and 3,218,324 ounces of silver. The ore lay along the contact between gneissoid quartzite and hornblende gneiss of the Kisseynew complex, on the southwest limb of an overturned syncline. The pyrrhotite–chalcopyrite–sphalerite ore apparently replaced a pegmatite sill that followed the contact, and formed two long, shallow lenses that are separated by a gap of 3,600 feet. The gap coincides with a cross-anticline and it is presumed that the two lenses were originally one body, the ore in the gap having been removed by erosion. The northwestern lens had a vertical extent of 500 to 800 feet; the southeastern about 250 feet. The combined length of both lenses, including the gap, was nearly 16,000 feet.

Other deposits. In the southern part of Churchill Province, west of Flin Flon and 25 miles north of LaRonge, Saskatchewan, the *Anglo–Rouyn* (6) mines copper deposit was found in 1915. It was brought into production in 1966 because of improved accessibility by road. Three *en echelon* ore zones lie in a strong shear zone at a contact between arkose and greywacke. The chalcopyrite lenses have a total of 2 million tons of ore averaging 2.4 per cent copper. Concentrates from a 900-ton-per-day plant are shipped to Flin Flon. At *Rottenstone Lake*, 90 miles north of LaRonge, production was begun in 1965 at a rate of 125 tons a day. The ore, reported to carry about 2 per cent copper and 2 per cent nickel, consists of sulphide minerals in a small mass of ultrabasic rock occurring at a 'buckle' in gneiss of Kisseynew type.

At *Hanson Lake* (7), Saskatchewan, 60 miles west of Flin Flon, production was begun in 1967. A 350-ton-per-day plant produced a zinc and a lead–copper–silver concentrate. Mill heads were reported to average 7.35 per cent zinc, 4.15 per cent lead, 0.40 per cent copper, and 4 ounces of silver per ton. The ore is in lenses in a shear zone crossing recrystallized tuff between dacite flows near a sill of quartz porphyry.

Many occurrences containing copper have been found in other parts of Churchill Province, mainly in Saskatchewan and Manitoba, at the East Arm of Great Slave Lake, and in parts of Ungava and Labrador. Some of these may respond to further testing or improved transport facilities. These regions include many belts containing rocks and structures favourable in a general way for prospecting, because they show similarities to those in which ore has been found. The Aphebian rocks of the Labrador Geosyncline and the Cape Smith–Wakeham Bay belt contain several deposits of copper, zinc, and other minerals, besides those described under nickel. For example, one deposit near Attikamagen Lake is reported

to be 660 feet long and 13 feet wide, and to have an indicated average of 6.75 per cent zinc, 1.4 per cent copper, with minor lead, gold, and silver.

Copper Deposits of Bear and Slave Provinces

No zinc and relatively little copper have been produced in these provinces. Copper was produced as a byproduct at the Eldorado uranium mine. In 1965 the *Echo Bay* (5) property east of Eldorado began producing silver and copper, 140 tons of ore per day being sent to the Eldorado concentrator. The ore averaged 2.09 per cent copper and yielded 1,617,882 pounds of copper in 1966. The deposit is described in the section on silver. Native copper from the Coppermine area had been used by natives for tools, weapons, and trade long ago, and was the object of Hearne's famous journey from Churchill in 1771. The deposits have been investigated at various times. Increased prices for copper, general improvement in northern transport and development, and interesting results from drilling have contributed to recent activity. Native copper occurrences having some of the characteristics of those of the Coppermine area were found many years ago at Bathurst Inlet. They are in strata of the Aphebian Goulborn Group overlying the Archean crystalline rocks of Slave Province. A fairly large copper–zinc deposit has been indicated in volcanics of the Yellowknife type at High Lake in the northern part of Slave Province, and a zinc–copper one at Indian Mountain Lake in its southern part.

The *Coppermine* deposits are scattered in a belt extending about 70 miles from the northeast end of Dismal Lake to Coppermine River. The rocks are basalt flows dipping 12 degrees north and forming the lower part of the Helikian Coppermine River Group. The flows are broken by numerous fractures and faults, the more prominent of which strike north to northeast, with a less prominent group striking north to northwest. The deposits are either native copper and chalcocite amygdules that are commonly associated with individual flow tops, or quartz–carbonate veins and breccia zones in the fractures and faults. Some of the veins and breccia occurrences seem to be more important than the amygdaloidal ones so far as prospecting and testing have been carried out, but less is known about the amygdaloidal deposits. Chalcocite is the main mineral in most veins and breccia zones, but in some, bornite or chalcopyrite predominates. One particular flow has high copper content where drilled in several of the deposits. Mineralized zones as much as 175 feet wide and 1,000 feet long were found. One zone is estimated to contain 62,000 tons averaging 8.78 per cent copper. In 1967, more than 10,000 claims were staked. Diamond drilling of certain deposits was done to greater depths than previously, and one 55-foot section was reported to have averaged 6.4 per cent copper. A preliminary estimate of a zone 800 feet long reportedly indicated 10,000 tons per vertical foot, averaging 3 per cent copper. The genesis of the Coppermine deposits remains to be established. Most of the chalcocite and native copper occurrences of the world are considered supergene. The Coppermine deposits have some interesting analogies with the native copper deposits of Michigan in Keweenawan strata, but the latter are characteristically native copper, little chalcocite being reported.

Zinc–Lead–Copper Deposits of Grenville Province

The New Calumet and Tétreault mines in the southern part of Grenville Province have been worked mainly for zinc. They produced smaller amounts of other metals including copper, but no mines have been worked mainly for copper. Occurrences of chalcopyrite have been reported from various places mainly in the Bancroft area of Ontario and near Portneuf, Quebec, but this may be only because prospecting and geological studies have been more extensive there than in many other parts of the province. Occurrences of zinc have been reported from various parts, mainly in the Ottawa valley and near Portneuf, Quebec. The apparent concentration of zinc, and also of lead, in the southwestern part of Grenville Province may be significant geologically because in that part of the province limestone and related rocks are abundant. Furthermore, the deposits in Grenville Province are not far from the overlapping Ordovician carbonates of the St. Lawrence Platform, in which a few small veins containing sphalerite and galena have been found. This suggests that some zinc–lead deposits in Grenville Province may be post-Ordovician in age although the few isotopic age determinations so far available for these deposits do not provide conclusive evidence of this.

The *New Calumet* (41) mine, Quebec, is at present the only producer of zinc in Grenville Province. The orebody is in a sheet-like mass of biotite–hornblende gneiss that strikes northerly and dips 35 to 40 degrees east. The gneissic body ranges in thickness from a few tens of feet to about 300 feet, and may be a bed of altered impure limestone. The presence of gahnite suggests that the rock contained zinc before being metamorphosed. The principal ore minerals are sphalerite with some galena. They are accompanied by small amounts of chalcopyrite, native gold, and silver minerals. Part of the ore is massive or nearly massive sulphide; other parts consist of sulphides disseminated through a gangue of rock minerals, mainly altered feldspar and pyroxene. A less common type of ore is a dark calcite–tremolite rock carrying crystals of auriferous galena and veined by stringers of calcite with coarse auriferous galena. The property was discovered in 1893 but production did not begin until 1943. To the end of September, 1966, it had yielded more than 417 million pounds of zinc, 117 million pounds of lead, 5 million pounds of copper, 9 million ounces of silver, and 52,000 ounces of gold. Ore reserves then were reported to average 8.64 per cent zinc, 2.58 per cent lead, and 4.88 ounces of silver per ton.

Considerable zinc and lead were obtained from the *Tétreault* (69) mine near Portneuf, Quebec. Masses of sphalerite and galena were found along the footwall of a band of altered Grenville limestones. They varied from less than a foot to more than 50 feet in width and consisted of sphalerite with minor amounts of other sulphides, or of a fine-grained mixture of sphalerite, galena, pyrrhotite, pyrite, and minor amounts of chalcopyrite. Average ore contained about 9 per cent zinc, 3 per cent lead, 0.1 per cent copper, 0.09 ounce of gold, and 8.3 ounces of silver per ton. Mining was carried on from 1912 to 1929, 1934 to 1937, and 1948 to 1955. To the end of 1954 the mine had produced about 83,000 tons of zinc, 61,000 tons of lead, several million ounces of silver, and several thousand ounces of gold.

Lead

The Canadian Shield has supplied surprisingly little lead compared to its output of other metals. An important question that awaits more rock analyses for an answer is whether the rocks themselves have an abnormally low lead content or whether they have normal amounts that rarely became concentrated as deposits. Of the total Canadian production of lead in 1966 only 1.6 per cent was derived from the Shield. This was mainly from the *New Calumet* (41) and *Coniagas* (8) mines of Quebec, worked primarily for zinc, and the rest was a byproduct of various mines. The New Calumet mine is described in the previous section. Mining of zinc–lead ore was begun at *Hanson Lake* (7), Saskatchewan, in 1967. Some lead concentrate was produced from ore from the *Chisel Lake* (8) zinc mine in Manitoba, whose ore carried 0.4 per cent lead, and the *Geco* (36) zinc–copper mine in Ontario which produced 840 tons of lead in 1966. Small to moderate amounts of lead were produced several years ago from a few mines in which lead predominated. These are described briefly below, together with occurrences on Hudson Bay that are of a different type and as yet unproductive.

About 25,000 tons of lead were produced from 1914 to 1932 from the *Kingdon* (100) mine near Galetta, Ontario. A fault, striking north 65 degrees west, cuts through limestone and other rocks of the Grenville Group. The fissure vein was filled with galena and calcite with minor amounts of other minerals. It had an average width of 5 feet, and was mined for more than 2,700 feet along strike and to a depth of more than 1,300 feet.

The *Jardun* (69) mine near Sault Ste. Marie, Ontario, was mined at intervals between 1878 and 1904. Production was resumed in 1954 and in that year it produced about 1,300 tons of lead, 550 tons of zinc, as well as 23,000 ounces of silver. The orebody consisted of sphalerite, galena, pyrite, and chalcopyrite within a band of Archean greenstone schist bounded by granite. In 1956, ore reserves were 304,000 tons averaging 3.14 per cent lead, 3.52 per cent zinc, and 1.65 ounces of silver per ton. The mine was closed in 1957.

At least 2,000 tons of ore are reported to have been taken from the *Frontenac* mine north of Kingston, Ontario, from 1875 to 1880. The galena had a low silver content and occurred in a calcite vein in sedimentary gneiss. From 1903 to 1916 more than 2.6 million pounds of lead were obtained from a similar deposit at the *Hollandia* mine north of Madoc, and small shipments are understood to have been made from other veins in these parts of Grenville Province.

The *Wright* mine on Lake Timiskaming near Ville Marie, Quebec, is of historical interest because Indians showed the occurrences to a French exploring party in 1686 and it was indicated on a map published in France in 1744. The argentiferous galena in a brecciated zone was mined in 1890–91. Diamond drilling, in 1947, was reported to have indicated 25,000 tons containing 5.9 per cent lead and 1.3 per cent zinc.

Deposits of sulphide minerals along the east coast of Hudson Bay near Richmond Gulf and Great Whale River were trenched and drilled in 1947–48 and found to be mainly disseminations of pyrite occurring as massive lenses and veins in concretionary cherty limestone and dolomite of the Aphebian Manitounuk Group. Some galena and sphalerite are present and a little chalcopyrite. Assays are reported to indicate a little gold and silver. One of the localities, 6 miles south of Little Whale River, contains a main mineralized zone 8 to 20 feet thick and another 5 to 10 feet thick. Quartz veins and pegmatite containing galena have been found at Bathurst Inlet, District of Mackenzie.

PRECIOUS METALS

Gold

Gold is found throughout the Shield and has been mined in every province or territory in Canada in which it is extensively exposed. Although considerable gold is recovered as a byproduct in the mining of copper, zinc, and nickel deposits (the Horne copper mine, for example, which is one of the largest gold producers in Quebec) the greater part of the production of gold has come from six principal gold camps: Porcupine, Kirkland Lake–Larder Lake, northwestern Quebec, Red Lake, Yellowknife, and Little Long Lac. The first three camps account for about three quarters of the total production. They are grouped in a relatively small area that extends a hundred miles

east and west of the Ontario–Quebec boundary. The other camps are in northwestern Ontario and in the Northwest Territories. All but one of the principal camps and virtually all the isolated mines are in Superior Province. The other camp, the Yellowknife, is in Slave Province. Gold deposits in Churchill and Grenville Provinces are few and have produced very little. The distribution of gold occurrences is less affected by economic or other non-geological factors than is the distribution of prospects for any other metal. Economic gold production has been feasible at one time in almost every part of the Shield and prospecting has been correspondingly widespread and thorough.

The first discoveries of gold in the Shield were made about 1866 in Grenville Province close to the early settlements in southeastern Ontario. The veins were erratic and small. Discoveries in Superior Province in the Lake of the Woods area of northwestern Ontario followed on completion of the Canadian Pacific Railway in 1886. They raised great expectations and spurred considerable promotional activity at the turn of the century. More than 100,000 ounces of gold are reported to have been produced between 1897 and 1903. More than half this amount appears to have come from the *Wendigo* (16) mine.

The Cobalt silver rush set the stage for the discovery of the major camps of the Shield and establishment of gold mining as a permanent industry. Prospecting spread out from Cobalt into the Larder Lake area where in 1906 gold was discovered. Additional discoveries were made in the rush that followed although thirty years were to elapse before significant production began. In the Porcupine area the first discoveries were made in 1909. Production began the following year and has continued to the present. In the Kirkland Lake camp gold was first discovered in 1911. Shipment of high-grade ore began in 1913 but the establishment of mines, beset by hardships and setbacks, was not achieved until 1917. The economic recession of 1930 to 1940, which gave gold mining and prospecting the double stimulus of an increase in the price of gold and a simultaneous decrease in the cost of both labour and supplies, was the principal factor that led to the development of the remaining camps, although in all but the Yellowknife camp, gold had been discovered earlier.

During the early prospecting activity in northwestern Ontario gold had been discovered in 1897 at Red Lake. Further discoveries were made during 1922–25 but it was not until 1930 with the Howey mine that production began. In the Little Long Lac area the first prospecting was for iron. Gold-bearing quartz veins were discovered in iron-formation in 1917. Renewed activity beginning with additional discoveries in 1931 culminated in production in 1938. Although gold had been discovered as early as 1923 in northwestern Quebec, the large low-grade deposits typical of the camp had to wait many years before development. Production began in 1935. Gold was first discovered in the Yellowknife area in sediments but the deposits were all small. The discovery of gold in the volcanics during mapping by the Geological Survey of Canada in 1935 led to the development of the principal deposits. Production began in 1938.

The depression brought gold to first place in value among the mineral products of Canada, taking over from coal in 1931; it maintained this position for more than twenty years until it fell behind petroleum in 1952. During the second world war, particularly after the entry of the United States in 1941, gold mining and exploration decreased. The increased activity that followed the war was short lived and with continued inflation and the fixed price of gold, gold mining has become less profitable and exploration correspondingly less attractive.

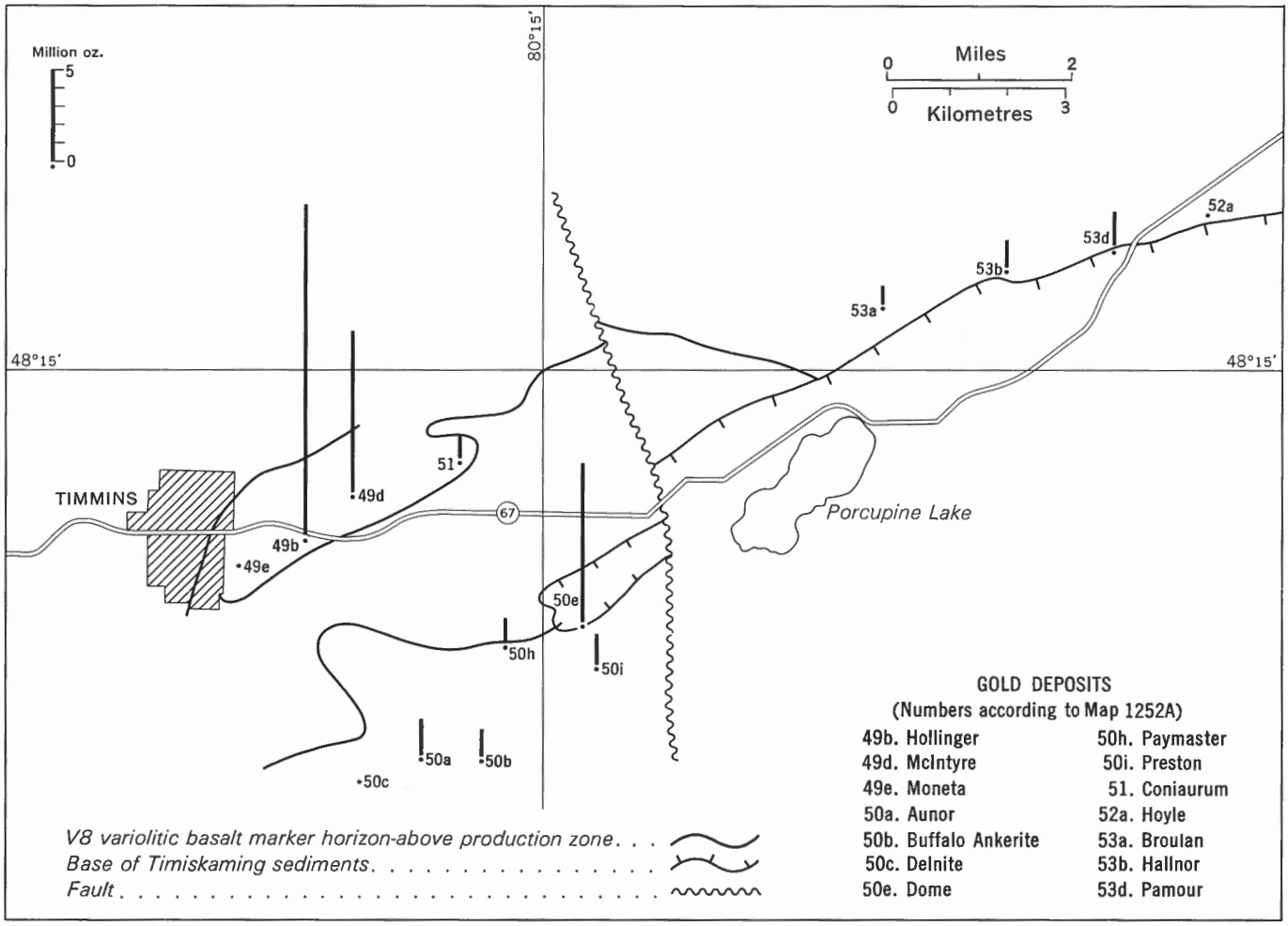
In the Canadian Shield gold deposits show a close relationship to the belts of Archean volcanic rocks. Most of the deposits occur in basic lavas, tuffs, and sediments closely associated with or derived from them, or with small intrusive bodies, principally acidic types, that intrude them. The association with volcanics is even more marked where total quantity of gold rather than number of deposits is considered. The three principal camps, Porcupine, Kirkland Lake–Larder Lake, and northwestern Quebec, lie in the extensive complex of volcanic rocks of the Abitibi belt. The volcanic area containing the Red Lake camp forms part of an interrupted chain of similar areas extending easterly from Rice Lake in Manitoba some 250 miles to Pickle Lake in Ontario forming the Uchi belt. Each area contains one or more deposits, and there are twenty-two mines altogether. Little Long Lac and Yellowknife camps are in similar but smaller belts. Outside the principal camps the scattered distribution of mines reflects the paucity and limited extent of the remaining volcanic areas. Most of these are in Superior Province. The rocks in all appear to be Archean (pre-Kenoran Orogeny). This appears true even of areas in the southeastern part of Churchill Province.

In some camps the distribution of mines appears to be partly stratigraphically controlled. For example, the most productive parts of the Porcupine camp lie in or close to No. 95 flow or its equivalents. A similarity in the stratigraphic sequence of volcanics and sediments of the Red Lake and Porcupine camps has been noted by Ferguson (1966). However, the formation of orebodies and the distribution of ore shoots within them is clearly controlled by faults or other local structural features. In some camps, such as Kirkland Lake–Larder Lake, faults exert a dominant influence on the camp as a whole. Of the two controls the structural was given more attention during the period of most active exploitation of the mines. Recognition of the structural controls within a camp provided a very effective tool to predict and locate ore shoots. It is only recently that the stratigraphic component in gold ore distribution has been widely recognized and its implications considered.

Superior Province

Porcupine camp, Ontario (Fig. V-28). The oldest rocks are the Archean Keewatin volcanics that form a layered sequence estimated to have a maximum thickness of 10,500 feet. The basal Tisdale Group consists of a conformable succession of pillowed, flow-structured, and massive meta-basalts. Several persistent stratigraphic units can be recognized, in particular a group of variolitic and fragmental flows in the upper part. Fine-grained, cherty, or carbonaceous sediments are present locally between flows and are particularly well developed at certain stratigraphic positions. Some 60 to 300 feet of sediments of this type overlie the Tisdale Group and are, in turn, overlain by as much as 2,000 feet of acid pyroclastic volcanics, mainly latite breccia, comprising the Krist Group. Interbedded with the pyroclastics are banded chert and carbonaceous slate, and above them is a sequence of argillite, black slate, and minor greywacke of the Hoyle Group variously estimated at 3,000 to 7,000 feet thick. Minor discordances occur within the volcanics and between the volcanics and the predominantly sedimentary part of the sequence. However, for a predominantly volcanic assemblage the general conformability of the lower part is remarkable and indicates uniform accumulation of flood basalts in a subaqueous or submarine environment. Overlying the Keewatin rocks with marked angular discordance is the Timiskaming Group, 1,500 feet thick, and consisting principally of slate, greywacke, quartzite, and conglomerate. The conglomerate is present at and near the base of the group and also near the base of the lowest quartzite.

Both acidic and basic intrusions are present. Most important from the point of view of the gold deposits are porphyry stocks that intrude the Tisdale volcanics, but which are considered by some to be equivalent in age to the volcanics of the Krist Group. The gold deposits of the Hollinger and McIntyre mines are grouped in the volcanics around these intrusions, although few auriferous veins penetrate far into the porphyry. The porphyry masses are pipe-like, in their lower parts at least, and differ slightly one from another in composition or texture. There are seven such masses at the McIntyre mine for example and, although they approach one another at depth, separated in some instances only by thin screens of schistose lava, they tend to maintain separate identities.



GSC

FIGURE V-28. Gold deposits of the Porcupine camp, Ontario (by D. R. E. Whitmore).

The ore comprised the quartz veins and the adjacent mineralized schist. Many of the veins formed complex sheeted zones or *en echelon* swarms and were commonly contorted. Thus the orebodies were complex units defined largely by assays. Mineralized schist predominated over quartz. The quartz veins contained ankerite, sulphides, tourmaline, minor albite, and scheelite. The adjoining schist was silicified, carbonatized, and contained disseminated pyrite. The sulphide minerals in the veins were pyrite, pyrrhotite, sphalerite, chalcopyrite, and galena. Locally arsenopyrite occurred in some abundance, as for example in the deeper parts of the Hollinger and Delnite mines. For the most part gold appeared in native form. Tellurides occurred in the Hollinger, McIntyre, and some other properties but were not characteristic of the camp. A few orebodies, as at the Moneta, consisted predominantly of sulphides, apparently a replacement in a volcanic breccia.

Volcanic rocks of the Porcupine area form an easterly plunging syncline. In the eastern part of the syncline, centred somewhat south of its axial portion, is a discordant trough of Timiskaming sediments with basic and ultrabasic intrusions. Mines of the camp fall into three groups: those along the north limb of the syncline in the volcanics, those along the south limb, and those near the unconformity at the base of the Timiskaming Group.

Hollinger (49b), the largest mine of this group and of the camp as a whole is developed towards the western end of a complex anticlinal arch on the north limb of the main syncline which altogether extends some 3 miles easterly from Moneta to Coniaurum. Ore is contained in a complex system of veins in a zone 6,000 feet long and 4,000 feet wide forming a flat arc that strikes N60°E and plunges 55°E, approximately conformable to the attitude of the bordering Pearl Lake porphyry. Orebodies included: (1) well-defined continuous quartz veins locally branching, pinching, and swelling; (2) sinuous veins either replacing drag-folds or themselves folded; (3) tabular vein zones consisting of parallel stringers of quartz in pyritized lava; and (4) *en echelon* vein zones. Many veins show a complex history of fracturing with later introduction or redeposition of quartz with gold.

McIntyre (49d), another large producer, adjoins the Hollinger to the northeast and shares the same vein system. Many of the veins lay beneath the pitching porphyry mass, not reaching the surface. Ore in the *Coniaurum* (51) mine east of McIntyre is in veins that occur mainly in dacite flows on the flanks of a porphyry mass, or in deep re-entrants within it. In the upper levels the veins extended 600 to 700 feet from the porphyry. This distance decreased with depth. Ore at the *Moneta Porcupine* (49e), adjoining Hollinger at the west end of the camp, was largely a heavy sulphide replacement consisting of as much as 13% pyrite in brecciated pillowed andesite and in andesite with conspicuous leucoxene. Ore from the two flows showed consistent differences both in grade and texture.

Of the group on the south limb, the *Dome* (50e) was comparable in size with the Hollinger and McIntyre. It lay athwart the unconformity separating the Keewatin volcanics from the Timiskaming Group. The latter formed a narrow synclinorium extending obliquely from the main syncline that plunges northeast. The original orebodies, more than thirty in number, lay in the sediments. They consisted of quartz and mineralized wallrock. Most appeared to be associated with conglomeratic facies. Some were very large, as long as 600 feet, and many were very irregular in outline. Some orebodies crosscut the bedding but most did not. A few showed a relationship to embayments in the sediment-volcanic contact. Later orebodies were developed in veins in the volcanics below the unconformity. The veins formed as related groups controlled by an anticlinal nose in the greenstone. One well-developed type consisted of an *en echelon* swarm within a dacite flow.

Preston (50i) mine, southwest of the Dome, is developed on a drag-fold on the south limb of the main syncline. Two quartz–feldspar porphyry stocks comprise the main host for the orebodies which are of three kinds: (1) stockworks of quartz–carbonate stringers with pyrite and minor arsenopyrite in the porphyry, (2) single quartz and quartz–tourmaline veins in the porphyry and extending into the volcanics, and (3) shatter zones in cross-faults. *Paymaster* (50h) lay west of Preston on the south limb proper. Much of the ore lay close to a tuffaceous flow top and was zoned relative to a quartz porphyry. The west end of the veins was barren. An intermediate section showed refractured quartz–carbonate veins with gold. The inner portion showed late, fine-grained, well-mineralized quartz.

Other mines on the south limb included the *Buffalo Ankerite* (50b), which lay along both sides of a synclinal cross-fold. The orebodies were in quartz–ankerite–tourmaline veins and in pyritized dacite. The *Aunor* (50a) and *Delnite* (50c) mines were developed on brittle flow rocks between zones of chlorite or talc chlorite schist. At the Aunor both parallel and branching veins were present in pillowed andesite. At Delnite the veins formed a ladder-like series. In all three mines plunge of the orebodies was to the west. To the east orebodies at the *Broulan* (53a), *Hallnor* (53b), *Pamour* (53d), and *Hoyle* (52a) are developed on both sides of the unconformity at the base of the Timiskaming sediments. Dunbar (1948) notes that the orebodies occur in the general vicinity of the No. 95 flow where it was eroded.

Kirkland Lake–Larder Lake camp, Ontario (Fig. V-29). The mines of the camp lie in an east-west trending trough of Archean sediments, tuffs, and trachytes set in older basic volcanics. The rocks dip steeply and face south towards a complex and persistent zone of schist, the Larder Lake break, which forms the south boundary of the trough. The break, thought to be a thrust fault, is interrupted by Kenoran acidic intrusions and is therefore an early struc-

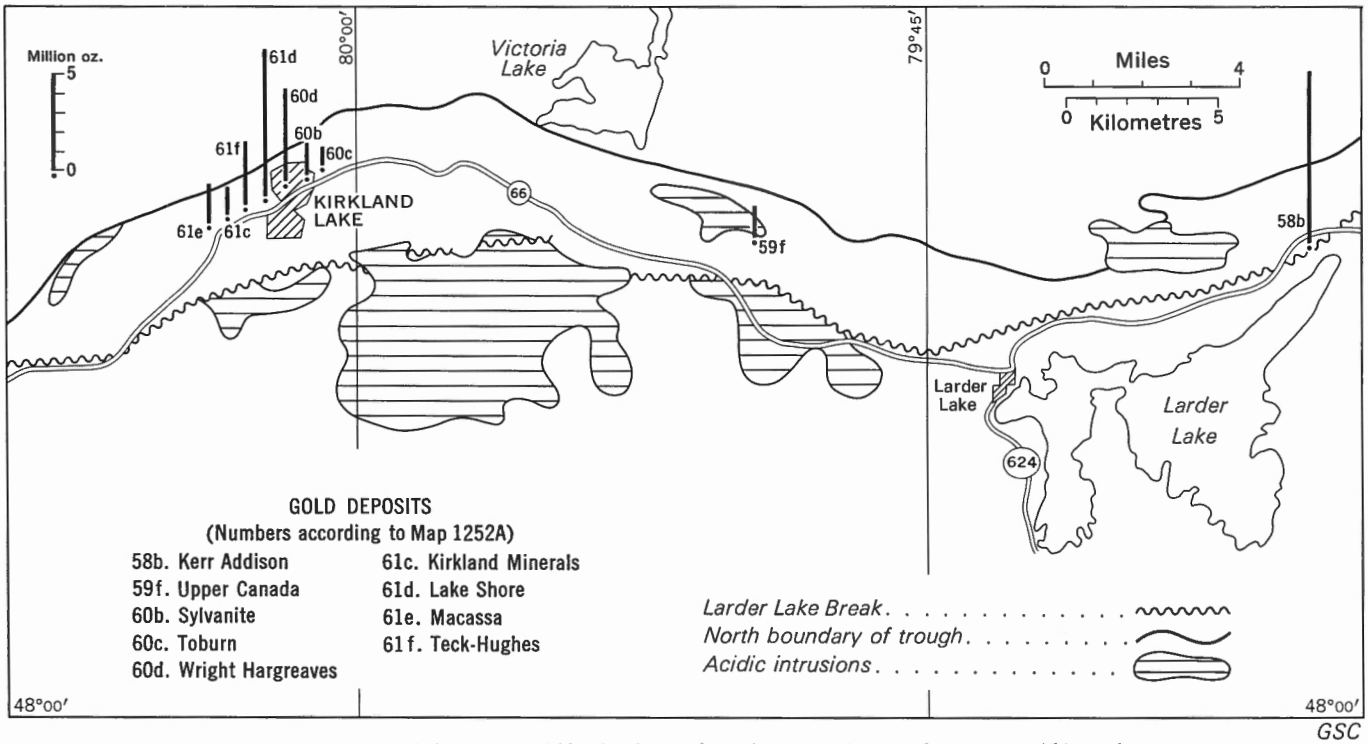


FIGURE V-29. Gold deposits of Kirkland Lake–Larder Lake camp, Ontario (by D. R. E. Whitmore).

ture that may be related in some way to the formation and filling of the initial trough itself. In many ways it is analogous to the Bouzan–Cadillac break of Quebec; the two are also in alignment. Principal mines of the region fall into three groups. To the west is Kirkland Lake proper a continuous series of seven mines lying just north of the axial portion of the trough. In the centre of the trough 9 miles to the east is Upper Canada Mines. At the south boundary on the Larder Lake break is Kerr Addison.

At Kirkland Lake seven mines—the *Macassa* (61e), *Kirkland Minerals* (61c), *Teck-Hughes* (61f), *Lake Shore* (61d), *Wright Hargreaves* (60d), *Sylvanite* (60b), and *Toburn* (60c)—are developed on veins in a composite fault zone comprising the Kirkland Lake fault, or main break, two important branch faults in the middle of the camp, and a number of smaller splays. The zone cuts sediments and a complex of syenitic intrusions elongated parallel with the sediments and pitching west. Ore is found in all rocks traversed by the fault system and consists of quartz-filled fissure veins, breccias, and gash veins tributary to the fault fissures.

Quartz with some calcite is the principal gangue although it does not form a large part of the ore as milled. Gold is native in gangue and in fractures in the wall-rock. Calaverite and petzite as well as other tellurides are relatively common. Some gold occurs with fine pyrite that constitutes as much as 2 per cent of the ore. The longest orebody, shared by the Teck-Hughes, Lake Shore, and Wright Hargreaves mines, was 6,400 feet long horizontally of which 2,600 feet was on the main break and 3,800 feet lay on the north vein fault. Average stoping width was 6 feet, although a few stopes were as much as 100 feet wide. Largest shoots were vertical in long section although others pitched west in conformity with the trace of geological contacts on the break.

Upper Canada (59f) mine occurs on a subsidiary break cutting tuff, trachyte, trachyte porphyry, and a syenite porphyry. Some evidence suggests that the intrusions are partly contemporaneous with the tuff. The break consists of branching and subparallel fractures, some filled with gouge. Orebodies are complex silicified zones with tourmaline, calcite, and quartz of several ages. Gold and tellurides occur in the quartz and with pyrite in the wall-rock.

The *Kerr Addison* (58b) is the largest single producer in the camp. Orebodies lie in and just south of a zone of carbonatized volcanics 600 feet wide that forms part of the Larder Lake break. They include irregular lenticular masses of quartz stringers within the break and silicified flows with auriferous pyrite immediately south of it.

Northwestern Quebec (Fig. V-30). Eight of the ten principal gold producers of Quebec lie within an east-west trending area 16 miles long and 3 miles wide centred on Lac DeMontigny. The west end of the area containing four of the mines—*Canadian Malartic* (32c), *Barnat* (32a), *East Malartic* (32d), and *Malartic Gold Fields* (33a)—is intersected by a persistent narrow west-northwesterly trending zone of schist, the Cadillac break. For some 20 miles west of the intersection numerous gold prospects occur along the Cadillac break, but only one medium-sized producer, the *O'Brien* (25b), and a few small ones,

the *Lapa Cadillac* (26b), *West Malartic* (26c), and *Pandora* (25c), are productive. East of the intersection there is little gold showing along the Cadillac break. The gold-bearing area extends east and north of the break, centred on Bourlamaque batholith and several smaller granodiorite stocks around or within which the deposits are clustered. These include the remaining four larger deposits—*Lamaque* (34b), *Sigma* (34d), *Sullivan Consolidated* (31b), and *Siscoe* (31a)—as well as several smaller ones such as *Perron* (36b) and *Bevcon* (37).

Three of the four mines at the intersection are grouped around the western end of an elongated peridotite mass 7 miles long that borders the Cadillac break. *Barnat* and *East Malartic* orebodies lie in small syenite porphyry and diorite intrusions close to the peridotite contact. *Canadian Malartic* is more distant in sediments and porphyry south of the break. The fourth mine, *Malartic Gold Fields,* lies in schist re-entrants along the northern contact of the peridotite, the orebodies having formed principally in small diorite pipes and dykes within the schist. The orebodies in all four deposits form a coherent group similar to one another and unlike those east of the Cadillac break. Although gold has been found in all rocks present along the break the orebodies are restricted to greywacke, diorite, and porphyry. They occur in zones of shattering, silicification, and pyritization. Small intrusive pipes or dykes surrounded by schist may be entirely converted to ore. Shattering in the larger intrusions and greywacke is more localized, but commonly occurs at the contacts. Drag-folds control the position and shape of some orebodies.

In the shattered zones the quartz veins are barren; the gold is in the altered wall-rock and associated with pyrite, virtually the only sulphide present. The amount of pyrite, which may reach 20% by volume, varies with the host rock, and in a gross way the grade of the ore varies similarly. Diorite contains the most pyrite and orebodies within it average 0.17 to 0.23 ounce per ton. Porphyry contains only a quarter as much pyrite, and ore averages 0.11 to 0.17 ounce per ton. Greywacke contains somewhat less pyrite, the ore averaging 0.09 to 0.14 ounce per ton. Silver content of the ore also varies with the host rock. The highest Au:Ag ratio is 1:1; these orebodies occur in the greywacke.

The deposits of the eastern part of the camp are more scattered. They consist of well-defined quartz veins with spectacular amounts of visible gold. Arsenopyrite as well as pyrite is commonly present.

Lamaque, the largest single gold producer in Quebec is developed on a small, oval, concentrically zoned intrusion in tuff. Granodiorite forms the centre and quartz–diorite the periphery. The intrusion plunges steeply northeast and is cut by a series of faults dipping gently southwest within which the veins are associated. The *Sigma* mine comprises a group of south-dipping veins that forms a shatter zone along the north side of a shear zone in volcanic rocks. *Siscoe* mine lies at the western extremity of the Bourlamaque batholith. Most of the ore came from quartz veins within the intrusion, the balance from a zone of shearing along its south margin. The *Sullivan Consolidated* deposit consists of quartz veins filling fractures cutting the western nose of the Bourlamaque batholith. Sulphides in the veins include chalcopyrite, sphalerite, and

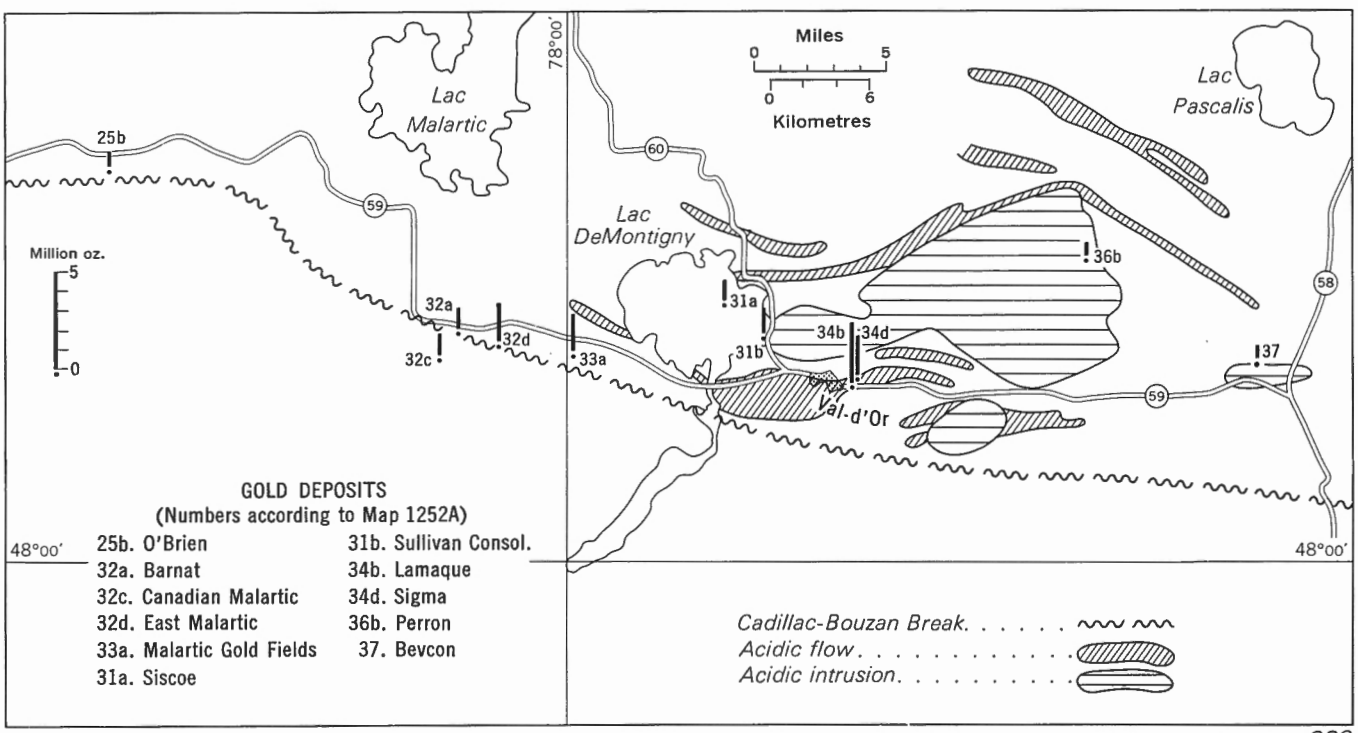


FIGURE V-30. Gold deposits of northwestern Quebec (by D. R. E. Whitmore).

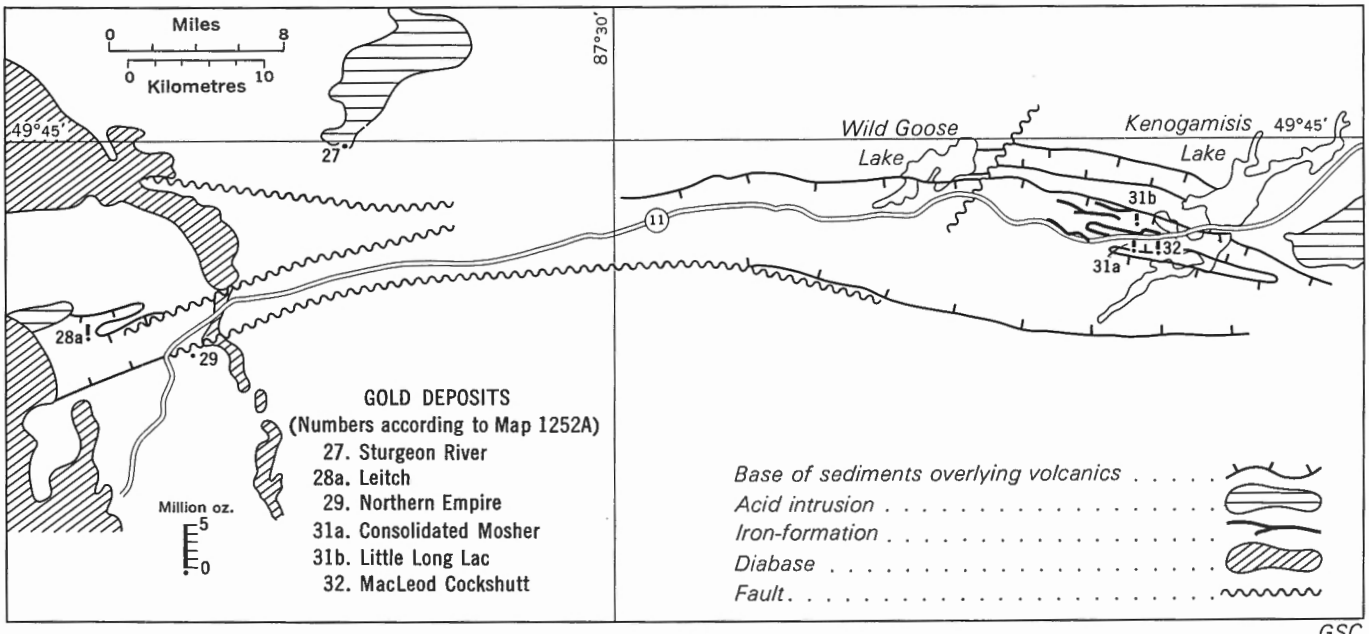


FIGURE V-31. Gold deposits of Little Long Lac camp, Ontario (by D. R. E. Whitmore).

galena. On the eastern edge of the Bourlamaque batholith, the *Perron* consists of quartz veins in flat fractures subsidiary to a steeply dipping barren shear zone cutting into the granodiorite. At *Bevcon,* auriferous quartz veins with pyrite and minor bismuth lie in a sheared and fractured zone between the north side of a small granodiorite body and a porphyry dyke.

Little Long Lac camp, Ontario (Fig. V-31). Extending eastward for 110 miles from the flat-lying, lower Proterozoic sediments and diabase sills of Nipigon basin is a belt of greenstone and poorly sorted clastic sediments about 20 miles wide. Rock types are asymmetrically arranged in it with greenstones predominating in the northern part, sediments and mica schists in the southern. Gold deposits occur in the central and western part of the area. Three of the four largest mines, *Consolidated Mosher* (Hardrock) (31a), *MacLeod-Cockshutt* (32), and *Little Long Lac* (31b) lie at the eastern limit of the camp. Gold is found in two principal types of orebodies and a number of subtypes. All types are present in the most easterly mines; those to the west have less variety. One principal type consists of sulphide replacement masses, with as much as 35% quartz, in iron-formation and greywacke. Pyrite, and arsenopyrite are the principal sulphides present in all orebodies. The other type consists of quartz stringer zones in the sediments. Some stringer zones are remarkably persistent although the individual veins may be narrow.

In the west the mines are more scattered and are developed on simple quartz–gold veins that contain no other minerals. The veins cut greywacke at the *Leitch* (28a), greenstone at the *Northern Empire* (29), and greenstone and granodiorite at *Sturgeon River* (27) mine.

Red Lake camp, Ontario (Fig. V-32). In the Red Lake area of northwestern Ontario twelve mines have produced gold since 1930. The deposits occur in an area of complexly folded greenstone, 35 miles long by 15 miles wide, whose long axis trends somewhat north of east. Two of the largest mines, *Campbell* (9b) and *Dickenson* (9d), and one of the smallest, *H. G. Young* (8), share the principal vein system of the camp, accounting for almost half the gold produced. The system is developed in andesite lavas

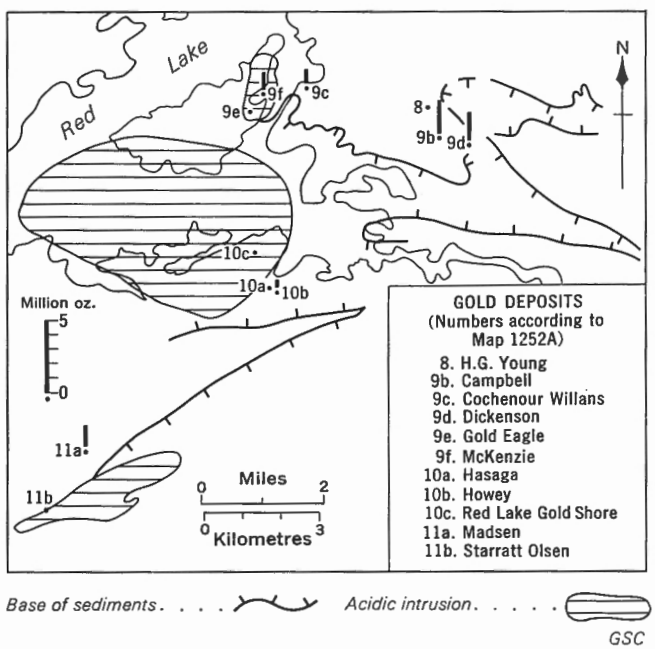


FIGURE V-32. Gold deposits of Red Lake camp, Ontario (by D. R. E. Whitmore).

adjacent to a persistent band of rhyolite tuff. The main lode, a sheeted swarm of quartz veins, extends a considerable distance from the tuff but a number of other small veins lie along or close to the tuff. The second largest producer, the *Madsen* (11a) mine, is also associated with tuff. The ore occurs in a series of *en echelon* lenses of silicified rock with feldspar porphyry, possibly originally tuffaceous sediment, that lies between quartz porphyry and talc schist. The presence of garnets indicates a higher metamorphic grade than elsewhere in the camp. Other deposits with similar associations are the *Cochenour* (9c) and nearby *McMarmac* (9g) in the northeastern part of the camp, and the *Starratt Olsen* (11b) at the southwestern extremity of the greenstone belt.

The remaining deposits are more closely related to intrusions. In contrast to the deposits of the volcanic association previously described, which are typically either cherty quartz and carbonate replacement zones or shear zones with heavy sulphides, the deposits with the intrusive rocks are well-defined quartz veins and stringers with relatively little sulphide mineralization. Three are related to the main granite stock of the camp. At the *McKenzie* (9f) the quartz veins occur in fractures and shear zones along a thrust fault cutting the stock and dipping 35°W. Veins at the *Gold Eagle* (9e) crosscut a narrow granitized sedimentary inclusion in the granite. Orebodies at *Red Lake Gold Shore* (10c) are pipe-like masses of quartz within the stock. Except for the McKenzie all are small.

The *Howey* (10b) and *Hasaga* (10a) mines were developed on an intricate stockwork of quartz stringers in a narrow part of a quartz porphyry dyke cutting a tongue of andesite breccia that projected into the main granite stock.

The deposits associated with the intrusions are generally lower grade than those closely associated with the tuff. They are also characterized by tellurides that are absent in the deposits in the tuff, but on the other hand they contain little arsenopyrite or pyrrhotite which are abundant in most tuff deposits.

Several of the volcanic segments forming part of the Uchi belt that extends east and west of Red Lake contain more than one mine. With the exception of those in the Bissett area in Manitoba and Pickle Lake in Ontario the mines have been small and short lived.

In southeastern Manitoba, the *San Antonio* (18b) and *Forty-four* (18a) mines are developed on a thick part of a diabase sill that dips 45° northeasterly within the tuff of the Rice Lake Group. The veins occur in two complementary sets, ending near the margins of the sill. One is a set of shear zones across the strike of the sill and dips 60° northwest. The other, a set of fracture zones subparallel with the strike of the sill, dips vertically. The veins consist of quartz and carbonate with minor chlorite and albite. Pyrite and minor chalcopyrite occur in the quartz with native gold. The San Antonio mine occurs in the Rice Lake volcanics northwest of an elliptical stock of quartz diorite 9 miles long. Southeast of the stock are three much smaller producers. *Ogama-Rockland* (19) consists of quartz veins with sparse pyrite and chalcopyrite in shear zones cutting quartz diorite near the margin of the mass. *Central Manitoba* (20) occurs in the volcanics and consists of a group of quartz veins, some *en echelon*, in a zone cutting across andesite and gabbro between two barren carbonatized shear zones. At the *Gunnar* (21) mine, quartz veins occur in basalt and andesite near the end of an irregular granite dyke.

One hundred and sixty miles east of Red Lake, in Ontario, in an isolated segment of the Uchi belt, are two adjoining mines. On the west the *Central Patricia* (4) orebody lies in a band of iron-formation, the sulphides filling cross-fractures. The cross-fractures contain pyrrhotite, arsenopyrite, and chlorite and are from a quarter inch to ten inches wide. Gold appears related to the chlorite. At the *Pickle Crow* (3) mine to the east are two main producing veins, one crosscutting the iron-formation at a low angle and the other cutting a quartz porphyry. The two veins are parallel with each other both in strike and dip. They consist of quartz and gold, with tourmaline and very minor pyrite, pyrrhotite, and chalcopyrite.

Slave Province

Yellowknife camp (Fig. IV-12). More than 80 per cent of the gold produced in the Northwest Territories comes from a small area of volcanics of the Archean Yellowknife Group on the west side of Yellowknife Bay. The volcanic rocks form a steeply dipping homoclinal sequence facing southeasterly, bounded on the west by a large granite mass. Small stocks of granite intrude the volcanics. The principal orebodies lie within shear zones transecting the volcanics at high angles. They consist of chlorite schist and may be as much as 200 feet wide. The zones form a single system of related shears, now separated into two parts by a large northerly trending post-mineralization fault, the West Bay fault. Horizontal displacement on the fault in the order of several miles is west side south. In vertical section the shear zones show complex curving outlines, as if folded, and it has been suggested they represent early thrust faults subsequently deformed. However, the schist composing them shows in many places a remarkable consistency in orientation regardless of the attitude of the zone and would appear to have developed after folding.

The most important orebodies consist of as much as 90 per cent auriferous quartz intimately mixed with sericite schist, and carbonate within the shear zones. Fine pyrite is the principal sulphide with arsenopyrite, and minor sphalerite, chalcopyrite, sulpharsenides, and sulphantimonides. The orebodies appear somewhat related to sharp changes in attitude of the shear zones. This type of orebody is characteristic of the *Giant* (8) mine east of the West Bay fault and of the deeper levels of the *Con* (9a) mine west of it. In the early days of the camp at the *Con Rycon* (9c), and *Negus* (9b) mines relatively narrow shear zones subsidiary to a main shear contained a somewhat different, higher grade ore. The minor shears

were more chloritic, with narrow, fractured, and vuggy quartz veins that contained sulphosalts and in places spectacular quantities of visible gold.

Other deposits are numerous in the sediments overlying the volcanics, but very few even approach mineable dimensions. For the most part these are simple bedded veins or saddle reefs as at the *Consolidated Discovery* (6), *Thompson-Lundmark* (7), and the *Ptarmigan*. The Consolidated Discovery deposit lies in argillaceous and quartzose greywacke near tuffaceous volcanics on a nose of amphibolitized pillow lava. The original vein lies conformably within the sediments in a steeply northward plunging and westerly pitching fold, which becomes broader with depth. Additional ore lies in a shatter zone within the pillow lava. Pyrrhotite is the chief metallic mineral with minor pyrite, galena, arsenopyrite, and chalcopyrite.

Churchill Province

Volcanic areas are fewer in Churchill than in Superior Province. Although gold occurrences are found in all areas, only that extending between Flin Flon and Herb Lake, Manitoba, has mines. In the Flin Flon–Herb Lake belt the structure is complex. The belt is divided by cross-folds and igneous intrusions into many segments. Three mines occur in separate isolated segments. The largest, the *Nor-Acme* (9), produced more than half a million ounces of gold from 1949 to 1958. The orebody occurred along a thrust fault that dips 45°N separating feldspathic sediments and volcanics of the footwall and coarse mafic pyroclastic rocks of the hanging-wall. The ore consisted of disseminated gold in silicified and carbonatized country rocks also containing arsenopyrite, pyrrhotite, and pyrite. Vein quartz did not exceed 5 per cent. Ore shoots where the mineralized zone thickened to mineable dimensions, were controlled by rolls in the fault plane that pitched northeasterly at 30 degrees.

At *Laguna* (11) and *Gurney* (7) the gold occurs in quartz veins. The vein at Laguna exceeded 2,100 feet in length and paralleled the long axis of a quartz–feldspar body. It contained abundant arsenopyrite with minor galena, sphalerite, pyrite, and gold and, at depth, pyrrhotite and chalcopyrite. At Gurney the veins occurred in shear zones in tuff and contained pyrite, pyrrhotite, chalcopyrite, sphalerite, and galena. Both these mines were much smaller than Nor-Acme, the Laguna about one-tenth smaller and the Gurney one-twentieth.

At the *Box* (5) mine on the north shore of Lake Athabasca, a granitic sill or a granitized sedimentary layer, up to 120 feet thick, in Tazin sedimentary gneisses, contains a network of auriferous quartz veins with pyrite, galena, sphalerite, and free gold. The overall grade was less than 0.05 ounce per ton.

Grenville Province

Scattered gold occurrences are found throughout southeastern Ontario northeasterly of Havelock. In a general way the area corresponds with the southern limit of a complex chain of small volcanic belts stretching across this part of Grenville Province. Only a few of the deposits are associated with the volcanics directly, although most occur in diorite that may in part be derived from volcanics. Surface enrichment in the weathered zone was a common feature. The deposits were all small. At *Cordova* (112) veins of quartz and carbonate containing pyrite lay in shear zones cutting diorite of variable composition and texture at the margin of a large mass of gabbro. At *Deloro* (111a) shear zones cut diorite, possibly metamorphosed lava, near the margin of a granitic stock. Veins consisted of quartz and carbonate with arsenopyrite and native gold.

Silver

In 1967 some 25 million ounces of silver were produced from the Canadian Shield, equivalent to 64 per cent of the silver production of Canada. The principal types of deposits from which silver is obtained and their production in 1967 follow:

1. *Skarn deposits,* mined essentially for their copper, zinc, and lead contents. Silver is a byproduct. These deposits produced 1.2 per cent of the total silver obtained from the Shield.

2. *Massive Ni–Cu sulphide deposits* (Sudbury type), mined essentially for their nickel, copper, and cobalt contents, with silver as a byproduct. Some 6.5 per cent of the total silver from the Shield was obtained from these deposits.

3. *Massive Cu–Zn sulphide deposits* (Flin Flon type) mined essentially for their copper and zinc contents, with silver as a byproduct. About 61 per cent of the total silver obtained from the Shield came from these deposits.

4. *Gold–quartz deposits,* mined essentially for their gold content. Silver is a byproduct. These deposits produced 1.6 per cent of the total silver obtained from the Shield.

5. *Native silver–Ni–Co–arsenide deposits.* Some of these, such as the ones at Port Radium, were mined essentially for uranium with silver as a byproduct. Others, such as those in the Cobalt, South Lorrain, and Gowganda areas, are mined essentially for the silver with cobalt, copper, and arsenic as byproducts. This type of deposit provided 26.7 per cent of the silver obtained from the Shield.

6. *Sulphide vein deposits,* containing pyrite, sphalerite, chalcopyrite, and argentiferous galena. Most of these have been worked in the Thunder Bay district of Ontario mainly for their silver content. There was no silver production from deposits of this type in 1967.

The four types of deposits that yield silver as a byproduct are described in more detail in other sections and

need only be considered briefly here; those mined essentially for silver are described in more detail below. A comprehensive report on silver, containing a metallogenic map on which are recorded the location of the principal silver deposits and prospects in the Shield, has been published by Boyle (1968).

Deposits Yielding Silver as a Byproduct

Skarn Deposits

Most deposits in this category occur in Grenville Province and are associated with the common skarn minerals that are developed in limestones, dolomites, or calcareous schists. The form of the deposits is irregular and bunchy, but many are tabular, and follow certain beds that have been selectively altered.

The deposits usually contain a characteristic suite of relatively high-temperature Ca–Mg–Fe–silicate and carbonate minerals such as garnet, epidote, vesuvianite, diopside, tremolite, scapolite, wollastonite, and crystalline calcite and dolomite. The sulphide minerals are generally chalcopyrite, bornite, pyrite, pyrrhotite, galena, sphalerite, and molybdenite. Magnetite and hematite occur in many of the deposits. The silver is characteristically associated with galena in most deposits, although in a few deposits of this type it may be associated with copper sulphides or native gold.

The *Tétreault* (69) deposit, 45 miles west of Quebec City, produced several million ounces of silver before production ceased in 1954. The silver was associated principally with galena and probably occurred mainly in tetrahedrite. Electrum and native silver have also been reported and accounted for part of the silver and gold content of the ore. The grade was 7 to 10 per cent Zn, 1 to 3 per cent Pb, 0.09 ounce Au, and 5 to 9 ounces Ag per ton. The orebodies were irregular lenses and tabular bodies of disseminated and massive sphalerite, galena, pyrrhotite, and chalcopyrite in silicified limestone and metasomatized paragneiss consisting of tremolite, diopside, wilsonite, scapolite, talc, and other Ca–Mg–Fe silicates and carbonate minerals.

The *New Calumet* (41) deposit on the Ottawa River is a tabular body of massive and disseminated sulphides in a highly altered impure limestone now essentially composed of pyroxene, tremolite, feldspar, chlorite, garnet, and calcite. The principal sulphides are pyrite, pyrrhotite, sphalerite, and galena. The silver content ranges between 5 and 10 ounces to the ton, and there is about 0.05 ounce gold to the ton. The silver is closely associated with the galena and is present in various silver-bearing minerals, including tetrahedrite, acanthite, and polybasite. The gold is mainly in the native form associated with all the sulphides and as minute grains in the silicate gangue. One variety of ore, characterized by fine-grained pyrite and pyrrhotite in coarse calcite with feldspar and tremolite, is relatively rich in native gold. This native gold appears to have been introduced late in the mineralization history of the deposit. It carries minor amounts of silver.

Massive Ni–Cu Sulphide Deposits (Sudbury Type)

These deposits contain pentlandite, pyrrhotite, and chalcopyrite within or associated with basic rocks of the gabbro clan. They are described in the section on nickel. Most silver is apparently in the chalcopyrite in many of the deposits and is recovered in refining.

Massive Cu–Zn Sulphide Deposits (Flin Flon Type)

These deposits are mined essentially for their copper and zinc but supply by far the largest amount of silver won from the Canadian Shield. They are described in the section on copper–zinc. The deposits are generally large lenses or irregular bodies consisting of pyrite, pyrrhotite, chalcopyrite, sphalerite, and minor galena. Much of the silver is in chalcopyrite or in a variety of accessory minerals such as native gold, electrum, native silver, galena, tetrahedrite, tennantite, and other sulphosalts. One of the largest massive sulphide bodies with a huge potential for silver production in the Canadian Shield is the recently discovered *Kidd Creek* (48) deposit near Timmins, Ontario. This deposit is said to contain some 60 million tons of ore averaging 4.85 ounces Ag per ton, 1.33 per cent Cu, and 7.08 per cent Zn. The total content of silver is, therefore, of the order of 300 million ounces, an amount approaching that produced from the whole of the Cobalt camp. The sulphide minerals are mainly pyrite, chalcopyrite, and sphalerite. In addition there are small amounts of bornite, covellite, digenite, stromeyerite, pyrrhotite, marcasite, galena, and arsenopyrite. The silver occurs mainly native in small inclusions in the pyrite.

Gold–Quartz Deposits

Most of these deposits occur in shear zones, faults, and fractures in the Archean greenstone belts of the Canadian Shield or in shear zones, fractures, drag-folds, and saddle reefs in the greywackes and slates associated with the greenstones. The silver is mainly in native gold in a gangue of quartz and carbonates. Some silver is present in tetrahedrite and other sulphosalts in some deposits and in tellurides in others. One or two deposits of this type contain a little of their silver as the native metal.

Deposits Mined Essentially for Silver

Deposits mined essentially for their silver content include the native silver–Ni–Co–arsenide deposits of the Cobalt, South Lorrain, Elk Lake, and Gowganda areas of Ontario, and those in the Great Bear Lake area, District of Mackenzie. The deposits of the Thunder Bay district of Ontario are mainly of the sulphide vein type, although the

orebody of the principal producing mine, *Silver Islet*, was of the native silver type.

Cobalt District, Ontario (96–98). Principal mines operating in the Cobalt area, in 1967, were Glen Lake, Hiho, Silverfields, Silver Town, Silver Regent, Agnico, Sudbury Contact, Deer Horn, and Langis. The silver deposits were discovered in 1903 during the building of the Timiskaming and Northern Ontario Railway, and since that time the area has yielded a large part of the Canadian silver production and some cobalt, copper, nickel, arsenic, and bismuth. The bonanza years lasted from 1904 until about 1930, after which there was a gradual decline. Today the camp is experiencing a rejuvenation. Cumulative production of silver to the end of 1967 was about 500 million ounces. In addition, some 25 million pounds of cobalt, 3 million pounds of nickel, and 1.5 million pounds of copper have been extracted. The nature of the veins at a typical deposit in the Cobalt area is shown on Figures V-33 and -34. The host rocks are the steeply dipping Keewatin basic and intermediate lavas (greenstones) and interflow sediments, the unconformably overlying flat to gently dipping Coleman Formation of the Cobalt Group that consists of conglomerate, greywacke, and quartzite, and the Nipissing diabase sill, which cuts across all these rocks at a low angle.

Most of the high-grade deposits are in the Cobalt Group and the Nipissing diabase. The deposits are in short veins, although some have been traced for a thousand feet or more along their strike and dip. A typical orebody consists of one or two anastamosing veins, sometimes more, varying from a few tenths of an inch to a foot or more in width. Some deposits occur in extensive faults or in fractures parallel with or related to the faults. Examples of this feature were the orebodies in the Cobalt Lake fault and those in subsidiary and parallel fractures associated with this structure. The regional faults, in general, are not the controlling features in localizing orebodies (Thomson, 1957). The fissures and fractures are largely parallel with the contact between flows and sediments in the Keewatin, or are related to basins and arches in the Nipissing diabase, the upper and the lower contacts of the intrusion, and the basal contact of the Cobalt Group, particularly where the sediments fill small basins in the underlying Keewatin greenstones.

The veins have a complex mineral assemblage. The principal gangue is white or pink dolomite, with calcite, quartz, and hematite. The metallic minerals include native

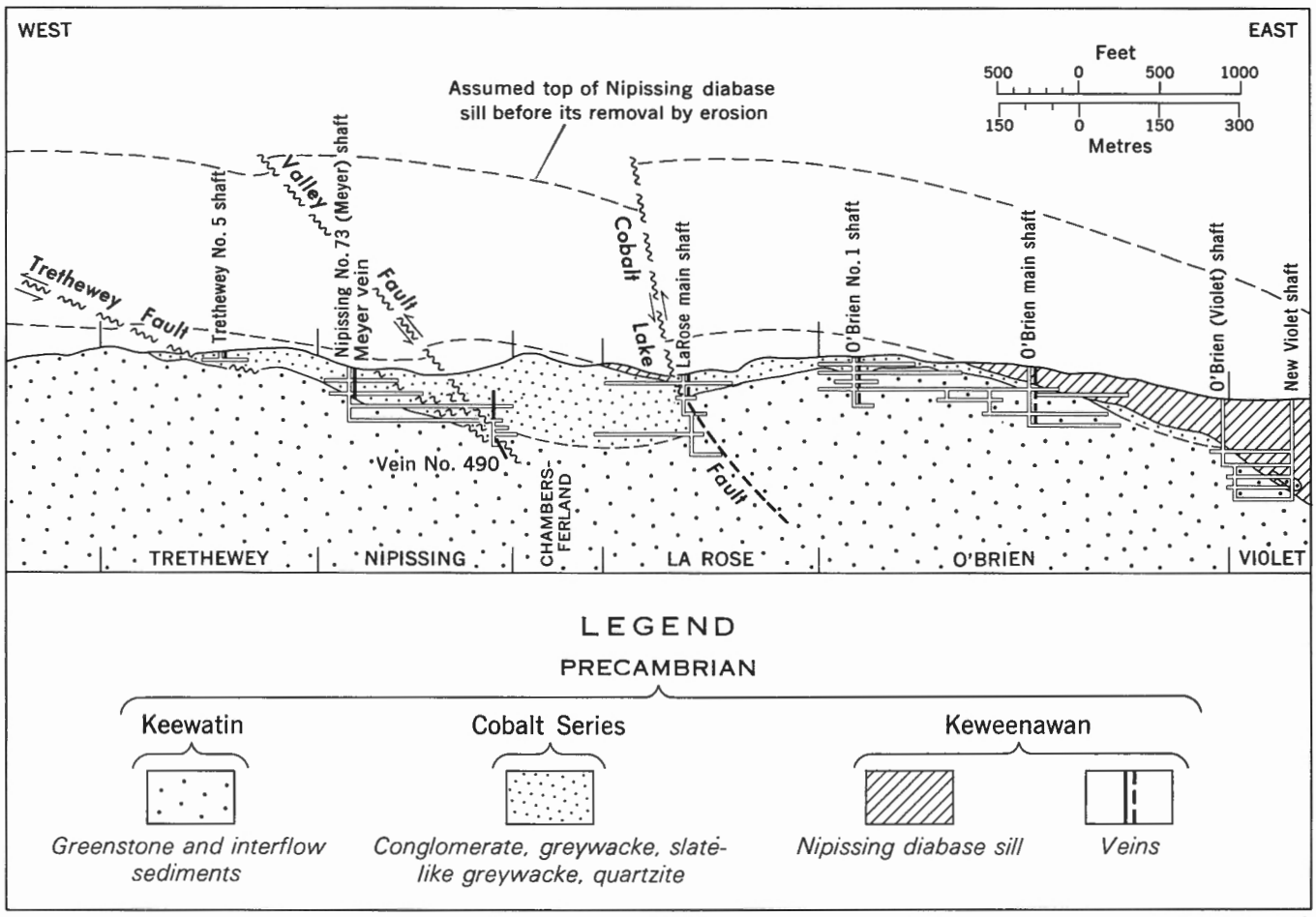


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FIGURE V-33. Section showing generalized geological features of Cobalt area, Ontario (after Knight, Miller, Thompson, and others).

silver, dyscrasite, argentite, smaltite–chloanthite, loellingite, safflorite, rammelsbergite, skutterudite, arsenopyrite, gersdorffite, cobaltite, glaucodot, niccolite, breithauptite, chalcopyrite, galena, pyrite, pyrrhotite, sphalerite, tetrahedrite, native bismuth, and minor amounts of pentlandite, polybasite, stephanite, ruby silver, and stromeyerite. Native silver and the Co–Ni arsenides are the most abundant and characteristic minerals. Secondary minerals include erythrite, annabergite, scorodite, manganese oxides (wad), and limonite. The native silver occurs as specks, spangles, and masses, some of which are huge slabs weighing as much as 1,600 pounds. Both the native silver and dyscrasite contain mercury. The silver may be intimately intergrown with the Ni–Co arsenides, dolomite, calcite, and other minerals or it may be alone, often without any gangue minerals, in tiny fractures in the wall-rocks. The Ni–Co arsenides, calcite, and other minerals are intimately intergrown, and there has been much controversy on their paragenesis and also on their relationship to the native silver. Many of the arsenides exhibit a 'concretionary' or 'tubercular' texture that suggested to Lindgren and others crystallization from a gel. There are probably no silver veins without cobalt and nickel arsenides, but there are veins with abundant cobalt minerals that have little or no silver.

Many veins in the diabase are marked by narrow alteration zones as much as an inch wide that have good bilateral symmetry and appear as a narrow dark band immediately adjacent to the vein followed outward by a light grey, bleached band. The light band consists of severely sericitized feldspar, epidote, clinozoisite, magnesium-rich carbonate, leucoxene, biotite, pyrite, apatite, and quartz, all alteration products of the diabase, which when fresh contains sodic labradorite, augite, some secondary hornblende and biotite, titaniferous magnetite, pyrite, biotite, apatite, and interstitial quartz. The dark band is gradational with the light one and consists of pennine chlorite, minor epidote, oligoclase, carbonate, leucoxene, quartz, pyrite, and apatite. The ophitic texture of the diabase, retained in the light band, is destroyed in the dark one. Some of the veins in the Cobalt sediments are also marked by a faint zone of wall-rock alteration (Boyle, 1968). The zone is rarely more than an inch or so wide and is essentially a grey bleached area that grades imperceptibly into the green sedimentary rocks. In places there is evidence of a darker chloritic zone adjacent to the veins. The bleached zone consists of a matted aggregate of clastic grains of quartz, highly altered zoisitized feldspar, abundant carbonate, and much pennine chlorite. The darker zone is due to greater amounts of chlorite. The fresh sediment contains clastic grains of quartz and feldspar in a matrix of chloritic material and minor carbonate. The texture in the bleached zones is not much different from that in the relatively fresh sediment.

South Lorrain, Ontario. These deposits are essentially mineralogically similar to those at Cobalt. Some veins occur in the Nipissing diabase near the upper contact of the sill; others occur in the Keewatin rocks above the sill. One of the veins in the Keeley mine (Wood's vein) was deeply oxidized to a depth of 600 feet or more. Much of the silver in this oxidized vein was apparently of secondary origin.

Gowganda, Ontario. The principal producing mine in this area is the Siscoe. The deposits are similar to those at Cobalt and South Lorrain and their geological setting is much the same. The same suite of Ni–Co

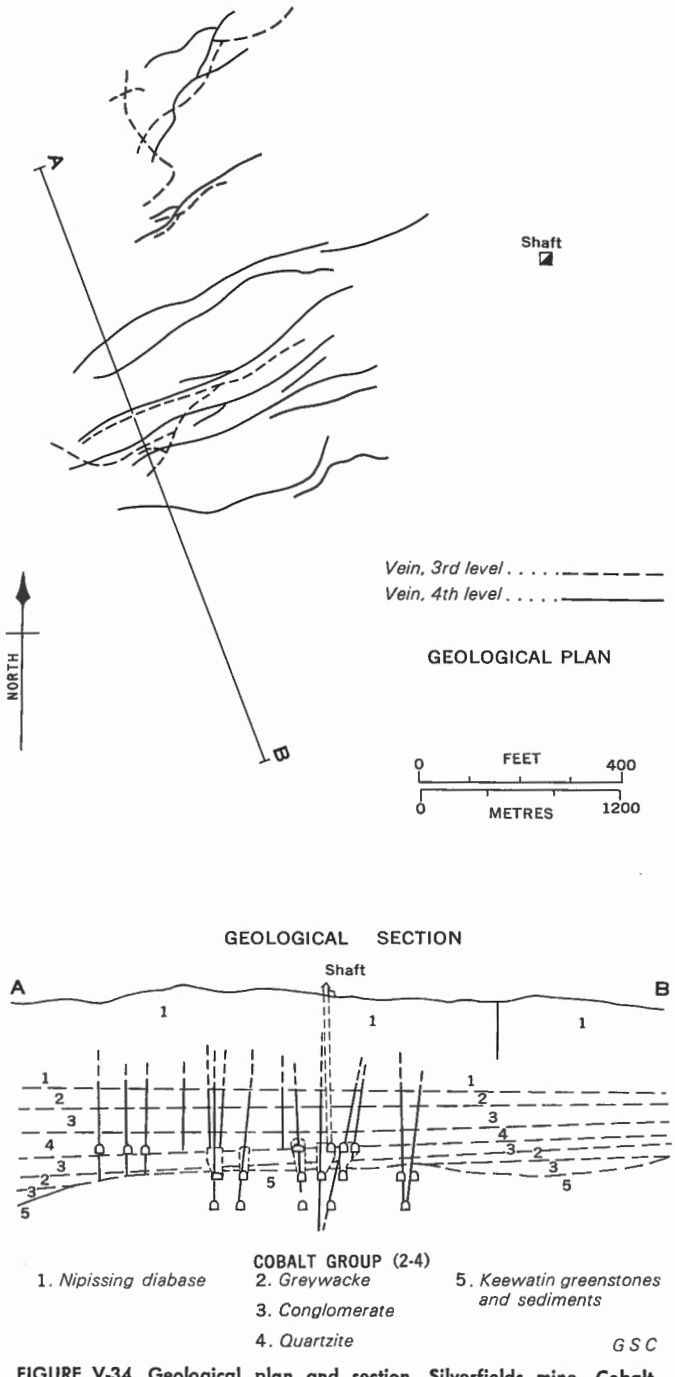


FIGURE V-34. Geological plan and section, Silverfields mine, Cobalt, Ontario (by R. W. Boyle).

arsenides is present as well as the other common metallic minerals. The principal economic mineral is native silver. There is some bismuthinite, and hematite is present in a few of the veins. The principal gangue is calcite, but some veins contain more quartz than calcite. Epidote and axinite occur and are generally earlier than the metallic minerals. Most of the veins in the Gowganda area are fissure-fillings, and are localized mainly in a Nipissing diabase sill, 300 to 400 feet from its upper contact. A few productive veins occur in the Keewatin greenstones and Cobalt conglomerates.

Origin of deposits. The origin of the Cobalt deposits and those in nearby areas has been debated for many years and still remains an enigma. Summaries of the various early theories may be found in Knight (1924) and Moore (1934). Most early investigators considered the diabase to be the source of the silver, the veins originating during differentiation of the sills. Miller (1913) studied the Cobalt deposits for many years, at times favouring the theory that the metals were leached out of the Keewatin greenstones and other associated rocks, but at other times he thought that the diabase and the ores came from one and the same magma.

Whitman (1920, 1928) took a different view of the origin of the veins at Cobalt from that of most investigators. He substantiated his theory at least in part by laboratory experiments. He concluded that:

1. The cobalt–nickel–silver ores of the Cobalt district were derived by diffusion and metasomatic fixation from the sill of Nipissing diabase with which they are associated.

2. They were deposited essentially in their present form below the groundwater level, not by circulating solutions, but by migrant ions traversing virtually stagnant or slowly circulating aqueous solutions that coursed all parts of the diabase. Deposition took place in such favourable seats of deposition as were accessible in the neighbourhood of the margins of the diabase.

3. Mineral-laden water filled all the pores, joints, and fractures of the diabase and its neighbouring rocks and through it moved the ions of vein material, at a temperature considerably below the melting point of the diabase, and at a pressure of several thousand feet of hydrostatic head.

Boyle (1968) enumerated a number of features that appear to bear directly on the problem, as follows:

1. The deposits, in addition to silver, are greatly enriched in cobalt, nickel, bismuth, arsenic, and sulphur, and a source for all these elements must be found before any adequate theory can be formulated.

2. The deposits are structurally controlled in fractures or faults that cut all the rocks in the area except perhaps the late diabase dykes. The Nipissing diabase sills were completely crystallized before the veins were formed, and accordingly the sills could not produce the constituents in the veins by the classical differentiation mechanism.

3. Diabase is lacking in many areas where native silver deposits identical in mineralization to those at Cobalt are present, as for example Jáchymov, Czechoslovakia, and Kongsberg, Norway. Diabase therefore, may not be the key to the source of all the elements in the veins.

4. Many veins at Cobalt cut deeply into the Keewatin rocks, occurring in both greenstones and interbedded sediments. Some veins are present in the Cobalt conglomerate and Nipissing diabase where they overlie the Keewatin sedimentary layers.

5. Many of the Keewatin greenstones, and the graphitic sediments especially, contain abundant sulphide minerals, mainly pyrite and pyrrhotite. The graphitic sediments also contain small amounts of galena, sphalerite, and chalcopyrite. These sulphides could be interpreted as having been introduced, but their presence in similar sediments in many parts of the Canadian Shield suggests that they were originally sedimentary. They have been recrystallized and probably were partly mobilized during regional metamorphism.

Trace element contents of the rocks at Cobalt are shown in Table V-10. The black pyritic sediments interbedded with the Keewatin greenstones have the greatest amounts of all the elements analyzed. This feature is not unique for the Cobalt district as is shown by the data from the Yellowknife area, District of Mackenzie. The greenstones, likewise, are relatively rich in most of the elements found in the veins at Cobalt. The Nipissing diabase, in areas beyond the effects of mineralization at the Cobalt camp, is remarkably low in the vein elements, except for nickel and cobalt. The Cobalt conglomerates and greywackes are, likewise, low in most of the vein elements. It would appear, then, that the only readily available sources of arsenic, antimony, and bismuth are the Keewatin sediments and greenstones. Because the Cobalt veins are so restricted in their lateral and vertical extent, their metallic constituents were probably derived from sources nearby. As the fractures dilated they drew in the more mobile constituents of the Keewatin greenstones and sediments, namely, Ni, Co, As, Ag, Bi, S, $MgCO_3$, and $CaCO_3$. The Nipissing diabase may have contributed some Ni and Co, and the heat associated with the intrusion of the sill may have had a stimulating effect in mobilizing the elements. The mode of migration of the vein constituents was probably by diffusion through a static water medium as suggested by Whitman. The Cobalt veins are considered to be essentially secretion veins, and their constituents to be late distillates from the country rocks.

Thunder Bay, Ontario. The silver deposits in the Thunder Bay district of western Ontario lie in two belts, the "grey argillite" or "Island belt", and the "black slate" or "Mainland belt" (Oja, 1967). The Island belt includes the islands of diabase in western Lake Superior. The Mainland belt is roughly 4 miles wide and extends northeast and southwest of the city of Port Arthur. The older rocks are steeply dipping metamorphosed Archean volcanic

rocks, gneisses, and schists intruded or granitized to granite, granite gneiss, and migmatite during the Kenoran Orogeny. Unconformably overlying these rocks are the Aphebian Gunflint and Rove Formations of the Animikie Group, which are in turn overlain, apparently unconformably, by the Helikian Sibley sediments. All these formations are intruded by Keweenawan diabase sills and dykes and severely faulted, chiefly northeast and northwest.

The principal deposit in the Island belt was the *Silver Islet* mine which produced, from 1868 to 1884, more than $3 million in silver. It was the first silver mine to be worked in Canada. The problems with which the miners had to deal on such a small islet of rock some 80 feet in diameter, exposed to the fury of Lake Superior, are legendary.

The steeply dipping vein system was mainly in a diabase dyke, 250 feet wide, that cuts through relatively flat lying Animikie argillites, greywacke, and slates. The main vein averaged 8 feet wide and produced to a depth of some 1,300 feet, below which it became too low grade to be worked economically at that time. The gangue was mainly calcite and manganiferous dolomite with a little quartz. Rhodochrosite and barite occurred in places. The metallic minerals included abundant native silver, argentite, galena, sphalerite, chalcopyrite, pyrite, marcasite, tetrahedrite, domeykite, niccolite, cobaltite, smaltite, breithaup-

TABLE V-10 *Analyses of rocks from Cobalt and South Lorrain, Ontario (Boyle, 1968) (all values in parts per million except where noted)*

Description of Samples	Cu	Pb	Zn	Ni	Co	Bi	Ag	As	Sb	S	Au
Composite sample of Keewatin greenstone, South Lorrain area	330	<5	95	130	67	NF	0.30	15	2.5	1,700	ND
Composite sample of Keewatin greenstone, Cobalt area	120	<5	215	105	69	NF	0.19	2	0.5	775	ND
Composite sample of Cobalt conglomerate and greywacke, Cobalt area	20	<5	20	60	25	NF	<0.05	<2	<1	180	ND
Nipissing diabase: average values computed from 36 samples from drill hole through diabase, Henwood twp., Cobalt area	83	<2	70	128	40	<0.05	0.11	<2	<1	590	ND
Composite sample of Keewatin black pyritiferous slate, schist, and greywacke, Cobalt area	420	75	2,400	160	74	0.83	0.83	140	12.5	~6%	ND
Sulphides (mainly pyrite with some pyrrhotite, chalcopyrite, etc.) separated from above sample	750	200	4,400	570	217	NF	5.7	1,150	46	ND	0.128
Sulphides (mainly pyrite and pyrrhotite) separated from Keewatin greenstone, South Lorrain area	ND	ND	ND	1,500	3,000	NF	7	ND	ND	ND	ND
Composite sample of black pyritiferous slate, schist, greywacke, tuff, etc., Yellowknife area (range in ppm)	<5–400	<5–20	10–1,600	10–110	<5–110	ND	0.33–1.6	<5–15	<1–1.0	~5%	0.01–0.07

Gold analyses by Mines Branch, Ottawa. Other analyses by Geochemical laboratories, Geological Survey of Canada.
NF = not found; ND = not determined.

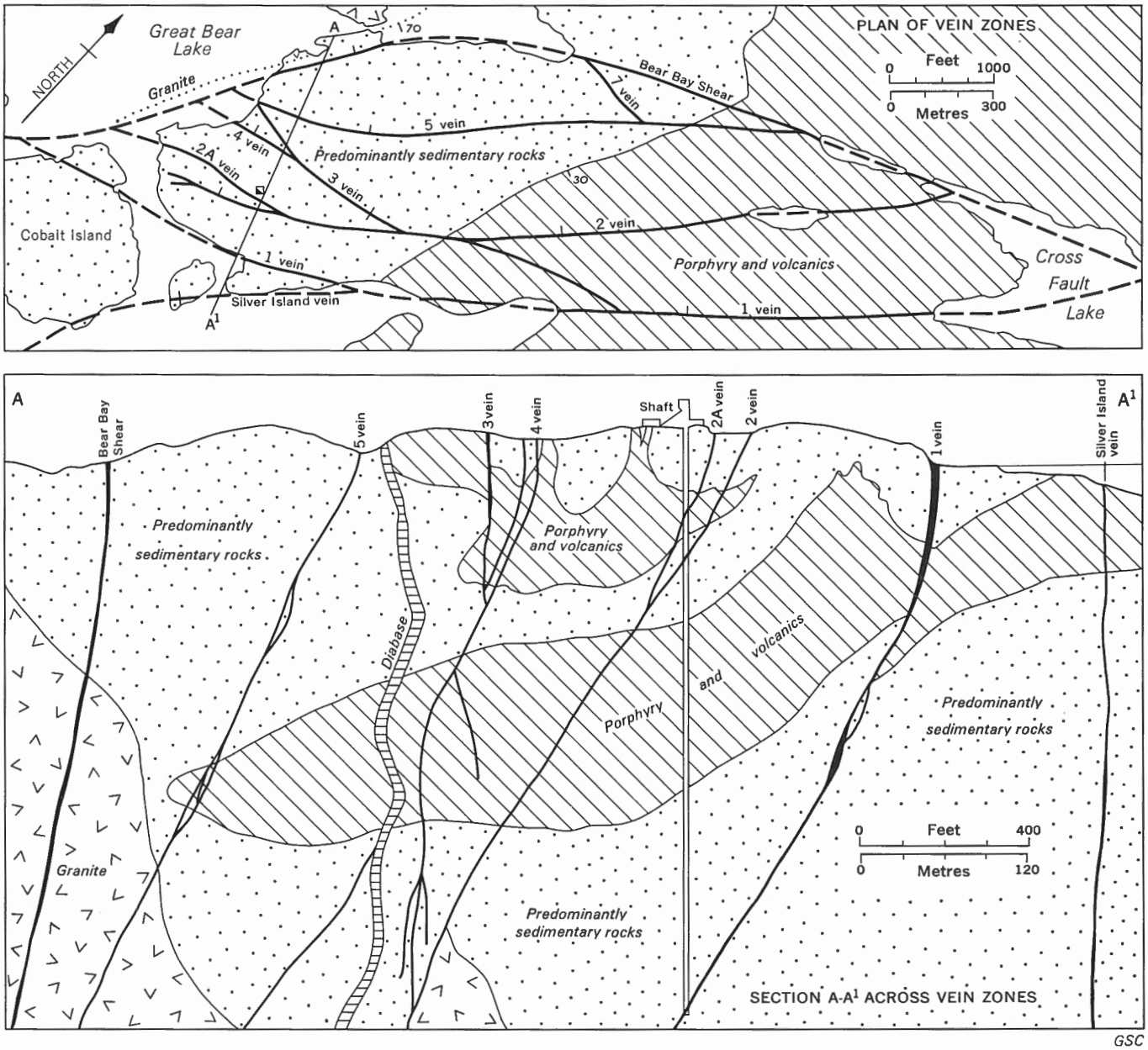


FIGURE V-35. Generalized plan and section of geology in the vicinity of Port Radium mine, Port Radium, Northwest Territories (Campbell, 1957).

tite(?), millerite(?), and other poorly differentiated arsenic, antimony, cobalt, nickel, and silver minerals. Graphite (or carbonaceous matter) occurred in quantity in parts of the vein. Methane and hydrogen sulphide were encountered in relatively large quantities in some parts of the vein, and flows of salt water were common. The principal secondary minerals were quartz, calcite, barite, marcasite, nickel bloom (annabergite), cobalt bloom (erythrite), pyrolusite, native silver, and chlorargyrite. The shoots occurred as fabulously rich bonanzas along the vein system and were separated by relatively lean stretches.

The diabase dyke, which the vein cuts nearly at right angles, acted only as a structural site for the mineralization. It probably played little part in the mineralization of the vein, although it may have supplied some of the gangue elements and perhaps some cobalt and nickel. The sediments seem to be the most likely source of the metals, arsenic, sulphur, and the abundant graphite.

The prospects and mines in the Mainland belt include the Beaver, Silver Mountain, Badger and Porcupine, Rabbit Mountain, Shuniah, Jarvis, Thunder Bay, 3A and Beck, and several others. Each of the first three have produced about half a million dollars in silver. The country rocks are mainly flat lying, black, pyritic slates and argillites, greywacke, and phyllite of the Rove Formation that

have been intruded by Keweenawan diabase sills and broken by several normal faults giving rise to numerous buttes, mesas, and cuestas formed by the sills. The deposits are veins, lodes, and irregular stockworks in the steeply dipping faults and subsidiary fractures, which strike northeast or north to northwest. Most known veins occur in the Rove sediments, but some extend into the diabase sills and at least one, the Shuniah vein, cuts the basement complex. The gangue minerals are mainly calcite, white, smoky, and amethystine quartz, fluorite, barite, and some witherite. Metallic minerals include native silver, argentite, sphalerite, galena, pyrite, pyrrhotite, and chalcopyrite. Oja (1967) noted that most geophysical methods failed to locate the veins in the Mainland belt. Geochemical methods using zinc and silver as indicators in the humus and soil were found to be useful in tracing the veins.

Great Bear Lake area, District of Mackenzie. A number of silver deposits and occurrences are known in a belt that stretches along the eastern shore of Great Bear Lake southward to Hottah Lake. This belt includes the now exhausted Eldorado uranium mine at Port Radium. Additional description of the deposit is given in the section on Uranium.

The *Eldorado* (3) mine obtained its ore from veins and stockworks in faults, shear zones, and fractures that cut all the consolidated rocks of the area (Fig. V-35). Most productive deposits, however, occurred in the Echo Bay Group, generally in the lower part, but some were in the granodiorite and other granitic rocks. The principal gangue was quartz and hematite, but there was some carbonate, usually calcite. In some veins the principal economic mineral was pitchblende; in others native silver. Other metallic minerals included a great variety of Co–Ni arsenides and sulphides, chalcopyrite, argentite, galena, molybdenite, pyrite, and native bismuth. Secondary minerals included yellow and orange uranium ochres, azurite, malachite, erythrite, annabergite, and various manganese oxides. Campbell (1957) recognized five stages of mineralization in the Port Radium mine as follows: (1) hematite, quartz; (2) pitchblende, quartz, hematite; (3) quartz, Co–Ni arsenides and sulphides; (4) copper sulphides, chlorite, dolomite; (5) carbonate, silver, bismuth, chalcopyrite. This sequence is somewhat similar to that at Jáchymov, Czechoslovakia, although there are differences. The sequence of quartz and hematite followed by pitchblende and the Ni–Co arsenides, in turn with silver and bismuth as a late phase, is typical of deposits of this type. The principal alterations in the Port Radium veins were argillic, chloritization, hematitization, and carbonatization. There was also some silicification, sulphidization, and the development of apatite in some veins.

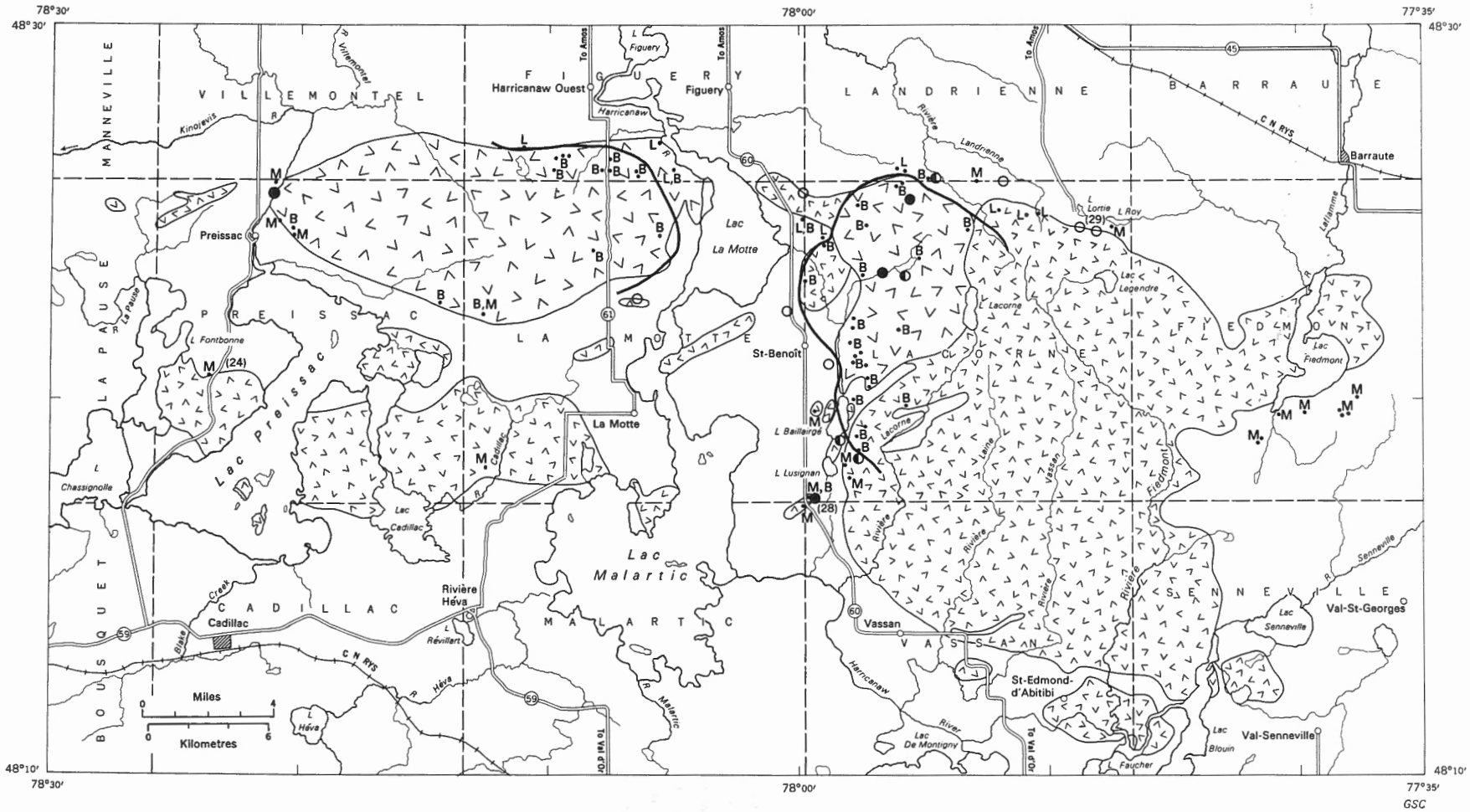
The *Echo Bay* (2) mine is producing silver about a mile northeast of Port Radium. The deposits are in irregular veins in fractured and shear zones in tuff, dacite, feldspar porphyry, and fine-grained banded sediments of the Echo Bay Group (Thorpe, 1966). Four principal northeast-striking veins, ranging from a few hundred feet to more than 1,000 feet in length, have been explored. Most dip steeply north and vary in width from a few inches to five feet. The principal gangue is manganiferous carbonate and quartz. Metallic minerals include the Ni–Co arsenides and sulphides, pyrite, argentiferous galena, sphalerite, chalcopyrite, native silver, acanthite (argentite), and stromeyerite. Several ages of mineralization are evident. In 1965, production was 1,408,246 ounces of silver from 35,609 tons of ore. Some copper and lead are also extracted.

A number of other silver veins in the Great Bear Lake area have received some attention in the past, but none has produced any quantity of ore. The *Camsell River* silver deposits on Camsell River (Lord, 1951) are veins and stockworks in fracture and shear zones in andesitic tuffs and agglomerates, diabase, and quartz–feldspar porphyry. The economic mineral is native silver in a gangue of quartz and carbonate. Ni–Co arsenides and sulphides, native bismuth, and bismuthinite are present in a number of veins, with some pyrite, chalcopyrite, sphalerite, and galena. Hematite and minor amounts of pitchblende are reported. Veins on the north shore of *Contact Lake* are in fractured and sheared zones in granodiorite, probably of Aphebian age (Furnival, 1939; Lord, 1951). The gangue is quartz and carbonate, and the minerals of interest are native silver and pitchblende. Other metallic minerals include the Ni–Co arsenides and sulphides, arsenopyrite, the common base metal sulphides, native bismuth, bismuthinite, pearceite, stromeyerite, argentite, and hessite.

Platinum Group

The metals of the platinum group include platinum, palladium, iridium, osmium, rhodium, and ruthenium. In Canada, these metals are produced solely as byproducts from the treatment of nickel–copper ores. Most come from the mines at Sudbury, Ontario, and Thompson, Manitoba. Minor production is obtained from nickel–copper concentrates shipped to Sudbury from Gordon Lake, Ontario, and Belleterre, Quebec.

Platinum and some rhodium are present in the mineral sperrylite, a platinum diarsenide that is scattered sparsely through the sulphides. Rare palladium bismuthides have been identified in Sudbury ores. Elements of the platinum group are held in solid solution in minute amounts in various copper–nickel arsenides, which are generally more abundant in the copper-rich sections of the ore zones. The average content of these metals in Sudbury ores is 0.025 ounce per ton, with platinum making up about half the total. In 1929, the last year for which separate records are reported, the yield was 12,474 ounces



Main areas containing muscovite granite

Other granitoid rocks of the Preissac-Lacorne batholith

Zone boundary

Location of pegmatite, aplite, or vein .....•
Mainly beryllium occurrence .....●
Main lithium occurrence .....○
Combined beryllium - lithium occurrence .....◐
Minor occurrences of beryllium, lithium .....B, L
Molybdenite .....M

PROPERTIES DESCRIBED IN TEXT

(24) Preissac Molybdenite
(28) Molybdenite Corporation (Lacorne)
(29) Quebec Lithium

FIGURE V-36. Regional zoning of lithium and beryllium occurrences, Preissac–Lacorne area, Quebec (by R. Mulligan).

platinum, 12,231 ounces palladium, 3,037 ounces rhodium, 1,376 ounces ruthenium, 497 ounces iridium, and no osmium. In 1965 a method was developed for recovering osmium. Since 1920, production essentially has been equally divided between platinum and the remainder of the group; for 1966 it was 396,059 troy ounces. Cumulative Canadian production was 11,187,500 troy ounces to the end of 1966.

MINOR METALS

Arsenic

Arsenopyrite is commonly associated with silver–cobalt ores and Canada's total production of refined white arsenic originates from this source. In 1966, 350 tons of arsenic oxide were produced as a byproduct from silver–cobalt ores at Cobalt, Ontario. In western Quebec, at the O'Brien mine and the Beattie–Duquesne mine, prior to 1966, crude white arsenic was recovered from the treatment of gold ores.

Beryllium

Beryllium occurrences are widespread in Slave, Superior, and Grenville Provinces of the Canadian Shield, and are also found in Churchill and Nain Provinces. Most occurrences are in granitic pegmatite dykes, and the beryllium is in the form of beryl or, rarely, chrysoberyl and other minerals. Most of the richer berylliferous dykes of Slave and Superior Provinces are associated with lithium minerals, as parts of either a regional or an internal zoned sequence. The most important of these areas are the *Preissac–Lacorne* district, Quebec (Fig. V-36), the *Cat Lake–Winnipeg River* district, Manitoba, and the *Yellowknife–Beaulieu River* district, District of Mackenzie. However, beryllium occurs much more extensively than lithium, although it has not been found in comparable concentrations. Some berylliferous pegmatites are associated with molybdenite, as at *Lacorne* (28), Quebec, where a small amount of byproduct beryl represents the only current production in Canada. Beryl is also found in molybdenite ore at the old Height of Land mine nearby.

The few non-pegmatitic beryllium occurrences of the Shield include the unique alkali-metasomatic deposit at *Seal Lake,* Labrador. Fine-grained barylite and eudidymite occur in zones of soda-rich paragneiss associated with syenitic intrusions. Some zones average 0.35 to 0.40 per cent BeO. Niobium is also present, together with minor zinc and rare-earth minerals. Most other beryllium occurrences are related to granitic intrusions. The berylliferous pegmatites, except for the complex lithium–beryllium ones, are as a rule unzoned or crudely zoned, although the beryl is commonly concentrated in or near quartz-rich central areas. Beryl is commonly associated with muscovite and the platy albite cleavelandite. In regionally zoned districts the berylliferous pegmatites are generally closer to the related granitic bodies than are the simple spodumene-bearing dykes. In the complex lithium–beryllium pegmatites the beryl is chiefly in the outer intermediate or wall zones, although some late alkali beryl is also present in the innermost lithium-rich and other zones.

No deposits are being mined primarily for beryllium at present, but beryl is recovered from the waste-sorting belt at Lacorne molybdenite mine. Some years ago, one or more shipments of beryl, totalling perhaps 50 tons with an average beryl content of 0.25 per cent, were made from the dykes in Lyndoch township, near Qaudeville, Ontario. Small amounts of beryl have been taken from several pegmatites in the Winnipeg River district, Manitoba. Some beryl was recovered from the Moose and Best Bet, and probably also the Peg Tantalum properties in the Yellowknife–Beaulieu district, Northwest Territories.

Bismuth

Bismuth, used in pharmaceuticals and chemical compounds, is recovered mainly as a byproduct from the *Preissac* (24b) and *Lacorne* (28) molybdenum deposits in Quebec. It occurs as the native metal or as the sulphide, bismuthinite. Small amounts of bismuth are also recovered from silver–cobalt ores. The deposits occur in quartz veins and in intrusive rocks of granitic or intermediate composition that contain varying amounts of feldspar, mica, bismuth, bismuthinite, molybdenite, and iron sulphides.

Cadmium

In 1966, a quarter of the Canadian cadmium production came from the Canadian Shield. The element occurs as a minor constituent of sphalerite, commonly ranging between 0.1 and 0.3 per cent but it can be as high as 0.7 per cent. Its concentration generally varies inversely as the iron content of the sphalerite. Cadmium is recovered from zinc concentrates of the Flin Flon area of Manitoba and Saskatchewan, the Manitouwadge area of Ontario, and the Matagami and Noranda areas of Quebec. The main uses of cadmium are in the plating of steel and the manufacture of pigment.

Caesium

Caesium deposits are rare, and the pollucite deposit at *Chemalloy Minerals,* Winnipeg River district, Manitoba, is the largest and richest known (Fig. V-37). It contains

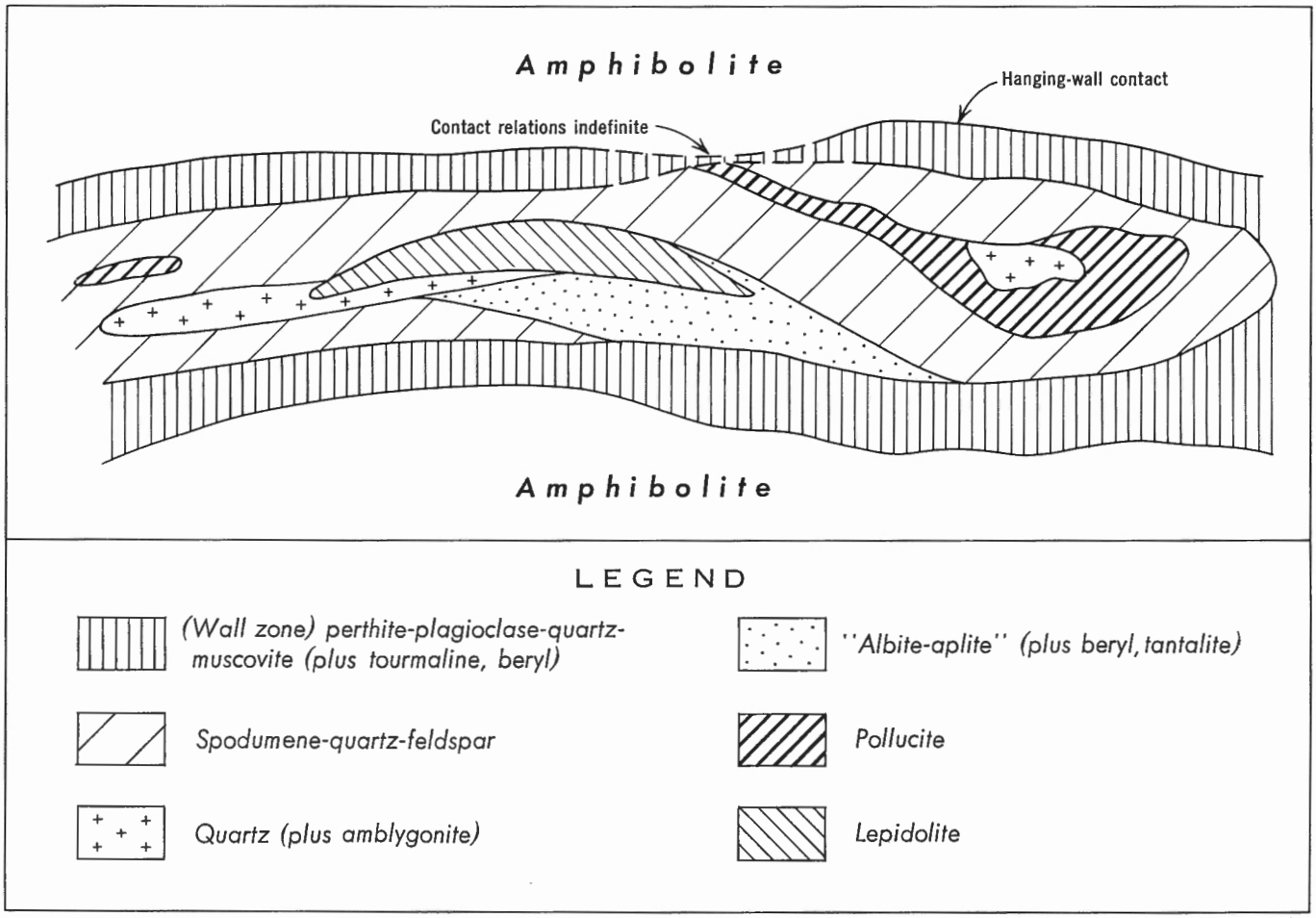


FIGURE V-37. Diagrammatic composite vertical section of Chemalloy Minerals Limited pegmatite (by R. Mulligan).

about 300,000 recoverable tons averaging more than 20 per cent Cs_2O. The pollucite occurs in the inner units of a highly complex pegmatite, and is associated with spodumene and lepidolite. Some pollucite is present in a complex pegmatite in the Lacorne area and a little has been reported from spodumene-bearing pegmatites elsewhere.

Lithium

Lithium occurrences are widespread in Archean metasedimentary and metavolcanic belts of Superior and Slave Provinces. The chief districts are near Lacorne, Quebec, Nipigon, Ontario, Winnipeg River, Manitoba, and Yellowknife, District of Mackenzie. Among other major fields are the East Braintree–West Hawk Lake district of Manitoba, the Lac la Croix, Root Lake, Dryden, and Zig–Zag Lake areas of Ontario, and the Lac Expanse and Assinica Lake areas of Quebec. Except for the Herb Lake deposit in Churchill Province near the boundary with Superior Province, lithium occurrences are rare in the younger Precambrian provinces. All the lithium deposits are in moderate to highly metamorphosed rocks near their contacts with granitic intrusions. The main lithium-bearing mineral is spodumene, although amblygonite and lepidolite are important constituents of some complex pegmatites in the Winnipeg River and Yellowknife districts. Petalite is rare; a little occurs in some pegmatites of the Winnipeg River area. Many deposits contain several million tons of ore grading 1.2 per cent or more Li_2O.

The lithium occurrences are mainly in unzoned pegmatite dykes. These contain spodumene crystals a few inches long oriented perpendicular to the walls and uniformly distributed between them. Other occurrences are well-zoned bodies that have tourmalinized wall zones, beryl-bearing feldspar–quartz–muscovite intermediate zones, and spodumene-rich inner zones. The latter locally contain quartz–amblygonite "cores" and lepidolite assemblages. In these bodies the spodumene is commonly coarser grained and random in orientation. Most zoned pegmatites are gently dipping sheets, whereas most unzoned ones are steeply dipping. A regional zoning is apparent in several districts, notably Lacorne (Fig. V-36) and Yellowknife. In these districts simple unzoned spodumene pegmatites lie farther from the central parts of the associated granitic plutons than the lithium-free berylliferous pegmatites and the complexly zoned lithium–beryllium pegmatites.

The *Quebec Lithium* (29) mine in the Preissac–Lacorne district, Quebec, is in an unzoned spodumene pegmatite. A belt 8,000 feet long and 2,000 feet wide contains numerous subparallel dykes as much as 2,000 feet long and 100 feet thick with a moderate to steep dip. The dykes pass from amphibolitized greenstone at the surface into granodiorite at depth, and are remarkably homogeneous in grade and texture. Reserves in the shaft area alone have been estimated at 15 million tons of ore averaging more than 1.2 per cent Li_2O. Mining and milling, at about 1,000 tons per day, began in 1955. In 1960, a chemicals plant was erected at the property to produce lithium carbonate and hydroxide. In recent years it has produced more than a million tons per year of 'contained lithia' valued at over $1.1 million.

In the Winnipeg River district of southeastern Manitoba, several pegmatites are of the complexly zoned type. The *Chemalloy Minerals* mine is developed in a virtually flat lying, domical lenticular sheet some 2,500 feet long, 1,500 feet wide, and 250 feet thick in the central explored area (Fig. V-37). An inner intermediate assemblage of spodumene–quartz–feldspar is overlain and underlain by a wall-zone of perthite–plagioclase–quartz–muscovite with tourmaline and minor beryl. The spodumene zone, in turn, virtually encloses core-pods of quartz with minor amblygonite, lenses rich in lepidolite and the caesium mineral pollucite, and an aplitic albite unit that carries late beryl and wodginite, a rare tin–tantalum mineral. A modern surface plant was completed in 1960 and extensive development work was done but only minor shipments, mostly for testing purposes, were made before the property was shut down. Reserves have been estimated at about 5 million tons averaging 2 per cent Li_2O. This reserve is mostly the spodumene ore but includes some lepidolite and the pollucite ore.

Magnesium, Magnesia

Defence requirements and the transportation industry have created a very great demand for magnesium metal, particularly for alloying with aluminum in aircraft construction and for smelting of other metals. The deposit at Haley, Ontario, near Renfrew, which came into production in 1942, is Canada's only magnesium and metallic calcium producer. Open-pit mining is carried out in a dolomite of exceptional purity, part of the Grenville Group, bounded on one side by quartzite and on the other by paragneiss. The dolomite is calcined to magnesium by the Pidgeon ferrosilicon process and then refined. Production has been fairly steady at 6,000 to 9,000 tons per year since 1955 and in 1966 was 6,786 tons.

Magnesia, derived from the minerals magnesite and brucite, is used mainly in the manufacture of basic refractories. Canadian production comes only from the Shield, and currently only from within the Grenville sediments. Dolomitic magnesite is mined at *Kilmar* (48), Quebec. At *Wakefield* (44), Quebec, a brucitic limestone was quarried. Its composition suggests that it was formed through thermal metamorphism of a pure dolomite. Some of the material mined was shipped to Arvida, Quebec, for conversion to magnesium chloride and thence to magnesium metal, but most was processed at Wakefield, and magnesia recovered. Magnesium hydroxide, used in the manufacture of pulp and paper by the Magnefite process was also produced at Wakefield. Magnesite and brucite production averaged $3,000,000 to $3,500,000 per year since 1955, and in 1966 was $3,948,599.

Molybdenum

Molybdenum occurs in molybdenite in pegmatites, quartz veins, disseminations in granite and syenite, skarns, and sulphide deposits, especially of the porphyry copper type. It is used mainly in the manufacture of steel. Although minor deposits are known in many places in the Canadian Shield, most production has been from deposits in the Preissac–Lacorne district, Quebec, in Superior Province. The deposits are in pegmatites and quartz veins in and near granitic bodies related to the Preissac–Lacorne batholith. They represent the outermost zone of a regionally zoned sequence of pegmatites also bearing lithium and beryllium (Fig. V-36). At the *Lacorne* (28) mine, molybdenite-bearing pegmatitic and quartz veins of slightly different ages form a complex network in mica schist cut by numerous granite dykes, near a stock or sill of granodiorite. The grade of ore mined has varied from 0.5 to 0.25 per cent MoS_2. Bismuth is an important byproduct, and the pegmatitic veins contain a little beryl. The Lacorne mine was the only important Canadian producer from 1944 until about 1963. On Indian Peninsula the deposits are similar pegmatitic and quartz veins in and related chiefly to muscovitic granite phases of a southern tongue of the batholith. They produced intermittently during World War II. The *Preissac* (24b) molybdenite property commenced production in 1965. It includes the Old Indian molybdenite mine, where early production was from quartz veins contained between two faults in the granite.

In Grenville Province molybdenum occurrences are numerous and of various types but significant production, mostly during World War I, was confined to a few deposits in Renfrew county, Ontario, and near Quyon and Maniwaki in Quebec. The deposits are in a belt containing crystalline limestone cut by syenitic and other intrusions. The most characteristic types are pyroxenite skarns with pyrite, pyrrhotite, and molybdenite. The Hunt and Spain mines in Renfrew county, Ontario, and deposits near Maniwaki, Quebec, were dominantly of this type. At the Moss mine, near Quyon, the molybdenite occurred chiefly as disseminations in a syenite complex, associated with feldspar, quartz, fluorite, magnetite, and sulphides. The Moss mine was at one time, during World War I, the world's leading molybdenum producer. It was reopened during World War II and produced about 150

tons per day of ore, grading about 0.2 per cent MoS_2, until 1944.

Selenium and Tellurium

Selenium and tellurium are recovered together as by-products in the electrolytic refining of copper from the nickel–copper ores produced at Sudbury, Ontario, and Thompson, Manitoba, and from the copper ores of the Noranda, Quebec, and Flin Flon, Manitoba areas. All Canadian selenium and tellurium came from the Shield until Gaspé Copper Mines Limited began production in 1955.

Tantalum and Niobium

Pegmatitic tantalite–columbite deposits were formerly the main source of both niobium (columbium) and tantalum but alkaline complexes now yield most of the niobium. Columbite–tantalite is a minor constituent of most lithium and beryllium pegmatites in the Canadian Shield but occurs in significant amount in only a few dykes, chiefly those of the main lithium–beryllium districts. The only recorded production was from the Yellowknife–Beaulieu district. Near *Ross Lake* beryl-liferous feldspar–quartz–muscovite pegmatites yielded 3,750 pounds of tantalite–columbite concentrates from 940 tons of rock quarried in 1946 and 1947. Near Hearne channel zoned lithium–beryllium pegmatites yielded 2,600 pounds of tantalite–columbite concentrate in 1946 and 1947, and 39,100 pounds from 18,928 tons milled in 1953 and 1954. In the Winnipeg River district, the zoned *Chemalloy Minerals* pegmatite at Bernic Lake contains columbite–tantalite and the rare tin tantalite, wodginite, in an interior albitite zone.

The largest reserves of niobium are associated with alkaline igneous complexes. These are more or less circular bodies composed of various rocks including sodium-rich and nepheline-rich syenites, ijolites, jacupirangites, carbonate, and metasomatized carbonate rocks. The deposits are in the complexes and the fenitized wall-rocks. Niobium-bearing minerals include pyrochlore, uranium pyrochlore, betafite, columbite, ilmenorutile, perovskite, and niocalite. Accessory minerals include apatite, magnetite, biotite, soda pyroxene, soda hornblende, pyrite and pyrrhotite. The largest deposits are in a Cretaceous, Monteregian Intrusion at Oka, Quebec. Others occur in central Superior Province extending north of Lake Superior through Kapuskasing. At *Oka* (49), Quebec, production of niobium concentrates began in 1961. Shipments of pyrochlore concentrates in 1965 amounted to 2.3 million pounds of contained columbium pentoxide, worth $2,350,000. Reserves are estimated at 62.7 million tons averaging 0.4 per cent Cb_2O_5.

Tin

No economic tin deposits have been found in the Canadian Shield. In the Yellowknife–Beaulieu district a few pegmatites near Sproule Lake and Hearne Channel carry appreciable concentrations. The tantalum–columbium concentrates from the Best Bet property were reported to contain 13.4 per cent tin. In the Winnipeg River district, Manitoba, attempts were made to mine pegmatites near Bernic and Shatford Lakes for tin. At the *Chemalloy Minerals* property near Bernic Lake, the albite–aplite zone of a complex pegmatite (Fig. V-37) contains the rare tin–tantalum mineral wodginite, as well as a little cassiterite. At Red Sucker Lake in northeast Manitoba an albitite dyke contains cassiterite.

Tungsten

The principal ore of tungsten in the Shield is scheelite, the calcium tungstate. It is found chiefly in gold ores and also in quartz veins in the Yellowknife–Beaulieu area of the Northwest Territories. No deposit worth mining for tungsten alone has yet been found, but to fill war requirements, the relatively small amounts occurring in gold ores were separated. At the Hollinger property in the Porcupine area, Ontario, where perhaps the largest bodies of scheelite are found, a mill was erected that treated 135 tons of ore daily. Ore from the other mines in the district was shipped to this mill. Some tungsten was obtained in the past from a deposit on Outpost Islands, Great Slave Lake. The ore is a gold–copper–tungsten–tin complex, and difficulty was encountered in producing a satisfactory tungsten concentrate. The tungsten mineral there is mainly ferberite, a tungstate of iron, and the ore is said to run about 1 per cent tungsten.

INDUSTRIAL MINERALS

Apatite

Apatite, the tri-calcium phosphate, was mined at one time in considerable quantity for the manufacture of superphosphate fertilizer. About the beginning of the century, however, most of the mines closed. The little apatite produced since then has been a byproduct of mica mining and used mainly for the manufacture of phosphorus. Production in 1941, about 2,500 tons, was the largest for many years; none has been produced since 1951. Almost all the apatite came from Cantley, Quebec, north of Ottawa, or from near Kingston, Ontario. It was found in irregular pockets in a pyroxenite formed by alteration of crystalline limestones of the Grenville Group.

Asbestos

A small amount of asbestos was produced from the Munro mine near Matheson, Ontario, from 1950 to 1964 and since then from the Hedman mine. Production from the former mine ranged from 25,000 to 30,000 tons per year, and from the latter, was 1,700 tons in 1966. The Munro deposit was in a vertically dipping, differentiated mafic sill, about 1,000 feet thick, intrusive into Keewatin volcanic rocks. Serpentinized dunite and peridotite form the southern half of the sill in the main ore zone at the surface, but are enveloped in a sheath of talc–carbonate rock that thickens with depth. Veins of asbestos were contained in the core of the ultramafic sill or in adjacent serpentinized peridotite, associated with a medium to light green, granular serpentine. Fibre was as much as an inch long, mostly rather harsh, although flexible. Crossfibre occurred in one- and two-fibre veins which formed a rectangular pattern.

Small bodies of serpentine that carry veins of asbestos in many places are common in the Grenville Group north and east of Ottawa. Opinions differ as to whether these represent intrusions of peridotite or metamorphosed crystalline limestone. The fibre is of high quality, low in iron and usually entirely free from magnetite. Attempts have been made from time to time to mine the deposits, but they are too small. Large bodies of actinolite were mined near Actinolite village, Ontario, intermittently between 1883 and 1927. The mineral appears to occur in a basalt or other greenstone that has been altered by the intrusion of granite gneiss. As dolomite or ferruginous carbonate are present in other parts of the belt it is possible however, that the rock is an altered crystalline limestone.

Elsewhere in the Shield, small deposits of chrysotile asbestos are known but none has proved profitable although several have yielded small quantities, especially those in northern Ontario from the Abitibi serpentine belt. A small amount was produced from an unusual deposit in Bannockburn township, Ontario. There, veinlets of asbestos occur in a shattered zone of rhyolite at its contact with a highly serpentinized body of peridotite. Extensive development work has been taking place at the Asbestos Hill deposits in the Ungava district of northern Quebec, estimated to have reserves of 20 million tons. Several showings of crocidolite, the blue, sodic and ferruginous asbestos, have been found near Knob Lake, Quebec, and are also being explored.

Corundum

Corundum is a constituent of the nepheline syenites of Grenville Province in southeastern Ontario. The corundum is chiefly a component of reddish alkali syenites, and of their pegmatitic facies, occurring in dykes as much as 18 feet wide. In places corundum forms as much as 10 per cent of the rock mass, but the average content of the rock milled was between 5 and 6 per cent. Mining of corundum began about 1900, and production reached a maximum in 1906. Between 1900 and 1921, 19,524 tons of the mineral were shipped. No commercial shipments have been made since 1946 when treatment of old tailings at the Craigmont property ceased. During the two years of operation about 2,600 tons of concentrate were shipped to the United States.

Feldspar

Feldspar has been replaced in the last ten years by nepheline syenite for use in the glass industry. Feldspar is now used as flux and in the manufacture of ceramics. Feldspar is mined from pegmatite dykes, and from the same general areas as apatite and mica. Canadian production has come from the Kingston and Bancroft areas of Ontario and the Gatineau and Buckingham areas of Quebec. The sole Canadian producer in 1966 was the Derry mine near Buckingham, Quebec. Hand-cobbed feldspar is produced from a large dyke. Production from the Baié Johan Beetz area and byproduct production from spodumene mining in the Val d'Or area, both in Quebec, ended in 1959. Production of feldspar, since a high of 55,000 tons in 1948, has averaged roughly 20,000 tons per year until 1959, and about 10,000 tons per year since then. Production in 1966 was 10,924 tons.

Fluorite, Barite, Celestite

These minerals occur in veins of Paleozoic age in southeastern Ontario and adjacent parts of Quebec. The veins are in Precambrian crystalline rocks and overlying flat-lying Paleozoic strata. The proportions of the principal minerals vary widely from one vein to another, and even in different parts of the same vein. Those that carry fluorite in commercial quantities are found near Madoc and Cardiff, Ontario. The veins near Madoc occur in two groups. Those of the Moira Lake group centre around a northwesterly trending fault that has been traced more than 5 miles. Most of them lie in the fault fissure, but some are in parallel subsidiary fractures. The Lee–Miller group lies a mile or two west of the Moira Lake group, and forms a string of deposits trending somewhat more northerly. Their linear arrangement suggests that they also lie along a fault. The vein materials are concentrated in lenses a few feet to 200 feet long, and 2 to 17 feet wide. The fluorite is partly massive and partly forms crystals in numerous vugs. Production from these veins has been mainly during times of war. From 1906 to 1920 nearly 20,000 tons of fluorite were mined and from 1940 to 1945, 38,671 tons were recovered. A few hundred tons of fluorite have been shipped annually in recent years from veins in the Madoc area. Production ceased in 1961 after an estimated 120,000 tons had been mined.

Garnet

Garnetiferous schists and gneisses are developed in various parts of the Shield, but very little garnet is mined as it does not meet the rather exacting specifications demanded for industrial use. In 1942, 17 tons were mined, all from the River Valley property 40 miles northwest of North Bay, and in 1944 only 3 tons were mined.

Graphite

Flakes of graphite form a common constituent of the crystalline limestones of the Grenville Group. In places these rocks have been acted on by silica-bearing solutions, presumably derived from granitic or other intrusions, and converted to a varying extent to silicate minerals such as feldspar, diopside, scapolite, and mica. Calc-silicate bodies also carry important amounts of graphite and some pyrite and quartz in places. These minerals appear to have been among the last to form, as they cut through and seemingly replace the silicates. In addition to this relationship, there appears also to have been a structural control, because the graphite bodies are much wider and richer at the crests of sharp folds than farther out along the limbs. The most important graphite deposit was the Black Donald mine, about 25 miles southwest of Renfrew, Ontario. This body was discovered about 1889, and was in operation, with interruptions, from 1895 to 1954. The deposit is a bed-like mass, 10 to 30 feet thick, that has been sharply folded into an asymmetrical syncline, plunging northeast at an angle of about 20 degrees. Available data seem to suggest that, at the northeast end of the workings, the north limb of the syncline rolls over into an anticline. The grade of the ore was unusually high. Much of the ore mined in the earlier days was 70 to 85 per cent graphite, and it has been estimated that the body as a whole averaged 55 to 65 per cent, although the last two years of salvage operation produced only about 15 per cent graphite. In the ten years from 1944 to 1953 about 23,000 tons of graphite were produced.

Kaolin

Kaolin deposits are known in various areas of Quebec and northern Ontario, but their small size and the presence of impurities preventing suitable beneficiation have generally hindered their development. The kaolin deposit near St. Remi, Quebec, is on a north-trending ridge about half a mile wide, composed of nearly vertical dipping beds of Grenville quartzite and garnet gneiss striking north-northwest. The eastern side of the ridge is massive and unbroken, but the west side, throughout a zone about 1,000 feet wide, is shattered to a friable condition by faulting. The shattered zone has been traced at least 7,000 feet. In it are vein-like masses of kaolin ranging in width from a few feet to more than 100 feet. Within them are fragments and disseminated grains of quartzite. The kaolin formed by replacement of the shattered quartzite presumably through the agency of ascending hot liquids or vapours. The average kaolin content of the whole shattered zone has been estimated to be about 11 per cent. Nearly 25,000 tons were mined in 1942, but none since 1946. A by-product is washed silica sand suitable for glass-making. Several other occurrences of kaolin have been discovered in Quebec. One, near Point Comfort on Thirty-one-mile Lake, carries high-grade china clay. Other deposits are near Brebeuf on Lake Labelle, and near Chateau Richer, but are not of sufficient size and uniformity to warrant development.

Kyanite

Kyanite is fairly common in the sedimentary gneisses in many parts of the Canadian Shield. Extensive occurrences are near Mattawa and Sudbury, Ontario, and in Labrador, Manitoba, and the Northwest Territories. At Mattawa selected areas contain 15 per cent kyanite or more. East of Sudbury the kyanite occurs in a gneiss with lenses of sillimanite. An estimated 2 million tons of kyanite grading 18 per cent are present, from which a mullite aggregate, useful to the metallurgical and glass industries, could be produced.

Mica

Phlogopite has been mined from the same areas and types of deposits as described for apatite. Closing of the mine at Cantley, Quebec in 1966 brought to an end its long production of amber mica. Scrap phlogopite is shipped from large waste dumps near Kingston, and other past producers in southeastern Ontario and southwestern Quebec. All the muscovite of the Shield has come from Ontario. It occurs in pegmatites, apparently where they are especially coarse grained, such as the Eau Claire deposit near Mattawa, Ontario, which produced minor amounts from 1956 to 1960, the Purdy mine near North Bay, a famous producer during World War II, and the Parry Sound district. Total Canadian mica production in 1966 was 270 tons.

Nepheline Syenite

The large deposit of nepheline syenite at Blue Mountain, near Peterborough, Ontario, provides the only Canadian production. Three quarters of the production is exported. The Blue Mountain syenite body is a pear-shaped mass about 5 miles long with a maximum width of 1½ miles. It contains about 50% soda feldspar, about 20 to 25% of both nepheline and potash feldspar, and small quantities of easily removed iron-bearing minerals. Production has risen steadily from 146,068 tons in 1955 to 366,696 tons in 1966. The Blue Mountain Intrusion is one of a string of nepheline syenite bodies in Grenville Province of southeastern Ontario. These bodies are

developed close to contacts between granite and crystalline limestones, and have commonly been regarded as differentiates of the granite. However, detailed studies, undertaken in connection with the mining, strongly indicate that they are due to the granitization of calcareous sedimentary rocks of the Grenville Group. The nepheline-rich parts are essentially concordant with the enclosing gneisses, and show a banding that possibly represents bedding parallel and continuous with that of the gneisses into which they may grade.

Silica

Silica is mined from the Canadian Shield both as quartz and quartzite. The smelters at Sudbury and Flin Flon have used low-grade copper or gold ores as flux, the metal content being a valuable byproduct. Many pegmatite dykes mined for feldspar contain segregated masses of almost pure quartz, and although much of this has been discarded as waste, some is sold to smelters or manufacturers of ferrosilicon, as from River Valley near North Bay and Verona north of Kingston, both in Ontario. The upper third of the Lorrain Formation of the Aphebian Cobalt Group is a very pure quartzite. It is quarried near Sudbury for smelter flux, near Sault Ste. Marie, Ontario, for manufacture of silica brick, and at Killarney, Ontario, for the production of ferrosilicon.

Sulphur

Sulphur in the form of sulphuric acid is produced during base-metal mining and smelting operations from smelter gases or byproduct pyrite or pyrrhotite. Although large pyrite deposits are known, it is unlikely that they will be used in view of the very large volumes mined as a byproduct. Production is effected at smelters where sulphuric acid can be marketed nearby, often to industries integrated with the producer. Pyrite deposits utilized on the Shield are at the Noranda, Quemont, and Normetal mines in Quebec. Smelter gas sulphuric acid is produced from Quebec and Ontario ores processed at Arvida and Valleyfield, Quebec, and Copper Cliff and Port Maitland, Ontario. Elemental sulphur is derived from refining of nickel sulphide matte from Sudbury, Ontario, and Thompson, Manitoba, and was also recovered until 1959 at Noranda. Sulphur is recovered as ammonia sulphate byproduct from the nickel ores at Lynn Lake, Manitoba.

Talc

All the talc produced from the Shield has been from deposits near Madoc, Ontario. The Henderson and Conley mines (110a) have operated since 1937, and several low-quality grades of ground talc have been recovered. Production in 1966 was 15,100 tons. White, foliated talc forms a nearly vertical tabular mass 25 to 75 feet wide and at least 1,100 feet long. It lies between beds of dolomitic limestone into which it grades sharply. Within the talc body can be seen traces of the bedding planes of the original dolomitic limestone from which it was derived. It is probable that the action of solutions from a nearby granite led to the formation of the talc, and that an intermediate stage in the alteration was the conversion of the limestone to tremolite.

SELECTED REFERENCES

Allan, J. D.
1950: The Lynn Lake nickel area, Manitoba; *Bull. Can. Inst. Mining Met.*, pp. 509–514.

Baragar, W. R. A.
1960: Petrology of basaltic rocks in part of the Labrador Trough; *Bull. Geol. Soc. Am.*, vol. 71, pp. 1589–1644.

1966: Geochemistry of the Yellowknife volcanic rocks; *Can. J. Earth Sci.*, vol. 3, pp. 9–30.

Beck, L. S.
1967: Uranium developments in Saskatchewan, present and future; *Can. Mining J.*, vol. 88, No. 4, pp. 126–129.

Bowen, N. L.
1911: Silver in Thunder Bay district; *Ont. Bur. Mines*, Ann. Rept., vol. 20, pt. 1, pp. 119–132.

Boyle, R. W.
1968: The geochemistry of silver and its deposits; *Geol. Surv. Can.*, Bull. 160.

Burrows, A. G.
1909: The Gowganda and Miller Lakes silver area; The South Lorrain silver area; *Ont. Bur. Mines*, Ann. Rept., vol. 18, pt. II, pp. 1–35.

1926: Gowganda silver area; *Ont. Dept. Mines*, Ann. Rept., vol. 35, pt. 3, pp. 1–61.

Byers, A. R., Kirkland, S. J. T., and Pearson, W. J.
1965: Geology and mineral deposits of the Flin Flon area, Saskatchewan; *Sask. Dept. Min. Res.*, Rept. 62.

Campbell, D. D.
1957: Port Radium mine; *in* Structural geology of Canadian ore deposits; *Can. Inst. Mining Met.*, vol. 2, pp. 177–189.

Chadbourn, C. H.
1923: Paragenesis of the ores of the Silver Islet mine, Thunder Bay region, Lake Superior; *Econ. Geol.*, vol. 18, pp. 77–82.

Chakraborty, K. L.
1966: Ferromagnesian silicate minerals in the metamorphosed iron-formation of Wabush Lake and adjacent areas, Newfoundland and Quebec; *Geol. Surv. Can.*, Bull. 143.

Clark, L. A.
1965: Geology and geothermometry of the Marbridge nickel deposit, Malartic, Quebec; *Econ. Geol.*, vol. 60, pp. 792–811.

Collins, W. H.
1913: The geology of the Gowganda Mining Division; *Geol. Surv. Can.*, Mem. 33.

1934–37: Life history of the Sudbury nickel irruptive (Parts I, II, III, IV); *Trans. Royal Soc. Can.*, vols. 28, 29, 30, 31.

Cunningham, L. J.
1964: A description of recent silver deposits, Cobalt, Ontario; *Can. Mining J.*, vol. 85, No. 5, pp. 49–53.

Davidson, C. F.
1957: On the occurrence of uranium in ancient conglomerates; *Econ. Geol.*, vol. 52, pp. 668–692.

Davies, J. F.
1960: Geology of the Thompson-Moak Lake District, Manitoba; *Can. Mining J.*, vol. 81, No. 4, pp. 101–104.

Derry, D. R.
1960: Evidence of the origin of the Blind River uranium deposits; *Econ. Geol.*, vol. 55, pp. 906–927.

Donaldson, J. A.
1965: The Dubawnt Group, Districts of Keewatin and Mackenzie; *Geol. Surv. Can.*, Paper 64-20.

Dubuc, F.
1966: Geology of the Adams mine; *Bull. Can. Inst. Mining Met.*, vol. 59, pp. 176–181.

Dugas, J. and Hogg, W. A.
1962: An outline of the Rouyn-Noranda area, Quebec; *Can. Mining J.*, vol. 83, No. 4, pp. 101–104.

Dugas, J., Latulippe, M., and Duquette, G.
1967: Annotated bibliography on metallic mineralization in the regions of Noranda, Matagami, Val d'Or, Chibougamau; *Que. Dept. Natl. Res.*, Spec. Paper 2.

Dunbar, W. R.
1948: Structural relations, Porcupine area, *in* Structural geology of Canadian ore deposits; *Can. Inst. Mining Met.*, vol. 2, pp. 442–464.

Duquette, G.
1966: General geology and asbestos mineralization in the Chibougamau district; *Can. Mining J.*, vol. 87, No. 4, pp. 70–75.

Eade, K. E., Fahrig, W. F., and Maxwell, J. A.
1966: Composition of crystalline rocks and fractionating effects of regional metamorphism; *Nature*, vol. 211, pp. 1245–1249.

Emslie, R. F. and Moore, J. M.
1961: Geological studies in the Lynn Lake-Fraser Lake area, Manitoba; *Man. Dept. Mines Natl. Res.*, Pub. 59-4.

Fahrig, W. F. and Eade, K. E.
1968: The chemical evaluation of the Canadian Shield; *Can. J. Earth Sci.*, vol. 5, pp. 1247–1252.

Ferguson, S. A.
1966: The relationship of mineralization to stratigraphy in the Porcupine and Red Lake areas, Ontario; *Geol. Assoc. Can.*, Spec. Paper No. 3, pp. 99–120.

Furnival, G. M.
1939: A silver-pitchblende deposit at Contact Lake, Great Bear Lake area, Canada; *Econ. Geol.*, vol. 34, pp. 739–776.

Gilmour, P.
1965: The origin of the massive sulphide mineralization in the Noranda district, northwestern Quebec; *Proc. Geol. Assoc. Can.*, vol. 16, pp. 63–81.

Goodwin, A. M.
1956: Facies relations in the Gunflint iron-formation; *Econ. Geol.*, vol. 51, No. 6.

1961: Genetic aspects of Michipicoten iron-formations; *Trans. Can. Inst. Mining Met.*, vol. 64.

1962: Structure, stratigraphy, and origin of iron-formations, Michipicoten area, Algoma district, Canada; *Bull. Geol. Soc. Am.*, vol. 73, pp. 561–586.

1965: Mineralized volcanic complexes in the Porcupine-Kirkland Lake-Noranda region; *Econ. Geol.*, vol. 60, pp. 955–971.

1968: Evolution of the Canadian Shield; *Proc. Geol. Assoc. Can.*, vol. 19, pp. 1–14.

(submitted) On the growth and mineralization of the Canadian Shield; *Can. Inst. Mining Met.*

Graham, A. R.
1930: Obonga Lake chromite area, district of Thunder Bay; *Ont. Dept. Mines*, Ann. Rept., No. 39, pt. 2, pp. 51–60.

Graham, R. B.
1951: Geology and mineral occurrence of the Chibougamau district; *Can. Mining J.*, vol. 72, No. 9, pp. 65–71.

Gross, G. A.
1960: Iron-formations and the Labrador Geosyncline; *Geol. Surv. Can.*, Paper 60-30.

1962: Iron deposits near Ungava Bay, Quebec; *Geol. Surv. Can.*, Bull. 82.

1965: Geology of iron deposits in Canada, Vol. I: General geology and evaluation of iron deposits; 1967, Vol.

Gross, G. A. (*cont.*)
II: Iron deposits in the Appalachian and Grenville regions of Canada; 1968, Vol. III: Iron ranges of the Labrador Geosyncline; *Geol. Surv. Can.,* Econ. Geol. Rept. No. 22.

1966a: The origin of high grade iron deposits on Baffin Island, N.W.T.; *Can. Mining J.,* vol. 87, No. 4, pp. 111–114.

1966b: Principal types of iron-formation and derived ores; *Bull. Can. Inst. Mining Met.,* vol. 59, pp. 150–153.

Hammond, P.
1949: Geology of Allard Lake ilmenite deposits; *Trans. Can. Inst. Mining Met.,* vol. 52, pp. 64–68.

1952: Allard Lake ilmenite deposits; *Econ. Geol.,* vol. 47, pp. 634–649.

Hargraves, R. B.
1959: Magnetic anisotropy and remnant magnetism in hemoilmenite from ore deposits at Allard Lake, Quebec; *J. Geophys. Research,* vol. 64.

Hawley, J. E.
1962: The Sudbury ores; their mineralogy and origin; *Can. Mineralogist,* vol. 7.

Holmes, S. W.
1957: Pronto mine; *in* Structural geology of Canadian ore deposits; *Can. Inst. Mining Met.,* vol. 2, pp. 324–339.

Jolliffe, A. W.
1966: Stratigraphy of the Steeprock Group, Steep Rock Lake, Ontario; *Geol. Assoc. Can.,* Spec. Paper No. 3, Precambrian Symposium, pp. 75–98.

Knight, C. W.
1924: Geology of the mine workings of Cobalt and South Lorrain silver areas; *Ont. Dept. Mines,* vol. 31, pt. 2, pp. 1–374.

Lang, A. H.
1970: Prospecting in Canada; *Geol. Surv. Can.,* Econ. Geol. Rept. No. 7, 4th ed.

Lang, A. H., Griffith, J. W., and Steacy, H. R.
1962: Canadian deposits of uranium and thorium; *Geol. Surv. Can.,* Econ. Geol. Rept. No. 16.

1967a: Discovery methods of post-1955 new producers; *Can. Mining J.,* vol. 88, No. 1, pp. 47–50.

1967b: 100 years of prospecting in Canada; *Can. Mining J.,* vol. 88, No. 5, pp. 55–63.

Langford, G. B.
1927: Shiningtree silver area, district of Timiskaming; *Ont. Dept. Mines,* Ann. Rept., vol. 36, pt. 2, pp. 87–99.

Latulippe, M.
1966: The relationship of mineralization to Precambrian stratigraphy in the Matagami Lake and Val d'Or districts of Quebec; *Geol. Assoc. Can.,* Spec. Paper No. 3, Precambrian Symposium, pp. 21–42.

Lindeman, E. and Bolten, L. L.
1917: Iron ore occurrence in Canada; vols. I and II; *Mines Branch,* Ser. No. 217.

Lord, C. S.
1951: Mineral industry of District of Mackenzie, Northwest Territories; *Geol. Surv. Can.,* Mem. 261.

Markland, G. D.
1966: Geology of the Moose Mountain mine and its application to mining and milling; *Bull. Can. Mining Met.,* vol. 59, No. 646, pp. 159–170.

Mellon, G. B.
1962: Petrology of Upper Cretaceous oolitic iron-rich rocks from northern Alberta; *Econ. Geol.,* vol. 57.

Miller, W. G.
1908: The cobalt-nickel arsenides and silver deposits of Timiskaming, 3rd ed.; *Ont. Bur. Mines,* Ann. Rept., vol. 16, pt. 2, pp. 1–212.

1913: The cobalt-nickel arsenides and silver deposits of Timiskaming, 4th ed.; *Ont. Bur. Mines,* Ann. Rept., vol. 19, pt. 2, pp. 1–279.

Milligan, G. C.
1960: Geology of the Lynn Lake district; *Man. Dept. Mines Natl. Res.,* Publication 57-1.

Moore, E. S.
1934: Genetic relations of silver deposits and Keweenawan diabase in Ontario; *Econ. Geol.,* vol. 29, pp. 725–756.

1956: Geology of the Miller Lake portion of the Gowganda silver area; *Ont. Dept. Mines,* Ann. Rept., vol. 64, pt. 5, pp. 1–41.

1957: Gowganda silver area; *in* Structural geology of Canadian ore deposits, vol. 2; *Can. Inst. Mining Met.,* pp. 388–392.

Naldrett, A. J. and Kullerud, G.
1967: Investigations of the nickel-copper ore and adjacent rocks of the Strathcona mine, Sudbury district, Ontario; *Ann. Report of the Director, Geophysical Laboratory,* pp. 302–320.

Oja, R. V.
1967: Geochemical investigations of the Thunder Bay silver area; Proceed. Symposium on Geochemical Prospecting, Ottawa, 1966: *Geol. Surv. Can.,* Paper 66-54, pp. 211–221.

Philpotts, A. R.
1961: Textures of the Ungava nickel ores; *Can. Mineralogist,* vol. 6, pp. 680–688.

Pienaar, P. J.
1963: Stratigraphy, petrology, and genesis of the Elliot Group, Blind River, Ontario, including the uraniferous conglomerate; *Geol. Surv. Can.,* Bull. 83.

Pye, E. G.
1957: Geology of the Manitouwadge area; *Ont. Dept. Mines,* Ann. Rept., vol. 66, pt. 8.

Reid, J. A.
1943: Mineral resources of the Timiskaming silver-cobalt area; *Ont. Dept. Mines,* Bull. 134.

Robertson, D. S. and Steenland, N. C.
1960: The Blind River uranium ores and their origin; *Econ. Geol.,* vol. 55, pp. 659–993.

Robertson, J. A.
1967: Recent geological investigations in the Elliot Lake-Blind River uranium area, Ontario; *Can. Mining J.,* vol. 88, No. 4, pp. 120–126.

Roscoe, S. M.
1965a: Atomic energy developments and future uranium requirements as envisaged at the Third International United Nations Conference on the Peaceful Uses of Atomic Energy, Geneva, September 1964; *Geol. Surv. Can.,* Paper 65-33.

1965b: Geochemical and isotopic studies, Noranda and Matagami areas; *in* Symposium on strata-bound sulphides; *Trans. Can. Inst. Mining Met.,* vol. 68, pp. 279–285.

1966: Unexplored uranium and thorium resources of Canada; *Geol. Surv. Can.,* Paper 66-12.

Roscoe, S. M. and Steacy, H. R.
1958: On the geology and radioactive deposits of Blind River region; *in* Papers of Second International Conference on the Peaceful Uses of Atomic Energy.

Rose, E. R.
1958: Iron deposits of eastern Ontario and adjoining Quebec; *Geol. Surv. Can.,* Bull. 45.

Ruttan, G. D.
1955: Geology of Lynn Lake; *Bull. Can. Inst. Mining Met.,* vol. 48, pp. 339–348.

Schiller, E. A.
1965: Echo Bay Mines Limited; *in* Mineral industry of the Northwest Territories, 1964; *Geol. Surv. Can.,* Paper 65-11, pp. 42–44.

Schiller, E. A. and Hornbrook, E. H.
1964: Echo Bay Group; *in* Mineral industry of the District of Mackenzie, 1963; *Geol. Surv. Can.,* Paper 64-22, pp. 16–19.

Shaw, D. M., Reilly, G. A., Muysson, J. R., Pattenden, G. E., and Campbell, F. E.
1967: An estimate of the chemical composition of the Canadian Precambrian Shield; *Can. J. Earth Sci.,* vol. 4, pp. 829–854.

Souch, B. E. and Podolsky, T.
1968: The sulphide ores of Sudbury: Their particular relation to a distinctive inclusion-bearing facies of the nickel irruptive; *in Soc. Econ. Geologists,* Spec. Paper, edited by H. D. B. Wilson.

Staff, Algoma Ore Properties
1956: Algoma Ore Properties: Part II — Helen mine geology; *Can. Mining J.,* vol. 77, No. 11, pp. 80–87.

Tanton, T. L.
1931: Fort William and Port Arthur, and Thunder Cape map-areas, Thunder Bay district, Ontario; *Geol. Surv. Can.,* Mem. 167.

1948: New Helen mine; *in* Structural geology of Canadian ore deposits; *Can. Inst. Mining Met.*

Thomson, J. E.
1956: Geology of the Sudbury Basin; *Ont. Dept. Mines,* Ann. Rept., vol. 65.

Thomson, J. E., Ferguson, S. A., Johnston, W. G. Q., Pye, E. G., Savage, W. S., and Thomson, R.
1957: Copper, nickel, lead, and zinc deposits in Ontario; *Ont. Dept. Mines,* Metal Resources Circular #2.

Thomson, R.
1957: Cobalt camp; *in* Structural geology of Canadian ore deposits; *Can. Inst. Mining Met.,* vol. 2, pp. 377–388.

1964: Cobalt silver area; *Ont. Dept. Mines,* Maps 2050, 2051, and 2052.

1965: Casey and Harris townships; *Ont. Dept. Mines,* Geol. Rept. No. 36.

Thorpe, R. I.
1966: Echo Bay Mines, Limited; *in* Mineral industry of the Northwest Territories, 1965; *Geol. Surv. Can.,* Paper 66-52, pp. 47–49.

Todd, E. W.
1926: Gowganda vein minerals; *Ont. Dept. Mines,* Ann. Rept., vol. 35, pt. 3, pp. 62–78.

Tyler, S. A. and Barghoorn, E. S.
1955: Survey of world iron ore resources, occurrence, appraisal and use; *Publ. United Nations Dept. Economic, Social Affairs.*

Whitman, A. R.
1920: Diffusion in vein-genesis at Cobalt; *Econ. Geol.,* vol. 15, pp. 136–149.

1928: Diffusion in ore genesis; *Econ. Geol.,* vol. 23, pp. 473–488.

Wilson, H. D. B.
1966: Alkalic and alkaline ring complexes in the Archaean; *Can. Geophys. Bull.,* vol. 19, p. 182.

Wilson, H. D. B., Andrews, P., Maxham, R. L., and Ramlal, K.
1965: Archaean volcanism in the Canadian Shield; *Can. J. Earth Sci.,* vol. 2, No. 3, pp. 161–175.

Wilson, H. D. B. and Brisbin, W. C.
1961: Regional structure of the Thompson-Moak Lake nickel belt; *Bull. Can. Inst. Mining Met.,* vol. 53, pp. 815–822.

Zurbrigg, H. F.
1963: Thompson mine geology; *Bull. Can. Inst. Mining Met.,* vol. 56, pp. 451–460.

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INTRODUCTION

Southeastern Canada lies southeast of the Canadian Shield and is composed of the St. Lawrence Platform, Appalachian Orogen, and Atlantic Continental Shelf (Fig. VI-1). These three major geological tectonic elements comprise a combined area of about 475,000 square miles, of which nearly three quarters is covered by sea.

St. Lawrence Platform borders the Canadian Shield. It is a narrow, northeast extension of the stable interior of North America bounded on the southeast by the Appalachian Orogen. The platform is underlain by relatively thin, nearly flat lying orthoquartzite, carbonate, and shale of early and middle Paleozoic age that lie unconformably on the crystalline rocks of the Canadian Shield. It is the oldest settled part of Canada, and therefore has long been an agricultural and highly industrialized region. The platform has an area of about 60,000 square miles and forms a remnant of a more extensive cratonic cover that was once continuous with the Hudson Platform to the north. St. Lawrence Platform is separated into three parts by crystalline rocks of the Canadian Shield: (1) southwestern Ontario, forming the marginal areas of Michigan Basin and Allegheny Trough; (2) Ottawa–Quebec Lowland (Quebec Basin and Ottawa Embayment); and (3) Anticosti–Mingan Islands and the coastal plain of western Newfoundland and southeastern coast of Labrador (Anticosti Basin).

The peninsula of southwestern Ontario is separated from the Ottawa–Quebec Lowland by the Precambrian rocks of the Frontenac Arch. The peninsula itself is underlain by a southwest-trending Precambrian basement high—the Algonquin Arch—from which Cambrian, Ordovician, Silurian, and Devonian rocks dip northwesterly into Michigan Basin and southeasterly into Allegheny Trough. The Paleozoic cover has a maximum thickness of nearly 5,000 feet near southern Lake Huron and beneath Lake Erie.

In the central or Ottawa–Quebec Lowland division of the platform the lower Paleozoic rocks are locally in fault contact with the Precambrian, which rises as an escarpment above the surface of the lowland. In Quebec the lowland is bordered on the southeast by thrusts referred to as "Logan's Line". Upper Cambrian and Upper Ordovician rocks vary in thickness from nearly 3,000 feet in Ottawa Embayment to about 9,500 feet in the central part of Quebec Basin.

The eastern division of the platform comprises Anticosti Basin, the Paleozoic rocks of which rise above the waters of the Gulf of St. Lawrence on Anticosti and

[1] The accounts of the geology of St. Lawrence Platform were prepared by B. V. Sanford, the Carboniferous and Permian systems by D. G. Kelley, and the Precambrian by H. Williams. In the remaining Paleozoic sections H. Williams is responsible for the geology of Newfoundland and W. H. Poole for that of the mainland. W. H. Poole is also responsible for the Mesozoic and Cenozoic sections and general coordination. When acknowledging, reference should be made to individual author and page number.

VI

Geology of Southeastern Canada

W.H. Poole, B.V. Sanford, H. Williams, and D.G. Kelley[1]

Gypsum in the Codroy Group, St. George's Basin, Newfoundland.

Mingan Islands and underlie narrow strips along the north shore of the Gulf of St. Lawrence and northwestern Newfoundland. The rocks range from Cambrian to Lower Devonian and are about 12,000 feet thick in the central part of Anticosti Basin.

On the Canadian Shield north of St. Lawrence Platform are several outliers of Paleozoic rocks. Most are small with only a few feet of flat-lying strata; others are preserved in tilted fault blocks and contain relatively thick successions.

The Appalachian Orogen extends from Newfoundland 2,000 miles southwestward along the Atlantic seaboard to Alabama, and northeastward to the edge of the Continental Shelf. The system was possibly once continuous with the Caledonian mountain chain on the eastern side of the north Atlantic in Ireland and Britain. To the southeast the orogen extends beneath the probably flat lying cover of upper Mesozoic and Cenozoic strata. The Appalachian Orogen in Southeastern Canada is a glacial region of uplands, highlands, lowlands, valleys, and fiords. The protolith of the orogen was an orthogeosyncline characterized by great mobility and relatively thick eugeosynclinal lower and middle Paleozoic sedimentary and volcanic deposits. The northwestern part is locally miogeosynclinal. Appalachian Orogen is divided into two parts: (1) a fold belt produced by the Ordovician Taconian Orogeny and the Devonian Acadian Orogeny; (2) an epieugeosyncline of late Paleozoic strata, part of which was mildly deformed by the Maritime Disturbance.

The Appalachian Geosyncline was dominated during the Cambrian and Ordovician by four facies belts: miogeosynclinal sediments in the northwest; a thick eugeosynclinal sequence in the centre; a relatively thin sequence of shale and minor limestone to the southeast; and an immensely thick greywacke–slate sequence still farther southeast. These rocks were locally deformed and intruded during the Ordovician Taconian Orogeny. In west Newfoundland two large klippen were transported westward from their place of deposition within the western part of the geosyncline onto the eastern edge of St. Lawrence Platform. The transported sequences include ultramafic Middle Ordovician plutons.

Silurian and Devonian deposition was restricted to several troughs separated by geanticlinal uplifts. Shallow-water marine sediments, conglomerate, volcanic rocks, and fluviatile terrestrial sandstones accumulated. During the Middle and Upper Devonian nearly the entire geosyncline was deformed, partly metamorphosed, intruded by granite batholiths, uplifted, and eroded during the Acadian Orogeny.

Subsequently, the fold belt acted as a platform upon which an epieugeosyncline with Upper Devonian to Permian deposits extended in a narrow zone from the Bay of Fundy to White Bay, Newfoundland. Deformation within the epieugeosyncline was restricted mainly to faulting and folding, local small intrusions, and incipient regional metamorphism. The deformed Carboniferous

rocks are in turn overlain by Upper Triassic terrestrial sedimentary and volcanic rocks deposited in a fault trough.

The Atlantic Continental Shelf comprises the slightly submerged area that extends eastward to the edge of the continental block. Its stratigraphy and structure are not known, but geophysical and drillhole data suggest that it consists mainly of relatively undisturbed Cretaceous and Cenozoic strata similar to those of the Atlantic Coastal Plain resting on a deformed Paleozoic basement.

PRECAMBRIAN

Tectonic Summary

The Precambrian of Southeastern Canada includes a variety of rocks with contrasting depositional, structural, and metamorphic histories. They are grouped into the four categories: (1) crystalline Helikian and older rocks of the eastern craton that underlie the Paleozoic strata of St. Lawrence Platform; (2) generally unmetamorphosed sedimentary and volcanic rocks, possibly early Hadrynian, that were deformed and locally intruded during the Hadrynian Avalonian Orogeny; (3) thick late Hadrynian sedimentary and volcanic rocks; (4) thin platformal quartzite, of latest Hadrynian and/or earliest Cambrian age, that unconformably and conformably overlies Hadrynian rocks and conformably underlies fossiliferous Lower Cambrian shale. In addition, poorly dated rocks that may be in part Hadrynian form the oldest recognizable rocks in the northwestern Appalachian Region. They are described with Cambrian rocks.

A peneplain that developed on Helikian and older rocks of Grenville Province of the Canadian Shield dips southeasterly below Paleozoic strata of the St. Lawrence Platform and under the northwestern Appalachian Geosyncline. It may extend beneath the entire geosyncline as far southeast as the edge of the continent under the Atlantic Ocean, but there is no direct evidence of this. Parts of the craton adjacent to the Appalachian Geosyncline were more or less continuously depressed during the Paleozoic and formed Allegheny Trough, Quebec Basin, and Anticosti Basin (Fig. VI-1). To the west, the intracratonal Michigan Basin was a strongly negative element. The intervening Algonquin Arch consisted of a broad elongate structure that was depressed to a much lesser extent but maintained some degree of subsidence during the Paleozoic. Cambrian and Lower Ordovician sediments thin toward it, and as a result of slight uplift, are bevelled and overlapped by Middle Ordovician sediments.

Precambrian rocks of indefinite age, possibly early Hadrynian, occur within the Trinity Belt of the southeastern Appalachian Orogen in eastern Newfoundland, Cape Breton Island, and southern New Brunswick. They are the oldest rocks exposed in the orogen, and if they are younger than the Grenvillian Orogeny they represent the first strata to be formed on or adjacent to the flanks of the craton. The tectonic element in which they were deposited cannot be defined. The rocks in Newfoundland are dominantly volcanic assemblages, whereas argillite, limestone, and quartzite were deposited in Cape Breton and New Brunswick. In Newfoundland, volcanic rocks, mainly subaerial, and red beds, were deposited on a basement that is now covered. Locally intercalated conglomerates containing granite pebbles suggest some tectonic activity; on the other hand, the sedimentary assemblages of Cape Breton Island and southern New Brunswick suggest platformal deposition on a stable basement, now covered. A comparison of these strata with similar rocks of the Grenvillian Orogen shows that they could be Aphebian and represent a remnant of a much larger craton upon which the Appalachian Geosyncline evolved.

During the middle Hadrynian Avalonian Orogeny the early Hadrynian volcanic and sedimentary rocks in eastern Newfoundland were folded, weakly metamorphosed, intruded by granite, uplifted, and eroded (Fig. VI-2). Probable lower Hadrynian rocks in Cape Breton Island and southern New Brunswick may also have been deformed, but the structural relations are obscure.

During the late Hadrynian, thick sediments and volcanics were deposited in the Trinity Belt in what must have been a deep trough. The lowest assemblages are slate and greywacke of deep-water marine facies succeeded by volcanic rocks and an upper assemblage of arkose and red conglomerate—a typical shallow-water continental facies. The younger rocks were deposited throughout Trinity Trough, whereas the older are known only in eastern Newfoundland. The upper Hadrynian rocks of Newfoundland were deposited in elongate troughs bordered by uplifted lands formed of older volcanic, sedimentary, and granitic rocks. The assemblage records a progressive shallowing of the seas, a change to non-marine conditions, and an increasing supply of coarse detritus.

In latest Hadrynian or earliest Cambrian time (Fig. VI-4) the site of Trinity Trough became Avalon Platform. A relatively thin, pure quartzose sandstone was deposited over much of the platform in a shallow-water sea. Stable, low-lying land existed in easternmost Newfoundland and northwestern Cape Breton. About the same time the oldest rocks in the Paleozoic Notre Dame Trough, described with the Cambrian, were deposited along the northwestern edge of Appalachian Geosyncline in the Eastern Townships of Quebec and the Burlington Peninsula of Newfoundland. These rocks are mainly sandy and shaly facies with some volcanics and carbonate beds. On St. Lawrence Platform thick, coarse, red, clastic beds were deposited in Lake Superior Basin near Manitoulin Island. They were presumably derived from a Precambrian land area located in northern Michigan.

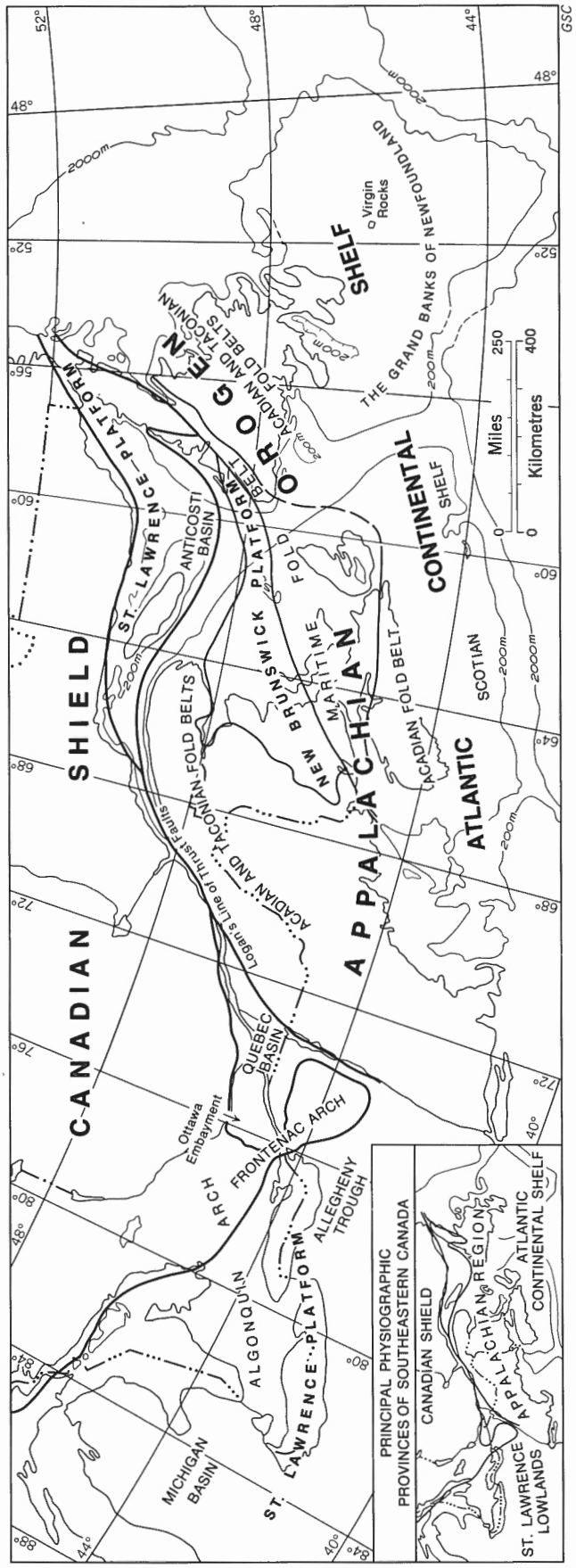


FIGURE VI-1 Principal geological elements of Southeastern Canada.

Helikian and Older

Helikian and older rocks of the Great Northern Inlier of Newfoundland and small inliers to the south are referred to as the Long Range and Indian Head Range Complexes (Clifford and Baird, 1962; Riley, 1962). They consist of schist and gneiss that have been tightly folded on northerly trending axes. The Long Range Complex was intruded by granites from which the biotite yielded K–Ar dates of 945 and 960 million years. Biotite from pegmatite and gneiss in the Indian Head Range Complex yielded dates of 830 and 900 million years.

The Long Range Complex consists of well-layered assemblages of psammitic schist and gneiss, quartzite, pelitic and semi-pelitic schist and gneiss, and hornblende schist and gneiss. Most are thought to be of sedimentary origin, and the assemblages of amphibole and plagioclase, with local occurrences of sillimanite, indicate regional metamorphism to almandine amphibolite facies. The Indian Head Range Complex occurs in two small inliers southwest of the Long Range Complex. It consists of mafic to silicic rocks that are largely of plutonic derivation and include anorthosite, pyroxenite, a variety of granitic gneisses, and granite pegmatite. The anorthosite is similar to those of the Grenville and Nain Provinces of the Canadian Shield where they have been interpreted as products of the Elsonian Orogeny. A large anorthosite body within Paleozoic schist and gneiss, 20 miles east of the Indian Head Range Complex, is also regarded as a Grenvillian inlier, but the relationship of the anorthosite to the Paleozoic rocks has been obscured by metamorphism and deformation. A northeast-trending swarm of diabase dykes cuts the Long Range Complex. These are believed to be feeders for the basalt flows that unconformably overlie gneiss and schist near the Strait of Belle Isle, and in turn are succeeded by Lower Cambrian strata. Mafic dykes, probably of equivalent age, also cut the Indian Head Range Complex.

Hadrynian

Early Hadrynian

In eastern Newfoundland the Harbour Main Group, probably early Hadrynian, comprises more than 6,000 feet of dominantly subaerial andesite, rhyolite, rhyolitic welded tuff, and intercalated red sandstone (McCartney, 1967; McCartney, *et al.*, 1966; Rose, 1952). In the lower half of the succession there is well-bedded green to grey siltstone and slate of probable marine origin. The volcanic rocks have a Rb–Sr date of 568±29 m.y. (Fairbairn, *et al.*, 1966). This date is equivalent to Middle Cambrian and much too young because the group is overlain unconformably by late Hadrynian and Lower Cambrian rocks.

The Love Cove Group (Jenness, 1963) is correlated lithologically with the Harbour Main Group and consists of 15,000 feet of alternating volcanic and sedimentary rocks. Silicic lavas and pyroclastic rocks of intermediate composition are present, and some basalt is probably represented by chlorite–epidote schists. Sedimentary rocks

are dominantly feldspathic greywacke with some metamorphosed conglomerate and slate. The Love Cove Group is everywhere more deformed and metamorphosed than nearby Hadrynian rocks, and pebbles of Love Cove chlorite schist have been reported in Hadrynian conglomerates. The Love Cove Group lies nearer the central Newfoundland axis of intense Paleozoic deformation than does the Harbour Main Group, and it has been locally feldspathized and granitized during the Paleozoic.

The Deer Park Pond and Southern Hills Formations of Burin Peninsula are dominantly volcanic assemblages that are possibly equivalent in part to the Harbour Main and Love Cove Groups. They are overlain by Hadrynian and Cambrian sedimentary rocks.

On Cape Breton Island the George River Group consists of quartzite and other clastic metasedimentary rocks, marble, quartzo-feldspathic schist and gneiss, amphibolite, and probable metavolcanic rocks (Weeks, 1954). In the type area two mappable units were recognized by early workers: a lower unit of quartzite, schist, and gneiss; and an upper unit of marble. The most distinctive rock types are marble and quartzite, and although abundant in the type area, they are subordinate to schist and gneiss in northern Cape Breton. Sedimentary features such as crossbedding, ripple-marks, and scour-and-fill structures are locally preserved and indicate shallow-water deposition. The George River Group is overlain with marked angular unconformity by Middle Cambrian strata, and Hadrynian rocks nearby conformably underlie the Cambrian.

The Green Head Group near Saint John, New Brunswick, resembles the George River Group in most respects and is composed mainly of limestone, quartzite, argillite, and limestone-conglomerate that locally grade into schist and gneiss (Alcock, 1938). Some quartzite is crossbedded, and certain limestone horizons contain the stromatolite *Archaeozoon acadiense*.

Avalonian Orogeny

During the middle Hadrynian, the Harbour Main Group in Newfoundland was deformed, weakly metamorphosed, intruded by the Holyrood granite, uplifted, and eroded during the Avalonian Orogeny. The Harbour Main Group is overlain with angular unconformity by Lower Cambrian strata and with local unconformity by the late Hadrynian Conception Group that locally contains clasts of granite like the Holyrood and hence is interpreted as younger than the granite (McCartney, 1967). The pre-orogenic rocks formed highlands and yielded detritus to narrow troughs and basins during the late Hadrynian. Avalonian metamorphism was low grade and produced slate in the Harbour Main and greenschist in the Love Cove Group. Folds are open and north-trending. The Holyrood granite consists dominantly of massive, coarse-grained, biotite quartz monzonite and granodiorite

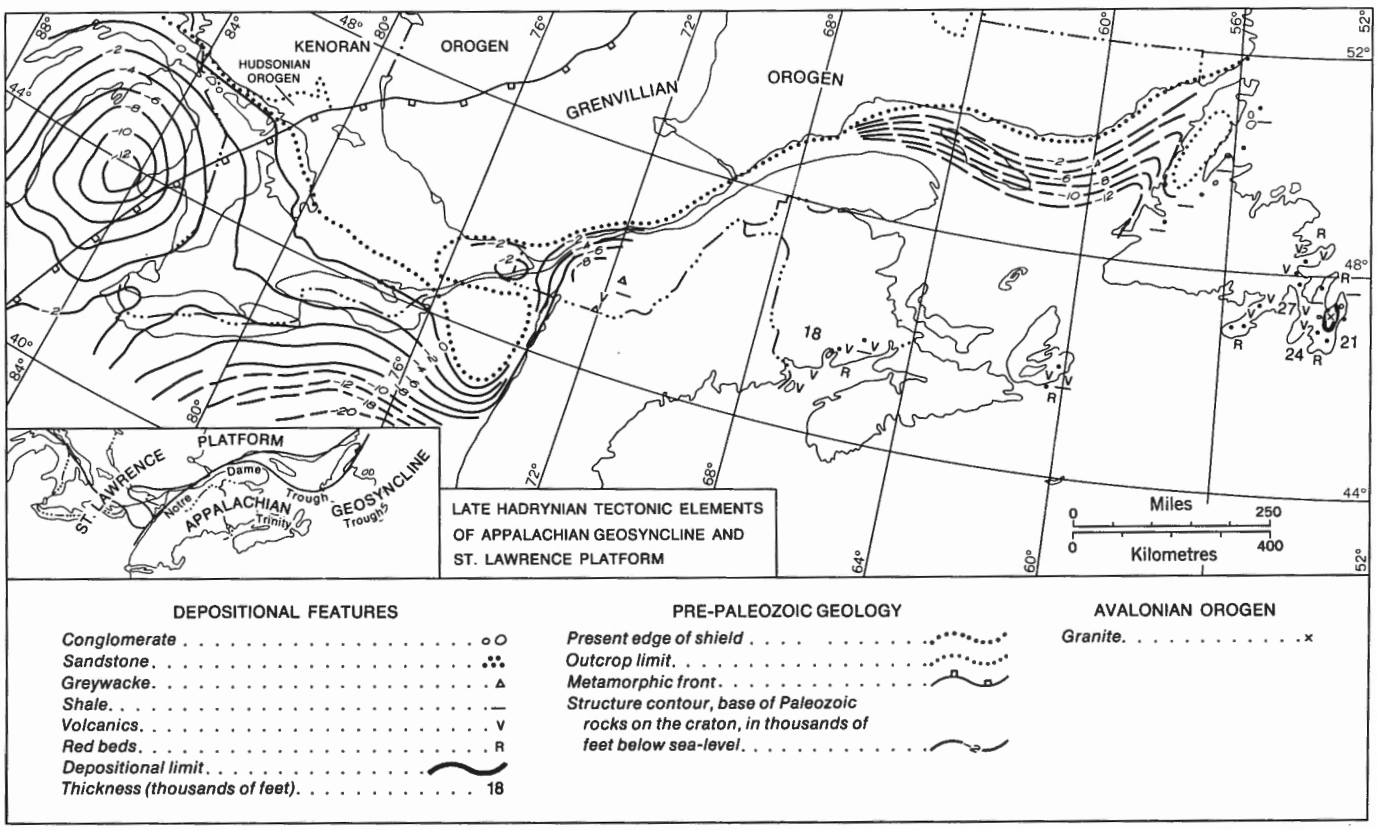


FIGURE VI-2. Late Hadrynian sedimentation, volcanism, and tectonism in Southeastern Canada, with features of the middle Hadrynian Avalonian Orogeny and the pre-Hadrynian basement surface of St. Lawrence Platform.

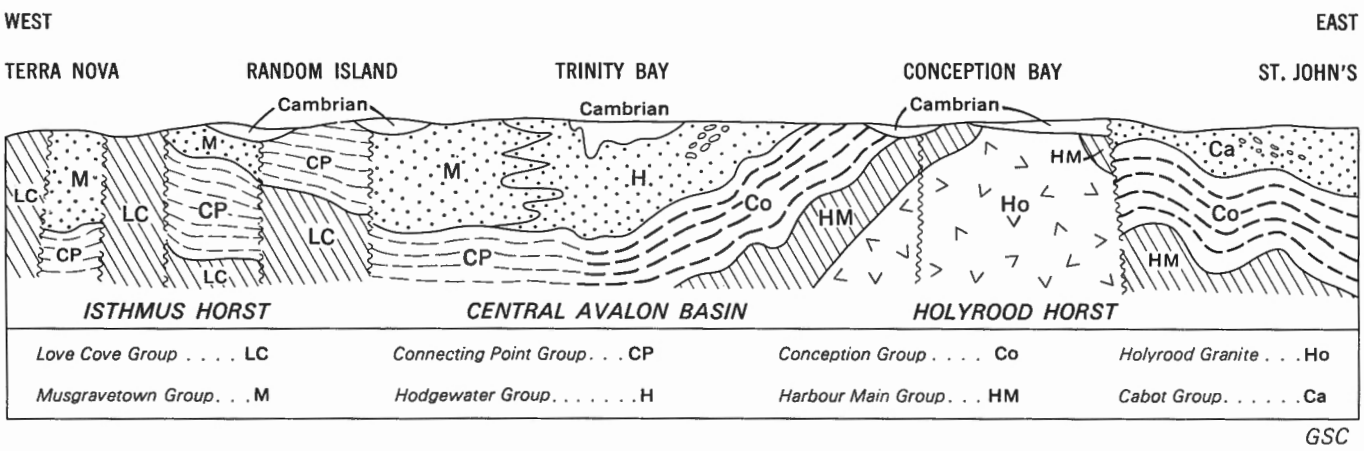


FIGURE VI-3. Diagrammatic cross-section of Precambrian and Cambrian rocks of Avalon Platform, eastern Newfoundland (modified from McCartney, et al., 1966).

that have been slightly cataclastized and altered. The granite yielded a whole-rock Rb–Sr date of 574±11 m.y. (McCartney, *et al.*, 1966), a date close to the Precambrian–Cambrian boundary and believed to be too young.

Evidence for the Avalonian Orogeny in Cape Breton Island and southern New Brunswick is sparse. The George River Group is overlain unconformably by Middle Cambrian rocks that farther east conformably overlie late Hadrynian volcanic rocks of the Fourchu Group. Structural relations of the Green Head Group and late Hadrynian volcanic rocks of the Coldbrook Group are obscure. Granitic clasts occur in both the Coldbrook and Cambrian strata, but the granite source has not been recognized. Metamorphism leading to schist and gneiss in the Green Head and George River Groups is believed to be Paleozoic.

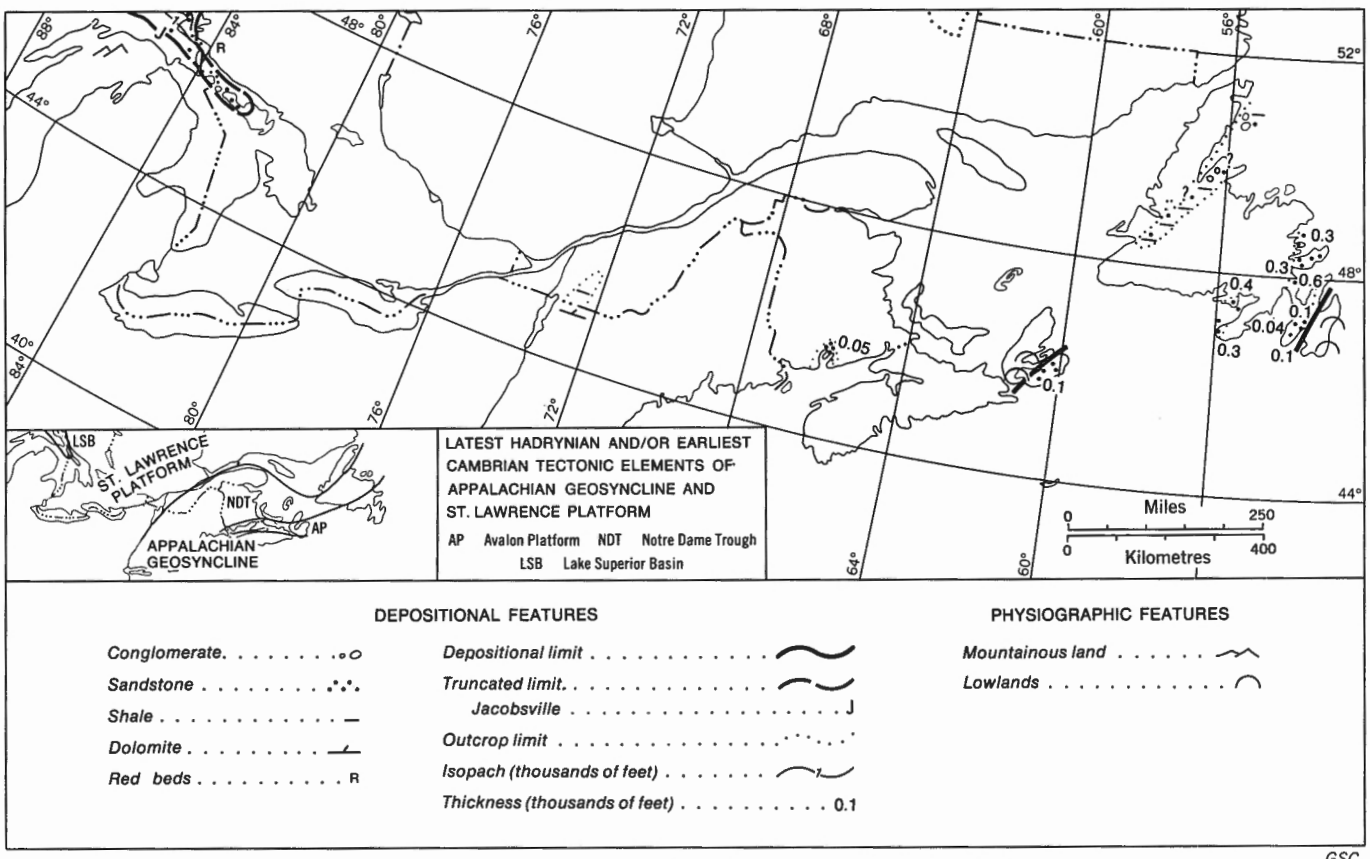


FIGURE VI-4. Latest Hadrynian and/or earliest Cambrian sedimentation and tectonism in Southeastern Canada.

Late Hadrynian (Fig. VI-2)

On Avalon Peninsula, Newfoundland, the Conception and Connecting Point Groups (McCartney, 1967; Jenness, 1963) are stratigraphically equivalent and lie at the base of the upper Hadrynian sequence (Fig. VI-4). The groups consist of slate, siltstone, and greywacke, with minor quartzite, conglomerate, and volcanic rocks. They were deposited in Trinity Trough. The Conception Group is about 7,000 feet thick and the Connecting Point Group between 9,000 and 30,000 feet thick. Locally, the Conception includes 100 feet of conglomerate and red sandstone at the base, and red sedimentary rocks of the Hibbs Hole Formation at the top. These lithologies suggest alternating changes between dominantly deep-water marine deposition and shallow-water continental deposition. Impressions of soft-bodied frond-like Metazoa as long as 30 cm have been recently discovered by S.B. Misra in ripple-marked mudstone of the upper part. The Conception Group conformably overlies the Harbour Main Group except near the Holyrood granite where it is unconformable; there the basal Conception conglomerates contain pebbles of Holyrood granite. The Connecting Point is faulted against older and most younger rocks. Local Hadrynian deformation is suggested by the direction of fold axes within the Connecting Point Group that in places trend a little west of north, at variance with prominent northeasterly trending fold axes in overlying Hadrynian rocks.

The Bull Arm Formation (McCartney, 1967; Jenness, 1963) consists of basalt, andesite, mafic and silicic volcanic breccia and pyroclastic rocks, and silicic lavas, as well as tuffaceous sedimentary rocks, red and green arkose, slate, siltstone, and conglomerate. A whole-rock Rb–Sr date on the volcanic rocks is 494±30 m.y. which is too young (Fairbairn, *et al.*, 1966). Other Rb–Sr dates on equivalent rocks in Cape Breton Island and southern New Brunswick are 509±40 m.y. and 495±30 m.y., respectively, and these also are too young. The Bull Arm Formation has a maximum thickness of 8,000 feet. Slate and siltstone are most common near the base and are similar to underlying beds of the Connecting Point Group. The contact is conformable, and the base of the Bull Arm Formation is drawn arbitrarily at the lowest volcanic member. In some places the Bull Arm is underlain by the Cannings Cove Formation that overlies the Connecting Point Group with angular unconformity. The Cannings Cove consists of more than 2,000 feet of red and green conglomerate and sandstone with clasts of volcanic rocks that resemble the Bull Arm, suggesting that its deposition was contemporaneous with the volcanism in adjoining regions.

Throughout Burin Peninsula some of the volcanic rocks included in the Deer Park Pond and Southern Hills Formations may be equivalent to the Bull Arm Formation.

Late Hadrynian sedimentary rocks in Newfoundland are generally referred to the Musgravetown, Hodgewater, and Cabot Groups (McCartney, 1967; Jenness, 1963; Rose, 1952), except in the vicinity of Fortune Bay where they are referred to the Dantzig Group, or Doten Cove and Chapel Island Formations. All these formations are overlain by white quartzite of the Random Formation or its equivalent, the Blue Pinion Formation; the quartzites are in turn succeeded by fossiliferous Cambrian shales. All upper Hadrynian sedimentary rocks below the Random Formation are considered equivalent, at least in part, but individual formations are not co-extensive except locally where Musgravetown beds have been traced through facies changes into strata of the Hodgewater Group. The Musgravetown Group consists of about 10,000 feet of arkosic sandstone, siltstone, slate, and conglomerate that conformably overlie the Bull Arm Formation. The Hodgewater and Cabot Groups are similar and have approximate maximum thicknesses of 17,000 and 14,000 feet, respectively. The Hodgewater and Cabot Groups lie east of the Musgravetown Group and both rest conformably on the Conception Group on the opposite flanks of the Holyrood horst.

On Cape Breton Island the upper Hadrynian Fourchu Group (Weeks, 1954) consists of silicic to intermediate pyroclastic rocks locally with intercalated flows, minor shale, siltstone, and greywacke. A distinctive pyroclastic member commonly occurs at the top of the succession. Many rocks of the Fourchu Group display a schistosity or parallel elongation of fragments in some places, whereas in others they are difficult to differentiate from nearby unmetamorphosed volcanic rocks of Middle Cambrian age. The Morrison River Formation conformably overlies the Fourchu Group and consists of a basal unit of crossbedded red sandstone with conglomerate interbeds and a middle unit of interbedded sandy slate and quartzite. Pebbles in the conglomerate are mainly vein quartz and sedimentary rocks, with only a few volcanic rocks. The formation has a maximum thickness of about 2,400 feet in the northeast, a minimum of 130 feet in the southwest, and apparently thins to zero in subsurface to the northwest.

In southern New Brunswick the upper Hadrynian Coldbrook Group consists of 18,000 to 33,500 feet of flows and pyroclastic rocks in roughly equal proportions, with silicic to intermediate varieties predominating over mafic types (Alcock, 1938). Minor conglomerate, phyllite, and schistose sandstone are also included. One conglomerate bed contains red granite pebbles, and the sandstones include numerous fragments of red feldspar, both of unknown provenance. The contact with the underlying Green Head Group has been interpreted as an angular unconformity, but this relationship is uncertain. The Coldbrook Group is overlain by the Ratcliffe Brook Formation (Hayes and Howell, 1937; Alcock, 1938), from 20 to 2,000 feet of fine-grained red micaceous sandstone with conglomerate at its base. Clasts are mainly volcanic pebbles and granite in one locality. Rapid variation in thickness suggests filling of an irregular erosion surface

on Coldbrook volcanics, but the nature of the contact is uncertain.

Latest Hadrynian and/or Earliest Cambrian (Fig. VI-4)

On Avalon Platform in eastern Newfoundland, Cape Breton Island, and southern New Brunswick, deposition of upper Hadrynian red beds in Trinity Trough changed gradationally to marine, white, pure quartzose sand without evidence of interruption in deposition. The quartzite is overlain conformably by fossiliferous Lower Cambrian shale. It is probably of the same general age in the three areas, but it may be partly transgressive and diachronous.

In Newfoundland the Random Formation consists of white quartzite pure enough to be a source for industrial silica (McCartney, 1967; Jenness, 1963). It is 200 to 300 feet thick. The lower part contains red shale and siltstone similar to the underlying Musgravetown and Hodgewater Groups; the upper part has beds of grey, red, and green shale like the overlying Cambrian formations.

On Cape Breton Island the upper part of the Morrison River Formation (Weeks, 1954) consists of as much as 350 feet of white quartzite that thins northwesterly to zero in central Cape Breton where Middle Cambrian rocks rest directly on the George River Group.

In southern New Brunswick the Glen Falls Formation (Hayes and Howell, 1937) consists of 20 to 50 feet of quartzose sandstone. The lower part is white sandstone and the upper 3 to 6 feet is black sandstone.

The Jacobsville Formation occurs as subsurface outliers beneath Paleozoic strata and rests with angular unconformity upon Aphebian and older crystalline rocks between western Manitoulin Island and Keweenawan Peninsula of northern Michigan (Hamblin, 1958). It consists of red sandstone, conglomerate, and shale of non-marine origin. The maximum thickness is more than 700 feet at Sault Ste. Marie. The Jacobsville was deposited along the north side of an east-trending land that extended across northern Michigan. The age of the formation is uncertain; it has been variously classified as Proterozoic or Lower, Middle, and Upper Cambrian. Inasmuch as the Jacobsville is disconformably overlain by Upper Cambrian coarse marine clastic strata and is lithologically unlike other Cambrian rocks in the region, it is probably Hadrynian and represents the oldest post-Grenvillian strata on St. Lawrence Platform.

PALEOZOIC

Cambrian

Tectonic Summary

During the Cambrian the limits and tectonic characteristics of the St. Lawrence Platform and Appalachian Geosyncline were clearly established for the first time (Figs. VI-5, 6). Within the geosyncline, thick non-volcanic clastic rocks were deposited along the northwestern and southeastern flanks of Notre Dame Trough that was bordered in southern Quebec by a zone of volcanism probably in late Cambrian time. A thin sequence of fossiliferous Cambrian shale with minor limestone was deposited on the folded and flat-lying rocks and granite within the Hadrynian Trinity Trough. Cambrian seas spread laterally to overlap the Precambrian lands, and by the late Cambrian at least, largely covered the lands and probably were connected with the seas of Notre Dame Trough. The thickness, distribution, sedimentary facies, and overlap relationships show that the Cambrian strata accumulated in northeast-trending depositional basins on Avalon Platform, and the faunal similarities suggest that they had direct marine connections. The platform was a gently subsiding stable element from Cambrian to early Ordovician. It was partly deformed by subsequent Paleozoic orogenies and partly preserved as stable blocks that shielded the Cambrian–Ordovician cover from the deformation in adjacent troughs. The relationships are unknown between the Cambrian strata of Avalon Platform and those of Notre Dame Trough to the west and Meguma Trough to the east.

Southeast of Avalon Platform very thick greywacke quartzite accumulated in Meguma Trough, largely by turbidity current deposition. The detritus was probably derived from a landmass lying to the southeast in an area now covered by the Atlantic Ocean.

Orthoquartzitic sandstone and carbonate rocks were deposited on St. Lawrence Platform. Eastern Anticosti Basin near Notre Dame Trough was inundated by shallow seas in the early Cambrian. The basal arkosic rocks and minor basaltic flows are overlain by a thick succession of Lower to Upper Cambrian orthoquartzitic sandstone and dolomite. During the late Cambrian the sea transgressed into Quebec Basin and Ottawa Embayment and onto Algonquin Arch in southwestern Ontario leaving marine deposits of sandstone and dolomite that rest unconformably on the Precambrian basement. Voluminous quartz detritus was shed into southern Quebec Basin from mountains along the north side of Frontenac Arch. The Cambrian strata deposited in Quebec Basin thicken southeastward and probably grade into geosynclinal rocks now exposed in the northwesterly displaced thrust sheets of Appalachian Orogen.

The fauna in the pelitic sequence covering Avalon Platform are typical of an European or Atlantic faunal realm of the Cambrian and are characterized by the trilobite *Paradoxides*. Those in the carbonates of the St. Law-

rence Platform are typical of the North American or Pacific faunal realm and include such characteristic fossils as archeocyathids and the trilobite *Olenellus*. The presence of the two distinct faunal provinces in relatively close proximity has been attributed to: (1) a linear land barrier—the "New Brunswick Geanticline", or a series of island arcs separating the two areas of deposition; (2) a deep-water trough along the central axis of the geosyncline that prevented mixing of the shallow-water fauna on each side; (3) Cambrian and older rocks on the southeast side of the Appalachian Geosyncline representing part of another continent that was separated from North America during Cambrian and Ordovician time by a proto-Atlantic Ocean. Presumably this early Paleozoic ocean basin closed during middle Paleozoic time and later reopened along a new line to become the present Atlantic Ocean during Mesozoic time. The simple geographical separation of the two realms has been complicated by the recent discovery of Middle Cambrian trilobites typical of both the Atlantic and Pacific realms in the axial part of Notre Dame Trough in northeastern Newfoundland.

Appalachian Geosyncline

Notre Dame Trough. Cambrian rocks are not sufficiently exposed or dated by fossils to reconstruct fully the tectonic conditions of deposition within the trough. At Quebec City, along the northwestern flank of the trough in *southern Quebec,* the oldest rocks are the Charny Formation (Osborne, 1956), which is part of what was formerly called the Sillery Formation. The Charny is perhaps 2,000 feet or more thick and is bounded above and below by thrust faults. It is mainly Lower Cambrian and consists of red, green, and grey marine shale, sandstone, and fine pebble-conglomerate. The Lauzon Formation is mainly Upper Cambrian and comprises about 2,000 feet of red shale; grey, black, and green siltstone and sandstone; and some limestone-conglomerate. Rocks of similar character occur here and there along the margin of the trough in southern Quebec. In the Eastern Townships of southern Quebec the uppermost Hadrynian and Cambrian Oak Hill Group forms the core of the Sutton Mountain anticlinorium (Cady, 1960, 1967; Eakins, 1964). The group consists of several formations totalling about 2,000 feet of rocks whose dominant lithologies in ascending order are intermediate to mafic volcanic rocks, greywacke, dolomite, quartzite, black slate, quartzite, dolomite, siltstone, quartzite, and black slate. These formations reflect deposition alternating between geosynclinal and platformal conditions and grade into metamorphosed rocks of the Sutton schist. Northeastward along trend (Béland, 1962) the core of the anticlinorium consists of the Rosaire Group overlain in the northwest by the Armagh Group and in

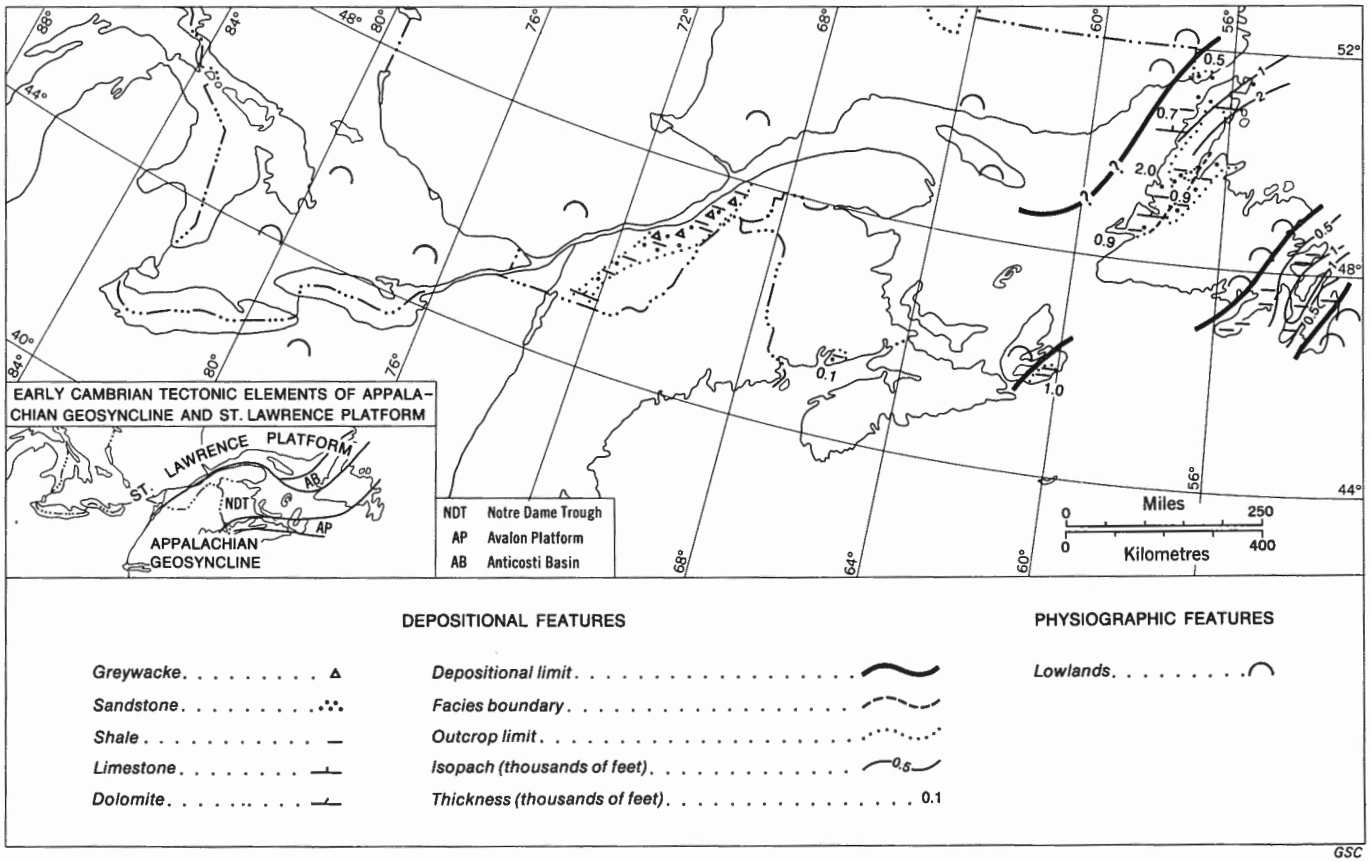


FIGURE VI-5. Lower Cambrian sedimentation and tectonism in Southeastern Canada.

the southeast by the Caldwell Group. The age and structural relationship of these groups is unknown, but perhaps most of these unfossiliferous rocks are of Cambrian age. The Rosaire consists of white and grey quartzite, siltstone, and slate a few thousand feet thick; the rocks are characteristic of marine shallow-water deposition in a tectonically stable environment such as a platform. The probably younger and equivalent Armagh and Caldwell Groups are each about 25,000 feet thick and consist of green, red, and grey impure sandstone; arkosic sandstone and greywacke; siltstone; slate; and quartzite. The Caldwell also contains some mafic volcanic rocks. The Rosaire and Caldwell Groups grade into schists of the Bennett Group. The sedimentary rocks of the Armagh and Caldwell Groups are similar to the Cambrian formations at Quebec City and their equivalents to the northeast and southwest. Parts of the Armagh and Caldwell Groups are probably early Ordovician. The abundant feldspar detritus, mainly plagioclase, suggests derivation from a crystalline terrane like the Canadian Shield to the north. Similar rocks of Cambrian and possibly Cambrian age occur along trend in northern Gaspé Peninsula. Late Middle and early Upper Cambrian trilobites have been collected from dark grey slate within the Quebec Group, as well as a Middle Cambrian trilobite from a limestone clast in a conglomerate (Ollerenshaw, 1967). A small area of late Middle and early Upper Cambrian limestone and shale of the Corner-of-the-Beach and Murphy Creek Formations occurs on eastern Gaspé Peninsula (McGerrigle, 1950). These rocks are somewhat unique because they lie south of the trend of the Quebec and Schickshock Groups. The Cambrian trilobites in Gaspé Peninsula are characteristic of the Pacific faunal realm.

In *western Newfoundland,* Cambrian and possibly Cambrian rocks occur along western Notre Dame Trough and in allochthonous sequences derived from the trough now resting on the St. Lawrence Platform (Poole, 1967). In the trough the Fleur de Lys Group of Burlington Peninsula (Neale and Nash, 1963; Neale and Kennedy, 1967) and its probable equivalents near Deer Lake the Mount Musgrave Formation and Grand Lake Brook Group (Brückner, 1966; Lilly, 1967), are undated, and stratigraphic relationships to adjacent rocks are not clear. The rocks are dominantly psammitic and pelitic schists several thousand feet thick, with minor plutonic boulder meta-conglomerates. All are regionally metamorphosed to the amphibolite or greenschist facies. Locally on Bur-

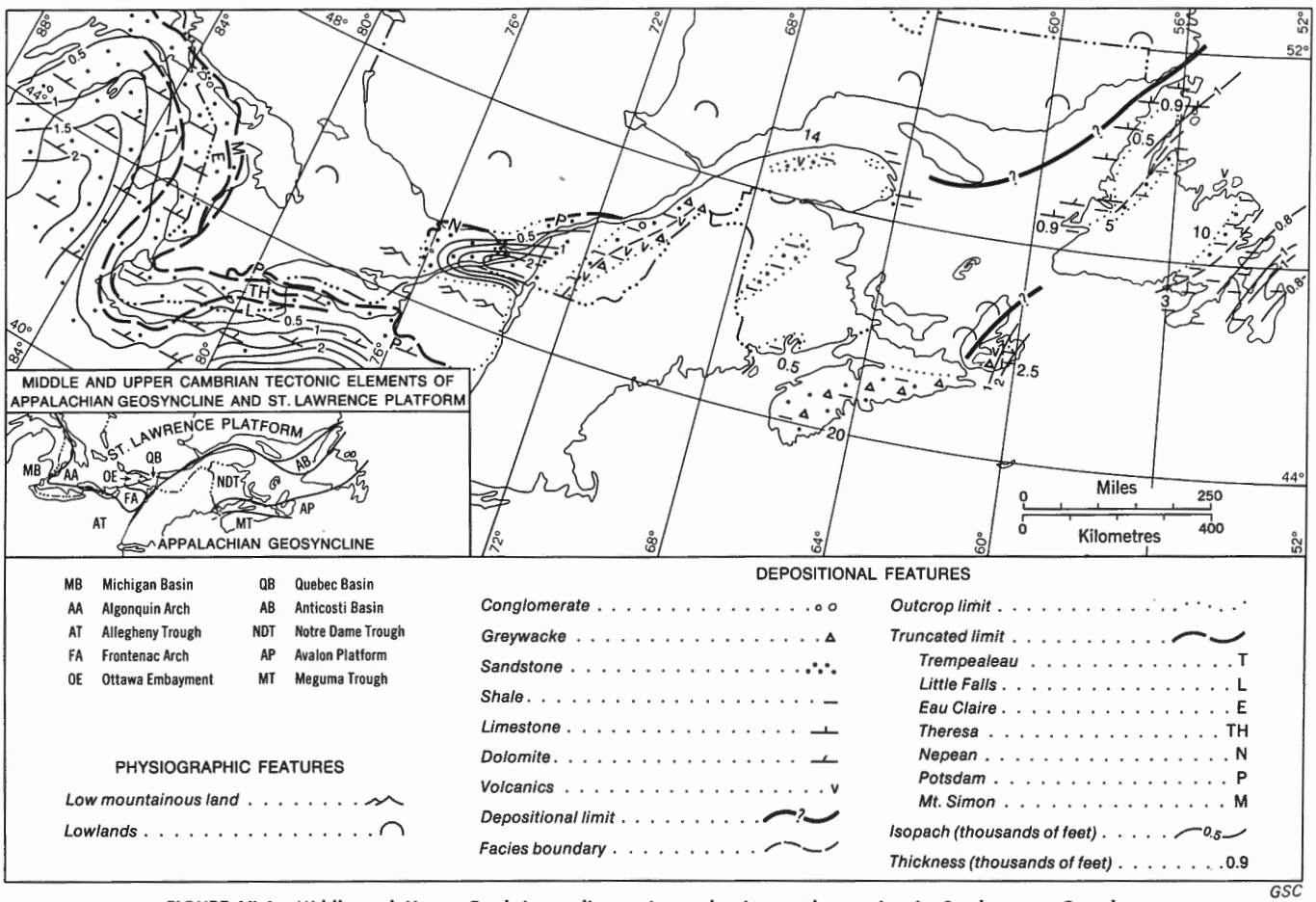


FIGURE VI-6. Middle and Upper Cambrian sedimentation, volcanism, and tectonism in Southeastern Canada.

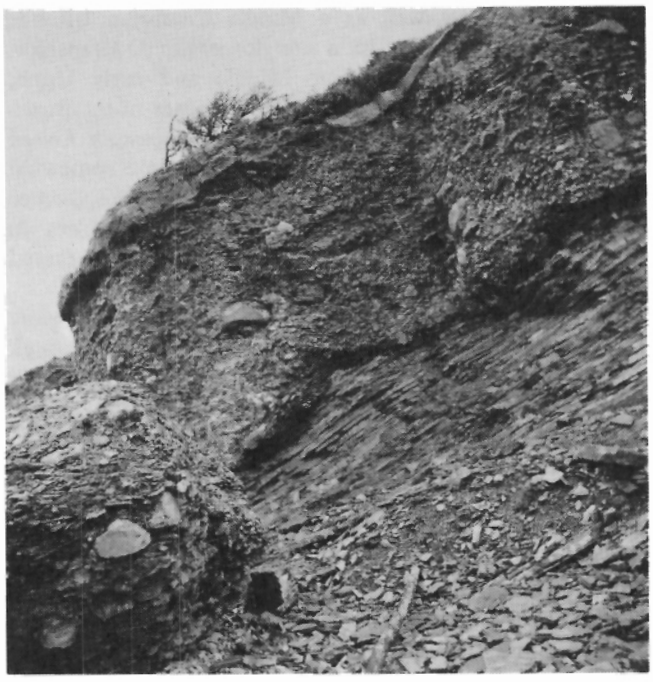


PLATE VI-1. Cambrian thin-bedded limestone and limestone breccia of Cow Head Group at northern end of Humber Arm klippe, Cow Head, Newfoundland.

lington Peninsula thin-bedded marble and limestone breccia beds occur along the western part of the Fleur de Lys outcrop belt, and green amphibolitic and chloritic schists of probable volcanic origin occur in the eastern exposures. The Mount Musgrave Formation and Grand Lake Brook Group appear to underlie or grade westerly into autochthonous Lower Cambrian carbonates of the Labrador Group on St. Lawrence Platform. Their distribution suggests that the contact with the Labrador Group is conformable and that they are partly older. These trough rocks have had a more involved structural and metamorphic history than nearby Paleozoic rocks in the trough to the east, implying that the contact is an unconformity or a fault. From the information at hand, the Fleur de Lys rocks and equivalents probably represent a marginal trough succession equivalent to or lying below the Cambrian strata of the St. Lawrence Platform.

The allochthonous Cambrian sequences of western Newfoundland occur within the Humber Arm klippe and the Hare Bay klippe (Rodgers and Neale, 1963). The Humber Arm klippe contains Cambrian rocks of two facies: a carbonate facies of the Cow Head Group to the north, and a clastic facies to the south and east. The lower part of the Cow Head Group (Kindle and Whittington, 1958) consists of 300 to 400 feet of fossiliferous limestone, shale- and limestone-conglomerate, and Middle and Late Cambrian breccia (Pl. VI-1). Limestone clasts are approximately the same age and lithology as the immediately underlying beds, but are of a different facies and contain a different fauna than the now exposed carbonate rocks of St. Lawrence Platform. Presumably the limestone clasts were derived from nearby contemporaneous carbonate banks not now exposed, the brecciated material being periodically discharged down submarine slopes into the limy muds accumulating at the base. This depositional environment was not local, for the conglomerates at Levis, Quebec, and in the Quebec Group along the south shore of the St. Lawrence River also contain boulders of Cambrian limestones remarkably similar lithologically and faunally to those in the Cow Head Group. Thus the facies from which the boulders were derived extended along strike, although not necessarily continuously, for about 800 miles. Probably this was an easterly facies of the carbonates of the St. Lawrence Platform. The clastic facies in the southern and eastern part of the klippe (Brückner, 1966; R. K. Stevens) consists of 2,500 to 3,000 feet of generally thin bedded shale, sandstone, limestone, and limestone-conglomerate, referred to in ascending order as the Summerside, Irishtown, and Cooks Brook Formations. Both the Irishtown and Cooks Brook Formations contain clasts of Early Cambrian limestone, and in addition the Cooks Brook contains indigenous Middle Cambrian fossils in its lower part and Tremadocian graptolites at the top. These rocks were at one time considered to be Middle Ordovician and to stratigraphically overlie Cambrian to Middle Ordovician autochthonous carbonates of the St. Lawrence Platform. With the discovery of Cambrian and Lower Ordovician fossils, however, it now appears certain that the Cow Head Group and clastic rocks to the south are in large part contemporaneous with the autochthonous carbonate sequence and are indeed allochthonous (Rodgers and Neale, 1963). The clastic facies was probably deposited farther east within the Notre Dame Trough than the platform–trough border zone where the Cow Head Group was deposited.

The Hare Bay klippe at the northern end of Great Northern Peninsula contains thrust slices of Maiden Point and Goose Cove Formations (Cooper, 1937) whose ages are unknown but are probably partly Cambrian. The Maiden Point consists of 6,000 feet or more of coarse greywacke sandstone and minor grey and red slate, and near the base, pillowed flows and pyroclastic rocks of andesitic and basaltic composition. Some of the volcanic rocks may be Lower Ordovician like those near Notre Dame Bay. The Goose Cove Formation consists of schist, gneiss, and amphibolite derived from andesitic and basaltic volcanic rocks that border ultramafic bodies within the klippe. The Goose Cove has apparently been thrust over the Maiden Point; their stratigraphic relationships are unknown.

In the axial part of Notre Dame Trough in northeastern Newfoundland, early Middle Cambrian trilobites of a probable Atlantic affinity have recently been discovered by M. Kay in limestone lenses within volcanic rocks of a formation hitherto believed to be Middle Ordovician. The volcanic rocks outcrop over only a few

hundred feet and may comprise a large exotic block, as suggested by outcrops of chaotic rocks nearby. If transported, however, the block has not moved far and indicates that Cambrian rocks of eugeosynclinal facies were deposited, at least locally, within the central parts of the trough in Newfoundland.

Along the eastern margin of Notre Dame Trough, in *east-central Newfoundland,* clastic rocks occupy a position in the trough comparable to the Fleur de Lys Group along the western margin. The lower unit of the Gander Lake Group (Jenness, 1963) and its probable equivalent rocks to the southwest, the Baie d'Espoir Group, form a monotonous sequence of siltstone, micaceous sandstone, slate, greywacke, and quartzite, some 10,000 feet thick or more. The lower unit is unfossiliferous and is overlain, presumably conformably, by Middle Ordovician slate and volcanic rocks of the middle unit. The base abuts the Hadrynian Love Cove Group along a contact that has been interpreted as a fault rather than an unconformity, chiefly because the Precambrian rocks are less intensely metamorphosed where the two groups are in juxtaposition.

Avalon Platform. Cambrian strata of the Avalon Platform are dominantly shale with minor sandstone and limestone, and locally, on Cape Breton Island, thick volcanic rocks. The total thickness ranges from less than 1,000 feet to a maximum of more than 4,000 feet in eastern Newfoundland. The sedimentary strata are mainly of marine shallow-water deposition and their lithologic sequence remains remarkably uniform throughout most of the region. The strata are abundantly fossiliferous in places, and the sequence of similar faunas suggests that the seas covering the platform in eastern Newfoundland, Cape Breton Island, and southern New Brunswick were continuous and that they extended into the Boston area to the southwest and also probably to the British Isles and Scandinavia. All the fauna are of the Atlantic faunal realm.

The Cambrian strata conformably overlie the basal transgressive quartzites of the Random, Morrison River, and Glen Falls Formations. Where Cambrian strata unconformably overlap Precambrian rocks, their age and thickness distribution indicate that the Lower and Middle Cambrian beds accumulated in northeast-trending troughs with the sea transgressing northwesterly. The deposition of late Middle and Upper Cambrian shales was more widespread, and the seas probably covered the entire Avalon Platform. The presence of thicker and more arenaceous beds near the western extremity of Avalon Platform at Fortune Bay, Newfoundland, suggests that the later Cambrian strata grade into the eastern deposits of Notre Dame Trough.

Cambrian strata of Avalon Platform are preserved in graben or synclinoria within a Precambrian terrane (Fig. VI-3). They are simply folded. Locally, where Cambrian strata overlap the deformed Precambrian Harbour Main Group and Holyrood granite of eastern Newfoundland, they are not folded and are broken only by normal faults.

In *eastern Newfoundland* (McCartney, 1967; Jenness, 1963; Hutchinson, 1962) the axis of maximum Cambrian deposition remained near Trinity Bay where more than 4,000 feet of shale and minor limestone was deposited. Successive Lower Cambrian formations overlapped eastward and westward across lowlands of Precambrian rocks that did not shed coarse clastic detritus. The oldest formation, the Bonavista, consists of red and green shale, minor limestone, and local basal conglomerate, succeeded

PLATE VI-2

Hadrynian Harbour Main Group, folded in the Hadrynian Avalonian Orogeny, overlain with angular unconformity by Lower Cambrian slate and limestone, folded probably in the Devonian Acadian Orogeny, Brigus South Point, Newfoundland.

by the Smith Point Formation of red and green algal limestone, the Brigus Formation of red and green shale with minor limestone interbeds and nodules, and the green shale of the early Middle Cambrian Chamberlains Brook Formation that locally contains manganese-rich beds and red shale at the base. The equivalent Youngs Cove Formation in Fortune Bay contains more siltstone, indicating the presence of a source land to the west. Overlying the Chamberlains Brook Formation is the late Middle Cambrian Manuels River Formation of grey and black shale with limestone interbeds and a few intercalated basalt flows and tuff, and the Upper Cambrian Elliott Cove Formation of grey, green, and black silty shale and siltstone. The same formational sequence in Bonavista Bay, northwest of Avalon Peninsula, is separated into a Lower and early Middle Cambrian red and green shale-bearing Adeyton Group and a late Middle Cambrian to Lower Ordovician grey and black shale-bearing Harcourt Group.

On eastern *Cape Breton Island* (Hutchinson, 1952; Weeks, 1954) Cambrian shale containing brachiopods and trilobites and a local greywacke–volcanic assemblage were deposited in a northeast-trending trough that was bounded on the west by a lowland during the Lower and Middle Cambrian. In the east part of the trough the upper Hadrynian and/or lowest Cambrian Morrison River Formation is overlain by 1,000 feet of grey, green, and red shale and siltstone of the late Lower Cambrian MacCodrum and Canoe Brook Formations. They are succeeded in the northwestern part of the trough by 1,500 feet of late Middle Cambrian dark grey and black shale and siltstone of the Trout Brook and MacLean Brook Formations, and in the southwestern part by more than 500 feet of silicic and mafic lava, pyroclastic rocks, greywacke, and shale of the late Middle Cambrian Bourinot Group. This is succeeded in turn by the Kelvin Glen Group comprising at least 2,300 feet of red and green shale and siltstone, and in the basal part red and green shale and siltstone and red and grey conglomerate with quartz and quartzo-feldspathic pebbles and red arkosic sandstone. In the west part of the trough the Middle Cambrian Bourinot Group rests with angular unconformity on the Hadrynian George River Group. In this region the Bourinot thins from 2,000 feet of entirely volcanic rocks at or near the centre of volcanism, northeastward to 600 feet and southwestward to 1,200 feet to several miles from the centre where the volcanics are interbedded with greywacke, quartzite, and shale. The overlying Middle Cambrian MacMullin Formation of grey siltstone and shale thins from about 1,000 feet to zero at the volcanic centre from both the northeast and southwest. The Upper Cambrian MacNeil Formation, several hundred feet of dark grey and black shale with rare black limestone interbeds, overlies Middle Cambrian strata in both eastern and western parts of the trough, and like the equivalent Elliott Cove Group strata of Newfoundland, shows that the sea had inundated the entire area by this time. In the western part of the trough the MacNeil Formation overlaps the MacMullin Formation to rest directly on the central high of Bourinot volcanic rocks.

Near Saint John, *southern New Brunswick*, within the St. John Group (Hayes and Howell, 1937; Alcock, 1938), about 1,000 feet of Cambrian dark grey and black shale with minor sandstone and limestone lies with structural conformity on uppermost Hadrynian and/or lowermost Cambrian quartzite of the Glen Falls Formation. The seven thin Cambrian formations have been defined largely by their age and faunal content. The oldest fossiliferous rocks, the late Lower Cambrian Hanford Brook Formation, consists of about 75 feet of grey sandstone and shale. It is overlain by about 145 feet of late Middle Cambrian black shale with thin interbeds and nodules of grey limestone, referred to in ascending order as the Fossil Brook, Porter Road, and Hastings Cove Formations. The overlying Upper Cambrian strata consist of more than 500 feet of dark grey and black shale with minor limestone and sandstone interbeds, referred to in ascending order as the Agnostus Cove, Black Shale Brook, and Narrows Formations.

Meguma Trough. In Nova Scotia the Goldenville Formation (Taylor, 1967), the lowest in the Meguma Group, consists of as much as 18,000 feet of lithic greywacke and feldspathic quartzite with minor conglomerate and slate. The strata are partly metamorphosed to biotite, greywacke, schist, and gneiss of the greenschist and almandine amphibolite facies. The Goldenville is unfossiliferous, but may be upper Cambrian as the overlying Halifax Formation contains Tremadocian graptolites. Clasts in the conglomerate are quartz, quartzite, and greywacke. Sole markings on the bases of greywacke beds suggest deposition by turbidity currents flowing northeasterly and easterly, subparallel to the present structural trend of the rocks. The source must have lain to the southeast in an area now covered by the Atlantic Ocean and the currents must have moved parallel with the axis of the trough, because thin black shale was deposited to the northwest on Avalon Platform.

St. Lawrence Platform

Lower Cambrian. Lower Cambrian strata of Anticosti Basin occur in western Newfoundland and nearby Labrador. The deposits record a stable environment of deposition. They thicken gradually southeasterly toward the present exposures of the Long Range and Indian Head Range basement complexes, indicating that these Precambrian inliers were not positive elements during the early Cambrian. Bordering Strait of Belle Isle the basal Bradore Formation of the Labrador Group (Schuchert and Dunbar, 1934) lies with angular unconformity on Precambrian crystalline rocks and consists of red to light grey arkose, orthoquartzitic sandstone, conglomerate, and shale. Columnar basalt flows are interlayered with red arkosic rocks near the base. The rocks are unfossiliferous

except for the occurrence of vertical worm tubes, *Scolithus linearis*. The formation thickens southeastward from Labrador to about 300 feet on each side of the Strait of Belle Isle. The equivalent Cloud Mountains Formation near Canada Bay is 585 feet thick. Crossbedding in sandstone in Labrador indicates southeasterly transport of detritus. The Bradore Formation is overlain conformably, or with slight disconformity, by the Forteau Formation, which consists of thin-bedded red and grey variegated shale and grey limestone containing archeocyathid reefs and sandy and oölitic beds. The Forteau Formation thickens southeasterly from 185 feet in southeastern Labrador to 386 feet in St. John Highlands of western Newfoundland and 700 feet near Canada Bay. Inland from the coast of Labrador the character of the Forteau Formation changes: the archeocyathid reefs become thinner and fewer, and the limestones gradually become more evenly bedded and more argillaceous. The Forteau Formation is overlain by orthoquartzitic sandstone, limestone, and shale of the Hawke Bay Formation, which is about 300 feet thick at the type section on Hawke Bay, western Newfoundland.

In central western Newfoundland Lower Cambrian strata of the Labrador Group locally exceed 2,000 feet in thickness. They are dominantly orthoquartzitic sandstone, limestone, and shale, but are readily divisible into the formations recognized to the north. The rocks unconformably overlie the Precambrian basement and grade southeasterly into metamorphic rocks that may be partly Precambrian. Near Port au Port in southwestern Newfoundland, 900 feet of fossiliferous Lower Cambrian strata of the Kippens Formation overlies plutonic rocks of the Indian Head Range Complex with marked unconformity (Riley, 1962). The Kippens Formation consists of shale, sandstone, and limestone, and has many lithological characteristics similar to the Forteau Formation.

Middle Cambrian. Middle Cambrian strata are known at only two localities in Anticosti Basin, both in western Newfoundland. At Canada Bay about 900 feet of limestone, dolomite, and orthoquartzitic sandstone comprise the Cloud Rapids and Treytown Pond Formations (Betz, 1939). The Cloud Rapids Formation, mainly bluish black limestone and grey shale, overlies the Forteau Formation with apparent disconformity marked by a thin pebble-conglomerate. It is conformably overlain by grey, fine-grained limestone of the Treytown Pond Formation, which in turn is succeeded by sparsely fossiliferous Lower Ordovician strata. In the seacliffs of Port au Port Peninsula about 850 feet of Middle Cambrian dolomite, shale, and

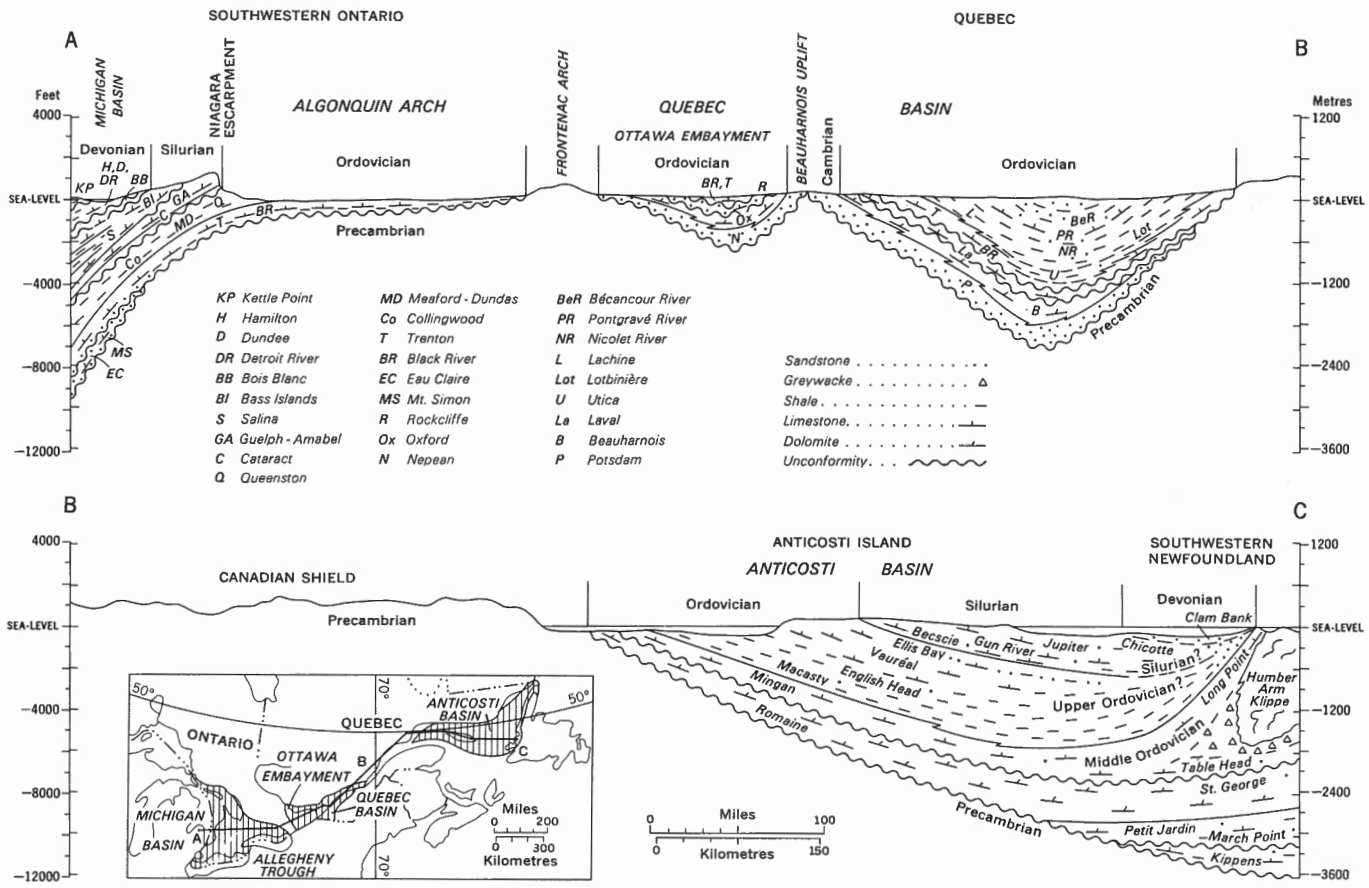


FIGURE VI-7. Cross-section of Paleozoic formations of the St. Lawrence Platform from Michigan Basin to Anticosti Basin (by B. V. Sanford).

a lower orthoquartzitic sandstone is referred to as the March Point Formation (Riley, 1962). The base is not exposed, and the Middle Cambrian beds are conformably overlain by Upper Cambrian and Lower Ordovician strata.

Middle Cambrian limestone clasts of platform facies are common in the conglomerates of the Humber Arm klippe and in those of the Quebec Group.

Upper Cambrian. Upper Cambrian strata were deposited throughout St. Lawrence Platform with the exception of Anticosti and Mingan Islands and possibly local areas in northwest Newfoundland.

In western Newfoundland, deposition in Anticosti Basin of dominantly carbonate rocks, initiated in Middle Cambrian time, probably continued in most places throughout the late Cambrian and into the early Ordovician (Fig. VI-7). Upper Cambrian strata have not been distinguished everywhere, largely because they are lithologically similar to, and grade upwards into, Lower Ordovician strata; they can only be separated faunally. Locally, about 500 feet of limestone, dolomite, and shale of the East Arm Formation near Bonne Bay and a more silty and shaly equivalent, the Petit Jardin Formation on Port au Port Peninsula, have been recognized. Faunal evidence has indicated recently that the basal part of the St. George Group, traditionally assigned to the Lower Ordovician, is Upper Cambrian.

In the Quebec Basin the basal Paleozoic transgressive sandstones are referred to as the Potsdam Formation (Clark, 1965), or locally in the Ottawa Embayment as the Nepean Formation (Wilson, 1946). They are considered correlative in part to rocks of known Upper Cambrian age exposed along the northern margins of the Adirondack Mountains in New York, although undoubtedly there are areas in eastern Ontario and Quebec where the Potsdam spans the Cambrian–Ordovician systematic boundary. The Potsdam Formation is as much as 2,000 feet thick. It is composed of a white, grey-buff, and reddish grey orthoquartzitic sandstone of exceptional maturity with quartz-feldspar pebble-conglomerate at the base or locally intercalated higher. Primary sedimentary structures point to depositional environments varying from terrestrial talus sheetwash fans bordering the areas of high relief such as the Frontenac Arch to those of low-energy lagoonal and tidal flats.

In southwestern Ontario the distribution of Upper Cambrian rocks was initially controlled by the prominent Algonquin and Frontenac Arches (Sanford and Quillian, 1959), but these tectonic elements were presumably covered by late Upper Cambrian to Lower Ordovician strata later eroded prior to the advance of Middle Ordovician seas (Fig. VI-8). During the Upper Cambrian the Algonquin Arch extended southward to connect with the Waverly Arch of west-central Ohio (Burgess, 1962). Basal Upper Cambrian deposits are white, grey, and locally red orthoquartzitic sandstone that thicken from zero at their erosionally truncated edges to 150 feet. These are termed the Potsdam southeast of Algonquin Arch, and the Mount Simon Formation to the west in Michigan Basin. The Potsdam is gradationally succeeded by the Theresa Formation, 350 feet of alternating orthoquartzitic sandstone and dolomite, and the Mount Simon by the lithologically similar Eau Claire Formation, 200 feet thick. Both formations locally overlap the older strata to rest directly on the Precambrian crystalline rocks. In the northern part of Michigan Basin the Eau Claire and Mount Simon Formations merge to form the Munising Formation consisting entirely of orthoquartzitic sandstone (Hamblin, 1958). This formation has a maximum thickness of 30 feet in the western part

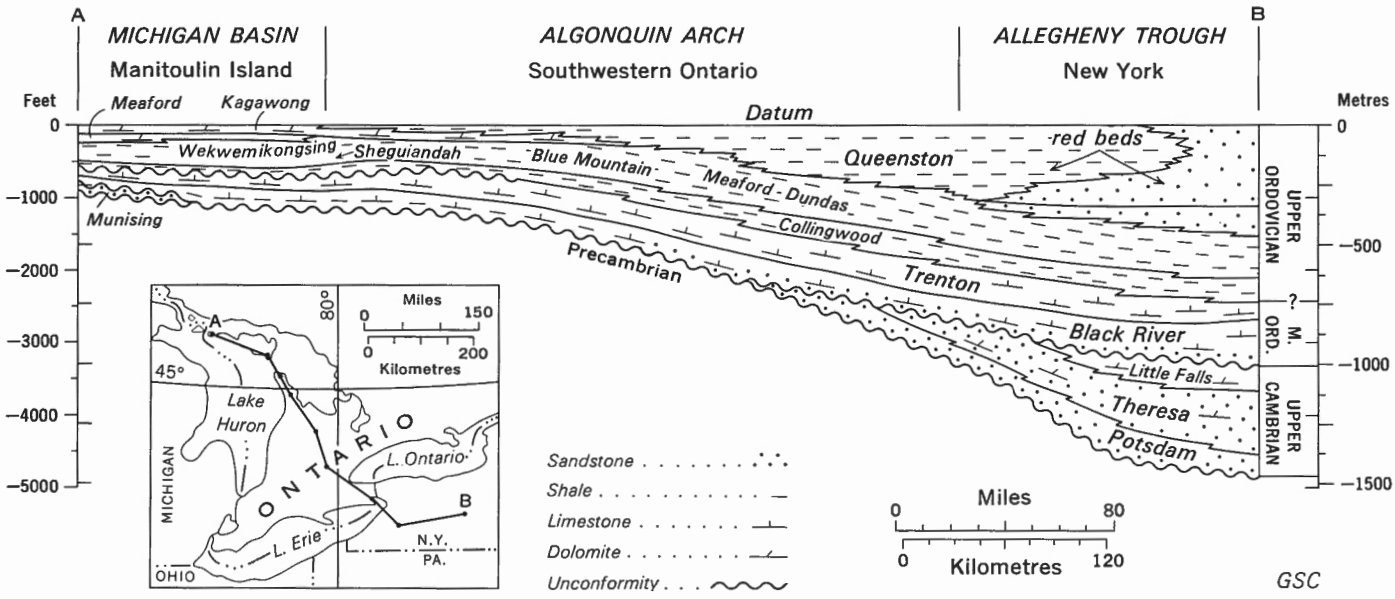


FIGURE VI-8. Cross-section of Cambrian and Ordovician formations in southwestern Ontario and northern New York (by B. V. Sanford).

of Manitoulin Island and increases to more than 200 feet in the northern peninsula of Michigan. Although detritus was presumably derived from the Precambrian crystalline rocks over which the Upper Cambrian sea transgressed, large land areas existed in northern Michigan and Wisconsin throughout Dresbachian and Franconian time, and constituted the main provenance for the considerable volume of detritus deposited within the northern and western parts of Michigan Basin.

The youngest Cambrian rocks in southwestern Ontario, the Little Falls Formation, lie beneath Lake Erie gradationally overlying the Theresa Formation. They consist of tan, finely crystalline dolomite, 100 feet thick at the International Boundary.

Ordovician

Tectonic Summary

During the Ordovician very thick, mainly eugeosynclinal sedimentary and volcanic rocks were deposited conformably on Cambrian rocks in Appalachian Geosyncline. On St. Lawrence Platform relatively thin carbonates and shale were deposited with angular unconformity on Precambrian crystalline rocks of the eastern craton or disconformably on Cambrian sandstones. In the Taconian Orogeny, during the Middle and Late Ordovician, parts of the geosyncline were folded, metamorphosed, intruded by ultramafic, mafic, and granitic bodies, uplifted, and eroded. St. Lawrence Platform was intermittently epeirogenically uplifted and eroded.

During the Early and early Middle Ordovician many thousands of feet of volcanics and greywacke accumulated in Notre Dame Trough, and thick paraplatformal orthoquartzite and shale accumulated in the central part of the trough in New Brunswick (Figs. VI-9, 10). Thin shale was deposited on Avalon Platform of the mainland, and thick, shallow-water siltstone and sandstone with interbeds of oölitic iron-formation accumulated on the platform in southeastern Newfoundland. Rather thin Lower Ordovician dolomite was deposited on St. Lawrence Platform and probably did not cover much of the shield. At the end of the Early Ordovician the platform was uplifted, and the Lower Ordovician and Cambrian rocks were eroded from Algonquin Arch and the margins of Quebec and Anticosti Basins. During the early Middle Ordovician, limestone, sandstone, and shale were deposited in Anticosti and Quebec Basins, whereas the site of Michigan Basin and Algonquin and Frontenac Arches remained land.

The early phase of the Taconian Orogeny occurred

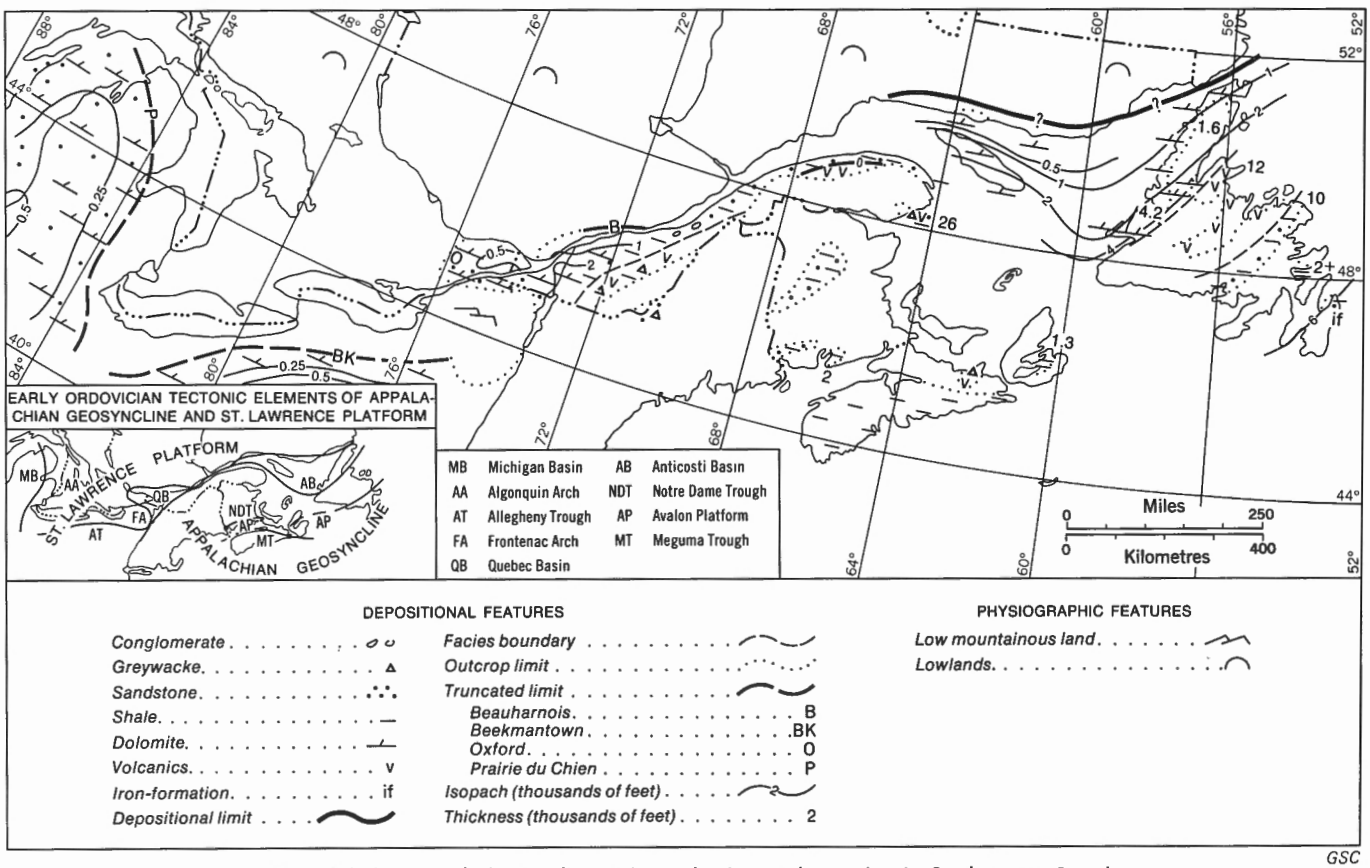


FIGURE VI-9. Lower Ordovician sedimentation, volcanism, and tectonism in Southeastern Canada.

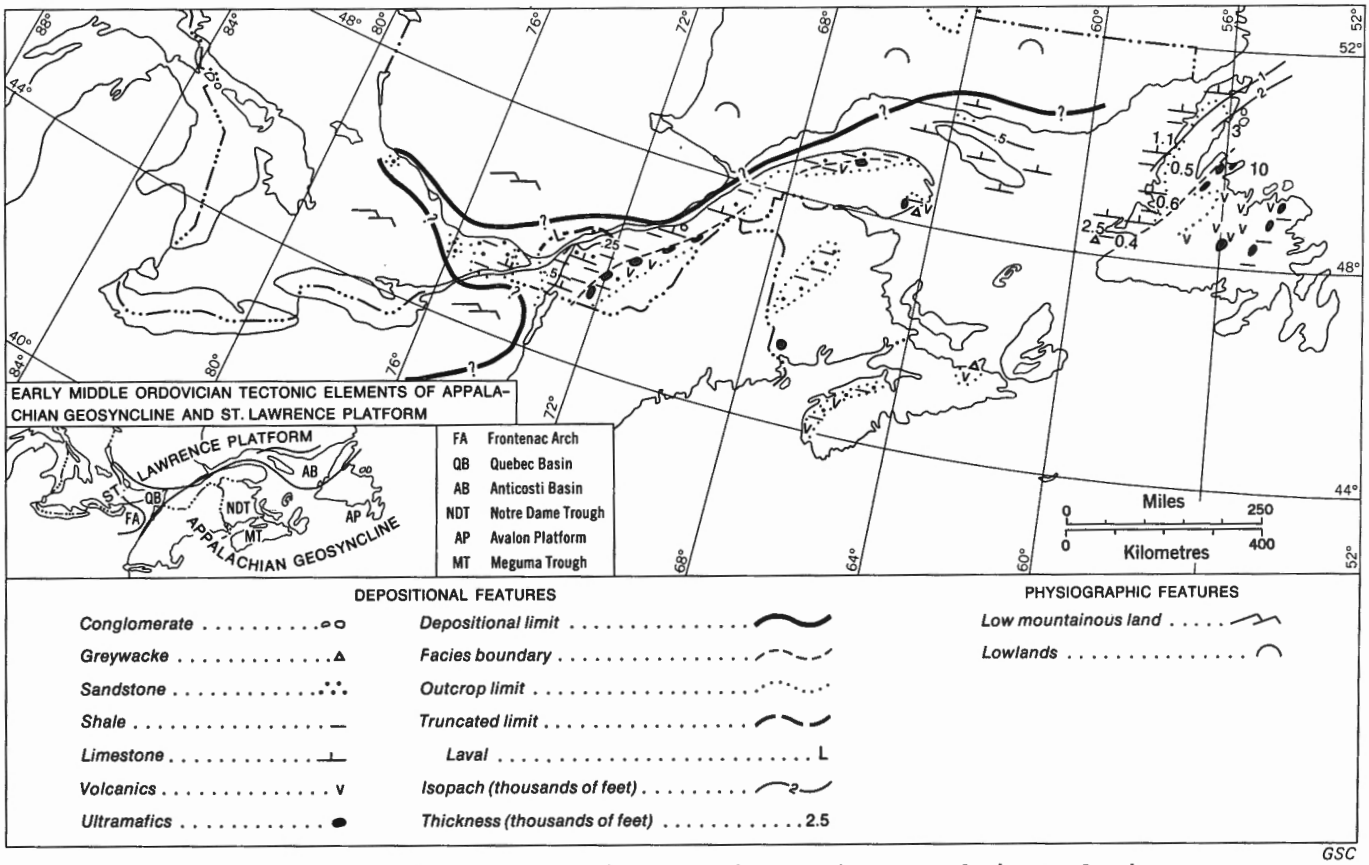


FIGURE VI-10. Early Middle Ordovician sedimentation, volcanism, and tectonism in Southeastern Canada.

during middle Middle Ordovician, about Ashby to early Wilderness (Fig. VI-11). Ultramafic bodies were emplaced in the volcanic belts of Notre Dame Trough. Quebec and Burlington Geanticlines were initiated, and folding, metamorphism, granite intrusion, uplift, and erosion occurred. Northwest of the geanticlines, adjacent to St. Lawrence Platform, a complementary trough developed in which greywacke and shale were deposited. In western Newfoundland Cambrian–Ordovician rocks and ultramafic–mafic bodies were thrust westward onto the platform. Strata of southwestern Avalon Platform were probably folded, metamorphosed, intruded by granite, uplifted, and eroded. No orogenic effects have been recognized on Avalon Platform in Newfoundland or in Meguma Trough. On St. Lawrence Platform, epeirogenic uplift coinciding with the early phase of Taconian Orogeny resulted in retreat of the sea and minor erosion.

During late Middle Ordovician thick black shale and greywacke were deposited along the northwest side and southwestern end of Quebec Geanticline. In axial Notre Dame Trough eugeosynclinal deposition was initiated in central New Brunswick and continued in central Newfoundland. Avalon Platform lacks late Middle and Upper Ordovician strata and during this time may have been a lowland of little deposition or under erosion. Eugeosynclinal deposition and volcanism also continued in Meguma Trough throughout the Middle and Late Ordovician without interruption by Taconian Orogeny. Late Middle Ordovician limestones were deposited over wide areas of the St. Lawrence Platform and these now form the oldest strata preserved in most outliers on the Canadian Shield. In Allegheny Trough and Quebec Basin limestone graded southeastward to thick shale sequences that were probably derived from Quebec Geanticline. In southwestern Newfoundland the Humber Arm klippe was partly covered by sandstone and limestone of late Middle Ordovician age.

The late phase of Taconian Orogeny, during the Late Ordovician, produced folding, metamorphism, granite intrusion, uplift, and erosion (Fig. VI-12). The older geanticlines were enlarged, and the Miramichi Geanticline was initiated. These elements subsequently controlled sedimentation until the Middle Devonian. Quebec Geanticline and the region to the northwest were subjected to folding and northwest-directed thrusting. The volume of late Ordovician detritus suggests that the southwestern part of the geanticline was uplifted more than the northeastern part. The Burlington Geanticline was probably uplifted and possibly folded at this time. Miramichi Geanticline originated within a volcanic belt; the rocks were folded, metamorphosed, intruded by granites, uplifted, and eroded. In the Matapedia facies belt, in axial Gaspé Trough between Quebec and Miramichi Geanticlines, deposition of limestone and shale continued from Middle Ordovician to early Silurian with-

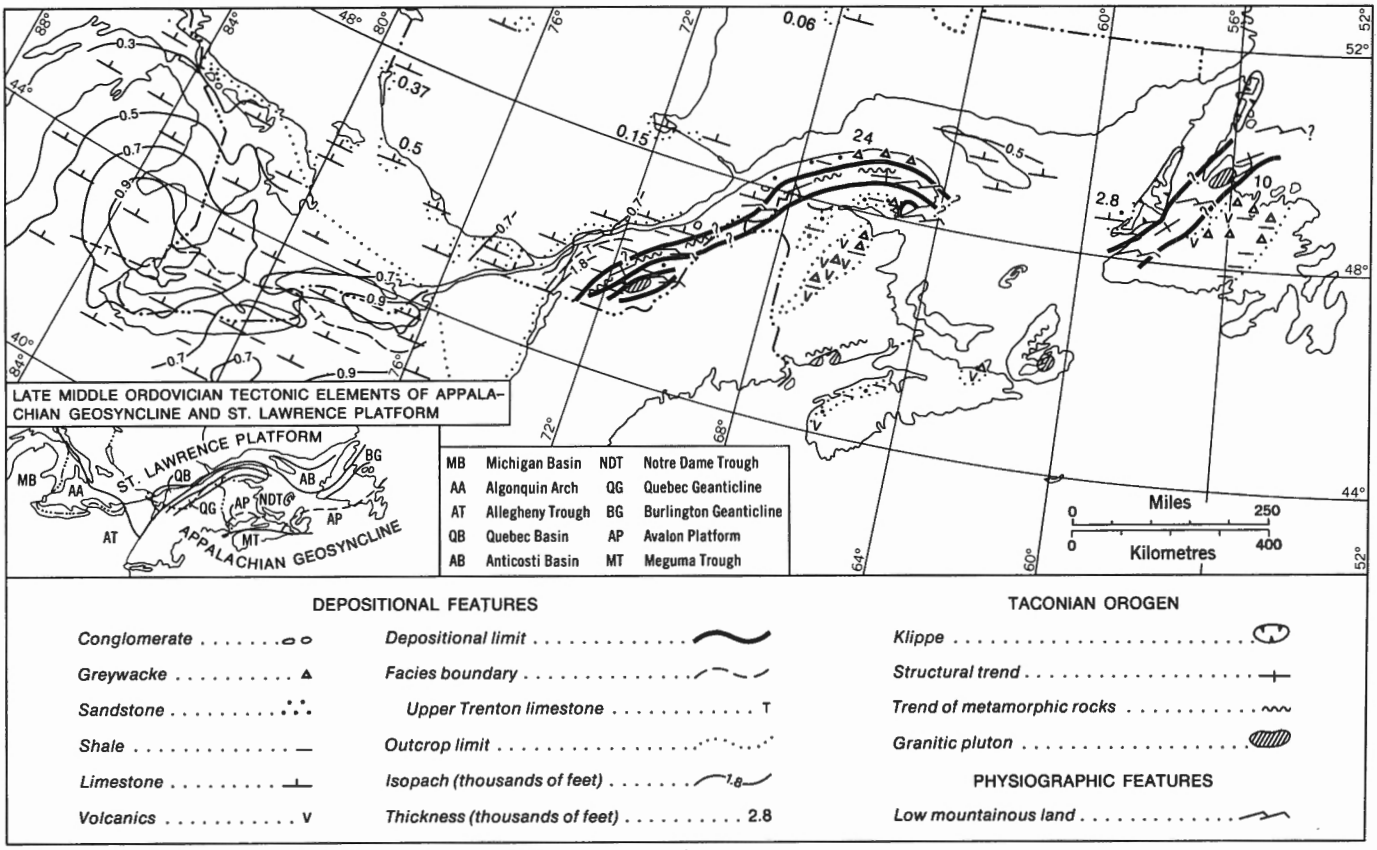


FIGURE VI-11. Late Middle Ordovician sedimentation, volcanism, and tectonism in Southeastern Canada, with some features of Taconian Orogeny produced during middle Middle Ordovician.

out reflecting the orogeny in the nearby geanticlines. Similarly, no orogenic effects of this phase have been recognized on Avalon Platform or in Meguma Trough.

Late Ordovician deposition in Appalachian Geosyncline was restricted by the growth of the geanticlines. Some sandstone and shale were deposited on Quebec Geanticline in the Eastern Townships. Deposition was continuous in the Matapedia facies belt. In Notre Dame Trough in Newfoundland volcanism gave way to deposition of greywacke and conglomerate which continued into the Silurian. On St. Lawrence Platform early Upper Ordovician black and grey marine shale was deposited in Allegheny Trough, Michigan, Quebec, and Anticosti Basins, and on the southern Canadian Shield. In latest Ordovician (Richmondian) fine to coarse clastic deltaic red beds derived from Quebec Geanticline were carried into Allegheny Trough and Quebec Basin and across Algonquin Arch into Michigan Basin. Deposition of normal marine limestones prevailed in western and northern Michigan Basin and western Anticosti Basin.

Lower and Early Middle Ordovician (Figs. VI-9, 10)

Appalachian Geosyncline. In *Notre Dame Trough,* Lower and early Middle Ordovician sedimentary and volcanic rocks have not generally been differentiated from similar, probable Cambrian rocks because fossils are sparse or lacking and deposition was apparently continuous almost everywhere. In southern Quebec the rocks can be separated into two facies belts that parallel the northwestern edge of the trough. Both the non-volcanic belt to the northwest and the volcanic belt to the southeast probably contain several thousand feet of strata. The facies boundary in the Eastern Townships corresponds roughly to the present anticlinorium, exposing older rocks of the Oak Hill, Sutton, Bennett, and Rosaire Formations; in Gaspé it falls along the north side of Shickshock Mountains. In the non-volcanic belt at Quebec City (Osborne, 1956) the Levis Formation is latest Cambrian to early Middle Ordovician and is bounded at the base and top by thrust faults. It consists of an unknown thickness of slate, siltstone, sandstone, and limestone-conglomerate. Slate and siltstone are grey, green, and red. The limestone-conglomerate occurs in lenticular beds of great lateral dimensions. About 95 per cent of the clasts are white to grey, fine-grained, massive to oölitic limestone; the remainder is dolomite and shale. The clasts vary from angular blocks and slabs to well rounded pebbles, cobbles, and boulders; the matrix is mainly carbonate. Clasts have yielded fossils of Lower, Middle, and Upper Cambrian and of Lower Ordovician age. One large Middle Cambrian block is more than 500 feet long and 40 feet thick. The source beds are not exposed; they probably lie to

the southeast beneath the thrust sheets of the folded Quebec Group.

Along the south shore of St. Lawrence River, northeast of Quebec City (Hubert, 1967), the Lower Ordovician Kamouraska Formation of orthoquartzite and limestone-conglomerate is underlain by Upper Cambrian and Lower Ordovician feldspathic sandstone, orthoquartzite, and limestone-conglomerate, and overlain by Lower Ordovician slate and siltstone. Detritus in the feldspathic sandstone was probably derived from the southeast near the anticlinorium bounding the non-volcanic facies belt on the southeast, whereas the detritus in the orthoquartzite and limestone-conglomerate was derived from the northwest. Still farther northeast, in northern Gaspé Peninsula, there is an unknown thickness of mainly Lower and some early Middle Ordovician graptolitic green-grey feldspathic sandstone and dark slate with minor grey, green, and red shale, conglomerate, limestone, and chert. Beds of orthoquartzite of the Kamouraska type and limestone-conglomerate are intercalated with Cambrian–Ordovician strata along almost the entire south shore of St. Lawrence River. Volcanic rocks are rare.

The volcanic facies belt in the Eastern Townships of southern Quebec (St-Julien, 1967) comprises unfossiliferous probable Upper Cambrian and Lower Ordovician rocks and possibly early Middle Ordovician rocks. They are unconformably overlain by late Middle Ordovician rocks, and farther southeast are blanketed by unconformably overlying Silurian and Devonian strata. In the Eastern Townships, the Caldwell Group and Brompton, Ascot, and Weedon Formations occur in separate areas; all are presumed to be about the same age. They consist of several thousand feet of silicic and mafic lava and tuff; grey, green, and red slate; and greywacke. Pillowed mafic lavas are common. Rocks of some formations have been metamorphosed to phyllite and schist. Orebodies of massive pyrite with some chalcopyrite and traces of lead and zinc sulphides are associated with schistose rhyolite and porphyry. In the southeasternmost Eastern Townships the Arnold River Formation is exposed in the core of the Boundary Mountain anticlinorium which is flanked and partly overlapped by Silurian strata. The formation is unfossiliferous but is probably Upper Cambrian and Lower Ordovician. It consists of thick, schistose feldspathic quartzite. The volcanic rocks reappear in the Shickshock Group in northern Gaspé Peninsula (Mattinson, 1964; Ollerenshaw, 1967). The group consists of several thousand feet of mafic lava, tuff, minor feldspathic sandstone, slate metamorphosed to amphibolite, amphibole schist, and mica schist. Pillow structures are common in some lavas. Stratigraphic and structural relations with the non-volcanic strata to the north are uncertain. Facies equivalence, locally complicated by faults, seems to be the most reasonable hypothesis. In south-

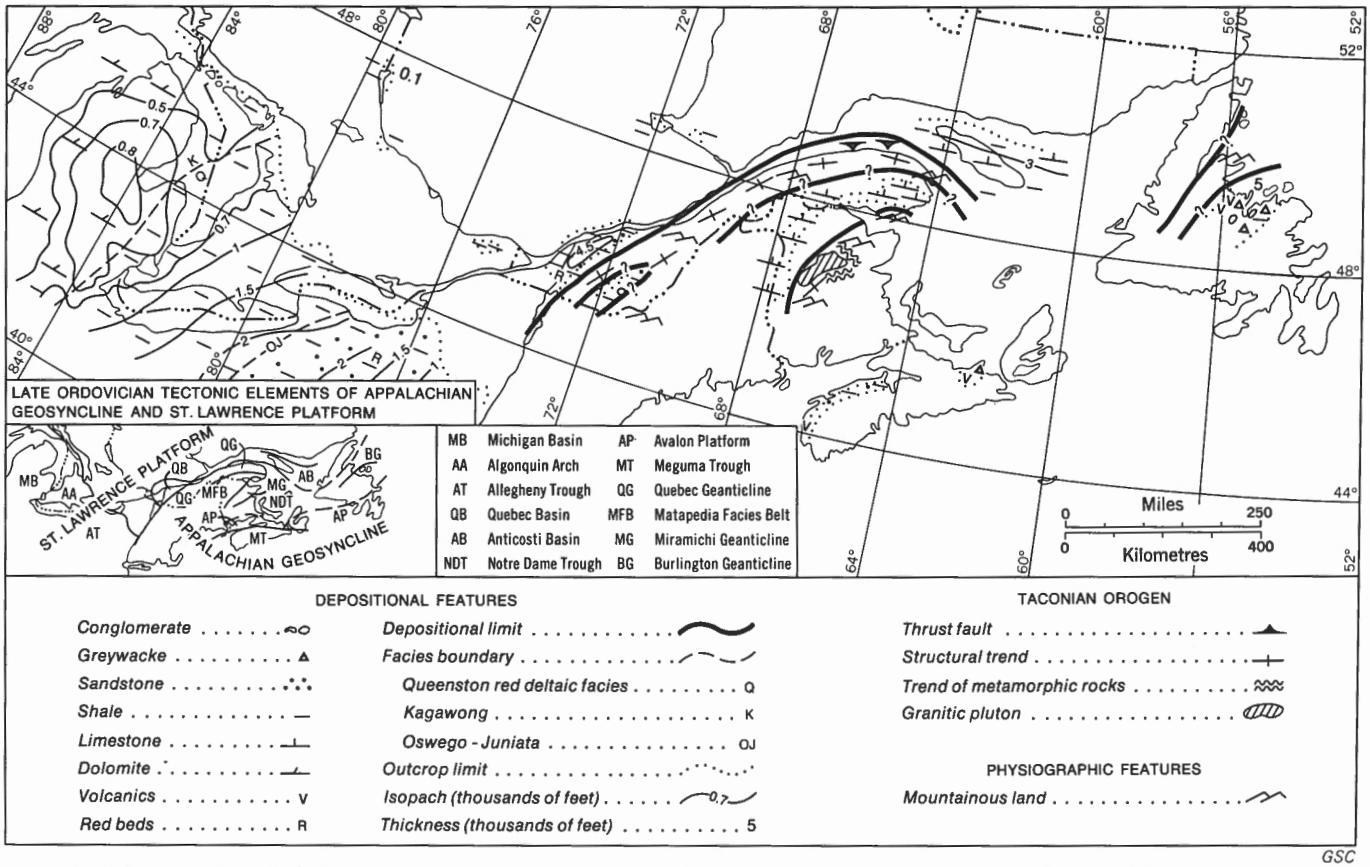


FIGURE VI-12. Upper Ordovician sedimentation, volcanism, and tectonism in Southeastern Canada, with some features of Taconian Orogeny.

eastern Gaspé Peninsula the Maquereau Group (Ayrton, 1967) is faulted against the late Middle Ordovician Mictaw Group and is unconformably overlain by the Silurian Chaleurs Bay Group. It is unfossiliferous and has been considered Lower Ordovician, Cambrian, or Precambrian. It is probably Upper Cambrian to early Middle Ordovician like the rocks south of St. Lawrence River. The Maquereau Group consists of several thousand feet of quartzose greywacke, red and green siltstone and slate, quartzite, and mafic volcanic rocks.

In central New Brunswick (Poole, 1963) several thousand feet of orthoquartzite and grey and green-brown slate and phyllite, in part metamorphosed to schist and gneiss, comprises the oldest rocks of the Miramichi Geanticline. Shelly fauna within the top 50 feet are of Lower or early Middle Ordovician age (R. B. Neuman). Similar quartzose strata in eastern Maine are considered to be Cambrian. The higher maturity of the strata indicates a more stable tectonic and shallow-water depositional environment than strata to the south or the volcanic–greywacke rocks to the north in southern Quebec. In southern New Brunswick black slate and quartzite of the Dark Argillite Division of the Charlotte Group, of unknown thickness, has yielded Arenigian graptolites.

In northern Nova Scotia, in Antigonish Highlands, the oldest rocks constitute the Browns Mountain Group (Williams, 1914). It is unfossiliferous and overlain with a disconformity or low-angle regional unconformity by the Silurian Arisaig Group. The Browns Mountain consists of 15,000 feet of silicic and mafic lava, tuff and breccia, greywacke, slate, and quartzite. Some slate is red and some felsic volcanics are ignimbrites. Hematitic quartzite and oölitic hematite beds a few feet thick occur in two places within the group. The iron-formation and some associated linguloid shells suggest correlation with Lower Ordovician hematite-bearing strata of southeastern Newfoundland.

Lower Ordovician strata in Newfoundland are autochthonous in Notre Dame Trough of central Newfoundland and allochthonous on strata of the St. Lawrence Platform, having been moved westward during the Taconian Orogeny in the middle Middle Ordovician. In Notre Dame Trough rocks of known and probable Lower Ordovician and early Middle Ordovician age cannot be separated. Those of the western trough are dominantly volcanic and have been assigned to the Baie Verte, Snooks Arm, Lushs Bight, and Wild Bight Groups, whereas those of the central trough are dominantly sedimentary and are included in the Exploits and Gander Lake Groups (Williams, 1964, 1969; Jenness, 1963). Graptolites and shelly fauna are scarce; age assignments and equivalence of strata are established generally by lithology and stratigraphic position. The Snooks Arm, Lushs Bight, and Wild Bight Groups consist of about 15,000 feet of mafic volcanic rocks with minor sedimentary rocks. The volcanic rocks are mainly massive and pillowed basalt lava, breccia, and tuff, all altered to greenstone. Less common are andesite, dacite, trachyte lava, and varicoloured pyroclastic rocks. Some basalts are spilitic having 4 to 4.5 per cent Na_2O. The sedimentary rocks are mainly greywacke, sandstone, and black, grey, green, and red slate. Chert forms beds between some basalt flows, a filling between pillows, and is interbedded with other sedimentary rocks. Limestone beds are rare and are commonly fossiliferous. The Baie Verte Group, west of Notre Dame Bay, is unfossiliferous but is lithologically similar to the lower Ordovician rocks described above. It apparently overlies schist and gneiss of Fleur de Lys Group with structural conformity. Massive chalcopyrite–pyrite bodies locally containing galena and sphalerite are associated with schistose mafic volcanic rocks. The lower part of Exploits Group contains some volcanic rocks and much slate, greywacke and minor conglomerate, chert, and limestone. Along the east side of Notre Dame Trough quartzite and grey slate within the lower member of Gander Lake Group is probably early Ordovician and has been described with the Cambrian system.

In western Newfoundland, Lower and early Middle Ordovician sedimentary and volcanic rocks form the upper parts of two klippen that rest on early Middle Ordovician limestone and black shale of the Table Head Formation. Within the Humber Arm klippe of southwestern Newfoundland (Brückner, 1966) black shale near the top of the Cooks Brook Formation contains Tremadocian graptolites. The conformably overlying Middle Arm Point Formation, 400 to 900 feet thick, consists of black and green shale with some interbeds of siltstone, dolomite breccia, quartzite, and sandstone, and has yielded Arenigian graptolites. The two conformably overlying formations are unfossiliferous, but are probably no younger than early Middle Ordovician because they were moved as part of the klippe during middle Middle Ordovician. They consist of the Blow-me-Down Brook Formation, 800 to 1,650 feet thick, of brown thick-bedded impure feldspathic sandstone with some conglomerate and interbedded red and green argillite, that is gradationally overlain by the "Humber Arm Volcanics", 1,200 to 3,000 feet thick, of mafic lava (both massive and pillowed) and pyroclastic rocks. Along the northeastern end of the Humber Arm klippe, Lower Ordovician limestone, shale, and limestone-conglomerate are believed to be part of the klippe, but unlike the klippe rocks to the south, were derived from a more stable depositional environment on the east edge of Anticosti Basin. The Green Point Formation (Kindle and Whittington, 1958) is 400 feet thick with top and bottom unexposed. It consists of grey and green-grey thin-bedded shale and limestone, minor red and green shale, and some interbeds of limestone-conglomerate (Pl. VI-3). Penecontemporaneous slumping or some diagenetic process has led to crumpling of thin limestone interbeds in shale to produce unusual folds with irregular trends that trace out polygonal outlines several inches in diameter. Anticlinal crests are bent, cracked, or broken (Pl. VI-4). Farther north in the klippe,

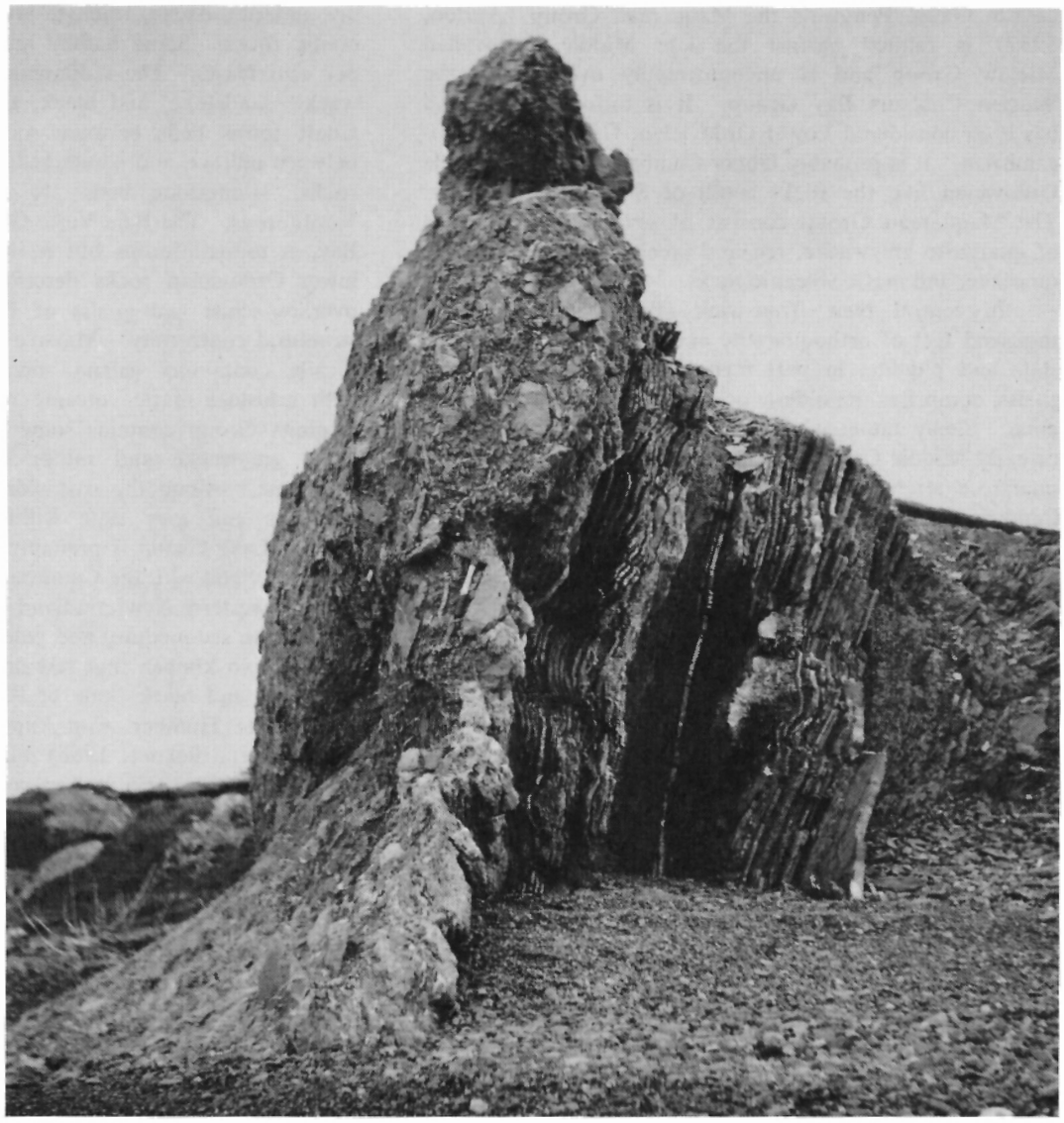


PLATE VI-3

Limestone breccia with interbedded shale and limestone of the Lower Ordovician Green Point Formation, Green Point, Newfoundland.

on Cow Head Peninsula, the upper 400 feet of the Cow Head Group consists of Lower and early Middle Ordovician limestone, limestone-conglomerate, and shale partings that are lithologically similar to the Cambrian lower part. Limestone boulders are slightly older than the strata; the boulders in the Ordovician strata range from Upper Cambrian in the lower beds to early Middle Ordovician (Whiterock) in the upper beds. The conglomerate beds, like those of the Green Point Formation, apparently originated as masses of limestone clasts that slid into areas of deposition of normal limestone. A few miles north and south of Cow Head Peninsula the Cow Head Group is overlain conformably by an unnamed formation—a few hundred feet of green sandstone and grey and red shale with Llanvirnian graptolites.

Within the Hare Bay klippe of northern Newfoundland (M. F. Tuke) the Lower Ordovician Northwest Arm Formation consists of 200 feet or more of black and green slaty argillite with interbeds of sandstone, limestone, greywacke, and conglomerate. The Northwest Arm Formation has been overthrust from the east by the Maiden Point and Goose Cove Formations that contain greywacke and volcanic rocks that are partly Lower Ordovician. The strata resemble the Canada Head Group and overlying volcanics exposed farther south in the Hare Bay klippe.

On *Avalon Platform* Lower Ordovician black shale was deposited in southern New Brunswick and Cape Breton Island; shale, sandstone, and iron-formation were deposited in southeastern Newfoundland. These strata are the youngest recognized Ordovician strata on the platform. At Saint John, New Brunswick (Hayes and Howell, 1937), the Navy Island Formation consists of 100 feet of thin-bedded black shale, with Tremadocian graptolites, that overlies similar black shale of the Upper Cambrian Narrows Formation, probably with slight dis-

conformity. The succeeding, Arenigian Suspension Bridge Formation consists of 50 feet of black graptolitic shale. In central Cape Breton Island (Hutchinson, 1952) the McLeod Brook Formation conformably overlies Upper Cambrian black shale and minor limestone of the MacNeil Formation, and consists of less than 1,300 feet of grey shale with a sparse brachiopod and graptolite fauna of Tremadocian and Arenigian age. In southeastern Newfoundland (Rose, 1952; Jenness, 1963) Tremadocian grey and black shale of the Clarenville Formation, perhaps as much as 2,000 feet thick, lies conformably on similar shales of the Upper Cambrian Elliott Cove Group on the west side of the Avalon Platform west of Trinity Bay. In Conception Bay, on the eastern side of the platform, 2,000 to 3,000 feet of Clarenville shale is believed to underlie the bay. The islands in the bay consist of Tremadocian and Arenigian strata. The older, Bell Island Group comprises an estimated 4,000 feet of grey, brown, and greenish micaceous sandstone, siltstone, and shale with minor hematitic beds. The conformably overlying Wabana Group, at least 1,000 feet thick, consists of grey, brown, and greenish shale, siltstone, micaceous sandstone, and oölitic hematite. Shallow-water deposition is indicated by crossbedding, ripple-marks, and mudcracks. Hematite beds in Wabana Group have been mined and have yielded an ore with relatively high phosphorus.

In *Meguma Trough* the Halifax Formation (Taylor, 1967) contains Tremadocian graptolites and conformably and gradationally overlies the probably Upper Cambrian Goldenville Formation. The Halifax consists of thin-bedded grey and minor greenish and black slate that thins southwesterly from more than 12,000 feet in the northeast near Wolfville, to 1,500 feet in westernmost Nova Scotia near Yarmouth.

St. Lawrence Platform. In the *Quebec Basin* (Clark, 1965; Wilson, 1946) the March Formation consists of interbedded orthoquartzitic sandstone and dolomite that form a transitional facies between the underlying orthoquartzitic sandstone and the overlying Oxford dolomite. The March varies in thickness from about 30 feet near Ottawa, to 250 feet at Montreal, and 500 feet in southeastern Quebec Basin. The Oxford Formation in the Ottawa area and its equivalent, the Beauharnois Formation in western Quebec, consist of bluish grey and brown, fine- to medium-

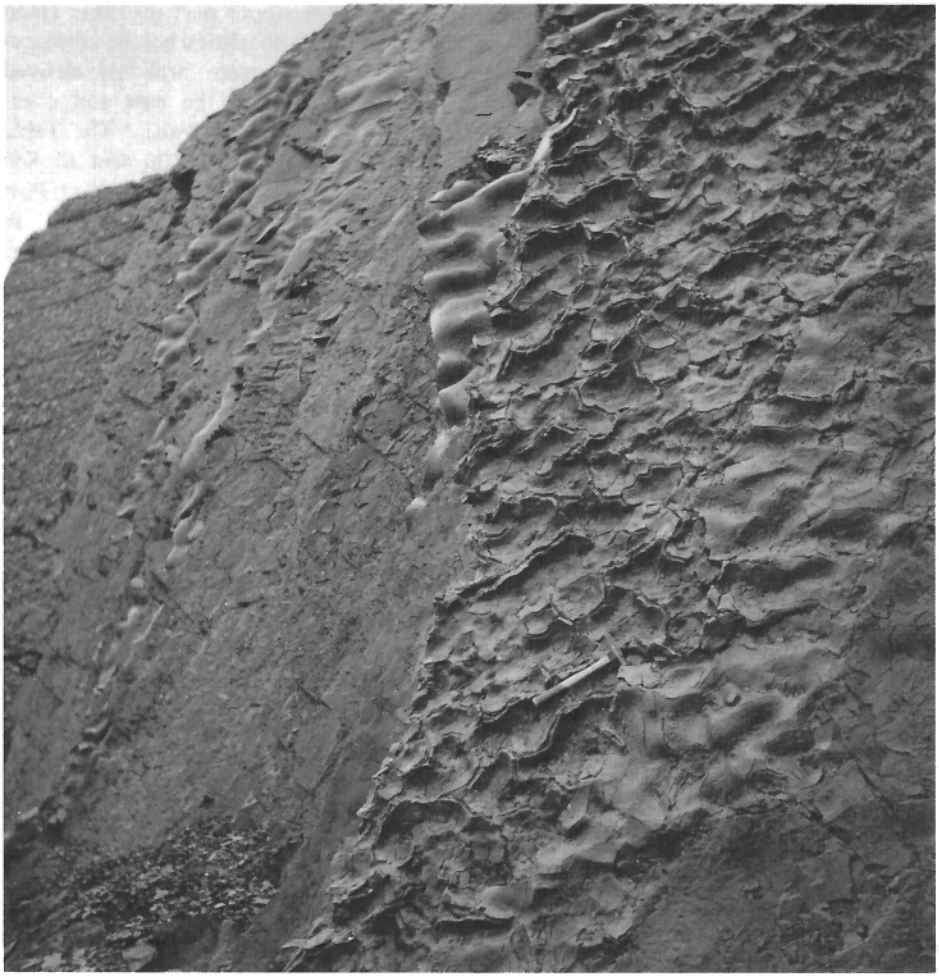


PLATE VI-4

Bedding planes of Lower Ordovician Green Point Formation showing crests of small anticlinal folds cracked and broken possibly by penecontemporaneous slumping, Green Point, Newfoundland.

crystalline dolomite that was deposited in a shallow-water near-shore environment. The upper beds consist of dark greyish brown, microcrystalline dolomite with interbeds of limestone, siltstone, and shale. They occur in the southeastern part of the basin and reflect a somewhat deeper water depositional environment. The Oxford is 410 feet thick; the Beauharnois is 800 feet thick near Montreal and thickens to 1,500 feet in the southeastern part of the basin.

The Rockcliffe and Laval Formations are of early Middle Ordovician (Marmor) age and form part of the Chazy Group (Wilson, 1946). They disconformably overlie Lower Ordovician dolomite and locally overlap its bevelled edges around the border of the basin to rest directly on Precambrian crystalline rocks. In the Ottawa Embayment, the Rockcliffe Formation, 250 feet thick, consists of olive-green and minor red shale and siltstone with lenses of coarse-grained protoquartzitic sandstone. The Laval Formation in eastern and southern Quebec Basin is more than 600 feet thick and consists of a basal unit of protoquartzitic sandstone and greenish grey shale and siltstone that grades vertically and laterally toward the basin to a thick unit of interbedded limestone, shale, and shaly dolomite. Calcarenite beds (St. Martin Member) intertongue with the Rockcliffe Formation in the eastern part of Ottawa Embayment and interdigitate throughout the middle and upper parts of the Laval Formation in Quebec Basin. Small bioherm reefs composed of coral and bryozoa colonies developed locally in the calcarenite facies at various horizons in the upper part of the Laval.

In western *Anticosti Basin,* the Lower Ordovician Romaine Formation is 260 feet thick where it unconformably overlies Precambrian crystalline rocks on the Quebec mainland (Twenhofel, 1938). It thickens southward to 1,200 feet in the subsurface beneath central Anticosti Island. The Romaine consists of greyish brown and bluish grey stromatolitic dolomite with a thin basal veneer of orthoquartzitic sandstone. On Mingan Islands the early Middle Ordovician (Marmor and Ashby) Mingan Formation rests disconformably on Lower Ordovician dolomite and consists, in ascending sequence, of as much as 39 feet of basal conglomerate, sandstone, and shale, 30 feet of bioclastic limestone and coarse calcarenite, and 96 feet of finely crystalline and aphanitic limestone. The formation thickens southward from 165 feet on Mingan Islands to about 500 feet in the subsurface of Anticosti Island.

In eastern Anticosti Basin, the St. George Group (Schuchert and Dunbar, 1934) outcrops in western Newfoundland and passes beneath the two klippen. It is primarily Lower Ordovician but locally includes some Cambrian. The group consists of thick-bedded, massive, grey- and buff-weathering dolomite with some interbedded dolomite and limestone in its upper part. It thickens southeastward from 1,600 feet along the north coast to 4,200 feet near Corner Brook. On the east side of Great Northern Peninsula the Chimney Arm Formation at Canada Bay lies disconformably on Middle Cambrian carbonates and dips beneath the Hare Bay klippe (Betz, 1939). It comprises more than 1,200 feet of black and grey dolomite and dark grey limestone with shaly interbeds. Mudcracked beds indicate a shallow-water depositional environment. West of White Bay the Doucers Formation is similar but unfossiliferous (Neale and Nash, 1963). It consists of 120 to 300 feet of fine-grained, white to blue-grey marble. The early Middle Ordovician (Whiterock to early Marmor) Table Head Formation at its type locality on the west coast of Newfoundland consists of 1,110 feet of limestone and shale that disconformably overlies Lower Ordovician dolomite (Whittington and Kindle, 1963). It comprises a lower unit of 810 feet of dark grey limestone, a middle unit of 270 feet of dark grey limestone and black shale with some contorted rubbly and slumped beds, and an upper unit of 30 feet of black shale. The formation is overlain conformably by at least 700 feet of unnamed and undated, but presumably early Middle Ordovician, grey siltstones and greenish sandstones exhibiting crossbeds and some graded beds and load casts. Similar sandstones overlie the Cow Head Group of the klippe and if they are the same formation, as seems probable, deposition there began earlier (that is during deposition of the upper part of Table Head limestone and shale) and in both localities before emplacement of the klippe. The sands were probably derived from within Notre Dame Trough to the east and overlapped progressively younger strata westward. The Table Head Formation thins southerly from 1,100 feet to 600 feet near Corner Brook and to 400 feet or more at Port au Port. The thinning is apparently southeastward, in the opposite direction to that of the underlying St. George Group. On Port au Port Peninsula the Table Head Formation is overlain by several hundred feet of limestone-conglomerate containing clasts of St. George and Table Head carbonate, which in turn is overlain by about 2,500 feet of greenish grey greywacke and shale of late Llanvirnian to early Caradocian age. The lower part of the greywacke sequence farther east on the peninsula was overridden by the Humber Arm klippe. Blocks from the klippe were incorporated in the greywacke sequence, apparently while the klippe rocks were displaced westward. In Canada Bay on northern Great Northern Peninsula, the Bide Arm and Englee Formations are largely correlative with the Table Head Formation. The Bide Arm rests on Lower Ordovician dolomite and limestone and consists of about 1,500 feet of dark grey limestone, blue-grey dolomite, and marble. The overlying Englee is about 1,500 feet of black slate with sandstone near the top.

Taconian Orogeny, Early Phase

Ultramafic intrusions. Bodies of ultramafic and mafic rocks and associated small granitic stocks and dykes occur in a belt along the western flank of Notre Dame Trough

in southern Quebec and western Newfoundland, along the eastern flank in eastern Newfoundland, as parts of two klippen in western Newfoundland, and as an isolated body in southern New Brunswick (Fig. VI-10). They were emplaced into Cambrian, Lower Ordovician, and probable early Middle Ordovician volcanic rocks during the early or middle Middle Ordovician. The associated small granitic bodies are spatially and apparently genetically related, and hence probably of the same age. The ultramafic rocks of southern Quebec contributed detritus to late Middle Ordovician strata. The bodies in the Humber Arm klippe were carried westward as part of the klippe, which after displacement was overlain by late Middle Ordovician (Wilderness) strata. The ultramafic bodies of the Hare Bay klippe and of western Notre Dame Trough are presumed to be the same age. In western Notre Dame Bay clasts of ultramafic rock and detrital chromite, from the body that intruded the volcanics of the lower Ordovician Snooks Arm Group, occur within the unconformably overlying, probably Silurian, Cape St. John Group. During later deformation in the Acadian Orogeny the ultramafic body moved upward as a solid intrusion to cut the Cape St. John Group. The bodies that intruded the Gander Lake Group of eastern Notre Dame Trough were emplaced into Lower or Middle Ordovician volcanic and sedimentary rocks, but the relationship and ages of nearby strata are not precisely known. Near the southwest end of the Gander Lake serpentinite belt, in central Newfoundland, an ultramafic body appears to have intruded the Silurian Botwood Group. Clasts of ultramafic rock do occur locally in conglomerates of the Lower and Middle Silurian Goldson Formation. The St. Stephen ultramafic body in eastern Notre Dame Trough in southwestern New Brunswick has intruded Lower Ordovician black slate and quartzite of the Charlotte Group. The intrusion probably contributed the diorite clasts found in the nearby mid-Silurian Oak Bay Formation. The small, elongate, serpentinized peridotite dyke-like body along an Acadian fault—the Rocky Brook–Millstream break in northern New Brunswick—is of uncertain age but has intruded Silurian strata with no thermal metamorphic effects. It is not known whether the emplacement of the recognized Ordovician ultramafic bodies was genetically related to the Taconian Orogeny or to volcanic processes. Most lack thermal aureoles.

The ultramafic rocks of the Eastern Townships are the host rocks for the famous chrysotile asbestos mines (Chap. VII). They consist of elongate bodies of peridotite, dunite, and minor pyroxenite and gabbro lying nearly concordant with the enclosing strata. Plugs and dykes of cataclastic granite and syenite cut the ultramafic bodies and are confined to them. Muscovite from two such bodies yielded K–Ar dates of 477 and 481 m.y., about early Middle Ordovician. The ultramafic rocks are intensely sheared and serpentinized and locally steatized and carbonatized. Soapstone and talc are mined in some localities. In contrast, the Mount Albert ultramafic body in northern Gaspé Peninsula has an ovoid surface outline and is believed to be a high-temperature mass. It is composed of dunite, peridotite, and minor pyroxenite. It has been little serpentinized and lacks granitic rocks. Gently dipping banding indicates an internal domal structure. In the thermal aureole, as much as 1,000 feet wide, greenschist of the Shickshock Group grades through amphibolite to garnetiferous hornblende–pyroxene granulite at the contact. Muscovite and biotite from garnetiferous micaceous quartzite within the aureole 700 feet from the contact yielded K–Ar dates of 495 m.y., early Ordovician. The St. Stephen body in southwestern New Brunswick consists of several square miles of gabbro and minor peridotite, and it too lacks internal granitic intrusions. Deposits of nickel and copper sulphides occur in the gabbro. Biotite from gabbro near the peridotite yielded a K–Ar date of 462 ± 20 m.y., Middle Ordovician.

In Newfoundland, in western Notre Dame Trough, peridotite and minor pyroxenite, generally serpentinized and locally steatized and carbonatized, contain chrysotile asbestos that is mined at Baie Verte. Small associated bodies of gabbro and diorite (but no granitic plugs and dykes) are probably genetically related to the ultramafic bodies, whereas other larger bodies cut Silurian rocks and are associated with Acadian granites. In the Gander River belt, in eastern Notre Dame Trough, the ultramafic rocks are generally elongate bodies of serpentinized peridotite and pyroxenite with closely associated stocks of gabbro and diorite and a few smaller bodies and dykes of albite granite. Locally the rocks are intensely sheared and altered to talc–carbonate. One such body contains 10 million tons or more of low-grade magnesite.

The ultramafic bodies in the two klippen of western Newfoundland were probably originally emplaced in the western Notre Dame Trough. In the Humber Arm klippe interbanded peridotite and dunite grade upward into banded gabbro in a body originally 60 miles long and now separated into several masses by west-directed thrust and tear faults. Layering dips gently to moderately west. The lower, ultramafic zone, 2½ to 4 miles thick, is concordant with the thermally metamorphosed underlying strata. Contact metamorphic rocks are 200 to 500 feet of biotite phyllite, amphibolite, and calcic hornfels. Gabbro in the upper part has intruded the volcanic rocks in the roof and developed an amphibolite and pyroxene–hornblende granulite contact facies. Elongate bodies, several miles long, of altered hornblende quartz diorite cut the gabbro and presumably are genetically related to and the same age as the ultramafic rocks. In the Hare Bay klippe banded serpentinized peridotite comprises a large dissected sheet, as much as 2,000 feet thick, capping several hills and underlain by greenschist and hornblende gneiss of the Goose Cove Formation. Contact metamorphic effects cannot be identified with certainty. Layering in the peridotite dips at gentle to moderate angles. Several gabbro stocks cut sedimentary rocks nearby and are probably related to the ultramafic rocks.

Deformation, metamorphism, and granitic intrusions. In southern Quebec the belt of Cambrian to possibly early Middle Ordovician volcanic rocks with its emplaced ultramafic–mafic bodies became uplifted during the first stage of development of Quebec Geanticline. Folding and regional metamorphism attributable to the early phase of Taconian Orogeny cannot be distinguished with certainty, although they are probably present. Early folds in pre-Middle Ordovician rocks in Sutton Mountains of the Eastern Townships are isoclinal and recumbent; they trend northwesterly to westerly in contrast with the later northeasterly trending structures. The rocks are in the greenschist facies of metamorphism. Muscovite yielded K–Ar dates ranging from 440 to 414 m.y., about Middle Ordovician to Middle Silurian. In northern Gaspé Peninsula the Shickshock Group is believed to have been regionally metamorphosed before the intrusion of the Mount Albert ultramafic body with its thermal aureole. The Shickshock grades southerly from phyllite and greenstone into biotite schist, and in one locality to garnetiferous schist and blue-green amphibole schist. The metamorphism and presumed associated recumbent and isoclinal folding may be Taconian effects, although muscovite from phyllite has yielded a K–Ar date of 530 m.y., about Middle Cambrian. In southeastern Gaspé Peninsula the undated phyllite of the Maquereau Group is complexly deformed into recumbent folds with subhorizontal axial plane cleavage that certainly developed before the unconformably overlying Silurian and probably before the late Middle Ordovician.

The Moulton Hill intrusion in the Eastern Townships is a coarse-grained granite stock that was later cataclastically deformed and altered to essentially quartz and albite. Clasts of volcanic rocks of the Ascot Formation, ultramafic rocks, and the Moulton Hill granite are contained in the unconformably overlying late Middle Ordovician Magog Formation. In northern Gaspé Peninsula late Middle Ordovician strata lying north of the uplifted belt contain detrital serpentine, chromite, and volcanic rocks probably derived from the Shickshock Group and ultramafic intrusions like the Mount Albert body. Relations of late Middle Ordovician strata to older rocks are uncertain and are obscured by younger faults.

Along the northwest side of Quebec Geanticline a trough developed in which was deposited a thick sequence of shale and greywacke of middle and late Middle Ordovician age. Such strata are a few thousand feet thick within the Notre Dame Trough of most of southern Quebec and as much as 24,000 feet thick in northern Gaspé Peninsula. Equivalent strata, if deposited on St. Lawrence Platform, have been either removed by erosion or overridden by the upper block of Logan's thrust. The southeast-thickening black shale in southeastern Quebec Basin is probably a relic of this sequence.

In western Newfoundland Burlington Geanticline was probably uplifted at this time, but stratigraphic evidence is lacking. The postulated uplift is a necessary part of the hypothesis in which the two Taconian klippen were thrust westward from this region onto the St. Lawrence Platform. Ages of folding, metamorphism, and granite intrusion are difficult to establish. The Fleur de Lys Group of the northern geanticline has been metamorphosed to greenschist and almandine amphibolite facies and contains a complex of superimposed folds, the oldest of which are recumbent and isoclinal. K–Ar dates on micas in the schists and gneisses record Devonian ages, probably as a result of degassing by nearby Devonian granite intrusions to the southwest. South of Corner Brook biotite from gneiss and associated granite yielded dates of 452 and 420 m.y., about early Middle Ordovician to Middle Silurian. The Burlington granodiorite in northern Burlington Geanticline is unconformably overlain by volcanics of probable Silurian age and may be a Taconian intrusion. It is massive, medium to coarse grained, and partly altered to epidote and chlorite.

West of Burlington Geanticline, during late Llanvirnian to earliest Caradocian time, thick greywacke and shale were deposited on the platformal carbonate of the Table Head Formation as the waters deepened and a trough developed. The klippen overrode part of this sequence; the Humber Arm klippe and probably the unnamed greywacke–shale sequence in front of the klippe are overlain by the middle Caradocian (late Wilderness) Long Point Formation.

The klippen either slid or were thrust westward from western Notre Dame Trough and the zone along the trough–platform boundary into the trough of greywacke–shale deposition, a distance of perhaps 25 to 60 miles. The time of displacement is early Caradocian (Porterfield and early Wilderness) as determined by the age of the overridden strata, age of the greywacke–shale with incorporated blocks, and in the Humber Arm klippe, age of the overlying, post-displacement Long Point Formation. The time of displacement of the Taconic klippe of New York and Vermont is considered to be later, in middle or late Caradocian (Barneveld). Rocks of the klippen are moderately to intensely folded, cleaved, and faulted (Pl. VI-5). Folds and cleavage parallel regional northeast trends; faults trend northeast to northwest. Near Corner Brook the southeast part of the Humber Arm klippe has southeasterly overturned folds associated with a southeast-directed thrust. The intensity of recrystallization within muscovite–chlorite subfacies decreases westward as the axial planes become vertical. In the Hare Bay klippe the Maiden Point Formation has recumbent folds. The Goose Cove basic schist and gneiss are in the greenschist and low almandine amphibolite facies. It has been suggested that these rocks were derived in their metamorphic form from some parts such as the Birchy schist of the Fleur de Lys Group in northern extension of Burlington Geanticline that may underlie the ocean east of the klippe.

On Avalon Platform, in Cape Breton Island and southern New Brunswick, Middle and Upper Ordovician

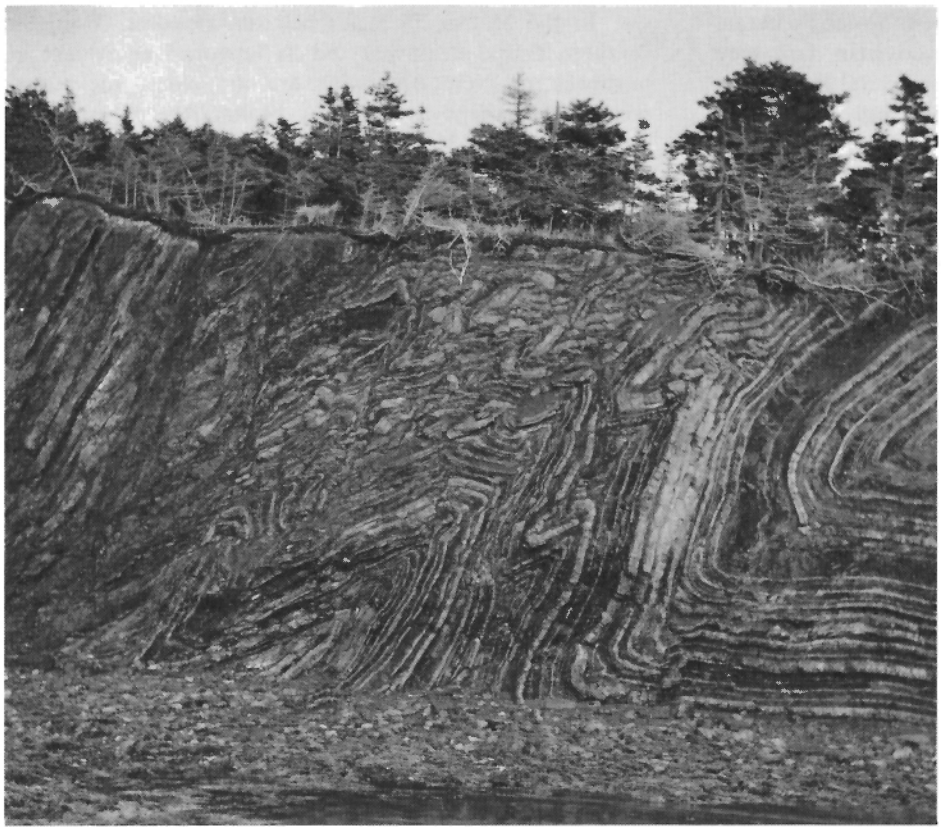


PLATE VI-5
Contorted Ordovician shale near base of Humber Arm klippe, Black Point, Port au Port, Newfoundland. Folds possibly developed during movement of klippe in the Ordovician, Taconian Orogeny.

strata are lacking, and relations of Silurian strata are obscured by Acadian deformation, except in southeastern Cape Breton Island where the undated but probably Silurian or Devonian Middle River Formation rests with angular unconformity on Middle Cambrian rocks. In central Cape Breton Island the Precambrian George River Group and its possible equivalents in northern Cape Breton Island were metamorphosed to marble and schist, possibly during the early phase of the Taconian Orogeny and probably during Acadian Orogeny. Similarly, in southern New Brunswick, parts of the Precambrian Green Head Group were metamorphosed to marble, schist, and biotite gneiss, and parts of the Coldbrook Group to phyllite, sericite schist, and amphibolite. A K–Ar date on biotite from Green Head biotite gneiss yielded 508 m.y., about late Cambrian.

Granites have intruded the metamorphic belt and are characterized by a wide variety of composition in contrast with the relatively uniform composition of the later Acadian intrusions. They range from gabbro through diorite, quartz diorite, granodiorite, syenodiorite, monzonite, and syenite to granite. Some are massive and coarse grained, others are cataclastic and foliated. Most are chloritized. They form the Milkish Head and Golden Grove bodies near Saint John, New Brunswick, and the bodies in the Boisdale and Coxheath Hills of central Cape Breton Island. The last two bodies contain associated copper and molybdenum deposits. The small lenticular anorthosite and diorite plutons of northern Cape Breton Island may belong to this suite. Similarly, some of the mixed granites in Antigonish Highlands of Nova Scotia may be Taconian intrusions.

K–Ar dates from biotite in granite and gabbro in southern New Brunswick are 479 and 500 m.y. Those from biotite and hornblende in two granites in Antigonish Highlands are 432 and 582 m.y., and those from biotite in granite and hornblende in syenodiorite in central Cape Breton Island are 493 and 584 m.y. Most dates suggest intrusion during Cambrian and early Ordovician, but they are interpreted as probably reflecting Taconian events, because in central Cape Breton Island the intrusions cut Middle Cambrian rocks that are succeeded conformably by Lower Ordovician shale. They could, however, reflect an earlier Taconian event in the Lower Ordovician.

Late Middle Ordovician (Fig. VI-11)

Appalachian Geosyncline. Late Middle Ordovician (Wilderness and Barneveld) strata are common in Notre Dame Trough, are probably present in Meguma Trough, but are probably lacking on Avalon Platform. In Notre Dame Trough of southern Quebec they lie in a miogeosynclinal trough northwest of the Quebec Geanticline and on the southeast side of the geanticline. Along the northwest side, near Lake Champlain (Cady, 1960), the Mystic

Formation consists of 75 feet of limestone-conglomerate that rests unconformably on Lower Ordovician dark grey shale and limestone. It contains blocks several feet across of Lower Ordovician limestone derived from as much as 1,350 feet stratigraphically below the unconformity. The overlying late Middle Ordovician Stanbridge Formation consists of about 2,000 feet of dark grey and black slate and minor siltstone. In the same belt, 15 miles south of Quebec City, are black sandstone and chert with pyritic black slate containing upper Porterfield and Wilderness graptolites. At Quebec City the youngest strata immediately southeast of Logan's Line are the Middle and possibly Upper Ordovician Citadel and Quebec City Formations of the Quebec Group (Osborne, 1956). The Citadel consists of an unknown thickness of shale and limestone-conglomerate. Clasts are dark grey limestone bearing Chazy and Black River fauna, and hence the formation is probably of Wilderness and Barneveld ages. The conformably overlying Quebec City Formation consists of more than 2,000 feet of thick-bedded, dark grey argillaceous limestone and shale. The age of the formation is probably Barneveld to Maysville. Near Lake Témiscouata the Trinité Group consists of an unknown thickness (probably more than 1,000 feet) of ribbon limestone, varicoloured slate, quartzite, limestone-conglomerate, and black slate that has yielded Wilderness graptolites (Lajoie, *et al.*, 1968). Along the northern Gaspé Peninsula coast for 100 miles are dark grey argillite and interbedded greywacke and calcisiltite containing Barneveld graptolites; a thickness of about 24,000 feet has been suggested. The rocks are characteristic of a flysch and turbidite facies as grading, scour marks, and flute casts are common. Sole marks at the base of greywacke beds indicate current flow toward the west, probably parallel to the trough axis. Detritus of serpentine, chromite, volcanic rocks, and chert indicate derivation from the Shickshock Group in Quebec Geanticline to the south.

Along the southeast side of Quebec Geanticline are late Middle Ordovician black slate, greywacke, and minor volcanic rocks similar in lithology and general thickness to those on the northwest side. In the Eastern Townships, the Beauceville and Magog Formations consist of dark grey slate, greywacke, sandstone, minor conglomerate, and chert; mafic and silicic volcanic rocks are common in some localities (St-Julien, 1967). Clasts in conglomerate and sandy rocks are feldspar, quartz, shale, volcanic rocks, and albite granite, all similar to nearby older rocks. Graptolites are of Wilderness and Barneveld ages. The basal contact is probably either a disconformity or low-angle unconformity. Thicknesses of the formations are unknown, but probably are several thousand feet.

In Gaspé Peninsula hard black shale lying south of Shickshock Group rocks of biotite metamorphic grade has yielded Normanskill graptolites. The strata probably form a horst within the Shickshock normal fault which has downdropped Silurian strata on the south.

In the Matapedia facies belt the Honorat Group in southern Gaspé Peninsula and its unnamed equivalent in northwestern New Brunswick are the oldest rocks and consist of perhaps as much as 14,000 feet of grey and greenish grey slaty argillite, siltstone, quartzite, quartzose greywacke, and grit (Skidmore, 1965). Some arenaceous beds are feldspathic and some are rich in volcanic detritus. The formations have yielded Middle or Upper Ordovician graptolites and shell fragments. Near the southeast coast of Gaspé Peninsula the Mictaw Formation contains Barneveld graptolites and is lithologically similar to the Honorat Group, but is separated from the Honorat and Matapedia Groups by Silurian strata (Ayrton, 1967). The Mictaw comprises more than 3,500 feet of dark greenish grey volcanic-rich sandstone, greywacke, siltstone, and slate of which the basal 1,000 feet is made up of conglomerate and minor interbeds of red siltstone. Clasts in the conglomerate are angular, generally from 3 to 6 inches in diameter but with boulders up to 1½ feet in diameter, and include greywacke, feldspathic quartzite, greenstone, quartz, and locally pink granite gneiss, all probably derived from Maquereau Group and associated rocks. Detrital muscovite from Mictaw sandstone and from unnamed quartzite equivalent to the Honorat Group in northwestern New Brunswick yielded K–Ar dates of 563 and 505 m.y. respectively, that is, Cambrian. The conglomerate has recently been interpreted as a talus deposit rather than a basal conglomerate (Ayrton, 1967).

The Matapedia Group conformably and gradationally overlies the Honorat Group and is at least 9,500 feet thick (Skidmore, 1965). It consists of dark blue-grey, dense argillaceous limestone in beds as thick as 3 inches interbedded with thinner beds and partings of grey shale and siltstone that produce a distinctive ribboned appearance. In southern Gaspé Peninsula the Matapedia Group comprises a more shaly Pabos Formation overlain by the White Head Formation with relatively more limestone. The Matapedia Group in easternmost Gaspé Peninsula overlies the Upper Cambrian Murphy Creek Formation with apparent angular unconformity. Graptolites date the Matapedia Group and its equivalents as late Middle Ordovician (Barneveld) to earliest Silurian in Maine and late Upper Ordovician to early Silurian in Gaspé Peninsula. The lower and upper contacts may be diachronous.

A eugeosynclinal assemblage of late Middle Ordovician and possibly younger rocks occurs in a belt extending southwesterly through central New Brunswick. In northeastern New Brunswick the Tetagouche Group consists of many thousands of feet of silicic and mafic flows, pyroclastic rocks and sills, greywacke, partly graphitic slate, and minor cherty iron-formation (Davies, 1966). A variety of quartz- and feldspar-bearing rocks of uncertain origin are variously referred to as "porphyry", quartz–feldspar– and quartz–augen schist and gneiss, and quartz–sericite–chlorite schist and gneiss. These rocks form tabular bodies, several miles long and a few thousand feet

thick, lying structurally concordant with bounding strata. More than a dozen bodies of massive base metal sulphides totalling over 125 million tons have been found in the Bathurst mining camp. The bodies are generally concordant with Tetagouche strata and are commonly located at or near augen schist. In central New Brunswick, north of Fredericton, similar strata, but with only minor silicic volcanics and without porphyry, rest conformably on unnamed Cambrian (?) and Lower Ordovician quartzite and slate (Poole, 1963). Andesite flows, tuff, and sills are associated with graphitic ribbon chert containing Wilderness graptolites and manganiferous iron-formation in the lower part of the assemblage. The upper part is mainly unfossiliferous greywacke and slate.

Late Middle Ordovician strata have not been recognized in southern New Brunswick. Part of the Browns Mountain Group of northern mainland Nova Scotia is probably of this age.

In Newfoundland, late Middle Ordovician rocks occur within the axial Notre Dame Trough in two belts extending southwesterly from Notre Dame Bay and separated by Silurian strata. The rocks apparently overlie older rocks conformably and pass upward in some places into Upper Ordovician rocks. In southwestern Notre Dame Bay about 8,500 feet of sedimentary rocks and minor mafic volcanic rocks are probably mainly late Middle Ordovician, although the upper 4,000 feet of strata may be faulted against the lower 4,500 feet (Espenshade, 1937). Both sequences are of the same general age. The lower sequence comprises three conformable formations. The Beaver Bight Formation rests conformably on the Wild Bight Formation of mainly mafic volcanic rocks, and consists of about 1,000 feet of thin-bedded tuffaceous greywacke, chert, and sandstone. Crossbedding, grading, and current scour structures are common. The overlying Shoal Arm Formation, about 1,500 feet thick, consists of interbedded grey sandstone and black shale and slate, and in the lowest 300 feet there are red, green, and black cherty shale and slate, some of which weathers to a black manganese oxide. Gull Island Formation consists of about 2,000 feet of massive brown-grey coarse-grained greywacke and minor conglomerate containing subangular detrital quartz, feldspar, hornblende, and epidote. Graded bedding is common. In the upper sequence the Julies Harbour Group comprises roughly 2,000 feet of a heterogeneous assemblage of: grey and black argillaceous sandstone and quartzite; greywacke; coarse conglomerate containing pebbles of granite, andesite, limestone and chert; chert; andesite; and a red and green cherty shale, which weathers to black manganese oxide, identical with beds of the Shoal Arm Formation. The overlying Burtons Head Group is also a heterogeneous assemblage about 2,000 feet thick of rocks much like those of Julies Harbour but containing more andesite.

On New World Island, in Bay of Exploits, the middle part of the Exploits Group contains late Middle Ordovician rocks whose lithology and stratigraphy vary from place to place (Kay, 1966, 1967). Argillite and conglomerate containing pebbles and boulders of greywacke, volcanics, and plutonic rocks are overlain by black argillite and chert with late Middle Ordovician graptolites. In another part of the island tuff is overlain by 100 feet of limestone that is overlain by 100 feet of black cherty argillite with Barneveld graptolites. In still another part, interbedded mafic lava, tuff, and cherty argillite have yielded late Middle Ordovician graptolites.

Southwest of eastern Notre Dame Bay the middle and upper units of the Gander Lake Group conformably overlie the lower unit that is probably early Middle Ordovician (Jenness, 1963). The middle unit consists of many thousands of feet of mafic pyroclastic rocks and flows; minor silicic volcanics; grey, green, black, and red slate; greywacke; and conglomerate. Ultramafic bodies intrude the volcanic rocks. The conglomerate contains pebbles and cobbles of chert, slate, volcanic rocks, quartz, granite, and limestone. The uncertain relationships with known Ordovician rocks and the lithology of the pebbles suggest that the conglomerate may be infolded Silurian. The upper unit comprises many thousands of feet of grey, green, and minor red and black slate with some greywacke, conglomerate, and mafic pyroclastic rocks. Conglomerate contains pebbles of quartz, chert, slate, and volcanic rocks. The middle unit has yielded Wilderness graptolites, and the upper unit Wilderness to early Upper Ordovician graptolites. Thus the Gander Lake Group may represent deposition throughout the entire Ordovician. The upper part of the Baie d'Espoir Group on the south coast of Newfoundland consists of about 20,000 feet of grey slate, phyllite, siltstone, and minor quartzite and greywacke, not unlike the middle and upper units of the Gander Lake Group.

Late Middle Ordovician strata have not been recognized on the Avalon Platform despite their occurrence in Notre Dame Trough and probably in Meguma Trough. The platform may have been a lowland separating the troughs, the site of little deposition or erosion. In Meguma Trough, late Middle Ordovician strata are probably represented within the thick White Rock Formation of sedimentary and volcanic rocks that are post-Lower Ordovician to pre-Upper Silurian.

St. Lawrence Platform. In southwestern Ontario (Sanford, 1961; Beards, 1967), late Middle Ordovician strata lie on Precambrian crystalline rocks on Algonquin Arch, and on the Upper Cambrian and Lower Ordovician in Michigan Basin and Allegheny Trough (Fig. VI-8). The Black River and Trenton Groups thicken from 700 feet on Algonquin Arch, to 900 feet in Michigan Basin, and to more than 900 feet in Allegheny Trough. The Black River Group of Wilderness age comprises three formations. (1) A lower transgressive unit, the Shadow Lake Formation, rests unconformably on Precambrian or Upper Cambrian rocks and consists of 20 to 30 feet of red and green shale, siltstone, minor limestone, and dolomite. In

the region of Manitoulin Island, similar strata are 2 feet to more than 40 feet thick. (2) The conformably overlying Gull River Formation consists of grey and cream-coloured lithographic limestone with interbeds of pelletoidal limestone and dolomite containing thin beds of bentonite in its upper part. From 75 feet over the Algonquin Arch the Gull River thickens to 130 feet on Manitoulin Island and to more than 400 feet beneath Lake Erie and southern Lake Huron. (3) The youngest formation of the Black River Group is the Coboconk Formation, consisting of interbedded lithographic limestone, calcisiltite, and calcarenite that thickens westward from 20 feet on Algonquin Arch to 100 feet near southern Lake Huron. Equivalent and lithologically similar beds on Manitoulin Island have a maximum thickness of about 25 feet.

The coarse clastic limestones of the Trenton Group are of late Wilderness and Barneveld age, and conformably overlie the Black River Group. A lower unit, the Kirkfield Formation, consists of interbedded finely crystalline shaly limestone, bioclastic limestone, and calcarenite. The Kirkfield thickens southeastward from 60 feet on Manitoulin Island to a maximum of 240 feet along the north shore of Lake Ontario. The succeeding Verulum Formation, comprising coarse bioclastic limestone and calcarenite with shale interbeds, increases in thickness from 80 feet on Manitoulin Island to a maximum of 140 feet beneath Lake Erie. The coarse limestones of the Kirkfield and Verulum Formations of shallow marine origin comprise the dominant facies of the Trenton Group throughout most of southwestern Ontario, but become fine textured and more shaly bordering Allegheny Trough. The Cobourg Formation is the highest of the group; it is made up of dark brown argillaceous and aphanitic limestones. From a maximum thickness of 200 feet in a narrow belt extending from the southern tip of Lake Huron to western Lake Ontario, the Cobourg thins northwest to 95 feet on Manitoulin Island and southeast to 40 feet beneath Lake Erie where it grades to black euxinic shale.

In Quebec Basin (Belyea, 1952; Clark, 1965; Wilson, 1946) the Black River and Trenton Groups vary in thickness from 730 feet in the Ottawa Embayment, to 700 feet north of St. Lawrence River east of Montreal, and to as much as 2,000 feet in southeastern Quebec Basin. The upper Trenton limestones in the western and northeastern parts of the basin grade southeastward into interbedded shale and limestone, a reflection of rapidly increasing subsidence of the Notre Dame Trough along the stable margin of the St. Lawrence Platform. The Black River Group comprises three conformable formations. (1) In western Quebec Basin a lower unit, the Pamelia Formation, overlies the Rockcliffe Formation. It consists of 70 feet of grey to black sandy shale grading upward to interbedded brown dolomite, lithographic limestone, and minor shale. The Pamelia thins eastward and may be absent in eastern and southern Quebec Basin. (2) The overlying Lowville Formation comprises dark greyish brown lithographic limestone that thins eastward from 155 feet in Ottawa Embayment to 40 feet in southern part of the Quebec Basin where it disconformably overlies the early Middle Ordovician Laval Formation. In the northeastern part of the basin it locally overlaps the Laval Formation and pre-Middle Ordovician strata and rests on Precambrian crystalline rocks. (3) The upper unit of the Black River Group is the Leray Formation, consisting of interbedded sublithographic limestone, calcisiltite, and calcarenite. It thins eastward from 65 feet in Ottawa Embayment to 21 feet near Montreal.

Formations of the Trenton Group in western and northwestern Quebec Basin are lithologically similar to those of southwestern Ontario, but somewhat unlike those of eastern and southern Quebec Basin where deposition occurred in a more rapidly subsiding environment. The Rockland Formation comprises the oldest strata of the Trenton Group in the Ottawa Embayment. It is 55 feet thick and consists of grey, argillaceous, finely crystalline limestone. The formation thins eastward to 19 feet near Montreal where it consists of dark grey, microcrystalline limestone termed the Ouareau Formation. Equivalent strata in the northeastern part of the Quebec Basin make up the Pont Rouge Formation, which is 32 feet thick. The overlying Hull Formation in Ottawa Embayment consists of 180 feet of dark blue-grey, finely crystalline limestone with shaly partings overlain by clean, coarse-grained calcarenite. Equivalent strata near Montreal are bioclastic limestone and coarse calcarenite, 300 feet thick, of the Deschambault Formation. Toward the northeast the upper 180 to 190 feet of the Deschambault gives place to a variety of limestone facies referred to as the St. Casimir Formation. In the Ottawa Embayment the succeeding Sherman Fall Formation consists of 25 feet of interbedded calcarenitic limestone and shale that presumably is equivalent to the Montreal Formation, 375 feet thick, composed of fine to coarse crystalline calcarenite and shale. Limestones of the Montreal Formation are fine textured toward the northeastern margin of the basin and merge with aphanitic limestones of the Neuville Formation, 470 feet thick. The youngest Trenton unit in Ottawa Embayment, the Cobourg Formation, consists of 180 feet of dark brown, aphanitic limestone that thickens to 500 feet near Montreal where it grades to interbedded dense limestone and shale of the Tetreauville Formation. The Tetreauville thins northeastward and ultimately merges with the Neuville limestone. In the subsurface the Tetreauville limestones pass abruptly into dark grey and black shales in the southern part of the Quebec Basin.

With the exception of the Gilmour Lake outlier, late Middle Ordovician (Wilderness–Barneveld) limestones form most of the strata in the Paleozoic outliers on the southern Canadian Shield where they rest directly on Precambrian crystalline rocks. Thickest and most complete sequences occur at Gilmour Lake (504 feet), Lake Timiskaming (374 feet), and Lake St. John (153 feet).

The limestones are for the most part lithologically similar to and the equivalent of the Black River and lower Trenton Groups of Wilderness age in southwestern Ontario, and in Quebec and Anticosti Basins. Rocks of Wilderness age commonly contain a clastic veneer at their base. At Lake Timiskaming (Sinclair, 1965), the Guigues Formation consists of 97 feet of coarse orthoquartzitic sandstone succeeded by the Bucke Formation—79 feet of grey, green, and red sandy shale. Strata of Wilderness age at Lake St. John are grey-brown limestones of the Tremblay Formation, 15 feet thick, overlain by limestone of Simard Formation, 63 feet thick. To the north in the Lake Manicouagan outlier 35 feet of thin-bedded black limestone is overlain by 25 feet of thin-bedded yellowish limestone, the youngest strata exposed. Grey-brown and tan late Barneveld limestones of the Farr Formation, 98 feet thick, and of the Shipshaw and Galets Formations, totalling 75 feet, were deposited disconformably on Wilderness limestone at Lake Timiskaming and Lake St. John, respectively.

In western Anticosti Basin (Roliff, 1968), in subsurface, about 1,000 feet of unnamed limestone equivalent to Black River and Trenton Groups rest disconformably on the Mingan Formation. The strata consisting of brown cherty limestones are not exposed, but presumably rise to form the bedrock surface between Anticosti and Mingan Islands.

In western Newfoundland late Middle Ordovician strata occur only in western Port au Port Peninsula. There, the Long Point Formation, of late Wilderness age, consists of about 2,800 feet of strata, a relatively thick sequence that indicates strong subsidence of this part of the platform. The lower 250 feet comprises nodular and argillaceous limestone that rests with angular unconformity on the western, leading edge of the Humber Arm klippe. The upper part of the formation consists of dark greenish shale, bluish calcareous sandstone, and minor thin limestone interbeds.

Taconian Orogeny, Late Phase

During the late phase of the Taconian Orogeny in the Upper Ordovician, late Middle Ordovician and older strata northwest of Quebec Geanticline in southern Quebec were folded and faulted, and the entire geanticlinal belt was uplifted and eroded (Fig. VI-12). Folds are open to tight with axial planes vertical to southeast dipping. Slaty cleavage is developed in pelitic beds. Many folds are overturned northwesterly, and thrust faults and associated transverse faults indicate northwestward transport. Late Middle Ordovician strata in the Eastern Townships are cleaved, and the open to tight folds are upright or slightly overturned to the northwest. Regional metamorphism is no higher than slate and phyllite grades. Strata of probable Upper Ordovician age lie conformably or with low-angle unconformity on late Middle Ordovician strata, and Silurian strata lie with angular unconformity on the Ordovician and older rocks. Uplift of southwestern Quebec Geanticline was apparently greater than the eastern part as a large volume of detritus derived from the geanticline was deposited in Quebec Basin and Allegheny Trough, whereas in Gaspé Peninsula little or no detritus was deposited in the Matapedia belt to the south nor in Anticosti Basin to the north.

In western Notre Dame Trough of Newfoundland the Burlington Geanticline was probably uplifted and eroded. It was probably the source of the conglomerates in the Notre Dame Trough of upper Late Ordovician and Lower Silurian age.

The Miramichi Geanticline was probably initiated in the late Ordovician and underwent regional metamorphism, folding, granite intrusion, uplift, and erosion. Much of the pre-late Middle Ordovician quartzite and shale formation of the core of the geanticline was metamorphosed to schist and gneiss, locally with sillimanite of the almandine amphibolite facies. Bedding and foliation in these rocks and in the overlying Middle and Upper (?) Ordovician Tetagouche Group trend partly northeast parallel with later Acadian structures and partly north to northwest quite unlike the Acadian structures in the Silurian and Devonian rocks flanking the geanticline. Strata in the core commonly have gentle dips, an indication of either recumbent folds or little deformation in contrast with the steep and generally open structures in the Silurian and Devonian rocks. Biotite quartz monzonite and granodiorite intruded the quartzite–slate geanticlinal core rocks and were penetratively deformed and altered to a cataclastic granite with weak foliation, and locally to zones of mylonite in and near the Catamaran fault that was reactivated during Acadian Orogeny. Muscovite and biotite from several samples of granite and gneiss give K–Ar dates ranging from 497 to 385 m.y. The younger dates reflect Acadian deformation and granite intrusion. Those in the 430 to 460 m.y. range suggest Upper Ordovician orogeny.

Upper Ordovician (Fig. VI-12)

Upper Ordovician strata are of restricted distribution in Appalachian Geosyncline, largely as a result of emergent land brought about by late Taconian uplifts, but are widespread in St. Lawrence Platform with the exception of western Newfoundland.

Appalachian Geosyncline. In the Eastern Townships the East Branch Pond and Sherbrooke Formations contain an Upper Ordovician shelly fauna (St-Julien, 1967). They are lithologically similar, a few thousand feet thick, lie with angular unconformity on late Middle Ordovician strata of the Magog Formation, and are unconformably overlain by Silurian strata. Farther northeast the Sherbrooke Formation lies conformably on Magog strata. Each formation consists of a basal conglomerate, sandstone, and some slate, overlain by sandstone and slate that pass upward into grey to dark grey slate. Clasts in the conglomerate are pebbles to boulders of various sedimen-

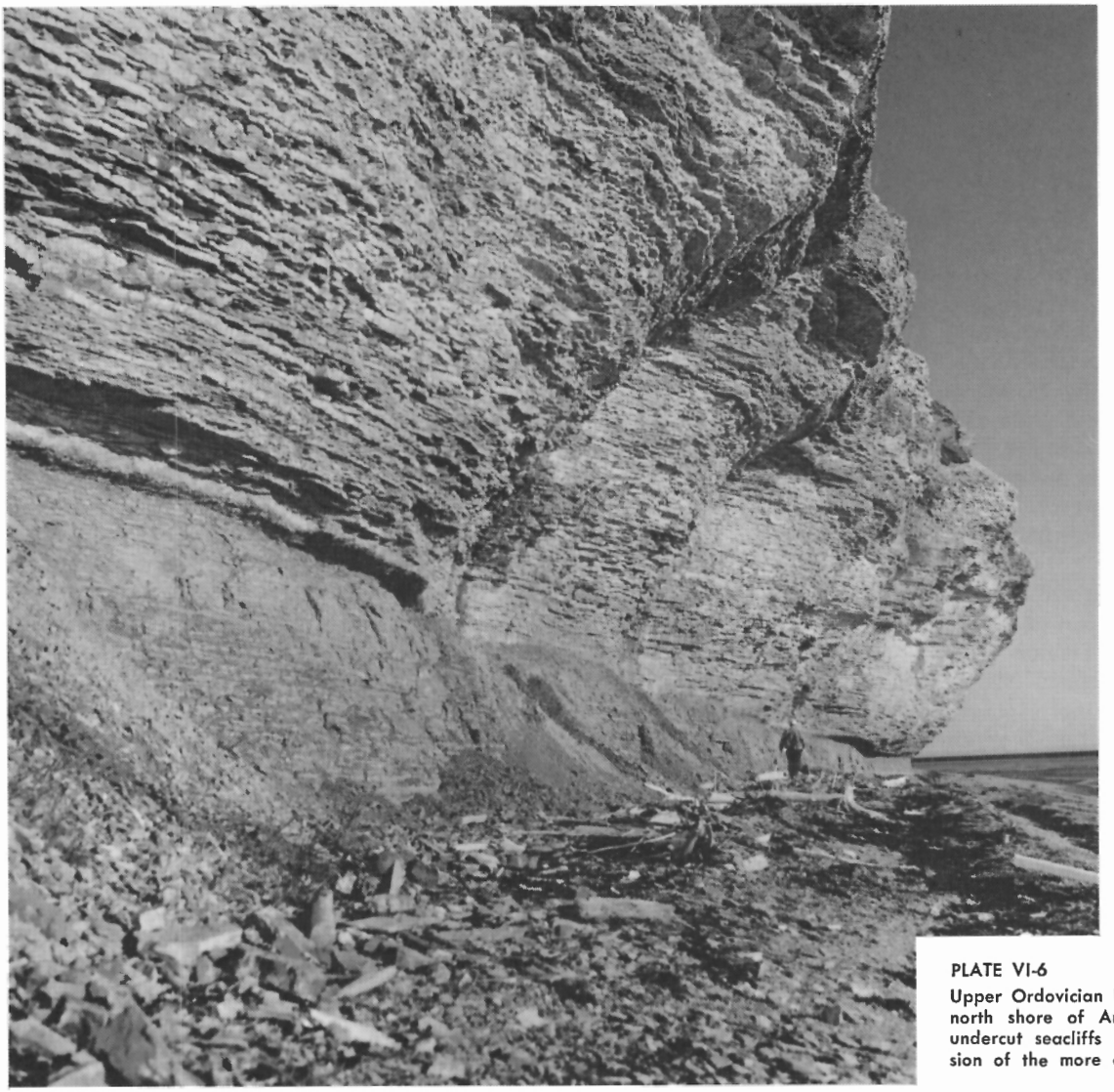


PLATE VI-6
Upper Ordovician English Head Formation, north shore of Anticosti Island, Quebec; undercut seacliffs produced by wave erosion of the more argillaceous limestones.

tary rocks, mafic and rhyolitic volcanics, albite granite, and rare serpentinized peridotite and pyroxenite.

In northern Nova Scotia quartzite containing a Middle or Upper Ordovician shelly fauna occurs as blocks within a late Paleozoic fault breccia and as boulders in nearby Mississippian conglomerate on Cape George. The quartzite is similar to some rocks associated with the iron-formation of the Browns Mountain Group, but otherwise its source is unknown. The nearby Malignant Cove Formation lacks fossils and consists of 20 feet of red, nonmarine, crossbedded conglomerate and grit containing a variety of fragments including chert, granite, rhyolite, and greywacke. It rests with angular unconformity on slate of Browns Mountain Group and is isolated by drift from younger rocks. Its age is unknown; it could be Carboniferous but its high degree of induration suggests pre-Carboniferous and probably pre-Silurian ages.

In axial Notre Dame Trough of northern Newfoundland (Kay, 1967), the upper part of Exploits Group is dominantly greywacke and fine pebble-conglomerate, several thousand feet thick, conformably overlying the Middle Ordovician slate and argillite and locally including lower Silurian. Brachiopods in part of the sequence are Upper Ordovician. In southwestern Notre Dame Bay (Espenshade, 1937) the Crescent Lake and Roberts Arm Formations are unfossiliferous and have been referred to the Upper Ordovician, although lithologically they are unlike presently known Upper Ordovician strata. The Crescent Lake Formation consists of at least 500 feet of red and green tuffaceous shale, chert and minor conglomerate, and sandstone. The conformably overlying Roberts Arm Group is 1,500 feet of pillowed basalt flows and minor rhyolite. The upper unit of Gander Lake Group, already described, has yielded graptolites of Wilderness and of Eden age, and like the Exploits Group it may be conformably overlain by a continuous sequence of uppermost Ordovician and Lower Silurian greywacke and conglomerate.

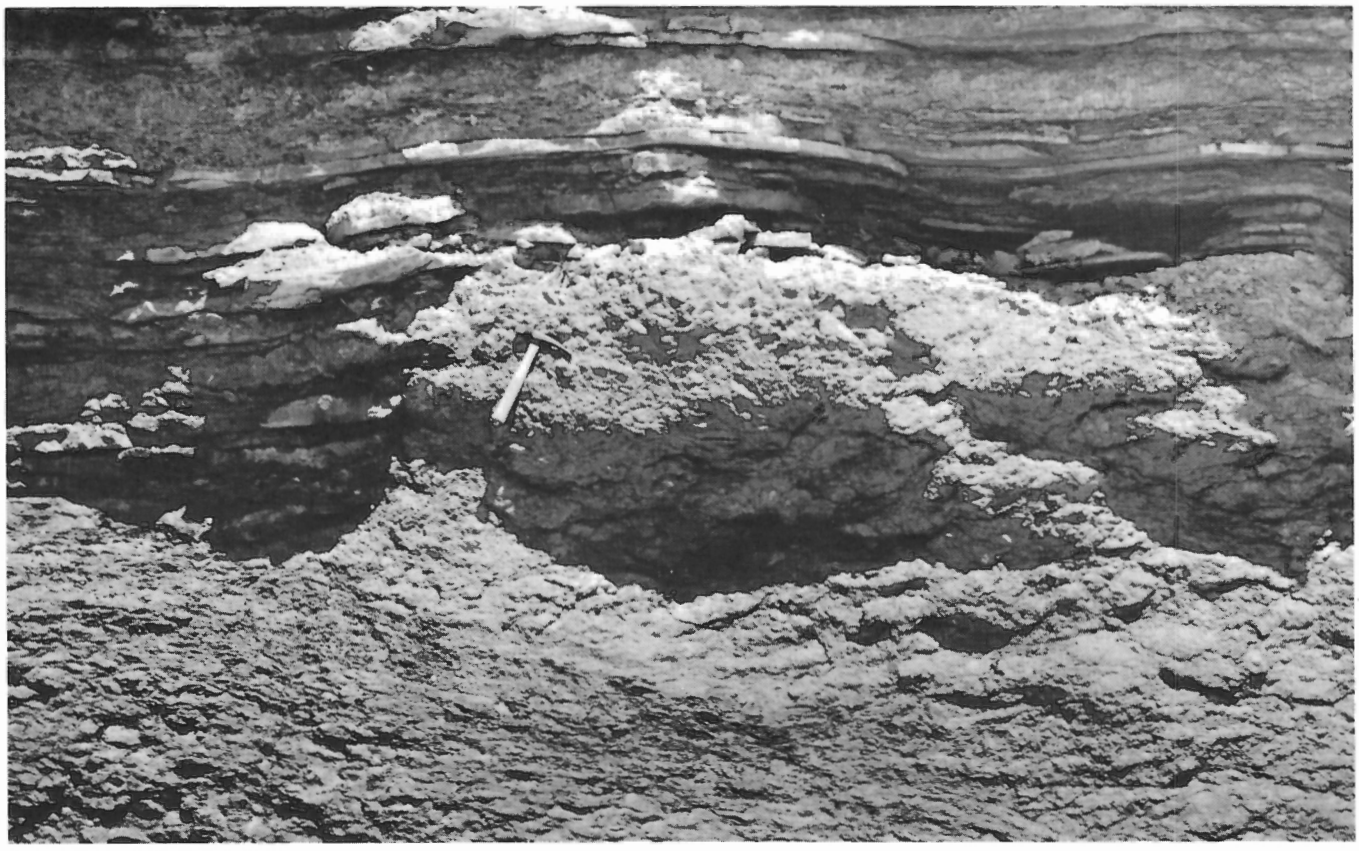


PLATE VI-7. Bioherm in Upper Ordovician, Ellis Bay limestone, Anticosti Island, Quebec.

St. Lawrence Platform. Upper Ordovician fine and coarse clastics of marine and non-marine origin occur in southeastern Allegheny Trough and southeastern Quebec Basin where they are 2,000 and 4,000 feet thick, respectively. The strata thin northwestward and ultimately grade to marine carbonate and shale, as much as 800 feet thick, in Michigan Basin. In western Anticosti Basin as much as 3,100 feet of limestone and shale was deposited.

In southwestern Ontario the Collingwood Formation (Eden) consists of black euxinic shale resting conformably on limestone of the Trenton Group (Sanford, 1961; Beards, 1967). Beneath eastern Lake Erie it may be partly Barneveld and a facies equivalent of the upper Trenton limestones to the northwest. From a thickness of 200 feet beneath eastern Lake Erie the Collingwood thins northwestward to 20 feet near southern Georgian Bay and thickens to 60 feet in the Manitoulin district where it disconformably overlies limestone of the Cobourg Formation. The succeeding Blue Mountain Formation of dark grey and brown shale is 250 feet thick near western Lake Ontario and thins northward to 120 feet near southern Georgian Bay. The equivalent Sheguiandah Formation on Manitoulin Island consists of 100 feet of soft brown, maroon, and grey shale. The Meaford–Dundas Formation (Maysvillian and early Richmondian) is made up of grey shale, siltstone, and minor limestone. These strata have a maximum thickness of 900 feet near western Lake Ontario and thin southward into Allegheny Trough where the upper beds interdigitate with red shale and siltstone of the overlying Queenston Formation. The unit also thins northwestward, and in the Manitoulin region the lower part is termed the Wekwemikongsing Formation —150 feet of grey shale with minor limestone interbeds. The upper part, the Meaford Formation, comprises 60 feet of grey and brown argillaceous limestone. The overlying Richmondian Queenston Formation is 1,100 feet thick beneath eastern Lake Erie and consists of semicontinental red shale and siltstone derived from the Taconian mountains to the east. The Queenston also thins northwestward giving place to 160 feet of bluish grey, argillaceous limestone and dolomite of the Kagawong Formation on Manitoulin Island.

In Quebec Basin (Fig. VI-7) Upper Ordovician strata are similar to those of southwestern Ontario, and except for the Lower Devonian limestone fragments in a Cretaceous diatreme breccia, are the youngest strata exposed (Clark, 1956; Wilson, 1946). They are about 4,500 feet thick in the southern part of the basin and thin to 879 feet in Ottawa Embayment. In the embayment the Edenian Eastview Formation, 20 feet thick, consists of interbedded limestone and black shale that gradationally overlie Cobourg limestones and are apparently absent in the northern part of the Quebec Basin. The gradationally overlying Billings Formation is represented by 170 feet

of black bituminous shale that thickens eastward to 300 feet and forms the Lachine and Lotbinière Formations in northern Quebec Basin disconformably overlying the Trenton Group. In the subsurface south of St. Lawrence River as much as 1,000 feet of similar strata usually referred to the Utica Group lie with gradational contact on the Trenton Group. The Carlsbad Formation (Maysville) in the Ottawa Embayment consists of shale and minor limestone 607 feet thick, increasing to more than 2,000 feet in southern Quebec Basin where the equivalent Nicolet River Formation consists of grey shale with siltstone and sandstone interbeds. These shales are overlain by blue-grey argillaceous limestone of the Richmondian Russell Formation, 40 feet thick, and Pontgravé River Formation near Montreal, 173 feet thick. The Queenston Formation represents the youngest Ordovician strata; it comprises 42 feet of red shale with minor limestone interbeds in the Ottawa Embayment that thicken eastward in southern Quebec Basin to 2,000 feet of nonmarine deltaic red shale, with minor limestone interbeds, and locally abundant red siltstone and sandstone.

On the Canadian Shield Upper Ordovician strata occur in outliers at Lake Timiskaming, Clear Lake, and Lake St. John (Sinclair, 1965). They are the youngest strata exposed at the last two localities. About 20 feet of early Edenian bituminous shale and minor limestone, equivalent to the Eastview and Collingwood Formations, rests conformably above Trenton limestone in the Clear Lake outlier. At Lake Timiskaming, the late Edenian Dawson Point Formation disconformably overlies the Middle Ordovician Farr Formation and consists of dark grey shale 98 feet thick. Equivalent beds at Lake St. John comprise 25 feet of black bituminous shales commonly referred to the Gloucester Formation that disconformably overlies the Galets Formation. Richmond strata occur only at Lake St. John and consist of limestone that is mostly covered by the lake waters.

In Anticosti Basin (Fig. VI-7) Upper Ordovician strata occur on Anticosti Island and beneath the Gulf of St. Lawrence. They are not present in western Newfoundland. On Anticosti Island (Bolton, 1961; Roliff, 1968) Upper Ordovician limestone and shale about 3,100 feet thick overlie Barneveld–Wilderness limestone and are succeeded by Lower Silurian (Alexandrian) rocks. They are lithologically similar to Upper Ordovician strata of western Michigan Basin, but are much thicker and lack the clastic Richmond red bed assemblage of Allegheny Trough and Quebec Basin. The Edenian Macasty Formation forms the bedrock surface beneath part of the Gulf of St. Lawrence north of Anticosti Island and in the subsurface consists of black bituminous shale, 200 feet thick, presumably equivalent to the Utica, Lachine, and Billings Formations of the Quebec Basin. The conformably succeeding 750 feet of alternating grey shale

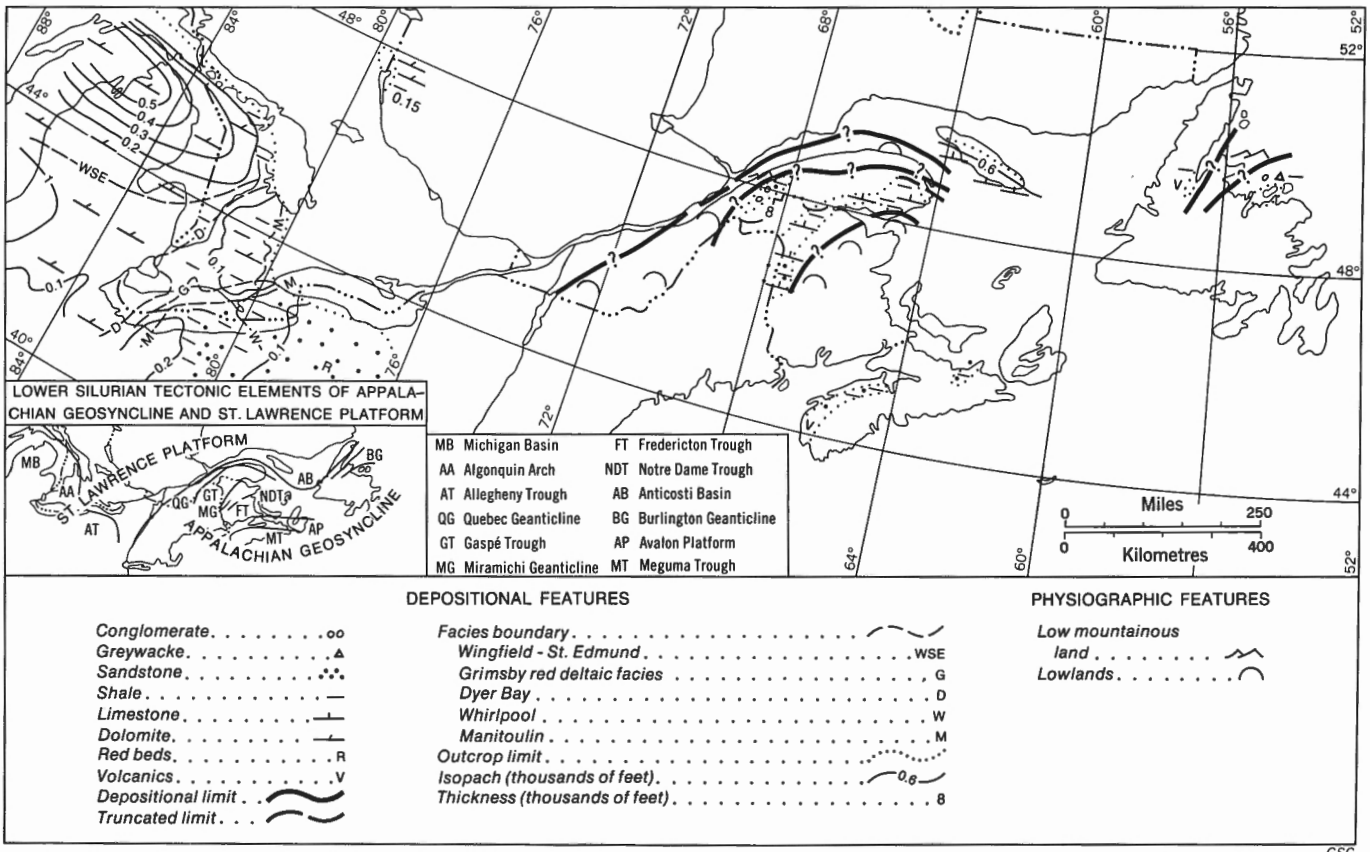


FIGURE VI-13. Lower Silurian sedimentation, volcanism, and tectonism in Southeastern Canada.

and limestone of the lower English Head Formation is known only in subsurface and probably forms the bedrock surface beneath the channel north of Anticosti Island. The succeeding early Richmondian upper English Head (Pl. VI-6) and Vauréal Formations, totalling more than 1,850 feet, consist of bluish grey, finely crystalline to semilithographic limestone and interbedded greenish grey shale. Although predominantly limestone, the shale and silt content of the English Head Formation increases toward the northeast end of Anticosti Island. The late Richmondian Ellis Bay Formation in western Anticosti Island comprises at least 200 feet of argillaceous limestone, shale, and limestone and contains bioherm reefs (Pl. VI-7). It thickens to 300 feet on northeastern Anticosti Island, grading to a dominantly sandstone facies.

Silurian

Tectonic Summary

During the Silurian, sedimentary and volcanic rocks thousands of feet thick were deposited within Appalachian Geosyncline, and carbonates and evaporites were deposited on St. Lawrence Platform. No granitic intrusions or episodes of folding are known to have occurred. Tectonic elements evident in the Ordovician persisted throughout the Silurian (Figs. VI-13, 14, 15).

In northern Gaspé Trough several thousand feet of siltstone, limestone, and quartzose sandstone, derived mainly from the northwest, were deposited unconformably on the folded Ordovician rocks of Quebec Geanticline. The age of the base of the sequence varies from early Llandovery to latest Ludlow. Along the axis of Gaspé Trough in the Matapedia facies belt, deposition of thin-bedded, possibly deep-water, limestone and shale continued from the late Ordovician into earliest Silurian, grading to shale and sandstone with local manganiferous deposits in the southwest, and to shale, siltstone, limestone, and volcanic rocks in the northeast. In southern Gaspé Trough, siltstone, sandstone, volcanics, and locally conglomerate were deposited adjacent to Miramichi Geanticline; these rocks probably lie unconformably on the Ordovician. In Fredericton Trough turbidites were deposited in the north; in the south they grade into mainly silicic volcanics and shallow-water green, red, and brown shale, sandstone, and minor limestone bordering Avalon Platform.

In Notre Dame Trough of Newfoundland lands along Burlington Geanticline and possibly also Avalon Platform bordered the Silurian depositional elements. No geanti-

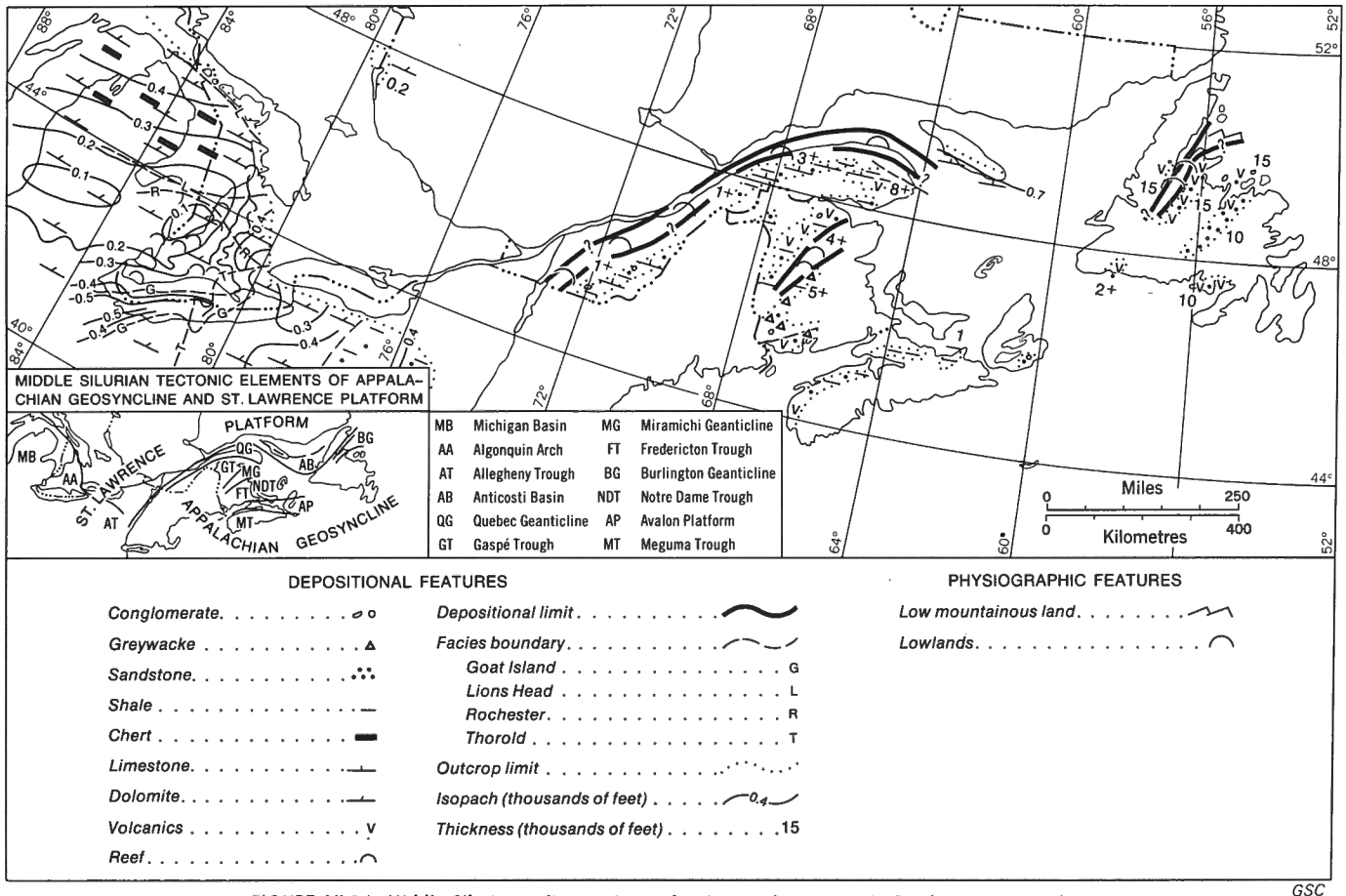


FIGURE VI-14. Middle Silurian sedimentation, volcanism, and tectonism in Southeastern Canada.

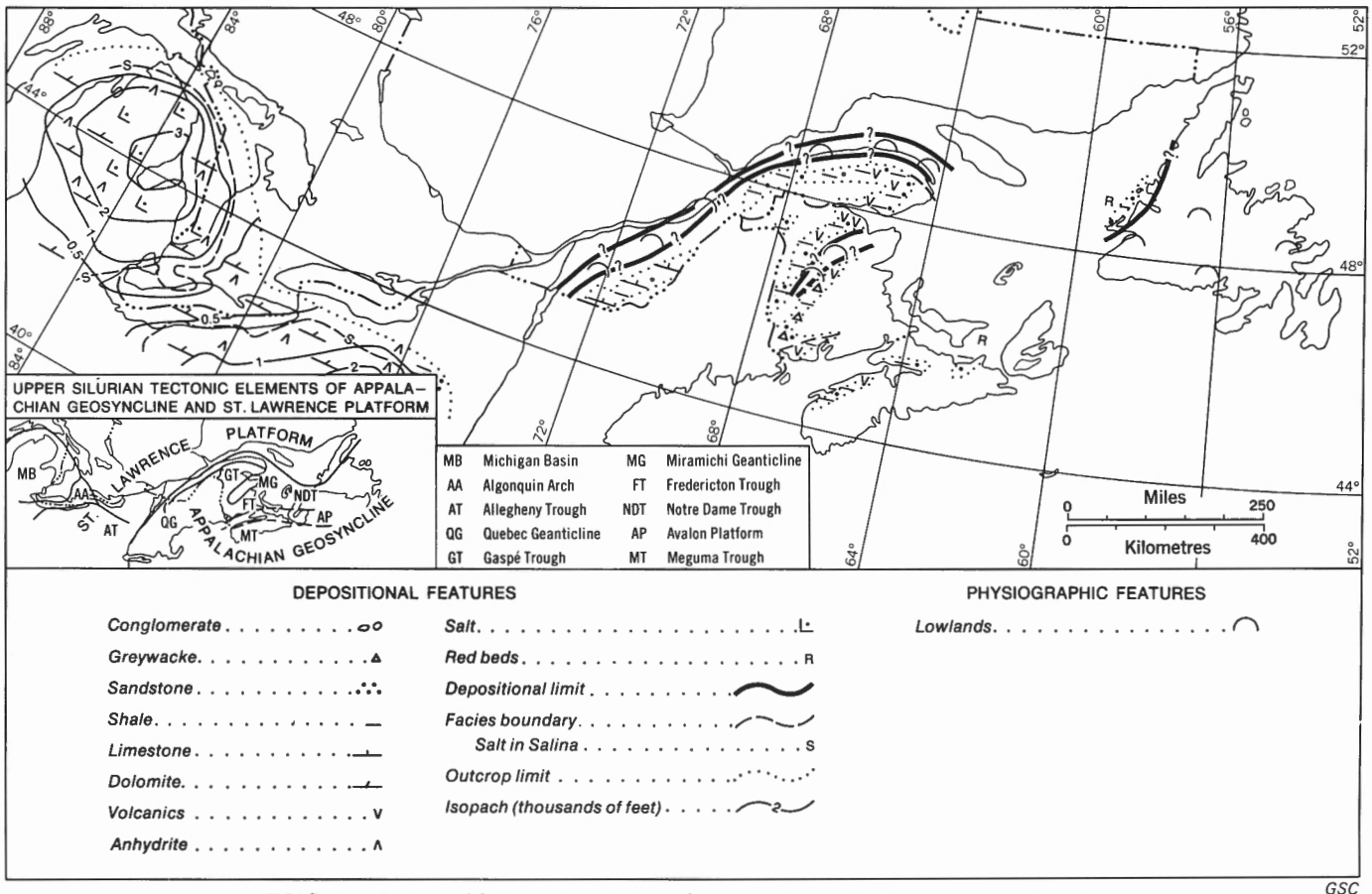


FIGURE VI-15. Upper Silurian sedimentation, volcanism, and tectonism in Southeastern Canada.

cline in the central part of the trough, analogous to Miramichi Geanticline, has been identified, although some facies suggest that such lands existed during much of the Silurian. During Llandoverian and Wenlockian times the depositional environment changed from marine to terrestrial. Thick, very coarse conglomerates indicate either strong uplift to the north beneath Notre Dame Bay, or possibly an extension of Burlington Geanticline.

There is no evidence of Silurian folding and plutonism, but the scarcity of Upper Silurian and Lower Devonian strata makes it difficult to separate older orogenic effects from those of the Devonian Acadian Orogeny. Greywacke was deposited conformably on Ordovician rocks in the northeastern axial part of Notre Dame Trough and is conformably overlain by conglomerate. The Wenlockian volcanics and overlying red and grey, mainly terrestrial sandstones with abundant fluviatile depositional features unconformably or disconformably succeed Ordovician and older rocks. The Silurian strata of Newfoundland generally reflect a change from marine to terrestrial conditions of deposition.

On Avalon Platform, Nova Scotia, a thick, complete Silurian sequence, mainly of shale, was deposited probably unconformably on Ordovician rocks, whereas in eastern Cape Breton Island, undated presumably Silurian sandstone and conglomerate were deposited unconformably on Cambrian rocks.

In Meguma Trough the very thick, undated quartzose sandstone, shale, greywacke, and silicic and mafic volcanics that were deposited conformably on Lower Ordovician slate were succeeded by Upper Silurian shale, siltstone, quartz sandstone, and local volcanic conglomerate.

On St. Lawrence Platform, Silurian strata are now confined to southwestern Ontario, Anticosti Island, and Lake Timiskaming outlier. Most of the southern Canadian Shield was probably covered by marine sedimentary rocks that were formerly connected, at various times, with those of Williston Basin and Hudson Platform. During the Early Silurian coarse red deltaic detritus from the Taconian mountains in eastern New York was spread westward across Allegheny Trough. On the margin of Michigan Basin it grades into marine shales and carbonate rocks. These facies also extended across the southern Canadian Shield to the Lake Timiskaming outlier. During the Middle Silurian large crinoid banks and complex biostromal or barrier reefs formed around Michigan Basin. Numerous patch and pinnacle reefs developed along the flanks of the rapidly subsiding Michigan Basin. Carbonates and fine clastics were being deposited in Allegheny

Trough to the southeast. Evaporite deposits dominated Upper Silurian sedimentation in Michigan Basin and Allegheny Trough, giving place to carbonates and fine clastics over Algonquin Arch in Ontario. In western Anticosti Basin, Alexandrian and Niagaran limestones were deposited conformably on Upper Ordovician limestone and are the youngest strata exposed. In eastern Anticosti Basin the Silurian may be represented in a coarse clastic red bed sequence, the upper part of which contains latest Silurian or earliest Devonian (Pridoli) fossils.

Appalachian Geosyncline

Gaspé Trough. In southern Quebec, Silurian strata of Gaspé Trough lie with angular unconformity on Cambrian to Middle Ordovician rocks of Quebec Geanticline, and in one place with low angular unconformity or disconformity on the Upper Ordovician. The Silurian seas did not cover the geanticline until the late Wenlockian and Ludlovian. Near Lake Memphremagog, Silurian strata form two synclinal remnants (Cooke, 1950). The basal, Peasley Pond Formation consists of unfossiliferous, well-stratified conglomerate and quartzite varying from a few feet to more than 250 feet in thickness. To the southeast the Peasley Pond is missing, and the overlying formations rest directly upon Ordovician rocks. Clasts in the conglomerate are mainly quartz pebbles with minor chert and fine-grained quartzite. The overlying Glenbrooke Formation is grey calcareous slate and slaty argillite of probable early Ludlovian age. In the west it is 900 feet thick but may be much thicker elsewhere. The gradationally overlying Sargent Bay Formation is the youngest Silurian exposed and consists of grey limestone and slaty argillaceous limestone of Ludlovian age. In the west it is 290 feet thick; farther east it is perhaps several thousand feet thick. To the east and northeast Silurian rocks similar to those described comprise the St. Francis, Cranbourne, and Lake Aylmer Groups. All are mainly Ludlovian limestone, in part sandy and argillaceous. Late Wenlockian to early Devonian conglomerates rest unconformably on Cambrian and Ordovician rocks. They may be as thick as 2,000 feet and contain clasts of quartz, various sedimentary rocks, silicic and mafic volcanics, and albite granite.

In the Gaspé Peninsula and Témiscouata and Matapedia regions the Silurian generally consists of four megafacies: Llandoverian shale and coarse clastics, Llandoverian and Wenlockian orthoquartzite, Wenlockian and Ludlovian limestone, and Ludlovian siltstone with minor limestone and coarse clastics. Volcanic rocks are intercalated mainly in the Wenlockian and Ludlovian strata in central and southern Gaspé Peninsula.

In the Témiscouata region, along northern Gaspé Trough, Silurian sedimentary strata thicken from 4,000 to 18,000 feet to the southeast and to 16,000 feet in a local basin in the northeast (Lajoie, *et al.*, 1968). The early and middle Llandoverian Cabano Formation is the oldest formation unconformably overlying the Cambrian to Middle Ordovician Quebec and Trinité Groups. It consists of grey lithic sandstone, conglomerate with clasts of the Quebec Group, and shale. It thickens southeasterly from zero to 8,000 feet where it is covered by younger strata, and thins northeasterly to zero. Source of the detritus is Quebec Geanticline to the northwest. The conformably overlying late Llandoverian Pointe Aux Trembles Formation and its northeastern, finer grained equivalent, the Lac Raymond Formation, thicken southeasterly from 1,000 to 6,000 feet. The Pointe Aux Trembles consists of volcanic sandstone and conglomerate with rare latite flows and tuff. Well-rounded clasts from 1 inch to 8 inches in diameter are volcanic rock. The Lac Raymond Formation is mainly greenish grey shale with interbeds of tuffaceous and pebbly sandstones containing quartz and volcanic rock. The source of the volcanic detritus was probably to the southeast in northwesternmost New Brunswick, now covered by Devonian strata. The overlying Robitaille Formation and laterally equivalent Asselin Formation are believed to be of early Ludlovian age and to overlie disconformably the Pointe Aux Trembles and Lac Raymond Formations. The Témiscouata region is inferred to have been a land area during the Wenlockian. The Robitaille consists of red to white siltstone and lithic and quartz sandstones with minor green shale, limestone, dolomite, and pebble-conglomerates. Along the northwest the Robitaille unconformably overlies the Quebec Group and reaches its maximum thickness of 1,900 feet. It intertongues northeasterly with the Val Brillant and Sayabec Formations that extend southwest from the Matapedia region. Along the southeast the Robitaille in one place is 700 feet thick and grades northeasterly into the Asselin Formation, which is 1,300 feet of granule conglomerate and sandstone containing detritus of quartz and silicic lava. The overlying Mont Wissick Group consists of three conformable formations. The oldest, the Sayabec Formation, is early Ludlovian. It conformably overlies the Robitaille Formation along the northwest and is missing in the southeast. It consists of up to 400 feet of argillaceous and silty limestone. The overlying Ludlovian St. Léon Formation is 2,300 to 3,500 feet thick and consists of grey and green siltstone and sandstone. To the southeast it overlies the Robitaille and Asselin Formations, and to the northwest it overlies the Sayabec Formation and thickens to 10,600 feet in a local basin. The middle 5,800 feet of the St. Léon consists of sandstone, conglomerate, and greenish grey siltstone of the Lac Des Baies Member.

In the Matapedia region (Béland, 1960) along northern Gaspé Trough about 10,000 feet of Silurian strata comprise four conformable formations. The Awantjish Formation, the oldest, consists of 150 to 1,000 feet of late Llandoverian green, grey, and rare red calcareous shale and siltstone that rest unconformably on folded Ordovician rocks in a small inlier. The conformably overlying late Llandoverian to early Wenlockian Val Brillant

Formation is 500 feet thick and thins northward to 90 feet as it overlaps the Awantjish to rest unconformably upon folded Ordovician rocks. It consists of white and pink quartzite with minor argillaceous quartzite, probably derived from the north. It grades upward through calcareous sandstone into limestone of the Wenlockian and lower Ludlovian Sayabec Formation, 1,200 to 1,500 feet thick, which consists of pure, grey limestone with mud-cracked shaly and silty interbeds. Locally, the limestone is a breccia of angular fragments of algae and corals in a limestone matrix. The Sayabec grades upward into the Ludlovian St. Léon Formation, 7,300 feet thick, consisting of grey to green and rarely red calcareous siltstone and fine-grained sandstone with minor red shale, limestone, sandstone, and conglomerate with quartz and quartzite pebbles. Some conglomerate consists of rounded fragments of limestone, silty limestone, and fossils in a limestone matrix; at one locality the fragments are as much as 15 feet across.

In Gaspé Peninsula and western New Brunswick, in the Matapedia facies belt along the axial region of Gaspé Trough, deposition of thin-bedded limestone and shale continued from late Ordovician to about middle Llandoverian without interruption and without recording the effects of late Ordovician uplifts of the Quebec and Miramichi Geanticlines. During this interval the belt may have behaved as an intra-trough platform covered by relatively deep water but shallower than the flanking parts of the Gaspé Trough. In western New Brunswick lower Llandoverian limestone and slate grade upward through slate to upper Llandoverian, Wenlockian, and Ludlovian thin-bedded, grey to green, and locally red micaceous siltstone, quartzite, and slate with local developments of greywacke, conglomerate, limestone, red slate, and manganiferous iron-formation. In central and eastern Gaspé Peninsula (Burk, 1964) local volcanic centres produced flows, pyroclastic rocks, and volcanic conglomerates. At the western end of St. John anticline (Skidmore, 1965) the upper Llandoverian to Ludlovian Sirois Formation is 4,000 feet or more thick and comprises two members. The older, Laforce Member, 1,800 feet thick at its type locality, overlies the White Head Formation with uncertain but probably conformable or disconformable relations. The Laforce consists of sandy limestone, limestone grit and conglomerate, calcareous sandstone, and within the lower 500 feet of the member, some volcanic conglomerate. The upper, unnamed member is 2,200 feet thick at its type locality and consists of green to grey calcareous siltstone, shale, and silty limestone. Farther east along the St. John anticline (Cumming, 1959) the Burnt Jam Brook Formation of late Llandoverian age overlies the White Head Formation and is partly equivalent to and partly older than the Laforce Member. The formation consists of 400 to 500 feet of green to grey shale overlain conformably by the Owl Capes Formation, 1,000 feet of limestone-conglomerate, sandy and silty limestone, and volcanic conglomerate. About 2 miles west is the Cedar Barn volcanic member, 1,800 feet of interbedded basic lava flows and volcanic conglomerate that appears to be equivalent to Owl Capes Formation and contributed volcanic detritus to it. These formations are probably Middle Silurian. The Cedar Barn and Owl Capes are apparently overlain by Sirois beds. About 10 miles to the south is the Mount Alexander Group (Skidmore, 1965) of 8,000 to 16,000 feet of volcanic and sedimentary Silurian rocks possibly ranging from Llandoverian to early Ludlovian. A basal unit of 2,400 feet of silty limestone rests with uncertain relations on the White Head Formation. The limestone is overlain by 2,000 feet of interbedded shaly to silty limestone and amygdaloidal andesite, succeeded by as much as 10,000 feet of dark green and dark red andesite, basalt, and keratophyre lava, agglomerate, and tuff. The uppermost unit consists of 2,000 feet of limestone. Only 3 to 4 miles to the north, where only 8,000 feet of Mount Alexander Group is exposed, there is less limestone and more siltstone and shale, a change apparently related to the distance from the volcanic centre. About 3,000 feet of andesite and basalt lava in the core of an anticline are overlain by 2,000 feet of calcareous siltstone and minor sandstone and limestone. Locally, conglomeratic limestone and conglomerate contain boulders as much as 2 feet across of mainly volcanic rock and limestone. These strata are succeeded by 3,000 feet of non-calcareous shale and siltstone.

In southern Gaspé Peninsula (Burk, 1964; Badgley, 1956) Silurian sedimentary and local volcanic rocks of the Chaleurs Bay Group lie between the Matapedia facies belt on the north and the folded Mictaw and Maquereau rocks on the south coast. The latter is probably a northeast extension of the Miramichi Geanticline. The basal, Weir Formation is early to late Llandoverian (Ayrton, 1967) and consists of 635 to 2,180 feet of greyish green siltstone with interbeds of quartz- and jasper-pebble conglomerate, arkosic sandstone, and silty limestone. The basal contact with Middle Ordovician Mictaw Group is not exposed but is probably an unconformity. The Clemville Formation conformably overlies the Weir in the north, but near the coast it lies unconformably on the Mictaw and Maquereau Groups, and farther west, unconformably on the Honorat Group. It consists of 90 to 2,000 feet of orthoquartzite, calcareous sandstone, siltstone, and quartz-pebble conglomerate. The overlying La Vieille Formation consists of 800 to 1,800 feet of grey to dark grey, partly nodular and reefal limestone, argillaceous limestone, and calcareous shales of late Llandoverian and Wenlockian age. The lower Ludlovian Gascons Formation is from 1,450 to 3,835 feet thick and consists of green to grey calcareous and non-calcareous siltstone, and minor limestone and red siltstone. The Bouleaux Formation is 800 to 2,600 feet of calcareous siltstone and silty limestone. It is transitional between the Gascons Formation and the overlying West Point Formation of crinoidal, coralline, and partly reefal limestones with red and grey siltstone, varying from 400 to 1,700

feet in thickness. The youngest Silurian, the Indian Point Formation, consists of 456 feet of siltstone, sandstone, and minor crinoidal limestone. The top is covered by Chaleurs Bay. At Black Cape, along the southern coast of Gaspé, the lenticular Black Cape Formation comprises 2,100 feet of andesite and basalt lava, breccia, volcanic conglomerate, and minor red siltstone and grey limestone lithologically and faunally similar to the West Point Formation. Farther west along the south coast Lower Devonian rocks overlap the Silurian strata to rest unconformably on the Honorat Group. A belt of Silurian sedimentary and volcanic rocks occurs southwestward along the northwest flank of Miramichi Geanticline. Rhyolite and andesite are interbedded with sandstone, siltstone, slate, and locally volcanic conglomerate, a late Llandoverian to Ludlovian assemblage. Adjacent to Miramichi Geanticline the Silurian andesite rests, possibly unconformably, on Ordovician rocks and is overlain by Ludlovian green and red slate, sandstone, conglomerate, and minor limestone. The volcanic and sedimentary formations appear to interfinger and pinch and swell in a complex fashion (Greiner and Potter, 1966).

Fredericton Trough. Silurian strata of Fredericton Trough are almost continuous with those of southern Gaspé Trough, extending around the southwestern end of Miramichi Geanticline. In the northeast they are covered by Carboniferous sediments and probably extend beneath the central and southern parts of the Gulf of St. Lawrence. North of Fredericton over 10,000 feet of turbidite, consisting mainly of graded grey greywacke and slate containing Wenlockian graptolites, lies in fault contact with Ordovician rocks (Poole, 1963). The basal part contains graded pebble-conglomerate and black slate. The pebbles are chert, quartzite, pelite, and metamorphic rocks possibly derived from Miramichi Geanticline. The middle part consists of green and red slate and greywacke that apparently thin toward the north. The upper part comprises grey slate and a more quartzose greywacke with Silurian graptolites; it becomes pebbly near the top. Amygdaloidal andesite, quartzose greywacke, and conglomerate with early Ludlovian graptolites lie adjacent to Miramichi Geanticline, but their relationships with older and other Silurian strata are unknown. Similar grey greywacke and slate near Fredericton have yielded early Ludlovian graptolites. Near the southwest end of Miramichi Geanticline an assemblage of greywacke, limestone, calcareous slate, andesite, and basalt (in one place with early Ludlovian shelly fauna) is probably mainly Silurian. North of St. Stephen, greywacke and slate, and thin-bedded micaceous siltstone, quartzite, and green slate like that of the Gaspé Trough in western New Brunswick, are probably Silurian and have been referred to as the Pale Argillite Division of the Charlotte Group.

In southeastern Fredericton Trough (Smith, 1966) Silurian volcanic and sedimentary rocks are complexly interfingered, varying markedly in proportions and lithology from place to place, but are not well dated. Northeast of St. Stephen the Oak Bay Formation consists of 300 feet of polymictic conglomerate that rests probably disconformably on Lower Ordovician rocks. Clasts are composed of well-rounded pebbles and some boulders as much as a foot in diameter. They consist mainly of rhyolite and porphyry, quartzite and diorite; one of the limestone pebbles contained a Silurian pentamerid brachiopod. The Oak Bay thins to zero northeasterly and grades upward into several thousand feet of graded greywacke and slate that contain a Ludlovian shelly fauna. Northeast of Passamaquoddy Bay is a belt of mainly Silurian rocks, the Mascarene Group, that was deposited along the border between Fredericton Trough and Avalon Platform. The group is a variable assemblage, probably many thousands of feet thick, of andesite, basalt, and rhyolite flows; breccias and tuffs interbedded with grey, green, black, and red shale; sandstone; and minor conglomerate and limestone—all metamorphosed generally to slate and phyllite grade. In Maine the oldest strata in the assemblage are late Llandoverian, but most strata in New Brunswick are probably Wenlockian and Ludlovian. Lower Devonian rocks have recently been recognized in the Mascarene assemblage. The welded rhyolitic rocks, red shale, and sandstone accumulated under shallow-water and subaerial conditions of deposition.

Notre Dame Trough in Newfoundland. Silurian and probable Silurian rocks, as thick as 15,000 to 20,000 feet, can be grouped into four, generally conformable lithologic units (Williams, 1967). In ascending order these are: (1) marine greywacke with interbeds of conglomerate, siltstone, and slate; (2) marine conglomerate with interbeds of greywacke and argillite; (3) volcanic rocks; and (4) fluviatile red and grey micaceous sandstone. Within the several outcrop belts the assemblages differ in which units are present, the relative proportions of rock types within the units, and their thicknesses. Various local formational and group names are used. The sequence is complete only in the northeastern axial part of the trough adjoining Notre Dame Bay. Elsewhere, only younger units are present on the flanks of the trough.

On New World Island in eastern Notre Dame Bay (Kay, 1967) several thousand feet of unnamed greywacke, siltstone, and pebble-conglomerate, containing Silurian fossils in upper parts of the section, lies conformably on Middle Ordovician graptolitic slate. Sole marks suggest current flow toward the south and southwest. The greywackes are conformably overlain by the Goldson Formation, more than 2,000 feet thick, consisting of grey to buff, brown, and red pebble- and boulder-conglomerate, with interbeds of sandstone, limy argillite, and coralline shale. Clasts are subangular to well-rounded volcanic rocks, chert, sandstone, argillite, diorite, granite, and metamorphic rocks, their proportions varying from place to place. The conglomerates show graded bedding, scouring, channelling, and locally, crossbedding. Sole

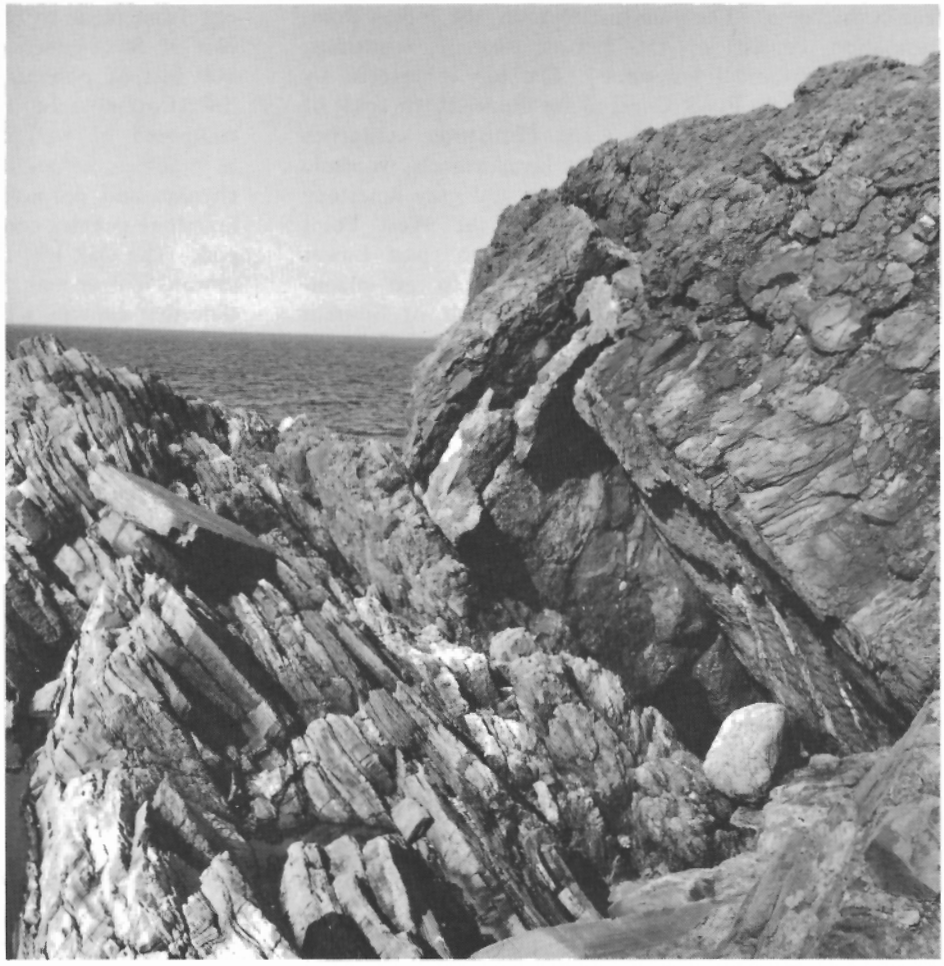


PLATE VI-8

Silurian red sandstone overlain by agglomerate, Botwood Group, Little Fogo Islands, Newfoundland.

marks on greywacke beds suggest a southerly flow, and the conglomerates are coarser and thicker in the northern exposures. A source in northern Notre Dame Bay region is suggested, probably a northeastern extension of Burlington Geanticline. In a few localities conglomerate directly overlies Middle Ordovician slate and volcanic rocks. Shells from clasts and from calcareous interbeds are Llandoverian, but in one locality shells found recently in the matrix of conglomerate are Upper Ordovician, suggesting that Goldson deposition occurred locally during Ordovician as well as Llandoverian time.

In southern Notre Dame Bay (Williams, 1967) near New Bay, about 1,000 feet of Goldson-type grey conglomerate lies conformably but abruptly on greywacke, siltstone, and slate locally containing Middle Ordovician graptolites. Elsewhere thicker undated greywacke may be in part late Ordovician and early Silurian. Clasts consist of pebbles and boulders of fossiliferous limestone and granite and of angular siltstone–slate blocks. One large lensoid limestone mass is 10 by 20 feet and composed almost entirely of Silurian corals. Much of the conglomerate appears to have slid into place.

Along eastern Notre Dame Bay and for 100 miles to the southwest the Silurian rocks have been assigned to a variety of formations by many geologists, but recently have been referred to the Botwood Group and to the Indian Islands Group near Horwood Bay. The Botwood Group consists of three units, each about 5,000 feet thick, in ascending order: (1) conglomerate and greywacke, (2) volcanic rocks, and (3) micaceous sandstone. To the northeast on Change Islands and on the islands north of Fogo Island, the volcanic rocks and micaceous sandstones are interbedded (Pl. VI-8).

South of Notre Dame Bay along the east side of the belt the micaceous sandstone unit overlies the conglomerate without the intervening volcanic formation, or lies with apparent structural conformity on Middle Ordovician slate. The conglomerate commonly contains pebbles of chert, volcanic and granitic rocks, large shale fragments, and fossiliferous limestone boulders. The interbedded greywacke is graded, and sole markings and convolute bedding are common. The volcanic unit includes purplish green, purple, red and green amygdaloidal and porphyritic andesitic lava and pyroclastic rocks. The micaceous sandstones are red, grey, and brown and are muscovitic and quartzose. They generally exhibit crossbedding, ripple-drift laminations, ripple-marks, and less commonly mud-cracks, rain prints, and erosion channels. These features

suggest continental, fluviatile, or shallow-water deposition with periodic subaerial exposure. Interbedded with the sandstone are pebble-conglomerate, micaceous siltstone and shale, and some calcareous shale and limestone. Fossils from the sandstone units, either indigenous to the sandstone or in clasts of a conglomerate, are late Llandoverian to Wenlockian, and where the sandstone lies directly on the Gander Lake Group a Ludlovian graptolite has been found. There is a strong possibility that the various units in the Botwood Group are partly facies equivalents. Toward the southwest the group is regionally metamorphosed to schist and gneiss. The Indian Islands Group consists of conglomerate with an underlying unit of argillite, siltstone, and coralline shale that is not present in the Botwood Group.

Southwest of western Notre Dame Bay is an extensive belt of Silurian volcanic rocks that locally are underlain by conglomerate and overlain by red sandstone. Rocks of the northern end of the belt are referred to the Springdale Group. Most of the rocks are similar to the Botwood Group in the east but the proportions are vastly different. The basal volcanic unit, which rests with uncertain relations on the Ordovician, consists of 10,000 feet of andesitic flows and pyroclastic rocks, and pale red to grey silicic tuff, agglomerate, and flows. Some silicic flows are flow layered and spherulitic. Other silicic rocks are quartz–feldspar porphyries representing both intrusions and crystal tuffs. In one locality the volcanic unit is underlain by a thin granitic pebble-conglomerate. Overlying the volcanic rocks near Notre Dame Bay is 5,600 feet of red sandstone and conglomerate with interlayered silicic and mafic flows. The sandstones contain features indicative of fluviatile or shallow-water deposition. To the southwest, near Red Indian Lake, red sandstone is intercalated in the volcanic rocks. Host rocks of the rich base-metal sulphide orebodies of the Buchans mine are volcanic rocks of probable Silurian age.

On Burlington Peninsula west of Notre Dame Bay the unfossiliferous Cape St. John Group consists of several thousand feet of silicic volcanic rocks, minor mafic volcanic rocks, and less than 5 per cent sedimentary rocks (Neale and Nash, 1963). Large areas of intrusive porphyry are intimately mixed with silicic volcanic rocks. Brown, red, and grey conglomerate, sandstone, and siltstone are intercalated in the volcanic assemblage and lie at its base. Clasts are generally volcanic rocks. Near Notre Dame Bay the Cape St. John Group lies unconformably on Lower Ordovician Snooks Arm Group and contains pebbles of Snooks Arm chert, argillite, volcanic rocks, and ultramafic rocks. To the southwest near Flatwater Pond, silicic volcanic rocks lie nonconformably on the Burlington granodiorite.

At La Poile Bay in southwestern Notre Dame Trough the undated (but probably Silurian) La Poile Group (Cooper, 1954) consists of 900 feet of polymictic pebble- and boulder-conglomerate, succeeded by 1,000 to 2,400 feet of arkosic grit, slate, and minor volcanic rocks, and by more than 10,000 feet of mainly silicic flows and pyroclastic rocks. Relations to older and younger formations are unknown. Along strike the La Poile Group passes into schist and gneiss.

West of White Bay (Neale and Nash, 1963) the Silurian is probably represented by three unfossiliferous formations as well as by the overlying Natlins Cove Formation that contains a late Llandoverian to early Wenlockian shelly fauna, like that of the Goldson conglomerate, and a recently discovered Ludlovian fauna. The Giles Cove Formation overlies Ordovician (?) Doucers Formation with uncertain relations. It consists of 1,000 feet of grey shale, and locally in the upper part includes 700 feet of interbedded andesite flows, tuff, silicic tuff, and agglomerate called the Deadmans Cove Member. The overlying polymictic conglomerate of the Jacksons Arm Formation, 300 feet thick, contains pebbles and boulders of silicic and mafic volcanic rocks, sedimentary rocks, and a few granitic rocks. The succeeding Simms Ridge Formation consists of 2,340 feet of grey to green arkosic sandstone and shale. The Natlins Cove Formation comprises some 10,700 feet of grey to greyish brown, feldspathic and argillaceous sandstone with interbeds of limestone, limy siltstone, and rare conglomerate. Clasts in the conglomerate consist of silicic volcanic rocks and quartz–feldspar porphyries, granite, and sedimentary rocks. Rhyolite and andesite of the Sops Island Member, 1,675 feet thick, occur in the middle of the Natlins Cove Formation and appear to be closely associated with intrusive quartz–feldspar porphyries like those on Burlington Peninsula.

Near Fortune Bay in southern Newfoundland (Williams, 1967) nearly 20,000 feet of unfossiliferous rocks, lithologically similar to the Silurian elsewhere in Newfoundland, overlies the Cambrian strata of Avalon Platform. The Grand Le Pierre Formation, 1,000 feet thick and the overlying Belle Bay Formation, 6,000 feet thick, consist of varicoloured silicic flows and tuff, minor basalt, and lenticular interbedded red, purple, and green siltstone, conglomerate, slate, greywacke, and minor chert. The Belle Bay overlies the Grand Le Pierre with local angular relations, and both rest with angular unconformity on the Cambrian Youngs Cove and Nine Mile Hill Formations. The Belle Bay Formation is locally overlain by 1,000 feet of tuffaceous slate, conglomerate, and greywacke of the Anderson Cove Formation. In most other places the Belle Bay Formation is overlain by the Rencontre Formation, 4,000 feet of red arkosic sandstone, conglomerate, siltstone, and shale with some mafic flows in the lower part. Clasts in the conglomerate are mainly silicic volcanic rocks. The sandstone has crossbeds, ripple-marks, and mudcracks. Crossbeds and cut-and-fill structures indicate a westward flow and suggest that there was land to the southeast.

Avalon Platform. In southern New Brunswick the Silurian rocks that lie on the northwest part of the

Cambrian and Lower Ordovician of Avalon Platform are mainly volcanic and clastic sedimentary rocks, and have been described under Fredericton Trough. In northern Nova Scotia, the Silurian and Lower Devonian Arisaig Group of Antigonish Highlands (Williams, 1914) consists of about 4,000 feet of mainly grey shale and fine-grained sandstone with abundant near-shore type shelly fossils. The lower 2,500 feet represents the entire Silurian system. The lowest formation, the Beechhill Cove, is early Llandoverian and rests disconformably or unconformably on the Ordovician Browns Mountain Group. It consists of 225 to 300 feet of green-grey sandstone and siltstone, locally with less than 2 feet of basal conglomerate containing quartz and rhyolite pebbles. The overlying Ross Brook Formation rests sharply on the Beechhill Cove and comprises 1,050 to 1,300 feet of middle and upper Llandoverian black shale, and towards the top, siltstone and fine sandstone. At least a dozen intercalated thin ash and tuff beds are present in the lowest 60 feet at Beechhill Cove. The conformably overlying French River Formation is early Wenlockian and consists of 280 feet of grey siltstone and shale. It is succeeded conformably by the McAdam Formation, 555 to 625 feet of upper Wenlockian and lower Ludlovian grey and black shale, siltstone, and some limestone concretions, phosphatic nodules, and a thin fossiliferous oölitic hematite bed. The upper Ludlovian Moydart Formation is 390 feet thick and comprises green shale, siltstone, and rarely limestone, overlain by nearly 30 feet of "Red Stratum" consisting of red shale and nodular limestone. The currents that transported detritus comprising the Beechhill Cove and McAdam Formations flowed south and southwest. Near Sunnybrae, strata equivalent to the Arisaig Group consist of two formations (Maehl, 1961). The older Glencoe Brook Formation is 910 feet thick and is similar in age and lithology to the Beechhill Cove. The conformably overlying Kerrowgare Formation is probably Llandoverian to Ludlovian and consists of several hundred feet of shale, slate, fine-grained sandstone, and an intercalated 2½-foot fossiliferous oölitic hematite bed like that of the McAdam Formation. In Cobequid Mountains farther west, several thousand feet of Silurian strata similar to the upper part of the Arisaig Group is underlain by silicic and mafic volcanic rocks.

On southeastern Cape Breton Island the unfossiliferous Middle River Group (Weeks, 1954) is probably Silurian and early Devonian and lies with angular unconformity on the Cambrian Kelvin Glen and Bourinot Groups. It consists of an unknown thickness of cross-bedded feldspathic sandstone, quartzite, and conglomerate. The conglomerate contains quartz and quartzite pebbles and volcanic cobbles derived from the Bourinot Group probably to the north and west.

In southeastern Newfoundland, as in southern New Brunswick, thick Silurian volcanic and sedimentary rocks of Notre Dame Trough rest on the northwestern part of Avalon Platform. Inasmuch as no other Silurian rocks of either geosynclinal or platformal aspect occur elsewhere on the platform, their existence and extent during the Silurian cannot be appraised.

Meguma Trough. In western Nova Scotia (Taylor, 1965; Crosby, 1962) Silurian rocks comprise three conformable formations. The upper two, the Kentville and New Canaan Formations, are largely if not entirely Ludlovian, and the lower one, the White Rock Formation, is undated. The entire assemblage consists of quartzite, slate, and volcanic rocks that thicken from about 2,000 feet in the northeast to nearly 20,000 feet in the southwest. Apart from the volcanic rocks and conglomerates, the strata represent the upper part of a clastic sequence that is probably a nearly continuous deposition from the Cambrian into the Devonian. The White Rock Formation increases in thickness from 100 to 500 feet near Wolfville to over 15,000 feet near Yarmouth. It lies conformably on the Halifax Formation except at Cape St. Mary where the basal White Rock rhyolite lies with an angular unconformity of 10 to 20 degrees on Halifax slate. This relationship is believed to be of local significance only. Near Wolfville the White Rock Formation consists of two massive orthoquartzite beds separated by grey slate and siltstone lithologically indistinguishable from the underlying Halifax Formation. It grades southwestward into an assemblage of andesite lava and tuff, slate, quartzite, conglomerate, rhyolite, and greywacke. Clasts in the conglomerates are pebbles or boulders as much as 2 feet across mainly of quartzite with minor quartz and rhyolite. The Ludlovian Kentville Formation conformably overlies the White Rock Formation, but in westernmost Nova Scotia it has not been recognized and equivalent strata may be included in the White Rock Formation. The Kentville varies in thickness from 1,600 feet near Wolfville to 3,500 feet in the southwest in the Nictaux–Torbrook area; it comprises grey siltstone and slate with minor argillaceous quartzite. The conformably overlying Ludlovian New Canaan Formation occurs only near Wolfville and consists of more than 1,000 feet of marine sedimentary andesite-breccia and minor siltstone, slate, and andesite flows. The top is not exposed.

St. Lawrence Platform

Southwestern Ontario. Alexandrian and early Niagaran rocks that form the Cataract Group of southwestern Ontario reflect a transgressive–regressive cycle of sedimentation (Sanford, 1964). They are 500 feet thick in Michigan Basin, thinning to 80 feet over Algonquin Arch (Fig. VI-16), and thickening to 175 feet in northwestern Allegheny Trough beneath eastern Lake Erie. The transgressive phase consists of tan and blue-grey, fine- to medium-crystalline dolomite of the Manitoulin Formation which is 80 feet thick bordering Michigan Basin. It thins southeast toward Niagara Peninsula and grades into the Whirlpool Formation—as much as 25 feet of white and grey, fine-grained, orthoquartzitic sandstone. As the

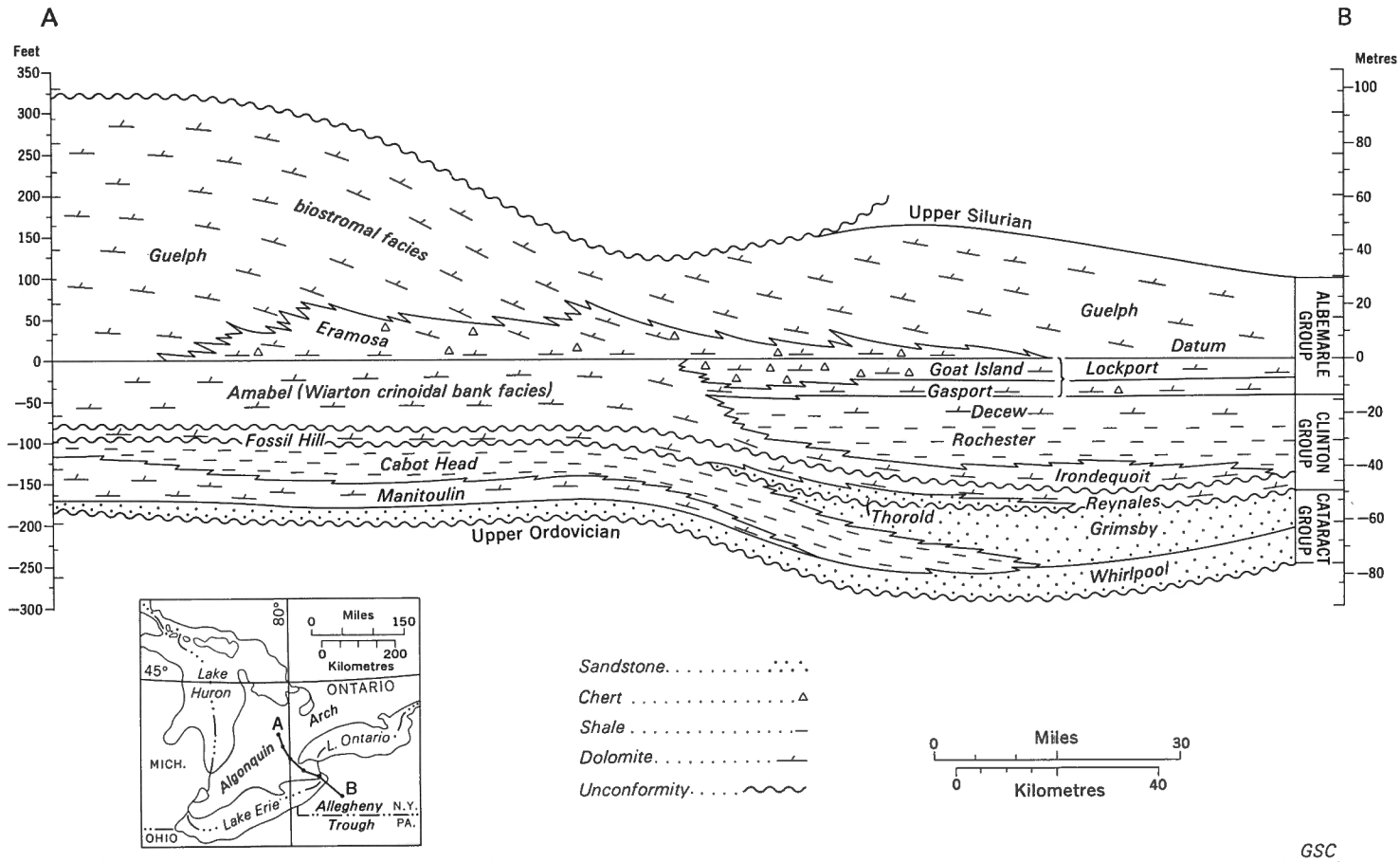


FIGURE VI-16. Cross-section of Lower and Middle Silurian strata, Algonquin Arch to northwestern Allegheny Trough, southwestern Ontario and New York (by B. V. Sanford).

Cataract sea regressed to the northwest, a time–transgressive deltaic red bed sequence was deposited (represented by the Grimsby Formation) that consists of protoquartzitic sandstone and siltstone, and the intertonguing more basinal grey-green and locally red marine shale of the Cabot Head Formation. The Grimsby thins northwestward from a maximum thickness of 80 feet beneath eastern Lake Erie, whereas the partly equivalent and underlying Cabot Head shale thickens northwestward to a maximum of 120 feet near Lake Huron. Around the margin of Michigan Basin (Fig. VI-17) the Cabot Head grades into the Dyer Bay Formation, 20 feet of fine- to medium-crystalline blue-grey mottled dolomite. Conformably succeeding the Dyer Bay is the Wingfield Formation composed of greyish brown and locally red and greyish green shaly aphanitic dolomite, 36 feet thick. It is overlain by the St. Edmund Formation consisting of greyish brown aphanitic dolomite varying in thickness from 12 feet in Bruce Peninsula to 90 feet in Manitoulin Island and the northern peninsula of Michigan.

Detritus in the Whirlpool and Grimsby Formations was derived from the southeast. The partly equivalent Medina red sandstones in western New York and Pennsylvania lie on Upper Ordovician coarse red beds, but east of the Lower Silurian depositional boundary much of the Upper Ordovician is missing and presumably eroded—the detritus constituting the Lower Silurian clastic beds of Allegheny Trough, Algonquin Arch, and southeastern Michigan Basin.

Middle and late Niagaran deposits comprising crinoid bank and complex biostromal barrier reefs constitute the Clinton and Albemarle Groups (Sanford, 1964). They formed on the shallow margins of the rapidly subsiding Michigan Basin. In Ontario these deposits form Manitoulin Island, Bruce Peninsula, and extend southeastward onto Algonquin Arch and into the subsurface beneath central and western Lake Erie (Fig. VI-16). Along the barrier complex, clean carbonate rocks of shallow marine origin, 450 to 550 feet thick, grade westward into basinal carbonates that thin to less than 100 feet in central Michigan Basin, and eastward into basinal carbonates and shale, 200 feet thick in northwestern Allegheny Trough beneath eastern Lake Erie. The Fossil Hill Formation of the Clinton Group consists of brown, fine- to medium-crystalline dolomite locally characterized by coral biostromes and massive lenses containing abundant *Pentamerus oblongus*. From a maximum thickness in Ontario of 80 feet in southern Bruce Peninsula, it thins

northwestward to 40 feet on Manitoulin Island and southeastward to 8 feet over Algonquin Arch. Southeast of the arch, the Fossil Hill grades into as much as 22 feet of fine-grained, orthoquartzitic sandstone of the Thorold Formation, 7 feet of grey fissile shale of the Neahga Formation, and 8 to 22 feet of brown, fine- to medium-grained dolomite of the Reynales Formation.

After deposition of the Fossil Hill and equivalent strata, the sea regressed from Michigan Basin and Algonquin Arch. Major erosion occurred on the arch during the hiatus. As the Niagaran sea advanced again into Ontario and Michigan, a variety of facies were produced, the most persistent of which is the white to bluish grey and beige, coarsely crystalline crinoidal dolomite of the Colpoy Bay and Wiarton Members of the Amabel Formation bordering Michigan Basin. The members are 150 feet thick on the crest of Algonquin Arch and intertongue with grey, cherty, fine-grained dolomite of the Lions Head Member in central Michigan Basin. Equivalent rocks in Niagara Peninsula and beneath eastern Lake Erie are the Irondequoit white to grey, crinoidal dolomite, 10 to 20 feet thick; the Rochester grey silty and dolomitic shales, 80 feet thick; the Decew grey argillaceous dolomite, 30 feet thick; and the Gasport and Goat Island Members of the Lockport Formation, white to grey crinoidal dolomite succeeded by grey, cherty dolomite, 60 feet thick (Pl. VI-9). Lateral migration of the Amabel crinoid bank facies occurred from time to time, and accounts for the presence of local wedges of coarse crinoidal deposits constituting the Irondequoit and Gasport Members within an otherwise basinal sequence. The Irondequoit is confined to Niagara Peninsula and eastern Lake Erie, but the Gasport is widely distributed throughout southwestern Ontario and reaches its maximum thickness of 150 feet near Lake St. Clair. During the final phase of Amabel–Lockport sedimentation the structural centre of Michigan Basin shifted southward. In Ontario this resulted in a southwestward migration of the Wiarton crinoid bank from the Algonquin Arch along a broad arc to central Lake Erie, and thence westward into northwestern Ohio to the newly established southern rim of Michigan Basin. The grey, fine-grained dolomite facies of the Lions Head also migrated southward, transgressing in time, to form the basinal facies of the carbonate bank throughout southern Michigan Basin. There, and in Niagara Peninsula and beneath eastern Lake Erie, these strata are known as the Goat Island Member of the Lockport Formation.

The youngest and most distinctive Niagaran rocks are the carbonates of the Guelph Formation, for they contain the major bioherm reef development of southwestern Ontario and Michigan. Consisting partly of a biostromal complex superimposed on the subjacent carbonate bank deposits of the Amabel Formation, the Guelph formed a fringing barrier reef that completely enveloped the rapidly subsiding Michigan Basin (Fig. VII-26). Cream to white, coarsely crystalline dolomite, 327 feet thick, forms the barrier reef that grades basinwards into inter-reef facies composed of brown and black, bituminous and cherty dolomite. Adjacent to the barrier reef in Michigan Basin are large bioherm patch reefs with a vertical relief of as much as 160 feet and a base several thousand acres in extent. Toward the centre of the basin, where subsidence was more rapid, small pinnacle reefs developed with a relief of 300 to 550 feet and a base of 300 to 500 acres. Although a few scattered bioherms occur within Guelph strata on the barrier and along its southeast margin in

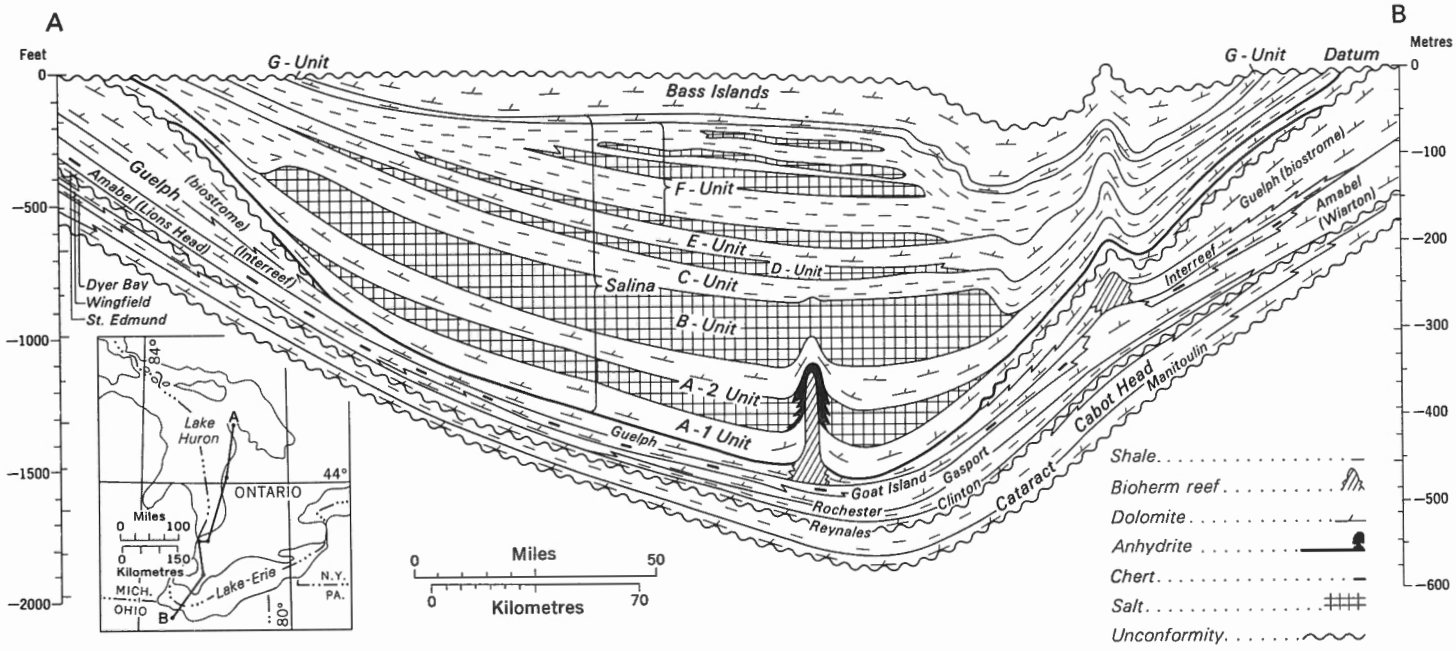


FIGURE VI-17. Cross-section of Silurian strata, eastern flank of Michigan Basin, southwestern Ontario (by B. V. Sanford).

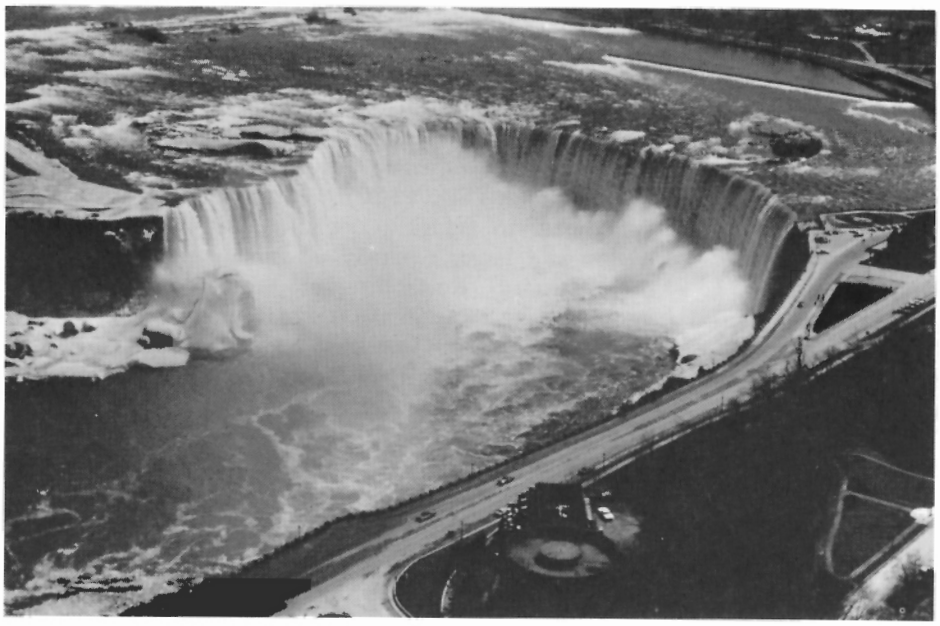


PLATE VI-9
Niagara Falls, Ontario. Falls are formed by resistant dolomites of the Silurian Lockport Formation overlying the softer Clinton and Cataract shales and sandstones and the Upper Ordovician Queenston red shales.

northwestern Allegheny Trough, nowhere in these regions are they known to have more than a few feet of vertical closure, and in general they reflect lack of continuous subsidence.

The Upper Silurian (Cayugan) Series of southwestern Ontario contains a wide variety of evaporite, carbonate, and clastic facies that comprise the Salina and Bass Islands (Bertie) Formations (Sanford, 1964). They have a combined maximum thickness of 1,700 feet in Lambton County near southern Lake Huron (Fig. VI-17) and thin eastward to about 345 feet on Algonquin Arch. The Salina Formation, with seven units designated from A to G in ascending sequence, consists of dolomite, limestone, shale, salt, and anhydrite. Where it has a maximum thickness of 1,340 feet near southernmost Lake Huron, an aggregate of 733 feet consists of salt. The salt beds occur within units designated A, B, D, and F; these gradually wedge out one by one toward the edge of Michigan Basin and grade into anhydrite, dolomite, and shale. The reconstructed depositional edge of Salina salts bordering the Michigan Basin roughly coincides with the margin of the subjacent Guelph barrier reef (Koepke and Sanford, 1965). The gradual migration of the salt edge to its present position much lower in the basin is the result of leaching during post-Silurian time. Completing the Cayugan sequence in Michigan Basin is the Bass Islands Formation consisting of cream to tan, finely sucrosic dolomite as thick as 300 feet, and the equivalent Bertie Formation, 30 to 100 feet thick, in Niagara Peninsula and eastern Lake Erie, composed of dark brown, aphanitic argillaceous dolomite.

Lake Timiskaming outlier. The Alexandrian and early Niagaran Wabi Group (Ollerenshaw and MacQueen, 1960) rests disconformably on early Upper Ordovician (Edenian) Dawson Point Formation and consists of 152 feet of impure carbonate rocks and shale that are lithologically similar to the formations that comprise the Cataract Group of Bruce Peninsula and Manitoulin Island and those names are applied accordingly. The lowest unit, the Manitoulin Formation, is 54 feet of grey limestone and dolomite with a shaly and sandy zone at the base. The overlying Cabot Head Formation comprises 33 feet of red and green shale containing anhydrite and gypsum. The shale grades upward into 25 feet of grey and blue-grey, medium-crystalline limestone and dolomite of the Dyer Bay Formation. The Dyer Bay Formation is succeeded by the St. Edmund Formation, 40 feet of light greenish grey aphanitic dolomite with interbeds of green and red nodular shale. The Thornloe Formation, the youngest Paleozoic strata at Lake Timiskaming, is middle Niagaran. It rests disconformably on the Wabi Group and consists of 196 feet of grey-buff to light brown, fine- to medium-crystalline limestone and dolomite with a foot of limestone-conglomerate at the base. The Thornloe is lithologically similar to and coeval with the Fossil Hill Formation of southern Ontario.

Anticosti Basin (Fig. VI-7). On Anticosti Island (Bolton, 1961; Roliff, 1968) rocks equivalent to the Alexandrian and early Niagaran Cataract and Wabi Groups of Ontario are represented by the Becscie and Gun River Formations which reach a combined thickness of about 600 feet. The Becscie, 265 feet thick, overlies the Upper Ordovician Ellis Bay conformably and consists of a lower whitish grey to blue-grey, finely crystalline limestone grading upward to green shale with nodular limestone interbeds. The succeeding Gun River, 308–343 feet thick, consists of ash-grey to yellowish white limestone alternating with shale in the upper part. Ripple-marks and intraforma-

tional conglomerate in both formations indicate shallow-water depositional environments.

The Niagaran Jupiter and Chicotte Formations, possibly equivalent to Clinton and Amabel strata of southwestern Ontario, are the youngest Paleozoic strata exposed and have a combined thickness of about 725 feet. The Jupiter Formation, 650 feet thick, consists of ash-grey finely crystalline limestone with thin, grey shale interbeds grading upward to light green and grey calcareous shale and argillaceous limestone. The Chicotte Formation, 73 feet thick, rests with abrupt contact on the Jupiter. It is composed of bioclastic limestone with skeletal fragments of crinoid columns and corals, and resembles the Wiarton Member of the Amabel Formation of Ontario.

On Port au Port Peninsula, Newfoundland, the basal beds of the Clam Bank Formation may be Silurian (Rodgers, 1965). They lie with structural conformity on the Middle Ordovician Long Point Formation. The Clam Bank consists of 1,500 feet of red sandstone, siltstone, shale, and some calcareous beds with Pridoli fossils in the upper part.

Devonian

Tectonic Summary

Lower Devonian sedimentation and volcanism in the Appalachian Geosyncline and St. Lawrence Platform reflect a continuation of Silurian depositional patterns, facies, and tectonic elements. In the geosyncline they were profoundly changed by the Acadian Orogeny during the Middle and Late Devonian. During the Late Devonian new tectonic elements were initiated, and terrestrial sedimentation began in the geosyncline that continued into the Carboniferous. Fine clastic sediments derived from the Acadian mountains spread across the western St. Lawrence Platform.

During the Early and early Middle Devonian (Figs. VI-18, 19) thick marine sediments and volcanics, passing upward into non-marine beds, were deposited conformably on the Silurian in Gaspé and Fredericton Troughs. The troughs were bounded by Quebec and Miramichi Geanticlines and Avalon Platform. Devonian volcanism occurred in the same regions as Silurian volcanism. Limestone was deposited in northwestern Gaspé Trough grading southeastward into shale, sandstone, and volcanic rocks of central and southeastern Gaspé Trough. Non-marine sandstone and conglomerate followed in the late Early and early Middle Devonian, perhaps reflecting the early Acadian orogenic phases in Miramichi Geanticline. On Avalon Platform in Nova Scotia deposition of marine siltstone was followed by non-marine red beds, and in the Middle Devonian by volcanic rocks, red sandstone, and conglomerate. In Meguma Trough marine shale was deposited with some limestone and oölitic iron-formation. In Notre Dame Trough in Newfoundland, shale and siltstone, largely non-marine and several thousand feet thick, were deposited in the southwestern part in a tectonic position comparable to the thick, non-marine sandstone sequence in northwestern Gaspé Trough. Rhyolite was apparently extruded in southeastern Notre Dame Trough.

During the Acadian Orogeny almost the entire Appalachian Geosyncline was deformed into northeasterly trending folds (Fig. VI-20). Parts were regionally metamorphosed to grades as high as almandine amphibolite facies, and large, generally discordant granite batholiths were intruded. Rocks that were not deformed during the orogeny were those of the Taconian-deformed northwestern part of Quebec Geanticline and a small part of Avalon Platform in eastern Newfoundland. The rocks were thrust northwestward and northward along Logan's Line onto St. Lawrence Platform. The entire belt, probably including the site of the present continental shelf, was uplifted, and the mountains underwent erosion.

Upper Devonian synorogenic and post-orogenic, non-marine red sandstone, conglomerate, and shale were deposited in local basins on the Acadian Orogen as the basal deposits of Fundy Epieugeosyncline. Deposition within the epieugeosyncline, which was bordered by narrow platforms, continued into the Carboniferous and was controlled largely by fault movements attributed to the Maritime Disturbance, the final phase of the Appalachian orogenies.

On western St. Lawrence Platform the Upper Silurian evaporite basins were emergent in the early Early Devonian. Subsequently, a thin, marine, Siegenian orthoquartzite was deposited in southwestern Ontario and Michigan but was largely removed by erosion as a result of epeirogenic uplift. Lower Devonian limestone occurs as blocks in a Cretaceous diatreme breccia near Montreal, but probably once extended throughout Quebec Basin. Late Lower and early Middle Devonian limestone and dolomite were deposited on the western part of the platform; from Algonquin Arch, the strata thicken northwestward into Michigan Basin and southeastward into Allegheny Trough. During the late Middle and the Late Devonian, coarse red beds of the Catskill Delta, derived from the Acadian mountains, spread northwestward into Allegheny Trough, grading into marine shale and siltstone on Algonquin Arch and to shale and limestone in western Michigan Basin. Devonian strata of southwestern Ontario are lithologically and faunally similar to those of Hudson Platform, suggesting that the seas extended through the intervening region. Devonian strata are not present in central and eastern St. Lawrence Platform except locally in southwestern Newfoundland. A coarse red bed sequence is partly Lower Devonian and was derived from mountains to the east.

Lower and Early Middle Devonian

Appalachian Geosyncline (Figs. VI-18, 19). In northwestern Gaspé Trough in southern Quebec, Lower and early Middle Devonian sedimentary and volcanic rocks lie

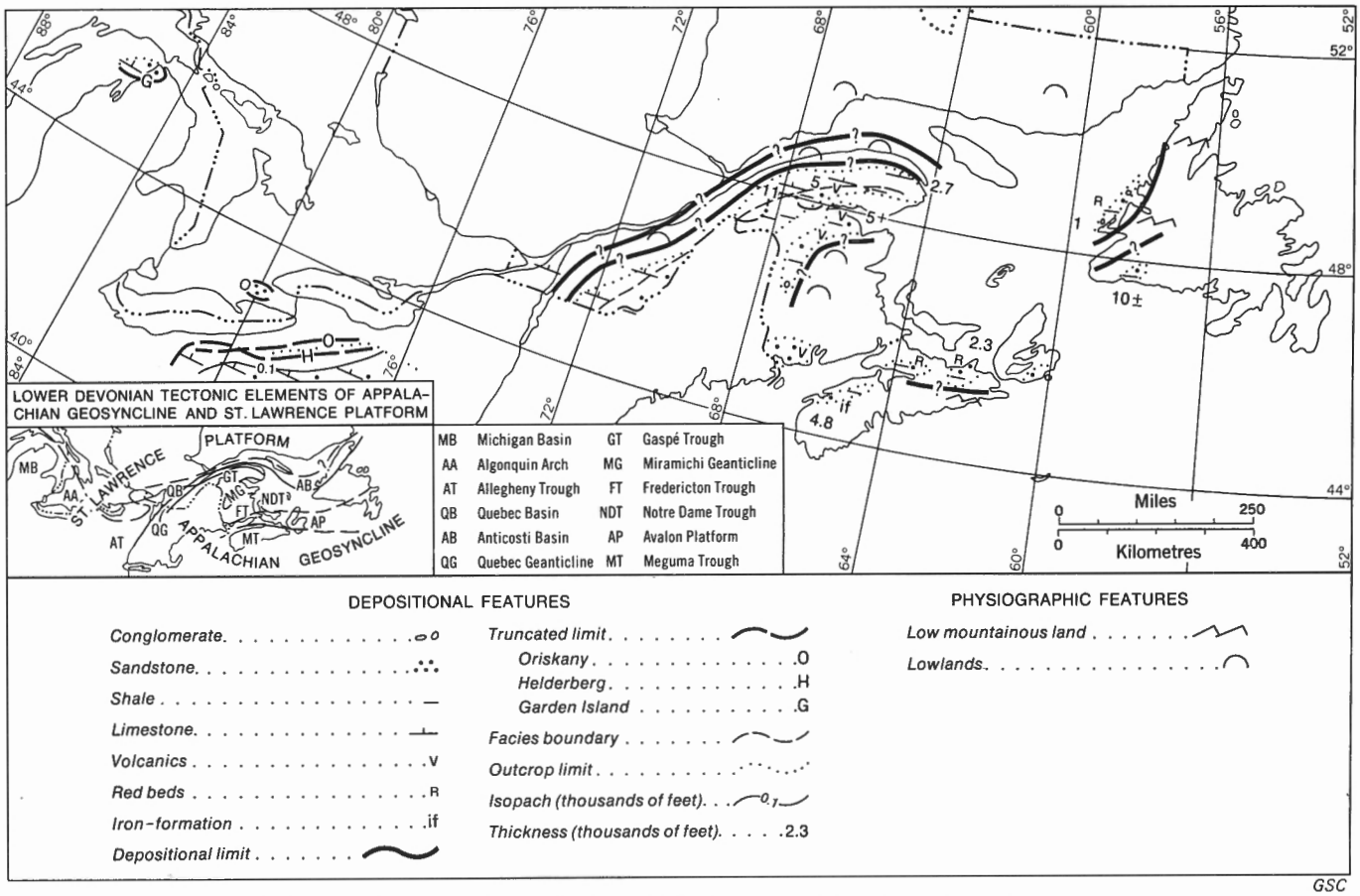


FIGURE VI-18. Early Lower Devonian sedimentation, volcanism, and tectonism in Southeastern Canada.

conformably on Upper Silurian strata, or locally overlap northwestward to rest directly with angular unconformity on the Cambrian and Ordovician of Quebec Geanticline. In the Eastern Townships the similar and laterally equivalent St. Francis and St. Juste Groups consist of an unknown thickness of thin-bedded limestone and calcareous slate with sandstone interbeds, apparently conformably overlain by thin-bedded dark grey slate and sandstone. The lower, calcareous strata are partly Upper Silurian. The base of the sequence is commonly a polymictic conglomerate resting with angular unconformity on Ordovician and older rocks. In one locality at least, a 50-foot conglomerate is apparently Lower Devonian. Thus the base of the sequence varies from perhaps Middle Silurian to Lower Devonian. To the southeast, along the International Boundary, the calcareous strata are missing, and Lower Devonian Seboomook and Compton Formations of thin-bedded dark grey pelites and sandstone have apparently overlapped the older strata in the subsurface to rest on probable Ordovician rocks of a small geanticlinal area. The possibility exists that some of the pelitic and sandy strata may be in part a southeastern facies equivalent to the upper part of the calcareous rocks. The Frontenac Formation overlies the Seboomook–Compton strata and is the youngest formation in Eastern Townships. It consists of dark grey slate and sandstone, and altered basic volcanic rocks many of which are pillowed flows.

In Gaspé Peninsula, northwesternmost New Brunswick, and Témiscouata, (McGerrigle, 1950; Béland, 1960; Lajoie, *et al.*, 1968) Lower and early Middle Devonian rocks consist of the Gaspé Limestone, the conformably overlying Gaspé Sandstone, and the pelitic and sandy Fortin and Témiscouata Formations that lie to the southeast and into which the limestone and lowermost part of the sandstone grade laterally. In the northern half of the belt Ludlovian St. Léon calcareous siltstones grade upward into Lower Devonian limestone of the Cape Bon Ami Formation. The contact may be time–transgressive, but it lies at the base of either the Gedinnian or the Pridoli. The Cape Bon Ami Formation consists mainly of dark grey argillaceous and silty limestone interbedded with dark grey limestone and calcareous shale. On Forillon Peninsula it is 1,100 feet thick and thickens to the west and south; it is from 2,000 to 3,000 feet thick along the northern edge as far west as Témiscouata. Southward into the Gaspé Trough it thickens to 3,500 feet and possibly to a maximum of 6,000 feet in parts of east-central Gaspé. On Forillon Peninsula (Cumming, 1959) the Cape Bon Ami is underlain by the Gedinnian St. Alban Formation and the Pridoli Griffon Cove Formation,

both of which apparently are correlatives of lower parts of Cape Bon Ami elsewhere. The gently dipping Griffon Cove lies unconformably on isoclinally folded Lower Ordovician rocks. It is 400 feet thick and eastward towards the coast wedges out to zero. It consists of quartz-pebble conglomerate and red and green shale passing upward into limestone that in turn grades upward into the St. Alban Formation of 345 feet of grey argillaceous limestone and greenish grey and maroon calcareous shale. The St. Alban overlaps the Griffon Cove beds to lie unconformably on the Ordovician rocks, and is gradationally overlain by the Cape Bon Ami Formation. In the west near Témiscouata, about 1,200 feet of sandstone, limestone, and minor dolomite make up the Lac Croche Formation of Pridoli age which there lies at the northwestern limit of Pridoli and Lower Devonian strata and is a more sandy correlative of the lower part of the Cape Bon Ami to the south and east.

The Grande Grève Formation conformably overlies the Cape Bon Ami and consists mainly of well-bedded, dark to light grey, hard siliceous and cherty limestone, calcareous siltstone, and minor sandstone. Silica occurs as chert nodules, chert beds, and in siliceous limestone interbedded with purer limestone. On Forillon Peninsula the formation is about 900 feet thick and thickens westward to 2,000 feet for some distance and then to a possible 9,000 feet northeast of Témiscouata Lake. In central Gaspé Peninsula the formation is about 3,000 feet thick. Oil occurs locally in cracks and vugs. A dozen thin intercalated beds of bentonite contain sanidine and biotite that yielded K–Ar dates of 388 and 382 m.y., respectively.

The Gaspé Sandstone (McGerrigle, 1950; Boucot, *et al.*, 1967) lies conformably on the Gaspé Limestone; it is composed mainly of three, dominantly non-marine, gradationally conformable formations in ascending order: York River, Battery Point, and Malbaie. The three formations were originally described in eastern Gaspé Peninsula, but only the lower two have been recognized in central and western Gaspé. The York River and Battery Point Formations are distinguished largely by the colour of strata and detrital feldspars. Variations in lithology led to definition of other formations in central and western Gaspé, and it seems probable that the boundaries are diachronous.

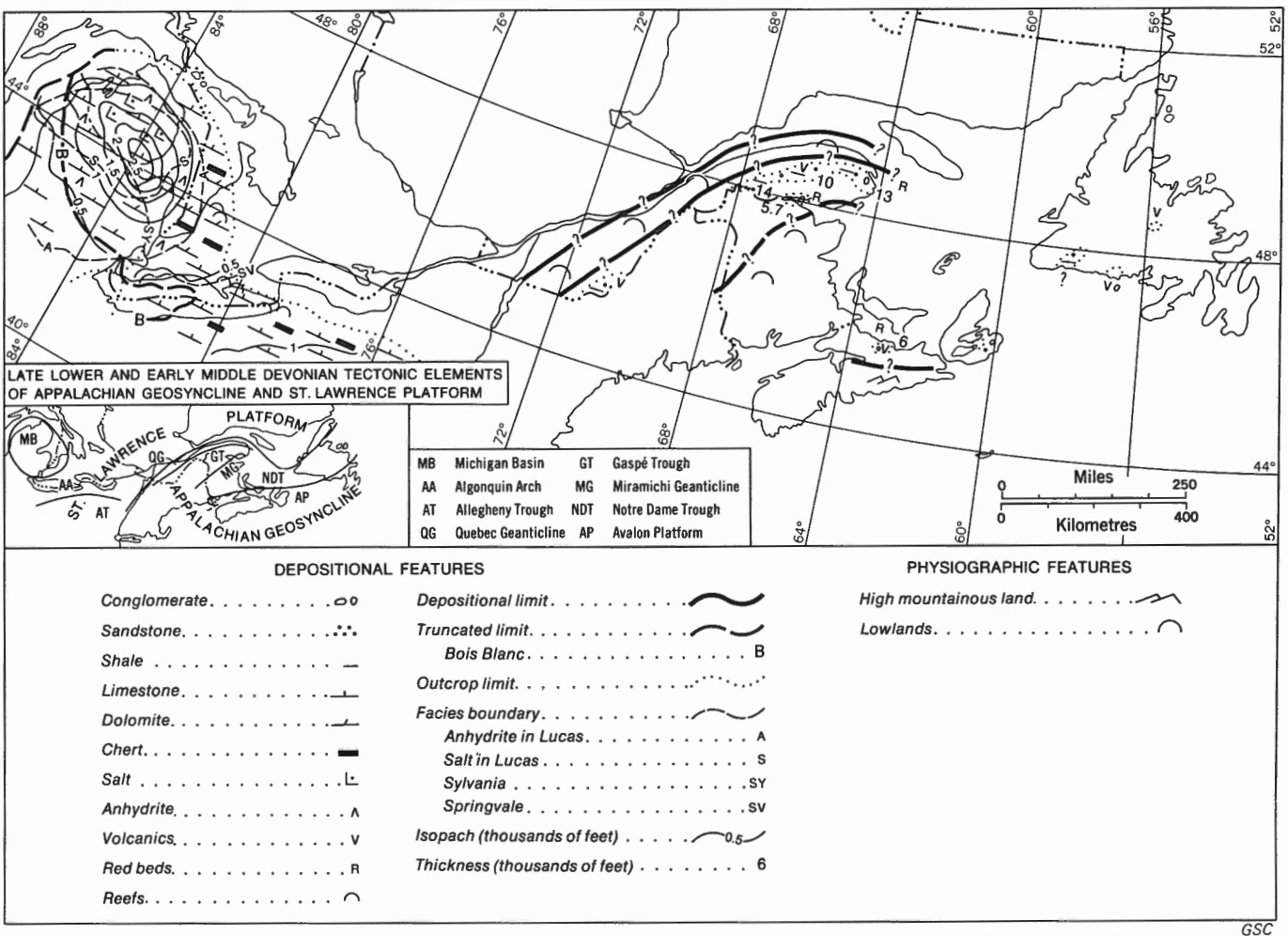


FIGURE VI-19. Late Lower and early Middle Devonian sedimentation, volcanism, and tectonism in Southeastern Canada.

The York River Formation consists of green to dark grey feldspathic sandstone and shales containing plant detritus and interbeds of calcareous sandstone and sandy limestone with a rich marine shelly fauna. The formation is 1,300 feet thick in northeasternmost Gaspé and thickens southward along the coastal region to about 6,000 feet; in western Gaspé it is 14,000 feet or more thick. The northern limit of the York River Formation in central Gaspé has a basal transitional facies, some 2,000 to 4,000 feet thick, of interbedded sandstone and shale of the York River type and limestone of the underlying Grande Grève type; this succession has been referred to as the York Lake Formation. In western Gaspé, sandstone beds similar and equivalent to the York River Formation were named the Heppel Formation; the upper part is a red sandstone facies called the Lake Branch Formation, about 4,000 to 5,000 feet thick. In central Gaspé, flows, tuffs, and breccias are intercalated in the York River Formation and its equivalents at horizons within the formation that vary from place to place. Locally, volcanic sequences are 2,000 feet thick and more. Most of the rocks are andesite and basalt, generally porphyritic (feldspar) and amygdaloidal; others are rhyolite and porphyritic rhyolite containing phenocrysts of quartz or feldspar.

The Battery Point Formation consists of a lower part of greenish grey feldspathic sandstone and an upper part of red and brown feldspathic sandstone, shale, and conglomerate. It contains a sparse marine fauna and abundant land plants in the lower part. Most detrital feldspar is pink, and like the York River consists of both potash feldspar and plagioclase. Clasts in the Battery Point consist of quartz, a variety of rocks, granite, and syenite. Ripple-marks and crossbeds are common in both formations. The Battery Point is 5,000 to 7,000 feet thick in eastern Gaspé and about 10,000 feet thick in central Gaspé.

The Malbaie Formation, the youngest unit of the Gaspé Sandstone, occurs only in easternmost Gaspé Peninsula. It comprises some 2,000 feet of grey to reddish brown pebble-conglomerate, sandstone, and minor green and red shale. Pebbles are mainly of limestone of the Ordovician and Silurian White Head and Lower Devonian Grande Grève Formations and sandstone of the underlying Battery Point Formation; other pebbles consist of quartz, chert, volcanics and rarely of granite, syenite, and gneiss. The Malbaie has been faulted and gently folded, and is unconformably overlain by the Carboniferous Bonaventure conglomerate. The entire Gaspé Sandstone succession comprises over 10,000 feet of clastic strata that were deposited in a narrow trough during a very short interval of time, perhaps as little as 10 to 15 million years. The trough probably developed as the area to the south, the Miramichi Geanticline, became uplifted during the early stage of Acadian Orogeny. The detritus was probably derived from the southern uplifted areas, but in the York River beds in central and northern Gaspé southwestward and westward longitudinal current flow is indicated by crossbedding. The Gaspé Sandstone records an increase in size of detritus; a decrease in abundance of marine fauna; an increase in abundance of land plants and spores to the middle of the Battery Point; a general change of strata colour from grey and dark grey to green, red, and reddish brown; and a change from mixed non-marine–marine strata to entirely non-marine continental strata. Oil seeps are common in the York River and Battery Point beds.

Between eastern Gaspé Peninsula and northwestern New Brunswick thin-bedded grey siltstone, slate and minor sandstone, limestone, and conglomerate constitute the Lower Devonian Fortin and Témiscouata Formations. These rocks form a belt that continues southwesterly through northern Maine into the southeast part of the Eastern Townships where they are included in the Seboomook Formation, St. Juste and St. Francis Groups, previously described. The Fortin and Témiscouata Formations represent a deeper water marine facies equivalent to the Gaspé Limestone and probably the lower part of the York River Formation. The facies belt lay between the carbonates to the north and the volcanic belt, including the Dalhousie Formation, to the south. In eastern Gaspé the Fortin Formation apparently pinches out northward between the underlying Grande Grève limestones and the overlying York River sandstones. The basal few feet of the Fortin is a conglomerate containing clasts of Grande Grève limestone. At its easternmost exposures the Fortin is about 5,000 feet thick; it is sandy and grades imperceptibly upward into the overlying York River Formation. Farther west, in east-central Gaspé, the Fortin Formation consists of an uncertain thickness, perhaps several thousand feet, of dark grey silty and fine sandy limestone and slate, minor feldspathic sandstone, and conglomerate. Much of the strata resembles the dark grey limestone, siltstone, and slate of the Cape Bon Ami Formation. In this region it rests on the Silurian and Lower Devonian Mount Alexander Group. Still farther west, in southwestern Gaspé and northern New Brunswick, dark grey slate, siltstone, and minor sandstone become dominant lithologies, and the formation is bounded by strike faults. Andesite and breccia of unknown thickness are intercalated in the Fortin Formation along the north fault-boundary in western Gaspé. In northwestern New Brunswick the formation rests on Upper Silurian strata; the basal strata are plant-bearing sandstones. E. Mencher reported that farther west, in northern Maine, the rocks lie with regional unconformity on Ordovician and Silurian rocks. In the Témiscouata region of adjacent parts of Quebec the Fortin-type rocks are referred to the Témiscouata Formation.

Lower Devonian sedimentary and volcanic strata in the southeastern part of Gaspé Trough lie conformably on the Silurian. Positively dated early Middle Devonian is lacking. In northern New Brunswick, at Dalhousie (Alcock, 1936; Greiner and Potter, 1966), the Dalhousie

Formation consists of an estimated 4,600 feet of interbedded sedimentary and volcanic rocks; among these the character and proportions of the rock types vary from place to place. A lower division is mainly of sediments, and a thick upper division is mainly of volcanic rocks. The sediments contain a rich marine fauna, now considered to be late Gedinnian (New Scotland). Sedimentary rocks consist of greenish calcareous and sandy shale, siltstone, and grey and buff shaly limestone, and boulder-conglomerate rich in volcanic clasts. Volcanic rocks are basalt and andesite flows, in part amygdaloidal and porphyritic (feldspar), breccias, tuffs, and palagonite tuff. The coarse nature of some volcanic breccias, in which some fragments are over 2 feet long, suggests that the volcanic vents were nearby. Similar rocks, but with different proportions of sediments, and volcanic rocks occur as a belt several miles wide and 100 miles long bordering Miramichi Geanticline on the northwest. Rhyolitic and trachytic flows and pyroclastic rocks accompany the volcanics. The sedimentary rocks are more pelitic and sandy, in places contain fine carbonaceous plant debris, and lack the limestones and abundant calcareous cement characteristic of the Dalhousie succession. Plant-bearing conglomerate and sandstone occur in one place at the southwestern end of the belt. During early Devonian the geanticline had a subdued topography and possibly was only partly emergent.

At the head of Chaleur Bay (Alcock, 1936) grey and green sandstone, conglomerate, and mudstone with a thin coal seam, probably several thousand feet thick and tentatively correlated with the Gaspé Sandstone, overlie the Dalhousie Formation probably disconformably. Clasts of mafic and silicic volcanic rocks probably derived from the Dalhousie are common. Plant fossils, fossil fish, and some marine invertebrates have been recovered. The conformably overlying Pirate Cove Formation is composed of 660 feet of non-marine red and green conglomerate and shale. These strata lack megafossils but contain spores similar to the Battery Point Formation of late Emsian and possibly younger age. The clasts, as large as a foot in diameter, consist of Matapedia limestone, Silurian sandstone and limestone, and minor igneous rocks. Coarse crossbeds and ripple-marks indicate current flow from the northwest, and together with the lithology and the occurrence of mudcracks, suggest an alluvial fan or flood plain environment of deposition.

In southeastern Fredericton Trough, along the coast of southern New Brunswick, early Lower Devonian rocks have been recognized but not clearly defined (Smith, 1966). They form the upper part of the mainly Silurian Mascarene Group, and consist of an unknown thickness of grey to brown sandstone, siltstone, and argillite with minor red shale and basalt; these strata are cut by rhyolite and andesite plugs of similar age. Deformed black shale, sandstone, and volcanic-breccia conglomerate contain plant fossils. Some 30 miles northwest of the Mascarene volcanic rocks are thin-bedded, greenish grey sandstones, siltstone, and slate, with abundant detrital muscovite, forming part of the Pale Argillite Division of the Charlotte Group. The presence of undated plant fossils in pregranite rocks suggests Lower or Middle Devonian age.

In Notre Dame Trough in Newfoundland, Lower and early Middle Devonian rocks definitely occur at one locality and possibly at two others; almost everywhere the youngest pre-Acadian stratified rocks are Wenlockian terrestrial sandstones. At La Poile Bay (Cooper, 1954), the Bay du Nord Group comprises an estimated 10,000 feet or more of slate, quartzite, conglomerate, and minor limestone. It passes laterally into schist and gneiss and is cut by Devonian granites. Relationship to the nearby, undated, possibly Silurian La Poile Group is obscure. The Bay du Nord contains plant fossils. The plants and the limestone suggest mixed marine and non-marine environments of deposition. The group may be equivalent to the Gaspé Sandstone assemblage: the two groups are probably the same age and both lie near the northwest boundary of the Notre Dame Trough, consist predominantly of a very thick clastic assemblage, and are marine and non-marine. In central and southern Newfoundland there is several hundred feet of flow-banded rhyolite tuff and agglomerate. At Cape la Hune on the south coast 50 feet of boulder-conglomerate and arkosic sandstone underlies the rhyolites and contains clasts of granite, gneiss, diorite, and other rocks; underlying rocks are not exposed. Rhyolites and conglomerates are cut by mid-Devonian Ackley-type granite. In central Newfoundland, near Stoney Lake, the rhyolites apparently overlie folded sandstones of the Botwood Group, but the contact is not exposed and the structural relations are uncertain. The Cape la Hune and Stoney Lake rocks are tentatively correlated, despite the lack of fossils, and are presumed to be Lower Devonian.

On the Avalon Platform, Lower and early Middle Devonian strata of a platformal nature occur in northern Nova Scotia and on Cape Breton Island. None has been recognized in southeastern Newfoundland and southern New Brunswick. In northern Nova Scotia (Williams, 1914) the Stonehouse Formation at the top of the Arisaig Group consists of about 1,300 feet of marine, greenish grey calcareous siltstone, shale, slate, sandstone, and lenses of limestone. The conformably overlying Knoydart Formation of probable late Gedinnian and Siegenian age consists of about 1,000 feet of non-marine, red and green sandstone, siltstone, and shale, locally with limestone nodules, and was deposited in a fluviatile and deltaic environment. The Knoydart contains fragments of fossil fish and some plant material. Current directions on crossbeds indicate flow toward the northwest apparently from an area with Ordovician rocks uplifted during an early stage of the Acadian Orogeny. Rocks similar to the Stonehouse and Knoydart Formations occur in eastern Cobequid Mountains. There, the probable Knoydart is transitionally overlain by andesite flows believed to be correlative with the lower part of the River John Group a few miles to the northeast. The group consists of more

than 6,000 feet of non-marine strata deposited in a fluviatile environment. The lower 1,500 feet comprises mainly grey and red siltstone, sandstone, shale and basalt flows with minor conglomerate, and petroliferous limestone. Albertite veins occur. The succeeding 4,500 feet consists of red-brown conglomerate, sandstone, and siltstone. Spores from the top of the lower part are probably Middle Devonian. Clasts are as much as 5 feet in diameter, and some are fossiliferous limestone derived from the Stonehouse Formation. The River John sandstones contain very little feldspar; the source area evidently did not include much granitic terrane, whereas the sandstone of the unconformably overlying Carboniferous strata contains abundant potash and plagioclase feldspar and quartz–feldspar rock fragments. Like that of the Knoydart, the source of River John detritus probably lay not far to the south, probably the Silurian strata of the eastern Cobequid Mountains.

In southeastern Cape Breton Island (Weeks, 1954) the probable Middle Devonian McAdam Lake Formation rests unconformably on Cambrian strata and possibly on granitic rocks of probable Ordovician age. It consists of an unknown thickness of folded grey conglomerate, arkose, plant-bearing shale, and some tuff, probably deposited under fluviatile conditions. The conglomerate contains pebbles of quartz and sandstone and some boulders of granite, rhyolite, and diorite.

In Meguma Trough the Lower Devonian Torbrook Formation (Smitheringale, 1960) conformably overlies the Ludlovian Kentville Formation in western Nova Scotia and is cut by Devonian granites. The Torbrook consists of about 5,000 feet of slate, siltstone, quartzite, and petroliferous limestone. Intercalated quartzitic iron-formation beds were mined. It has a rich brachiopod fauna. The lowest beds are unfossiliferous, and the uppermost contain some plant debris. The Torbrook represents a normal shallow-water marine deposit, but the iron-formation and plant debris suggest near-shore conditions. Marine deposition in the Meguma Trough ended during the early Devonian, about the same time as in Notre Dame Trough and on Avalon Platform.

St. Lawrence Platform (Figs. VI-18, 19). Lower and early Middle Devonian strata are preserved at three widely separated localities—on St. Lawrence Platform in southwestern Ontario, in a Cretaceous diatreme breccia in Quebec Basin, and in southwest Newfoundland. Most of the platform was probably submerged during much of late Early Devonian and periodically throughout the Middle and Late Devonian as the seas extended across the southern Canadian Shield to connect with those of Hudson Platform.

During the Gedinnian southwestern Ontario was undergoing erosion. Salt was leached from the Upper Silurian Salina Formation. The oldest Devonian rocks of the region, the Siegenian Oriskany Formation, are preserved as erosional remnants on the Niagara Peninsula and beneath adjacent parts of Lake Erie (Sanford, 1968). They consist of light grey, medium- to coarse-grained orthoquartzitic sandstone as much as 20 feet thick disconformably overlying the Upper Silurian Bertie Formation. The orthoquartzitic sandstones in Ontario and western New York were possibly derived from the crystalline rocks of Adirondack Mountains or the Canadian Shield, whereas those in the southeastern Allegheny Trough were derived from Ordovician and Silurian rocks in the Appalachian Geosyncline uplifted during an early phase of the Acadian Orogeny. The Emsian Bois Blanc Formation disconformably overlies the Oriskany or the Upper Silurian Bass Islands and Bertie Formations and is a correlative of the Scoharie Formation in eastern New York State (Oliver, 1966). In the Niagara Peninsula and beneath eastern Lake Erie the Bois Blanc consists of 15 to 40 feet of bluish grey, finely crystalline and silty limestone containing abundant grey nodular chert that in places exceeds the carbonate content. In this region the Bois Blanc commonly has a lower unit, the Springvale Member, consisting of light grey orthoquartzitic sandstones possibly derived in part from the subjacent Oriskany Formation. The sandstone may occur at the base of the Bois Blanc or alternate with cherty limestones at various horizons higher in the formation. The Bois Blanc grades laterally northwestward to grey and tan, medium granular dolomite bordering Lake Huron, where it increases to 150 feet in thickness.

Early Middle Devonian (Eifelian) limestone, dolomite, and minor sandstone disconformably overlie the Bois Blanc Formation. They reach a thickness of 600 feet near southern Lake Huron and thin to 250 feet beneath Lake Erie (Fig. VI-21). The early Eifelian Amherstburg Formation consists of brown, sucrosic, and locally bituminous dolomite as thick as 300 feet. Interdigitating with the lower beds in the Lake St. Clair region are strandline deposits of the Sylvania Member, as much as 80 feet of well-rounded and sorted orthoquartzitic eolian sandstone. The Amherstburg dolomite thins eastward and grades to grey, coarse-grained crinoidal and coral limestone of the Edgecliff Member, which forms the basal 75 to 100 feet of the Onondaga Formation in Niagara Peninsula and beneath eastern Lake Erie. Bioherm reefs occur in the Amherstburg and Edgecliff. Best known is the Formosa reef near Lake Huron; it covers an outcrop area of 65 square miles and has a relief of 90 feet. The Lucas Formation conformably overlies the Amherstburg, and in central Michigan Basin consists of salt and anhydrite that thins and grades laterally southeastward in Ontario, to 300 feet of light tan, finely crystalline dolomite with thin beds of anhydrite near southern Lake Huron, and thence to finely crystalline and sublithographic, high-calcium limestone of the Anderdon Formation bordering northern Lake Erie. During a late Eifelian epeirogenic uplift the Anderdon and much of the Lucas were removed by erosion from Niagara Peninsula and beneath eastern Lake Erie. The succeeding late Eifelian Dundee Formation, 100 feet of coarse crinoidal and finely crystalline

limestone, lies disconformably on the Lucas in Michigan Basin. It grades southeastward across the erosional edge of the Lucas into 200 feet of the brown, aphanitic, and cherty limestone of the Seneca–Moorehouse Members of the Onondaga Formation that rest disconformably on the Edgecliff.

In Quebec Basin, Lower Devonian limestone occurs as blocks in a Cretaceous diatreme breccia related to the Monteregian Intrusions on St. Helen's Island near Montreal. Fossils in the blocks are Gedinnian and Siegenian. The blocks preserved in the breccia provide the only evidence that post-Upper Ordovician seas encroached on Quebec Basin of the St. Lawrence Platform.

In Anticosti Basin (Fig. VI-7) the Clam Bank Formation occurs on the west shore of Port au Port Peninsula and has recently been traced in sporadic subsea outcrops a few miles offshore for about 80 miles to the northeast. The formation consists of about 1,500 feet of mainly terrestrial, coarse-grained and pebbly, crossbedded red sandstone, shale, and minor limestone (Rodgers, 1965). Clasts are mainly quartz and feldspar. The formation lies probably disconformably on the Middle Ordovician Long Point Formation. Brachiopods in the upper Clam Bank are Pridoli; some lower and upper strata may be Ludlovian and Gedinnian. The Clam Bank sediments were probably derived from an uplift to the east formed during an early stage of the Acadian Orogeny. The formation presumably grades westward to shale and limestone beneath the Gulf of St. Lawrence.

Acadian Orogeny

Regional metamorphism. During Acadian Orogeny, in the late Middle and early Late Devonian, most of the pelitic strata that were unmetamorphosed at the onset were regionally metamorphosed to argillite and slate. Other strata were metamorphosed to schist and gneiss of the greenschist and almandine amphibolite facies.

In southern Nova Scotia (Taylor and Schiller, 1966), biotite quartzite, schist, and slate pass southward into schist and metaquartzite containing oligoclase, andesine, almandine, staurolite, and sillimanite. Andalusite and cordierite are also common in these rocks and in pelitic schists in eastern Nova Scotia and may have formed during thermal metamorphism by nearby Devonian granites. In southernmost Nova Scotia, paragneiss and migmatite locally border the granites. Biotite from schist in southernmost Nova Scotia yielded K–Ar dates of 338 and 383

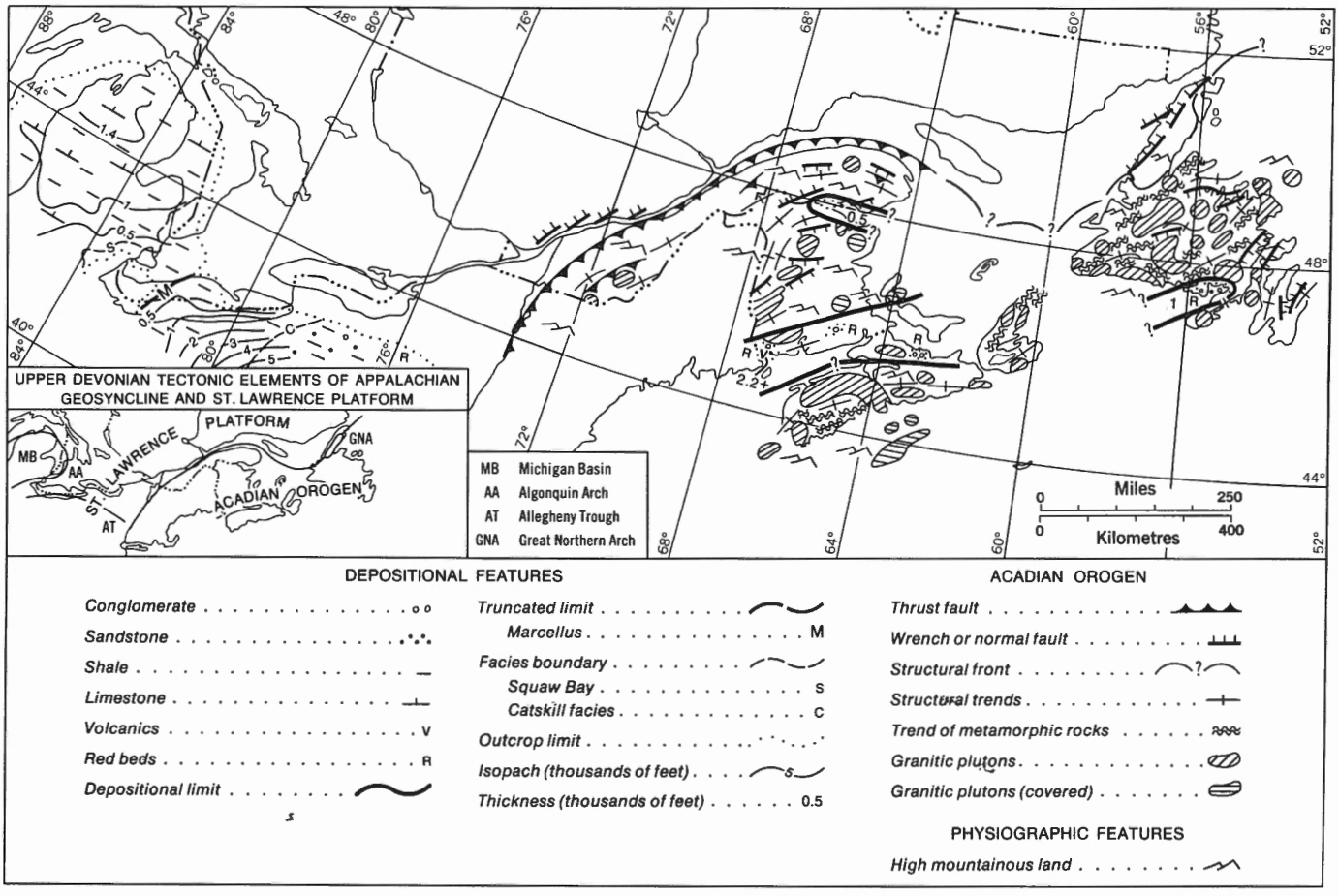


FIGURE VI-20. Late Middle and Upper Devonian sedimentation, volcanism, and tectonism in Southeastern Canada, and features of Acadian Orogeny.

m.y., both interpreted as indicating Devonian, pre-granite metamorphism.

In southern New Brunswick, most progressively regionally metamorphosed rocks with grades higher than greenschist facies probably developed in pre-Acadian times. Some basic schists, developed from Coldbrook Group volcanics, belong to the quartz–albite–epidote–biotite subfacies of the greenschist facies. A K–Ar date on lineated actinolite in amphibolite is 369 m.y., strongly suggestive of Acadian metamorphism.

On Cape Breton Island, and St. Paul Island 15 miles offshore, schists and gneisses have developed from the Precambrian George River Group and rocks correlated with it (Neale, 1963; Phinney, 1963). Progressive regional metamorphism possibly occurred in three periods of orogeny—the Avalonian, Taconian, and Acadian—but the effects of each episode in various parts of Cape Breton are not clear. Acadian regional metamorphism certainly occurred in northern Cape Breton and on St. Paul Island. Biotite from staurolite schist on St. Paul Island yielded a K–Ar date of 360 m.y., similar to the dates from recognized Acadian granites in the Appalachian Region. The rocks have been metamorphosed to greenschist and almandine amphibolite facies, and locally along some major Carboniferous faults amphibolite has been retrograded to greenschist. In the higher grade rocks, pelitic schists and gneisses contain a variable assemblage of staurolite, kyanite, almandine-rich garnet, hornblende, oligoclase, biotite, muscovite, and quartz. Metavolcanic rocks are schistose and gneissose amphibolites with hornblende, oligoclase, and garnet. Associated with the high-grade rocks are large areas of mixed granitic gneiss, pegmatite, paraschist and gneiss, and amphibolite.

In Newfoundland (Williams, 1969) regionally metamorphosed rocks with grades as high as almandine amphibolite facies form almost a quarter of the Acadian Orogen. They consist of paraschist, paragneiss, and migmatite. Metamorphism is probably Devonian but may also be late Silurian and older than the crosscutting Devonian granite stocks and batholiths. Metamorphism in western Newfoundland may be partly pre-Silurian. A belt of migmatite, schist, and gneiss extends from northeastern Newfoundland to near La Poile Bay on the south coast. Biotite in augen schist on the south coast yielded a K–Ar date of 393 m.y., a typical Acadian date. The rocks, which developed from lower Gander Lake Group, Love Cove Group, and equivalents, consist of interlayered schist, gneiss, quartzofeldspathic rocks of granitic composition, and augen schist and gneiss. Large tabular porphyroblasts of pink potash feldspar form as much as 50 per cent of the rock. The schists and gneisses contain garnet, sillimanite, kyanite, andalusite, and micas, an assemblage representing the almandine amphibolite facies. Westward and northward, the migmatite belt passes with decreasing metamorphic grade into biotite schist and gneiss, locally containing garnet, sillimanite, and kyanite. These rocks in turn grade through the biotite and chlorite zones of the greenschist facies to phyllite and slate. Eastward and southward, where not bordered by granite, the migmatites pass into greenschist facies and thence to phyllite and slate. The metamorphic rocks of much of south-central Newfoundland were developed from Ordovician and Silurian rocks. They extend southwestward to grade into Devonian strata near La Poile Bay and merge with the west-trending metamorphic rocks described above. The rocks are schist, gneiss and some granitic gneiss, migmatite, and amphibolite. Locally, they contain garnet, staurolite, and sillimanite typical of the almandine amphibolite facies, and cordierite and andalusite near granite plutons. In western Newfoundland a belt of metamorphic rocks extends from White Bay southwestward beneath Carboniferous cover to Grand Lake and thence to the southwest tip of Newfoundland near Port aux Basques. These rocks were probably metamorphosed during the Taconian and Acadian Orogenies. All the metamorphosed rocks are pre-Silurian except for Silurian volcanics at the northeast end that rest nonconformably on granodiorite. A Devonian age of metamorphism of the Fleur de Lys Group in the northeast is suggested by a K–Ar date of 355 m.y. on muscovite from a biotite–muscovite schist. On the other hand, a Taconian age is suggested by a K–Ar date of 452 m.y. on biotite from augen gneiss in the central part of the belt, and Middle Silurian ages of 420 m.y. on biotite in granite in central part and 415 and 420 m.y. on muscovite from pegmatites interlayered with schist, gneiss, and quartzite at the south end of the belt.

Near White Bay the Fleur de Lys Group (Neale and Kennedy, 1967) comprises complexly folded pelitic and psammitic schists and gneisses, minor amphibolite with mineral assemblages typical of the almandine amphibolite facies—staurolite, kyanite, garnet, and high greenschist facies. Biotite and garnet have been partly retrograded to chlorite. Near Grand Lake, the Grand Lake Brook Group and Mount Musgrave Formation consist of metamorphic rocks that increase in grade easterly from phyllite, marble, quartzite, and low-grade schists through biotite schist and gneisses of the high greenschist facies, interlayered with granitic rocks, to the lowest grade of the almandine amphibolite facies. The higher grade rocks contain biotite, garnet, sillimanite, cordierite, oligoclase, and quartz.

Structure. Almost the entire Appalachian geosynclinal belt was deformed by Acadian folds and faults, and in southern Quebec was thrust northwestward and northward onto the St. Lawrence Platform along Logan's Line. A narrow belt of Taconian folded rocks lying south of the thrusts was probably not refolded during the Acadian (Neale, *et al.*, 1961). Also, in the Conception Bay area of Avalon Peninsula, Newfoundland, the flat-lying Cambrian-Ordovician strata, underlain by Holyrood granite, were not folded although they were faulted, probably during Acadian Orogeny. Acadian folds generally have steep axial planes, and their axes plunge at angles varying from horizontal to steeply northeast and southwest. Slaty

PLATE VI-10

Recumbent Acadian folds in Ordovician slate and phyllite of Baie d'Espoir Group, formed by northwestward movement on subhorizontal axial plane cleavage, Baie d'Espoir, Newfoundland.

cleavage is generally parallel or subparallel to the axial planes. Phyllitic and fine-grained schistose rocks of various ages commonly exhibit an early isoclinal fold system which was later deformed by upright, more open folds. Even later, cross-folds and kink bands are common minor features.

Throughout the Appalachian Region, folds and faults form regional arcuate patterns that consistently curve from northeast to east to northeast in the shape of immense, open, right-lateral drag-folds (Map 1251A). Indeed, the boundary between the Appalachian Geosyncline and the St. Lawrence Platform traces out the same pattern. Major transcurrent faults parallel the belts. These patterns seem to be related to the trends of pre-Acadian tectonic elements.

On Avalon Peninsula, folds and faults in Ordovician and older rocks and faults in Devonian granites are presumed to be Acadian (McCartney, 1967). Folds are upright and vary from gentle open folds to tightly compressed; the Conception Bay area was apparently not folded during the Acadian. Several east-directed thrusts with net slips of a few thousand feet and less cut Cambrian and older rocks in the eastern half of Avalon Peninsula. The thrusts are cut by and perhaps synchronous with northwest- to northeast-trending steep faults, many of which have several miles of horizontal displacement and a few thousand feet of vertical displacement. In Trinity Bay the tear faults have both right-lateral and left-lateral displacements. Many of the major northerly trending, steep faults were apparently active in late Hadrynian time and were reactivated during Acadian Orogeny. In eastern Newfoundland, northwest of Avalon Peninsula, northerly trending, upright folds and long, steep faults cut Ordovician and older rocks. All folds and some faults are truncated by Devonian granite, but some faults cut the granite. Some Cambrian-Ordovician strata have been overturned to the west and some to the east. Complexly folded phyllites and siltstone occur at Baie d'Espoir, and probably extend northward through Gander Lake. Rocks with open folds and axial planes dipping about 55 degrees northwest are deformed farther south by recumbent shear folds with subhorizontal cleavage dipping 12 degrees southeast (Pl. VI-10). In northeast and central Newfoundland, folds in Ordovician strata are generally upright or northwesterly overturned and tightly compressed, whereas those in Silurian conglomerate and sandstone are

more open and locally overturned to the northwest. All faults are steep; some are intruded by granite and others cut granite. In Notre Dame Bay (Kay, 1967) several northeast-trending slices of northwesterly overturned Ordovician and Silurian strata, several thousand feet thick and dipping homoclinally southeast, are bounded by transcurrent faults.

Schists and gneisses of the Fleur de Lys Group (Neale and Kennedy, 1967) in western Newfoundland are complexly folded. The prominent, steeply dipping schistosity is parallel to the axial planes of tight and isoclinal folds in which locally an older isoclinal fold system is apparent. Steep strain-slip schistosity, which parallels the axial planes of the younger tight folds, cuts the prominent schistosity. Still later are flexure-slip folds and kink bands.

In central and eastern Nova Scotia (Fyson, 1966) three generations of Acadian folds and faults were developed. The oldest and most prominent folds are upright and low-plunging, and have a steep axial-plane cleavage. Younger north-trending cross-folds associated with a steep fracture cleavage are small and developed only locally. Both fold systems are older than the cross-cutting granite plutons. The youngest deformation is represented by northwest-trending kink bands that pass into left-lateral faults; these folds and faults are both pre- and post-granite. In southeastern Cape Breton Island, folds believed to be Acadian are upright and north-trending; associated Acadian faults are steep and right-lateral. In northern Nova Scotia the main Acadian folds are both upright and overturned southeasterly. They were deformed by minor cross-folds and by major northeast-trending steep faults and minor north- to northwest-trending faults. In New Brunswick, Acadian folds are generally upright and in places overturned to the northwest and southeast. They vary from open to tightly compressed and have axial-plane cleavage. Folds and cleavage with some variations trend northeasterly and are truncated by granite. Major strike faults and minor cross-faults cut the folded rocks; some are pre-granite and some are post-granite.

In the Eastern Townships of southern Quebec, all Silurian-Devonian strata southeast of Sherbrooke are overturned to the southeast in an extraordinarily large homocline (St-Julien, 1967). These rocks, with some unconformably underlying Cambrian-Ordovician rocks, have been thrust northwestward upon a belt of Middle and Upper Ordovician and the unconformably overlying Upper Silurian rocks. The Upper Silurian rocks themselves, near Lake Memphremagog, have upright tight and open folds, in places slightly overturned to the northwest, with a well-developed axial-plane cleavage. The northwestern limit of Acadian folding is uncertain, but it appears to extend no farther than the string of Taconian ultramafic bodies bordering the anticlinal Sutton–Bennett belt on the southeast. In the Témiscouata–Matapedia area folds in Silurian-Devonian rocks are generally broad and open and locally tight. Some beds are overturned to the northwest. Major faults are steep; some are clearly northwest-directed thrusts whereas others are normal with southeast side down. In Gaspé Peninsula (McGerrigle, 1950) Acadian folds are broad and open and they plunge east and west with low-angles to produce doubly plunging regional synclines and anticlines and elongate domal structures in northern Gaspé. In southern Gaspé the incompetent Fortin pelitic strata and Matapedia – White Head – Pabos thin-bedded limestones and shales are commonly closely folded and crumpled. Some strata and the limbs of some major folds are overturned northerly. Beds in southern Gaspé dip more steeply than those in the north, except near the unconformably underlying Mictaw Formation in southern Gaspé. Northern Gaspé rocks are cut by a few, steep, north-directed thrust faults and normal faults with the south side down. Horizontal displacement on the thrusts is presumed to be less than a few thousand feet. Longitudinal, steep, normal faults, extending for many miles, have vertical displacements of several thousand feet; some are downthrown on the south and others on the north. Other faults in eastern Gaspé trend northwesterly, more northerly than the fold and longitudinal normal and thrust faults, and transect folds and possibly the longitudinal faults. These oblique faults are probably of normal type with northeast side down, or they may be transcurrent. The location of the northerly limit of Acadian folding north of the Silurian-Devonian strata in the Témiscouata–Gaspé region is uncertain, but was probably somewhere south of St. Lawrence River.

The thrust faults comprising Logan's Line along the boundary between Appalachian Geosyncline and St. Lawrench Platform in southern Quebec bring Cambrian-Ordovician geosynclinal pelitic and psammitic strata northwestward and northward upon Middle and Upper Ordovician limestone and pelitic strata of the platform between Lake Champlain and along St. Lawrence River as far east as Anticosti Island. The folded and thrust-faulted pelitic strata of the St. Germain Complex in the Eastern Townships occur within the zone of Logan's Line. The thrusts mark the northerly limit of Paleozoic deformation. Some thrusting occurred during the late Taconian Orogeny but Acadian thrusting probably produced most of the present shortening, for if the thrusts of Logan's Line were late Taconian, coarse detritus derived from highlands in the upper plate would probably have been deposited on nearby Anticosti Island. On Anticosti Island, however, only carbonate and shale were deposited continuously from the Ordovician to the Silurian. Southwest of Quebec City, along the north side of the St. Lawrence River valley, are normal faults along which the Precambrian crystalline basement was raised against Paleozoic strata to the southeast. The faults may be Acadian or younger.

Along the west coast of Newfoundland and southeast coast of Labrador, several northeast-trending faults cut the Precambrian basement, flat-lying to gently folded Paleozoic cover strata and rocks of the Taconian klippen. The faults are steep and trend northeast. Some are

normal and some are reverse; in most the side adjoining the Gulf of St. Lawrence is down, producing a graben-like structure. On western Port au Port Peninsula the Lower Devonian Clam Bank Formation is cut by faults and locally overturned northwesterly. Many or all of these folds and related faults are probably Acadian, but some may be Carboniferous or younger.

Plutonic rocks. Acadian granites intrude strata of all ages as young as Lower Devonian in Appalachian Geosyncline except parts of southern Quebec, northwestern New Brunswick, and Avalon Peninsula. About 60 potassium–argon and a few rubidium–strontium isotopic age determinations have been made on minerals and whole-rock samples. The dates range from 420 to 250 m.y.; many are concentrated in the 350 to 375 m.y. range, about middle and late Devonian. Most New Brunswick granites provide dates on micas in the 380 to 395 m.y. range, which is from 20 to 40 m.y. older than the 350 to 380 m.y. range common to many Nova Scotia granites. Several dates between 400 and 450 m.y. were obtained from dioritic and gabbroic border phases of some Newfoundland granites, whereas the more granitic interiors have yielded dates of 350 to 400 m.y., even though the composite plutons cut Middle Silurian rocks (*ca.* 420 m.y.).

Acadian plutonic rocks of New Brunswick, Nova Scotia, and central Newfoundland reach large batholithic proportions, whereas those of southern Quebec and southeastern Newfoundland are small batholiths and stocks. Granite with abundant quartz is the most common plutonic rock; diorite and gabbro are much less common. Where granites and basic rocks occur together the granites intrude or grade into the basic rocks. Almost all are regionally discordant bodies with sharp contacts and steep walls and have hornfelsic thermal aureoles.

Diorite and gabbro form large bodies in western and southwestern New Brunswick and on Cape Breton Island. They form either discrete bodies or border phases of granite bodies, and consist of dark coloured rocks of various grain sizes and amounts of hornblende, pyroxene, and/or biotite. Small amounts of late-phase granodiorite and quartz diorite accompany the diorites and gabbros. Most of these basic rocks are chloritized and saussuritized.

Most granitic rocks are granodiorite and quartz monzonite with biotite; others contain hornblende and muscovite, generally accompanied by biotite. Younger phases of the granitic sequence (Poole, 1963) are commonly muscovitic, buff weathering, and either equigranular or porphyritic; many are associated with such minerals as fluorite, tourmaline, beryl, cassiterite, wolframite, and molybdenite, and some of these locally have been altered to greisen. Such granite bodies in central New Brunswick have steep walls and undulatory tops, and have been only partly unroofed. Granites in northern Gaspé Peninsula and southeastern Cape Breton Island are associated with bodies, sills, and dykes of rhyolite and porphyry. In northern Gaspé and northern New Brunswick skarns contain deposits of base metal sulphides, whereas in southern Nova Scotia gold–quartz veins, some with accessory scheelite, developed in Meguma strata. The granitic rocks of northern Cape Breton Island (Neale, 1963) comprise a suite much more varied in texture and composition; they have been emplaced in a metamorphic terrane of schist and gneiss interlayered with granitic rock and partly feldspathized. The schist and gneiss also form feldspathized inclusions in once-mobile granitic rock. Many such rocks are migmatites. Some coarse-grained granite contains microperthite porphyroblasts as long as 3 inches. The youngest granite bodies grade into the metamorphic rocks and consist of a composite of granodiorite, granite, and syenite, with biotite, muscovite, and hornblende. Some phases are gneissic.

Acadian plutonic rocks in Newfoundland comprise about a third of the outcrop area of the Appalachian geosynclinal belt and consist of several varieties ranging from gabbro to alkaline granite. The ultramafic bodies in Newfoundland are believed to be Ordovician, but one body of serpentinite, serpentinized peridotite, and layered gabbro, about 10 miles in diameter, appears to have intruded the Silurian Botwood Group, and, if so, could be Acadian. The mafic to silicic plutonic rocks comprise four general groups. Those of the presumably oldest group have intruded the Middle Silurian Botwood Group and have yielded biotite dates in the 350 to 450 m.y. range, suggesting a Middle Ordovician to late Devonian age. Most of the bodies are composite: dominantly massive to locally layered augite gabbro, hornblende diorite, and biotite–hornblende quartz diorite have been intruded by biotite, hornblende granodiorite, and quartz monzonite, with intergradational minor hornblende syenite and monzonite. Contacts with stratified host rocks are sharp and locally consist of agmatite; thermal aureoles are relatively narrow. Perhaps belonging to this group are the foliated hornblende–biotite granite, diorite, and gabbro of Burin Peninsula. The second group of plutons yielded K–Ar dates on micas from 350 to 370 m.y., about Middle and Upper Devonian. The plutons consist of a distinctive, uniformly massive, coarse-grained, pink to grey porphyritic biotite quartz monzonite commonly referred to as the Ackley granite type. Phenocrysts are tabular pink perthite crystals as long as 4 inches. The granites have sharp contacts and narrow thermal aureoles. The third group of plutons is least abundant. It occurs among the second group in eastern and southern Newfoundland, and consists of garnetiferous muscovite leuco-quartz monzonite. One K–Ar date on muscovite was 360 m.y. The rocks are massive, generally medium grained and equigranular, and contain disseminated pink garnets and abundant white potash feldspar. Associated with them are white pegmatites with accessory garnet, tourmaline, and beryl. The presumably youngest group of plutons occurs east of the main areas of granite intrusion and within the western part of the Cambrian-Ordovician Avalon Platform. The

plutons consist of massive, alkalic granite stocks and small batholiths on Burin Peninsula and near Treytown, Bonavista Bay. They are light pink to red, leucocratic, medium to coarse grained, equigranular, and massive. Miarolitic cavities are common in plutons of Burin Peninsula. The granites consist of abundant quartz and perthite and some albite, locally with riebeckite and fluorite. One sample analyzed about 11 per cent Al_2O_3 and over 8 per cent soda plus potash. Fluorite is mined from veins in the granites at St. Lawrence. Dykes and sheets of porphyritic rhyolite cut the Burin Peninsula strata and alkalic granites.

Diorite, diabase, and gabbro dykes cut Acadian folded rocks and plutons. Most are probably Devonian and others Mesozoic. They are generally not deformed, consist of plagioclase, hornblende, and augite, and some are slightly altered.

Late Middle and Upper Devonian

Appalachian Geosyncline (Fig. VI-20). On New Brunswick Platform, the Fleurant Formation along Chaleur Bay (Alcock, 1936) consists of 45 feet of fluviatile polymictic conglomerate that overlies the Pirate Cove Formation with a disconformity or low-angle unconformity. The conglomerate contains pebbles and boulders as much as 4 feet long, of Dalhousie volcanics, granite, Pirate Cove Formation, and a variety of other rocks. The Escuminac Formation conformably overlies the Fleurant and consists of 370 feet of non-marine grey shale and sandstone containing fish fossils and plants of early Upper Devonian age. The Escuminac is overlain unconformably by Carboniferous (Namurian?) conglomerate.

Along the northwest edge of the Fundy Epieugeosyncline in southern New Brunswick, the Perry Formation is composed of over 2,100 feet of terrestrial red sandstone, conglomerate, siltstone, and few basalt flows and tuff beds. Upper Devonian plants occur in nearby Maine. Clasts, as much as 6 inches in diameter, are of Mascarene volcanics, granite, and a variety of other rocks. Channels, trough crossbedding, and pebble imbrications indicate a southward current flow. Near Moncton the Memramcook Formation of non-marine red sandstone and conglomerate occurs at the base of a Mississippian sequence and recently has yielded Upper Devonian spores.

On Newfoundland Platform the Upper Devonian Great Bay de l'Eau, Terrenceville, and Pools Cove Formations consist of red conglomerate with arkosic sandstone, siltstone, and shale interbeds; they unconformably overlie Silurian and older strata. The first two formations contain Upper Devonian plants, but recently Terrenceville yielded spores that suggest an early Mississippian age. The Pools Cove is cut by a granite, clasts of which appear in the Great Bay de l'Eau. The formations are 1,000 to 3,000 feet thick and are tilted and gently folded. Clasts were derived from local older formations and granites. Ripple-marks, mudcracks, rain prints, and plant fossils suggest a terrestrial, probably fluviatile environment of deposition.

Deformational and plutonic events attributable to the late Devonian part of the Maritime Disturbance are difficult to distinguish from those that occurred during the Carboniferous and Permian. In most of the Appalachian Geosyncline the oldest, post-Middle Devonian strata are middle Mississippian or younger. Tilting, uplift, and erosion of Upper Devonian Escuminac Formation in Chaleur Bay was followed by deposition of Carboniferous (Namurian?) Bonaventure Formation. In Fortune Bay of southern Newfoundland the Upper Devonian Terrenceville Formation is tilted and gently folded and has been overthrust by Precambrian rocks from the southeast, possibly during the late Devonian. Forty miles to the west the Upper Devonian Great Bay de l'Eau Formation is tilted and broadly folded and has been intruded by the Belleoram granite stock. The stock is a massive, medium-grained hornblende–biotite quartz monzonite, the biotite yielding a K–Ar date of 342 m.y., very near the Devonian–Mississippian boundary. The roof of the stock is nearly planar and horizontal.

St. Lawrence Platform (Figs. VI-20, 21). In southwestern Ontario deposition of late Middle and Upper Devonian sediments continued during the Acadian Orogeny and the late Devonian interval of the Maritime Disturbance in the Appalachian Geosyncline (Sanford, 1968). The former distribution of these strata on the platform is unknown, but similar strata occur on the Hudson Platform, suggesting that the two regions were probably connected.

The Givetian Hamilton Group has a thickness of 300 feet near southern Lake Huron bordering the Michigan Basin, and thins to 200 feet beneath central Lake Erie in northern Allegheny Trough. The lower beds, the Marcellus Formation, consist of 50 feet of black bituminous shale and minor argillaceous limestone lying conformably on the Seneca limestone beneath central Lake Erie. During subsequent uplift and erosion the presumably more widespread Marcellus shales were stripped off. The succeeding Arkona shale and Ipperwash limestone, 150 feet thick beneath Lake Erie, transgress the erosional surface of the Marcellus and Dundee Formations and grade westward into 300 feet of alternating shale and limestone bordering Michigan Basin. Near Lake Huron the Hamilton Group consists of several formations which in ascending sequence form the Bell shale (60 feet), Rockport Quarry limestone (10 to 20 feet), Arkona shale (120 feet), Hungry Hollow limestone and shale (6 feet), Widder shale and limestone (45 feet), and Ipperwash limestone (94 feet).

Upper Devonian strata underlie the Chatham Sag between the Algonquin and Findlay Arches in southwestern Ontario, and form the youngest strata of the Paleozoic succession (Sanford, 1968). They have a maximum thickness of 350 feet in Ontario, thicken northwestward to 985 feet in northwestern Michigan, and southeastward to 1,000 feet along the south shore of Lake Erie. The Kettle Point Formation disconformably over-

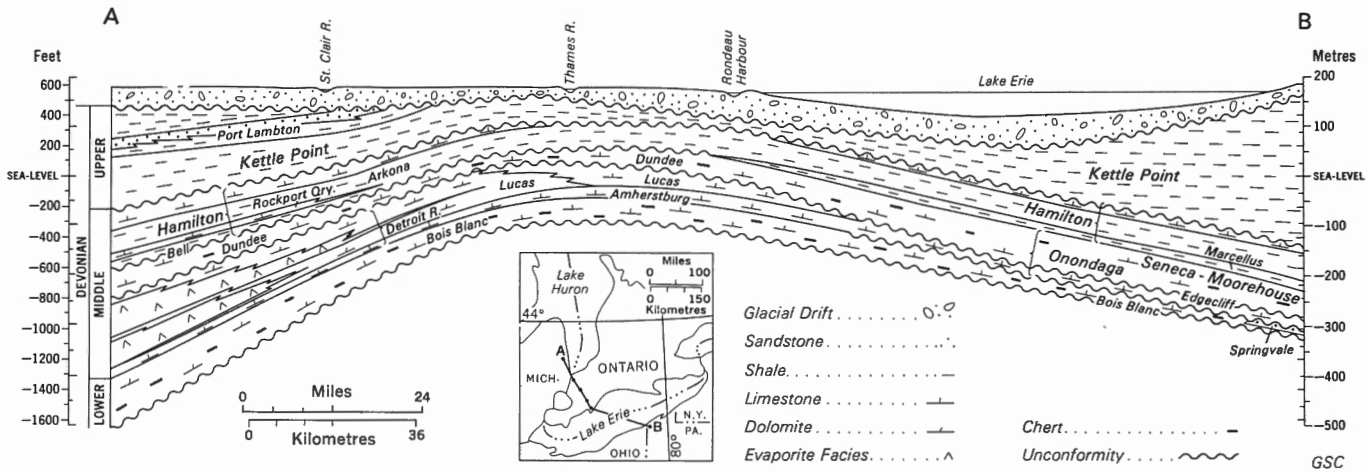


FIGURE VI-21. Cross-section through Devonian rocks of Algonquin Arch of southwestern Ontario (by B. V. Sanford).

lies the Hamilton Group and consists of black and dark brown bituminous shale with interbeds of greyish green shale. Where exposed on the shore of Lake Huron, the shales contain numerous calcareous concretions as much as several feet in diameter that are commonly referred to as "kettles" (Pl. VI-11). The Kettle Point is 250 feet thick near southern Lake Huron, and it thins southeastward to 100 feet or less in Chatham Sag then thickens to 1,000 feet along the south shore of Lake Erie. The Kettle Point is overlain conformably by three formations south of Lake Huron. These total 200 feet and thicken westward into Michigan Basin where they underlie non-marine Mississippian clastics not represented in southwestern Ontario. In ascending sequence they comprise the Bedford grey shale, Berea micaceous sandstone, and the Sunbury black shale.

Carboniferous and Permian

Tectonic Summary

Carboniferous rocks lie with regional unconformity on granites and pre-Middle Devonian strata deformed by the Acadian Orogeny, but locally lie conformably on post-Acadian Upper Devonian rocks. None occurs on St. Lawrence Platform in Canada.

Carboniferous sediments are almost entirely non-marine and were deposited in a series of connected troughs or intermontane basins within a regionally subsiding area, the Fundy Epieugeosyncline (Figs. VI-22 to 28). The area of greatest subsidence probably extended from the Bay of Fundy in southeastern New Brunswick to southwestern Newfoundland. It is within this area that the thickest and most complete sections of Carboniferous rocks are preserved. Although local unconformities are present within Carboniferous rocks (Pl. VI-12), sedimentation was probably continuous in one part or other of the epieugeosyncline until early Permian. The areas of deposition were, at most times, separated from one another by complementary positive areas from which detritus was derived, but were not always separated from one another throughout the entire Carboniferous and early Permian. At other times, what had been previously uplands and source areas became depositional basins.

A delicate balance in base-level between basins of deposition and source areas was maintained throughout much of Carboniferous time. This is inferred from the thousands of feet of coarse clastics fairly similar in composition, texture, and primary features that occur in some Carboniferous sections. The maintenance of source areas at a fairly consistent level relative to adjacent depositional basins was accomplished by continuous uplift of source areas, either as welts or by movement on bordering faults. Epeirogenic subsidence or uplift of the whole of the Carboniferous of the entire Fundy Epieugeosyncline and bordering platforms took place at the same time as folding or faulting within or along the boundaries of upland areas within it. These epeirogenic movements were mainly opposite to the local movements so that epeirogenic subsidence occurred at the same time as uplift of local source areas.

The combination of epeirogenic subsidence with local uplifts during Lower Carboniferous sedimentation resulted in onlap of each succeeding rock unit upon the flanks of positive areas. Such a pattern continued until late Lower Carboniferous, by which time much of the Acadian Orogen became covered by a shallow sea. During the preceding interval islands within the sea had been the source of non-marine deposits. Erosion and uplift of these islands continued during the marine deposition to produce coarse and fine marginal deposits. Epeirogenic uplift during the interval of marine deposition resulted in a withdrawal of the sea, first from the New Brunswick Platform and from some parts of the Moncton and Cumberland Basins, and eventually from the rest of the Appalachian Region. As the sea withdrew non-marine clastic sedi-

ments were deposited conformably above the marine sediments in the axial regions of the basins. By the end of the Lower Carboniferous, or early in the Upper Carboniferous, continental conditions had completely returned to eastern Canada.

During earliest Upper Carboniferous epeirogenic uplift continued. The area of deposition was smaller than that of the earlier marine deposition and the sediments generally have offlap relationships. Local areas were uplifted more than the regional uplift and continued as source areas for the alluvial sediments of the adjacent basins.

The combination of epeirogenic subsidence with local uplifts occurred again, probably from late Namurian to early Westphalian C. By the end of Westphalian B, or early in Westphalian C, local tectonic activity in the bordering uplands had ended with the result that succeeding Carboniferous sediments were essentially controlled by epeirogenic movements. From Westphalian D to early Permian either the supply of sediments was depleted or epeirogenic uplift again resulted in a restriction of deposition to eastern New Brunswick and Prince Edward Island, northern Nova Scotia, and western and eastern Cape Breton Island. These areas were possibly part of one, larger basin.

The non-marine sediments of the Carboniferous basins were mainly gravels, sands, silts, and muds deposited in fluvial and flood plain environments; and sands, silts, and muds laid down in lacustrine and paludal environments. The various facies occur as interfingering lenses and are commonly time–transgressive. These interdigitating facies were further complicated by the intercalations of alluvial gravels and sands. Fairly extensive coal-forming swamps were present in various parts of the basins throughout the Upper Carboniferous. Coal has been mined from strata of Westphalian A, B, C, and D ages. The marine sediments include fine-grained red beds, limestone, and evaporites that commonly grade laterally into fine- to coarse-grained red beds in the vicinity of uplands. Thin basalt, andesite, and rhyolite flows occur locally and at different stratigraphic levels within the Carboniferous.

The Carboniferous tectonic activity referred to as the Maritime Disturbance occurred mainly in the basin areas of Fundy Epieugeosyncline (Fig. VI-29). It is manifested by local unconformities, open folds of various amplitudes, and high-angle reverse and strike-slip faults that occur mainly along the border between basins and uplands. Also, small granitic stocks and dykes were emplaced at one locality during the Carboniferous. On the platforms evidence of the disturbance is non-existent or limited to very broad open folds and local faults. There the main tectonic activity was epeirogenic subsidence and uplift.

Unconformities in the epieugeosyncline are mainly local, adjacent to upland areas. Their differences in age at various locations indicate that movement of the uplands was not synchronous throughout, but varied somewhat from place to place. Also, the contact between two time-

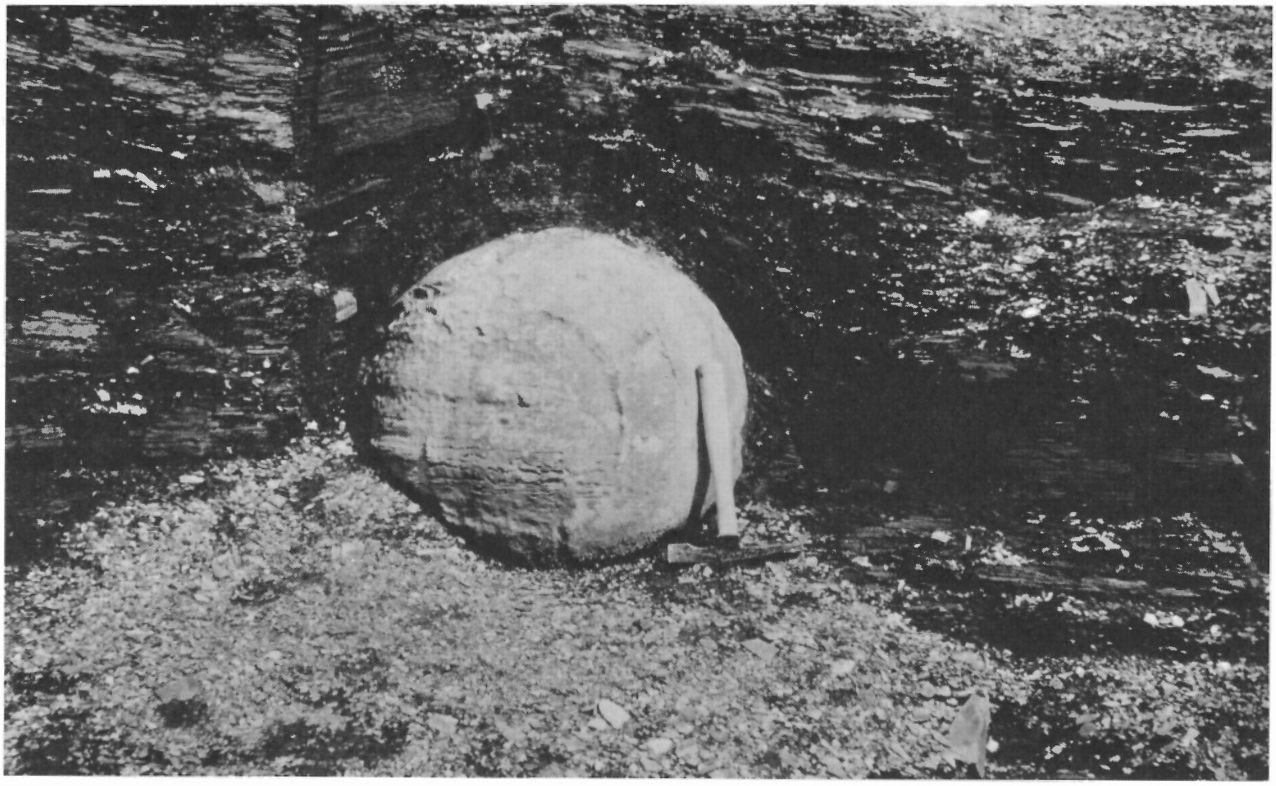
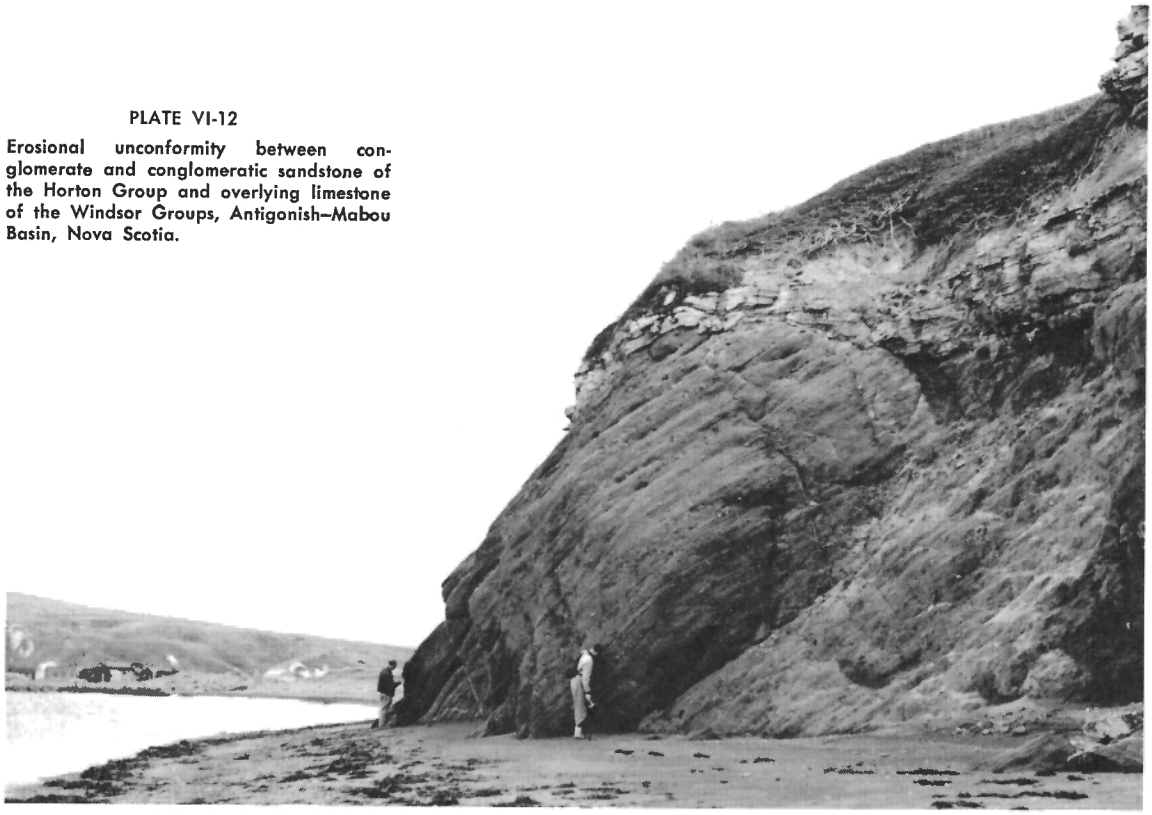


PLATE VI-11. Limestone concretion called a "kettle" in Upper Devonian black shale of Kettle Point Formation, southern Lake Huron, Ontario.

PLATE VI-12

Erosional unconformity between conglomerate and conglomeratic sandstone of the Horton Group and overlying limestone of the Windsor Groups, Antigonish–Mabou Basin, Nova Scotia.



stratigraphic units may be conformable adjacent to one upland but unconformable adjacent to another. Each basin had its own unique development, but sedimentation was continuous throughout the Carboniferous.

Westphalian A strata in the Moncton Basin, and mainly Westphalian C or younger strata elsewhere, extensively blanket all earlier Carboniferous rocks. The blanket is conformable to unconformable in the area of epieugeosynclinal activity and disconformable on the platform areas. These Carboniferous rocks have gentle dips except in the vicinity of faults; where folded, they are characterized by very broad open folds that are probably due to the terminal pulses of the Maritime Disturbance or to salt doming.

Stratigraphic Nomenclature

The subdivision of Carboniferous rocks most commonly used is the essentially time-stratigraphic subdivision of Bell (1958). His most recent subdivisions (Table VI-1) are but a slightly modified version of those he proposed in 1927. Although the major units are called groups and can be defined partly by lithology, they are primarily defined by their age as indicated by fossils. Strict adherence to Bell's subdivision on a time-stratigraphic basis has required the placing of "group" boundaries where no lithological change is present.

For many years Bell's subdivisions remained unchanged, but in recent years there has been a considerable increase in the basic knowledge of Carboniferous stratigraphy, sedimentation, and tectonics that has led to changes in interpretations. For example, Bell's groups were originally considered to be separated by intervals of non-deposition, except locally between the Windsor and Canso Groups. It is now recognized that the contacts between most, if not all, of the groups are conformable at some localities and that some are diachronous.

TABLE VI-1 *Carboniferous strata in the Maritime Provinces (after Bell, 1958)*

Group	Age
Pictou	Westphalian C and D
Local unconformity and disconformity	
Cumberland	Early Westphalian B
Local unconformity and disconformity	
Riversdale	Westphalian A
Local unconformity and disconformity	
Canso	Early Namurian and (?) Late Viséan
Conformity and disconformity	
Windsor	Viséan
Rare local unconformity and disconformity	
Horton	Tournaisian
Unconformity	

Attempts have been made to correlate Carboniferous rocks on the basis of unconformities, but the unconformities are now known to indicate local movement and their effects disappear over short distances. Furthermore, the unconformities occur at various stratigraphic levels in different areas. A possible exception that may have regional significance is the unconformity beneath the uppermost Carboniferous Pictou Group. The group is commonly unconformable on either older Carboniferous or pre-Carboniferous rocks in western Cape Breton Island and in most parts of the Cumberland Basin. In two areas of the Cumberland Basin the Pictou Group, as a time-stratigraphic unit, is possibly conformable with the underlying Cumberland Group, whereas in most basins the Pictou Group overlaps older strata without any angular discordance and with only a minor gap in the sedimentary record.

The Lower Carboniferous, Horton, and Windsor Groups are now used solely as rock-stratigraphic units. The Horton Group is essentially the same as defined by Bell, except for removal of the Tournaisian time restriction. The partly to entirely marine Windsor Group is also restricted in use to a rock-stratigraphic unit and is only applied to those strata that include marine limestone and/or evaporites. In the Upper Carboniferous the problem of sorting out stratigraphic units largely remains, although some progress has been made (Table VI-2). In the text to follow the word "group" is used in the same way as proposed or used by earlier workers, that is with a biostratigraphic or time-stratigraphic connotation. Without quotation marks group is used as a rock-stratigraphic term.

Lower Carboniferous

The Horton Group (Fig. VI-22). This is a sequence of mainly Tournaisian (early Lower Carboniferous) continental sedimentary and volcanic rocks that rest unconformably on rocks as old as Precambrian and are overlain conformably or disconformably, and rarely unconformably, by the partly marine strata of the Windsor Group. The type locality is in the southern part of Minas Basin where it is divided into two formations: a lower Horton Bluff Formation and an upper Cheverie Formation. These formations are not recognized beyond the type area. The term Horton Group has been used throughout Nova Scotia and New Brunswick, but lithologically comparable rocks in Newfoundland in the same stratigraphic position are called Anguille Group. The Horton Bluff Formation consists of 1,000 to 3,400 feet of siltstone, shale, and minor ferruginous limestone; the Cheverie consists of 600 feet sandstone, siltstone, shale and arkose. The fine-grained lithology of the Horton Bluff and Cheverie Formations appears to be limited to the Minas Basin and to the subsurface in Cumberland Basin.

In the Moncton, Antigonish–Mabou, St. George's, and White Bay Basins the Horton and Anguille Groups are typically composed of red or red and grey sandstone and conglomerate, succeeded by grey siltstone, sandstone, and shale, then by red to red and grey sandstone, siltstone, and conglomerate (Table VI-3). This sequence is more typical of Horton Group rocks than those in the area of the type section. Volcanic and minor sedimentary rocks occur at the base of the Horton in parts of the Antigonish–Mabou Basin. Sandstone, conglomerate, and siltstone of the Craignish Formation are areally the most common lowest Horton formation on Cape Breton Island, however. The Albert, Strathlorne, and Snakes Bight Formations appear to be correlative because they are similar in lithology and stratigraphic position, but fossil spores suggest that the Albert is older than the Strathlorne.

Earliest sedimentation of the Horton Group probably began in Moncton Basin and was soon followed by deposition in Antigonish–Mabou Basin. In New Brunswick, spores of probable Upper Devonian age have been obtained from the Memramcook Formation, the lowest part of the Horton Group. On Cape Breton, earliest Carboniferous spores (there is a slight possibility they may be late Devonian) have been obtained from the Fisset Brook Formation.

Continental sedimentation continued uninterrupted longer than elsewhere into the Viséan, in Moncton and Sydney Basins, and probably also in Cumberland Basin. Continental sediments of the Hillsborough and Grantmire Formations were being deposited at the same time as marine limestones of the Windsor Group.

Deposition of Horton sediments appears to have commenced in isolated basins with the source nearby. In the Antigonish–Mabou and Moncton Basins each succeeding rock unit was not only deposited upon, but overlapped the older rocks to rest directly on pre-Carboniferous rocks. Consequently, the size of the depositional basins continually increased, first by sediments joining

TABLE VI-2 *Carboniferous stratigraphy in the Maritime Provinces*

Group	Age
Pictou Local unconformity, disconformity, and conformity	Westphalian C to Early Permian
Cumberland Unconformity, disconformity, and conformity	Westphalian A, B, and ? early C
Riversdale Conformity, disconformity, and local unconformity	Late Namurian and Westphalian A
Canso Conformity and disconformity	Late Viséan to late Namurian
Windsor Conformity, disconformity, and rare local unconformity	Viséan to early Namurian
Horton Unconformity	Late Devonian, Tournaisian, and early Viséan

around the ends of the upland areas and later by covering the uplands themselves, the sediments then being derived from more distant sources. There is no evidence to suggest that Cumberland Basin was separated from Minas Basin during Horton deposition. Cobequid Upland does not appear to have been a source area for Horton sediments in Minas Basin. Antigonish Upland, however, was uplifted during Horton sedimentation, as suggested by onlap of coarse conglomerate whose source rocks appear to have been the upland and by the presence of a local unconformity within the group.

Because the Horton Group changes to a coarse facies near the margin of some basins, the adjacent upland areas are presumed to have existed throughout Horton sedimentation. For example, the Albert Formation of Moncton Basin grades southwest into a conglomeratic unit, and the Strathlorne Member in Antigonish–Mabou Basin also grades easterly into a conglomeratic unit. The conglomeratic units of both areas are similar in composition, texture, and other primary features to conglomerates both below and above the Strathlorne Member and Albert Formation. The widespread vertical and lateral distribution of polymictic conglomerate in the Horton Group with phenoclasts from pre-Horton rocks is most easily explained by periodic availability of source material that may have resulted from either uplift in the source areas (some of which were local uplands), or downsinking in the basin area, or by a combination of the two. The nature of the movement is unknown. It only locally affected Horton strata already deposited, however, as only local unconformities resulted. Uninterrupted sedimentation took place a few miles from the area of disturbance.

The Windsor Group (Figs. VI-23, 24). This group is partly or entirely composed of marine strata that conformably to unconformably overlie the Horton Group

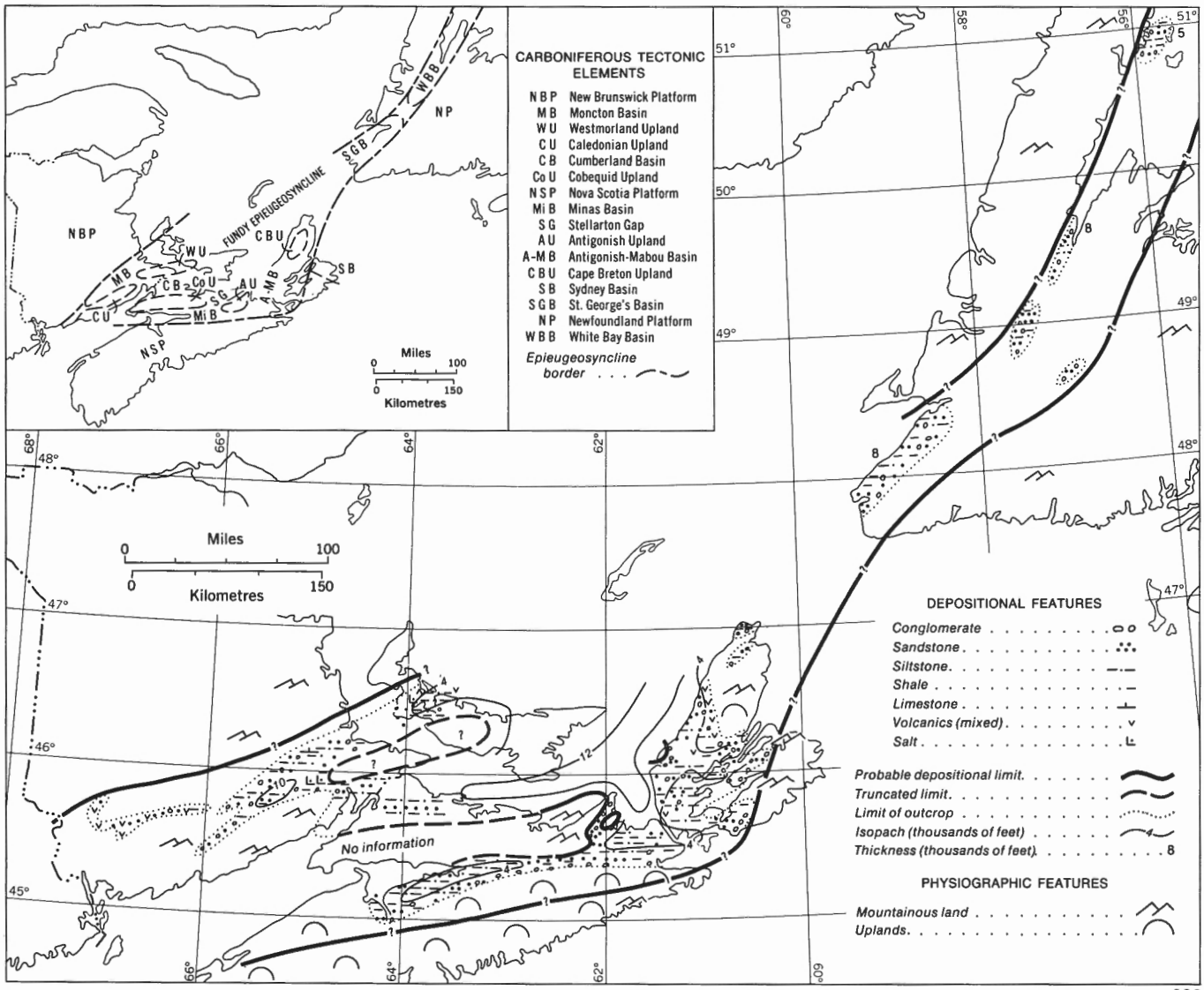


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FIGURE VI-22. Carboniferous, mainly Tournaisian (Horton Group), sedimentation, volcanism, and tectonism in Southeastern Canada.

TABLE VI-3 | *Subdivisions of the Horton and Anguille Groups*

Rock-stratigraphic unit		Lithology	Thickness (feet)
		NEW BRUNSWICK (Moncton Basin)	
Moncton Formation	Hillsborough Member	Red sandstone and conglomerate; basal ash bed?	±2,900
	Weldon Member	Red siltstone, shale, sandstone, and conglomerate	±5,000
Albert Formation		Dark grey, in part bituminous, shale and sandstone; oil shale; some limestone and salt	±5,500
Memramcook Formation		Red shale, sandstone, and conglomerate	±7,000
		CAPE BRETON ISLAND (Antigonish–Mabou Basin)	
Strathlorne–Ainslie Formation	Ainslie Member	Red and grey sandstone, siltstone, conglomerate; minor limestone and intraformational conglomerate	340–1,820
	Strathlorne Member	Grey sandstone, siltstone, shale; minor limestone	75–1,690
Craignish Formation		Grey arkosic sandstone and conglomerate, red siltstone, sandstone, and conglomerate; minor grey siltstone and sandstone	±65–8,000
Fisset Brook Formation		Andesite and minor rhyolitic rocks; red siltstone; minor conglomerate, and sandstone	800–1,500
		WESTERN NEWFOUNDLAND (St. George's Basin)	
Seacliffs Formation		Grey massive, feldspathic sandstone; grey thinly bedded, siltstone and shale; red and grey arkose; red siltstone	±1,700–4,000
Snakes Bight Formation		Thinly laminated, black, fine-grained argillaceous siltstone and dense, grey sandstone	±1,500
Cape John Formation		Grey siltstone, sandstone, and conglomerate; red siltstone	>1,500

and overlap pre-Carboniferous rocks. The type locality is near Windsor, Nova Scotia, partly in Minas Basin and partly on Nova Scotia Platform. There, the Windsor Group is 1,500 feet thick and divisible in ascending order into Subzones A, B, C, D, and E. The Windsor Group occurs in New Brunswick and on Magdalen Islands, but in Newfoundland correlative marine strata are included in the Codroy Group (*Frontispiece*). Continental strata equivalent to the Windsor Group are included with either the underlying Horton Group or the overlying Canso Group.

The Windsor Group consists of thick members of massive to poorly bedded, red or red and greenish grey, mottled siltstone, shale, and sandstone intercalated with gypsum, anhydrite, salt, and thin, tabular sequences of limestone and dolomite. Marginal facies of Windsor strata also commonly include polymictic conglomerate whose phenoclasts, like the Horton, are mainly pre-Carboniferous rocks. On Magdalen Islands, brecciated basalt, tuff, and agglomerate occur in the basal part of the Windsor, and in southern Antigonish–Mabou Basin a trachyte porphyry flow is present at the top of the basal Subzone A limestone. At Stellarton Gap, on the flank of Antigonish Upland, two thin flows of amygdaloidal basalt occur below Subzone E limestone, the lowest Windsor strata in that section. In Antigonish–Mabou Basin a few inches of bentonite are interbedded with basal Subzone A limestone. In St. George's Basin, above the Windsor-like section, but apparently correlative with Windsor strata of other areas, is 1,600 feet of dark grey shale, siltstone, and sandstone with thin beds of argillaceous limestone. These grey beds may be partly marine but they resemble

the lower part of the Canso Group that conformably overlie Subzone E limestone in Antigonish–Mabou Basin.

The oldest marine strata of Subzone A were limited to a long, narrow trough that embraced the Minas, Antigonish–Mabou, and St. George's Basins (Fig. VI-24). The basal member is a thinly laminated, fine-grained limestone 30–60 feet thick that is an important time-stratigraphic marker bed.

Subzone B sediments are the most widespread of the Windsor Group. During their deposition the sea covered all areas underlain by Subzone A strata and transgressed into the Cumberland and Moncton Basins and to Magdalen Islands. Marine strata were also deposited on the New Brunswick Platform during Subzone B time, but how the present isolated remnant was connected with Moncton Basin is unknown; possibly, the Windsor sea covered much of New Brunswick. However, the coarse clastics that occur along most present outcrop margins of the Windsor Group, which may be correlative with the Windsor Group but not necessarily with Subzone B, suggest that the maximum extent of the Windsor sea was not much greater than its present distribution. Subzone B deposits in St. George's Basin were probably more extensive, but rapid facies changes are common. Siltstone, limestone, evaporites, etc., outcrop along the present coast of Newfoundland and apparently grade to coarse clastics a few miles inland. Clastic rocks considered to be correlative with the Windsor Group, which are present in White Bay Basin, limit the extent of the Windsor sea in that direction.

Subzone C marine sediments apparently represent offlap relationships. The maximum extent of the Windsor sea during Subzone C time was less than during Subzone B time. Only one bed of Subzone C limestone is known in the Cumberland Basin, and above it are red clastics correlative in part with upper Subzone C or higher. Complete sections of Subzone C limestones are present in parts of Minas, Antigonish–Mabou, Sydney, and St. George's Basins and probably on Magdalen Islands.

Very few exposures are known of Subzone D limestones. They are probably more restricted than those of Subzone C, although present in Minas, Antigonish–Mabou, Sydney, and St. George's Basins.

Subzone E strata, generally the youngest of Windsor strata, have been found on Magdalen Islands and in St. George's, Sydney, Antigonish–Mabou, and Minas Basins,

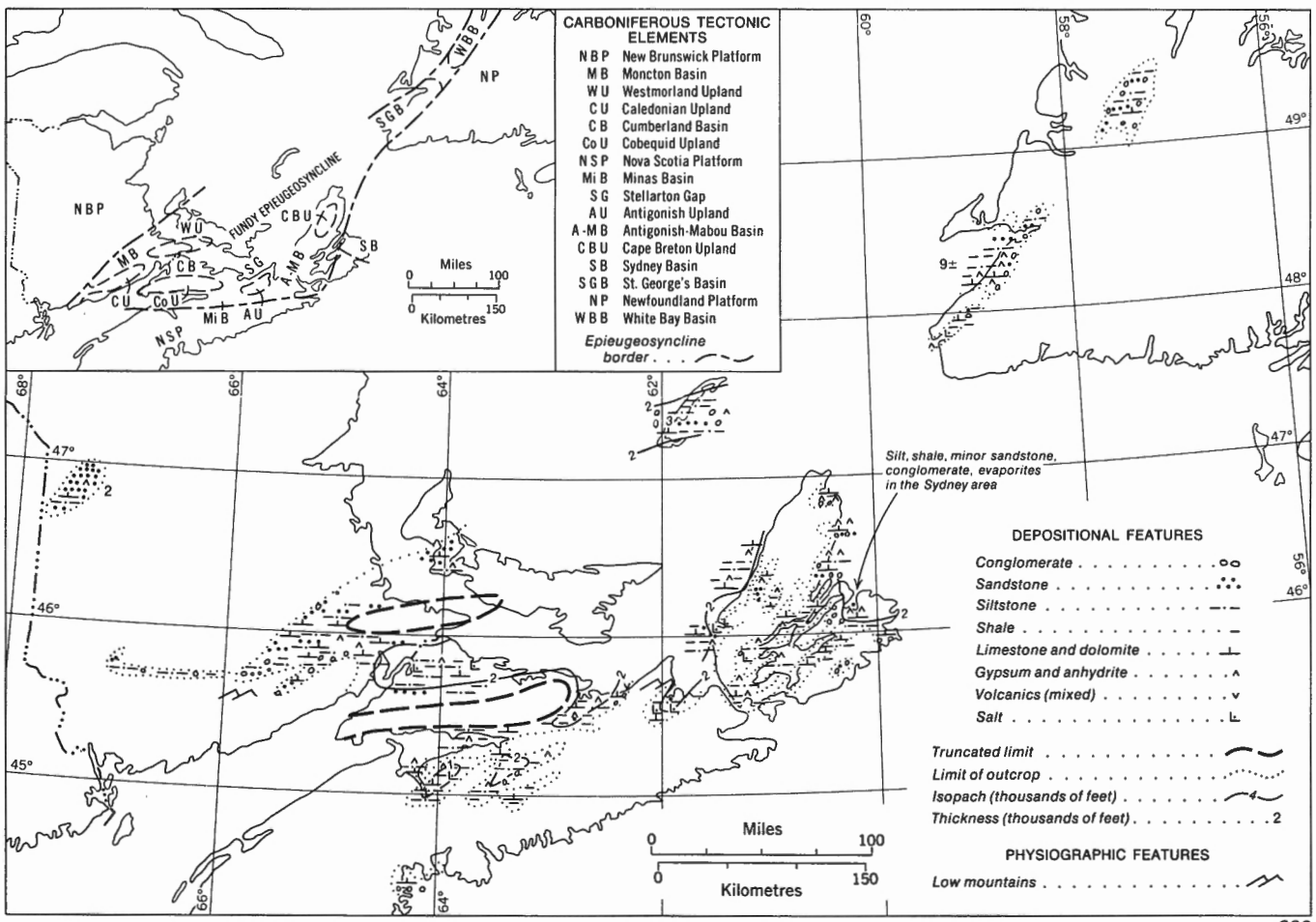

FIGURE VI-23. Carboniferous, mainly Viséan (Windsor Group), sedimentation, volcanism, and tectonism in Southeastern Canada.

at Stellarton Gap, and on Nova Scotia Platform. Subzone E limestone most commonly rests on a conformable Windsor section that includes all earlier subzones. In rare cases, however, it rests disconformably on Subzone B, as on Nova Scotia Platform, or unconformably on pre-Carboniferous rocks, as along the southeastern edge of Sydney Basin.

A single outcrop of limestone containing an assemblage of fossils assigned to Subzone F is present in a fault block near the northern boundary of Minas Basin. There is no evidence to support an age assignment younger than Subzone E, however. Withdrawal of the Windsor sea from the region soon after deposition of Subzone E limestone is apparent from the transitional contact between marine Windsor Group rocks and overlying partly brackish water rocks of the Canso Group.

Upper Carboniferous and Permian

The Canso Group (Fig. VI-25). This group is defined as the non-marine, red and grey shales that overlie marine Windsor Group or non-marine rocks of equivalent age and which, if fossiliferous, contain only early Namurian fossils. At the type locality along the eastern shore of the Strait of Canso in Antigonish–Mabou Basin the base of the Canso section is faulted against Windsor strata, and the top was arbitrarily chosen at a concealed interval. Later, the upper contact was extended upward to the base of a thick sandstone. The Canso, either as defined or redefined, is not a mappable unit, except possibly in the immediate vicinity of the type locality. The Canso "Group" in Nova Scotia consists of interfingering grey and red facies. The rocks are mainly fine-grained, red and grey sandstones, siltstone, and shale. Minor non-marine limestone occurs in the lower part of the group.

In Moncton Basin the upper part of the Hopewell Group, which consists of sandstones, siltstone, and conglomerate, has been correlated with the Canso "Group"; the lower part of the Hopewell Group has been correlated with the upper part of the Windsor Group. The Hopewell conformably overlies Lower Windsor strata of the Viséan age and is conformably to unconformably overlain by formations mainly of Westphalian A age.

In central New Brunswick Platform, 100 to 150 feet of conglomerate, tuff, and basalt are tentatively correlated with the Canso "Group". The basalt is commonly underlain by a few feet of coarse to fine red clastics that rest unconformably on pre-Carboniferous rocks. In the southwest the coarse clastics unconformably overlie red beds

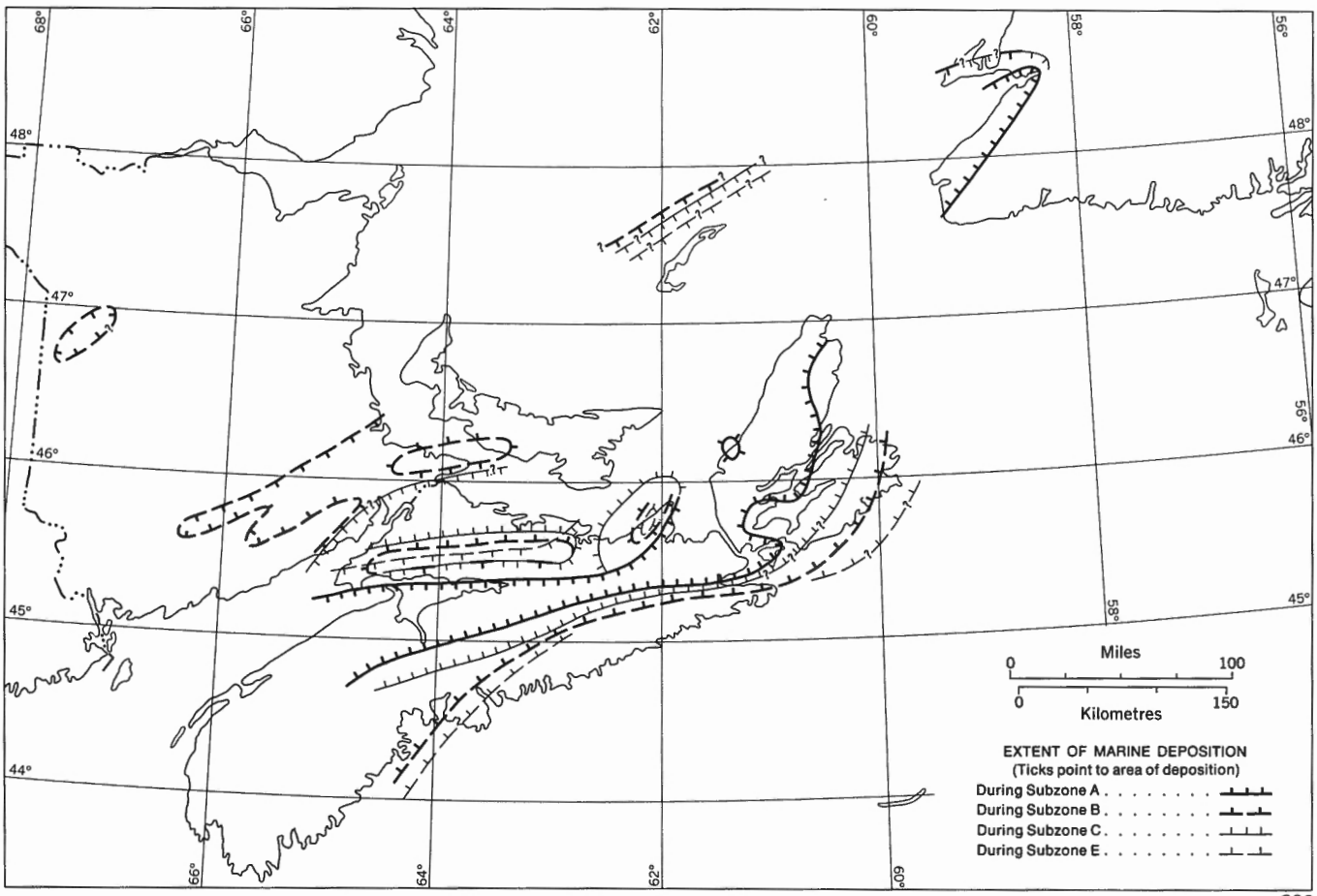

FIGURE VI-24. Extent of marine deposition of subzones of Windsor Group.

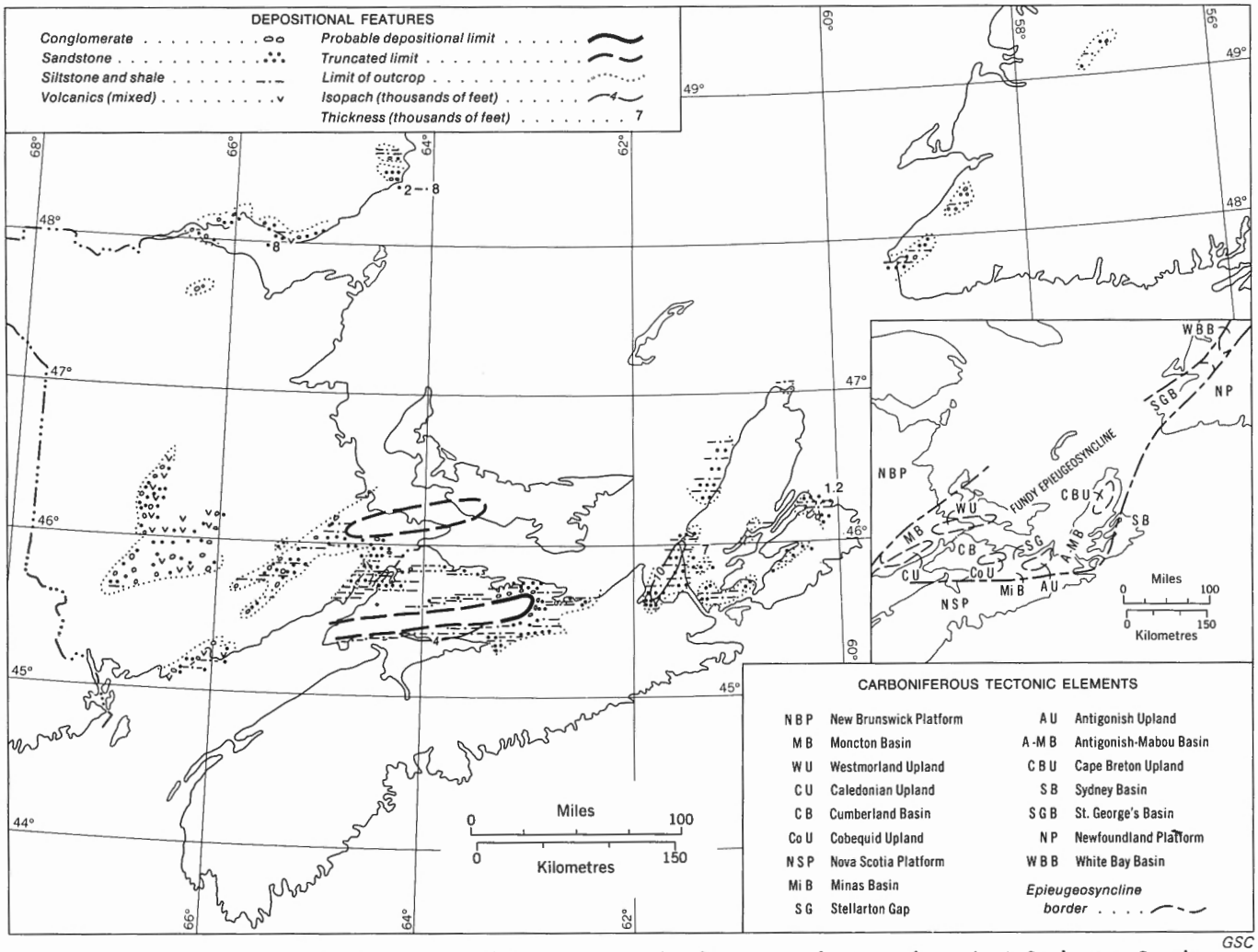

FIGURE VI-25. Carboniferous, Viséan to early Westphalian (Canso Group), sedimentation, volcanism, and tectonism in Southeastern Canada.

and rhyolite. These latter red beds are considered equivalent to a lower part of the Hopewell Group and the marine Windsor strata, and the rhyolite is correlated with the Horton Group. In northern New Brunswick and southern Gaspé Peninsula, conglomerate, sandstone, and shale with minor basalt and limestone of the Bonaventure Formation, and sandstone, shale, and conglomerate of the Cannes de Roches Formation are correlated with the Canso because of probable Namurian spores obtained from the Cannes de Roches. The Bonaventure Formation is probably the same age as the Cannes de Roches, but may have been deposited in a separate basin.

At the western end of Cumberland and Minas Basins in southern New Brunswick, the Mispek Group consists of conglomerate, sandstone, shale, tuff, basic and acidic intrusive and extrusive rocks. The Mispek is overlain by the Lancaster Formation, which contains an early Westphalian flora.

In St. George's Basin of Newfoundland, predominantly grey sandstone, shale, siltstone, and argillaceous limestone in the upper part of the Codroy Group, and conformably overlying predominantly grey sandstone, conglomeratic sandstone, siltstone, conglomerate, and minor silty limestone of the lower part of the Barachois Group have a flora similar to that of the Canso.

Deposition during the early Namurian in Minas, Sydney, and Antigonish–Mabou Basins appears to be mainly offlap sedimentation in areas of low relief whereby each succeeding bed is of increasingly restricted extent, relative to immediately underlying beds. Uplift of part of Cobequid Upland is indicated by conglomerate around most of the eastern end of the present Cobequid Mountains. Along the northern flank fine-grained red and grey sandstone and siltstone overlie a few feet of conglomerate that rests on pre-Carboniferous rocks.

The Riversdale Group (Fig. VI-26) includes the continental red and grey sandstone and shale that lie stratigraphically above the Canso "Group" and below the Cumberland Group. All strata correlative with the Riversdale "Group" are assumed to have the same age limits as the Riversdale. It is of late Namurian to early Westphalian

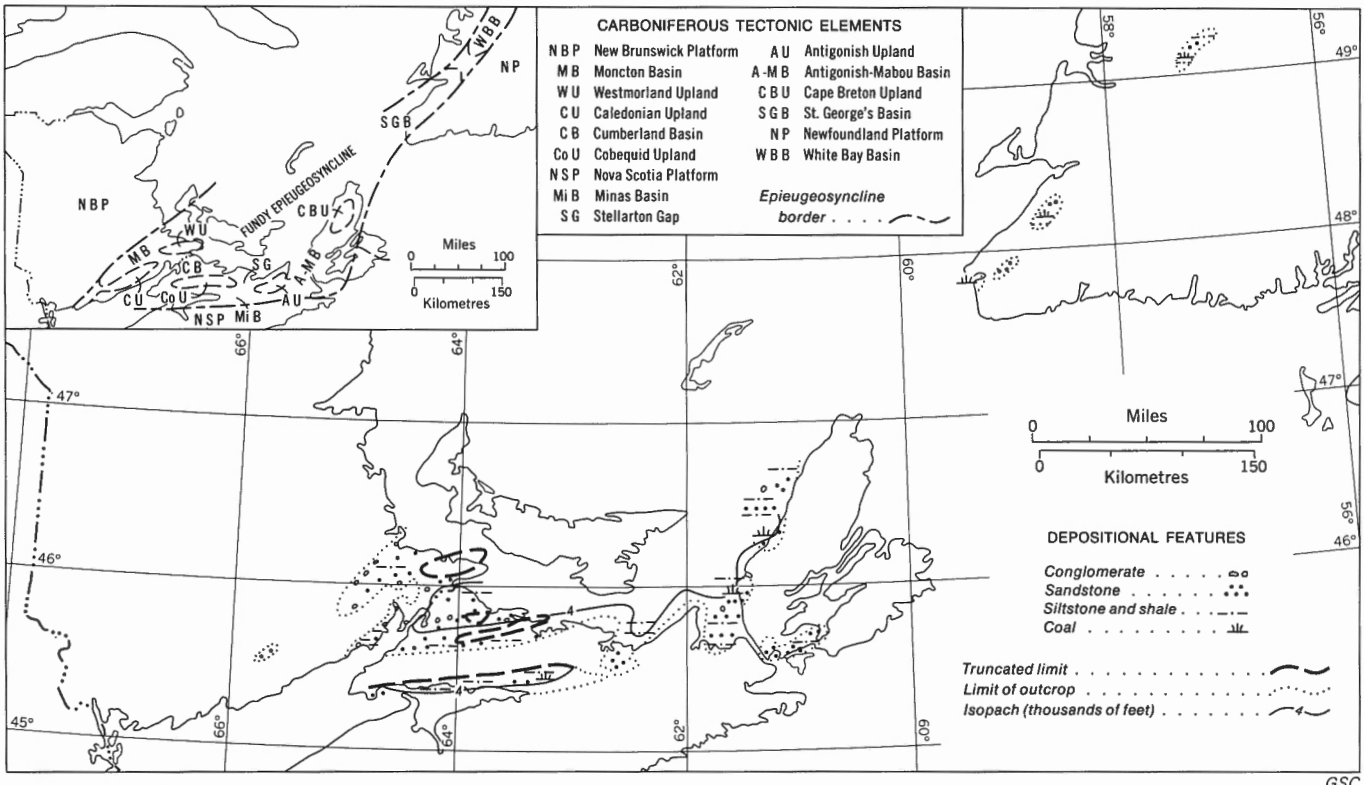

FIGURE VI-26. Carboniferous, mainly early Westphalian (Riversdale Group), sedimentation and tectonism in Southeastern Canada.

A age and in places is separated from older and younger strata by a disconformity or unconformity. Correlation of rocks with the Riversdale is based solely on the floral or faunal assemblage. The type locality is near Riversdale in Minas Basin, and the section exposed there is faulted so that neither the top nor the base is known. The Riversdale has not been divided into formations in the type area, but Riversdale or correlative strata have been subdivided in Cumberland and Moncton Basins. The lower unit is the Claremont Formation in Nova Scotia or the Enrage Formation in New Brunswick, and the upper is the Boss Point Formation. Local formational names, such as Port Hood Formation, have commonly been used interchangeably with the Riversdale. In St. George's and White Bay Basins, only part of the Barachois Group is correlative with the Riversdale.

Lithologically the Riversdale "Group" in the basins of Nova Scotia and New Brunswick consists of fine and coarse facies. In Minas Basin 4,000 to 5,000 feet of dark grey shale and siltstone with thin beds of sandstone and minor fine-grained red beds were originally assigned to the Riversdale. These clastics are similar to underlying Canso strata, and recent work has partially demonstrated that they belong to the same rock-stratigraphic unit as the Canso. Elsewhere the Riversdale consists of fine- to coarse-grained sandstone, shale, siltstone, and conglomerate with a local basal quartz-pebble conglomerate. The sandstone is commonly feldspathic, grey, yellow weathering, and in thick, massive beds that are commonly crossbedded and carry drift plant stems. Mineable seams of coal are present in the Mabou–Antigonish Basin, and thin seams are present in St. George's and White Bay Basins. The conglomerate at the base in Cumberland and Moncton Basins is apparently an alluvial fan that developed during uplift in either the late Namurian or early Westphalian A. The coarser facies of the Riversdale suggests rejuvenation of the source areas. The type of contact and spatial relationship between Riversdale strata and pre-Carboniferous rocks of upland areas are unknown, except in New Brunswick where the Enrage Formation was deposited on pre-Carboniferous rocks on the southeast side of Caledonian Upland. The Enrage and overlying Boss Point Formations are conformable where both are present in axial parts of Moncton and Cumberland Basins; in the axial part of Cumberland Basin they lie conformably on the Canso "Group". Where the Enrage is missing, in Moncton Basin, the Boss Point lies unconformably on all earlier Carboniferous rocks. The general coarsening of Riversdale lithology is therefore probably caused by local uplifts and rejuvenation of source areas.

The Cumberland Group (Fig. VI-27). This group was first defined to designate strata that lie either unconformably or disconformably above the Boss Point Formation of the Riversdale Group and unconformably below the Pictou Group. In the type section at Joggins in western Cumberland Basin over 9,000 feet of strata is present.

At Stellarton Gap the Cumberland "Group" is dominantly red sandstone but includes a basal fanglomerate that lies unconformably on Namurian strata.

In western Cumberland Basin the group consists of a basal, coarse, predominantly conglomeratic facies; a lower, fine-grained facies of grey shale, sandstone, and mineable coal seams; an upper, coarse conglomerate and sandstone facies; and fine clastic facies of red sandstone and siltstone at the top of the section. In southwestern New Brunswick red and grey sandstone, shale, grit, and conglomerate occur.

The floral assemblages of the Cumberland Group have been correlated with late Westphalian A or early Westphalian B. Megaflora and megafauna in the type area are mostly from the lower, fine-grained facies that contain the economically important coal seams. The age of strata in the upper part of the type section of Cumberland Group is possibly the same as that of the lower part of the Pictou "Group".

Deposition in Cumberland Basin was apparently very rapid in some places as suggested by the preservation of 30-foot trees in an upright position. Conglomerate was derived from the Cobequid Upland, the earliest indication that the western end of the Cobequid Mountains was a source area. The eastern end had been a source for a fanglomerate, probably in Namurian time, and the eastern Cobequids or Antigonish Upland was also the source for the Cumberland fanglomerate. It appears likely that Moncton Basin was static during late Westphalian A or early Westphalian B time as the Cumberland or equivalent strata in the Petitcodiac Group are thin or absent.

The Pictou Group (Fig. VI-28). In the type locality along River John in Nova Scotia the Pictou Group unconformably overlies rocks of Namurian age and embraces the highest beds in the axis of a syncline in Cumberland Basin. Its use, however, has been based on floral content, and although diagnostic flora were not present in the type section, which is predominantly red beds, the name was applied to all strata containing the characteristic flora. The flora is divided into three zones: the *Lonchopteris* zone of late Westphalian B to early Westphalian C, the *Linopteris obliqua* zone of Westphalian C to early Westphalian D, and the *Ptychocarpus unitus* zone representative of Westphalian D. Fossil spore age assignments are in agreement, and also add two additional zones representative of the Stephanian and early Permian. The Pictou Group in Cumberland Basin consists of about 8,000 feet of mainly red sandstone and siltstone, shale with arkosic grit, and minor grey sandstone, siltstone, and shale. Red beds are found at Stellarton Gap, along with grey sandstone and shale with oil shale and mineable seams of coal. These beds have been called the Stellarton Group.

Strata in Sydney Basin correlative with the Pictou are referred to the Morien Group. The group includes older strata than those at the Pictou type section and lies

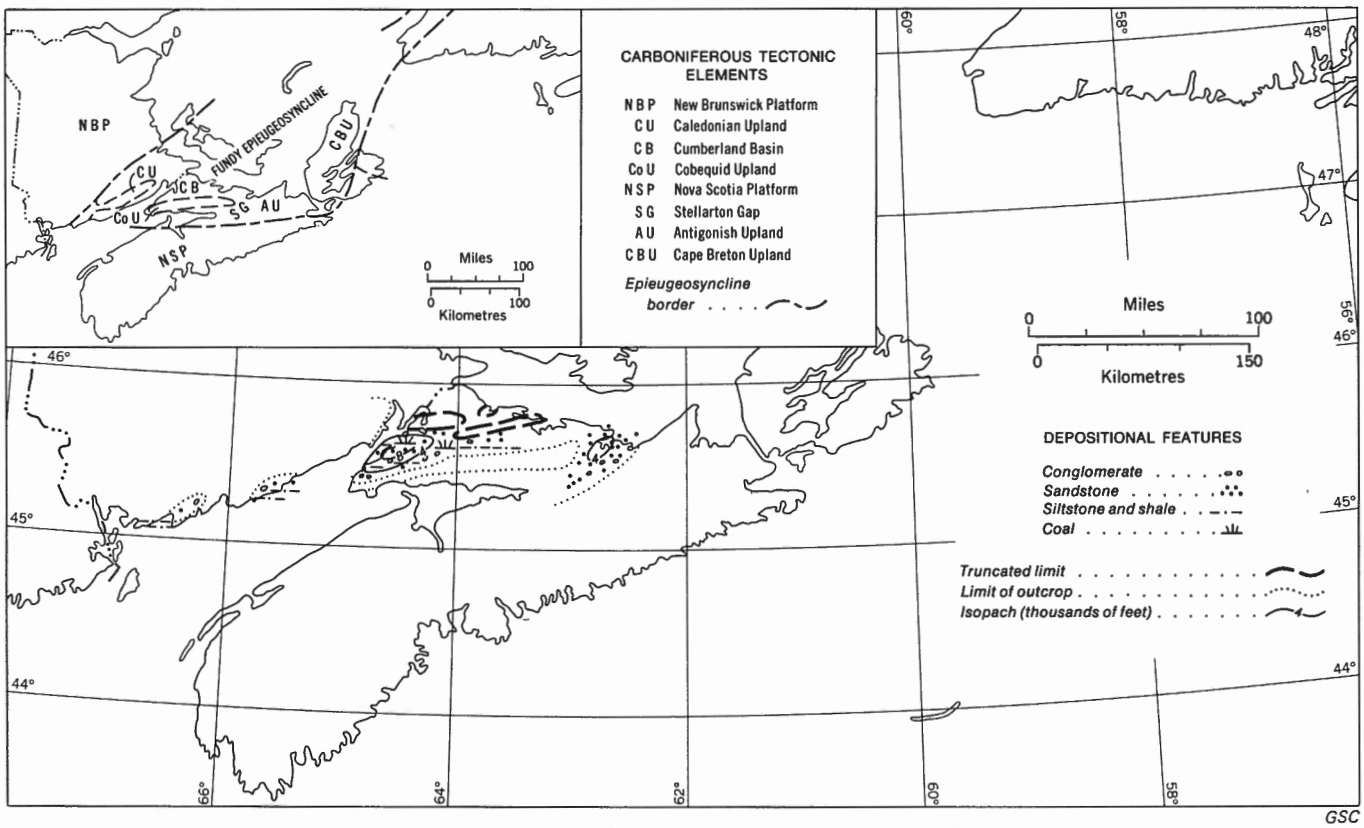

FIGURE VI-27. Carboniferous, early Westphalian (Cumberland Group), sedimentation and tectonism in Southeastern Canada.

disconformably on strata of Namurian and Viséan age, the Point Edward Formation and the Windsor Group. The group consists of 5,000 to 6,500 feet of grit, sandstone, conglomerate, siltstone, shale, and mineable coal seams. It thins to 2,000 to 2,500 feet in western Cape Breton Island. The coal seams are the most productive in the Atlantic Provinces.

Pictou strata in Moncton Basin and on New Brunswick Platform are 1,000 to 3,000 feet thick and consist predominantly of red and grey arkosic sandstone or mudstone, conglomerate, and minor shale. They are oldest in the southwest part of the platform and youngest in the southeast part near the present coastline. Their accumulation was mainly a lateral accretion or building outward of sediments toward the east or northeast, although not necessarily as a delta.

In two small areas in Antigonish–Mabou Basin Pictou strata unconformably overlie Windsor and Horton Groups and overlap pre-Carboniferous rocks.

The red beds of Prince Edward Island have generally been considered part of the Pictou even though they are partly Permian. The red sandstone on Magdalen Islands is tentatively considered part of the same sequence. In western Newfoundland, grey sandstone, siltstone, and conglomerate of Westphalian C or D age occur in a small area and are mainly drift covered.

Pictou strata, in general, constitute a transgressive sequence that spread laterally over all older rocks. The earliest Pictou strata (*Lonchopteris* zone) are probably present in all basins except possibly the Minas. The earliest deposition may have commenced without break in sedimentation at Stellarton Gap and in western Cumberland Basin. An unconformity between the Cumberland and Pictou Groups is present at one locality on a piercement salt structure in Cumberland Basin. It is interpreted to be of local significance only, and is related to the salt intrusion. No alluvial fan-type deposits have been recognized in Pictou strata except in Cumberland Basin where alluvium derived from Cobequid Upland may have continued into Westphalian C time. Otherwise there is no evidence of tectonic activity in the upland areas during Pictou deposition. Pictou strata are structurally conformable on earlier Carboniferous rocks on the platform areas and in Moncton and Sydney Basins.

Maritime Disturbance

Structure. Open folds and high-angle faults, whose latest movements were in Carboniferous and post-Carboniferous time, are the most common structural features in the region. Reverse and strike-slip faulting accompanied by folding occurred within the Fundy Epieugeosyncline during Carboniferous sedimentation as a result of the interaction between pre-Carboniferous basement rocks and rocks in the Carboniferous basins (Fig. VI-29). It appears that Carboniferous structures were mainly a response to deformation in the pre-Carboniferous basement.

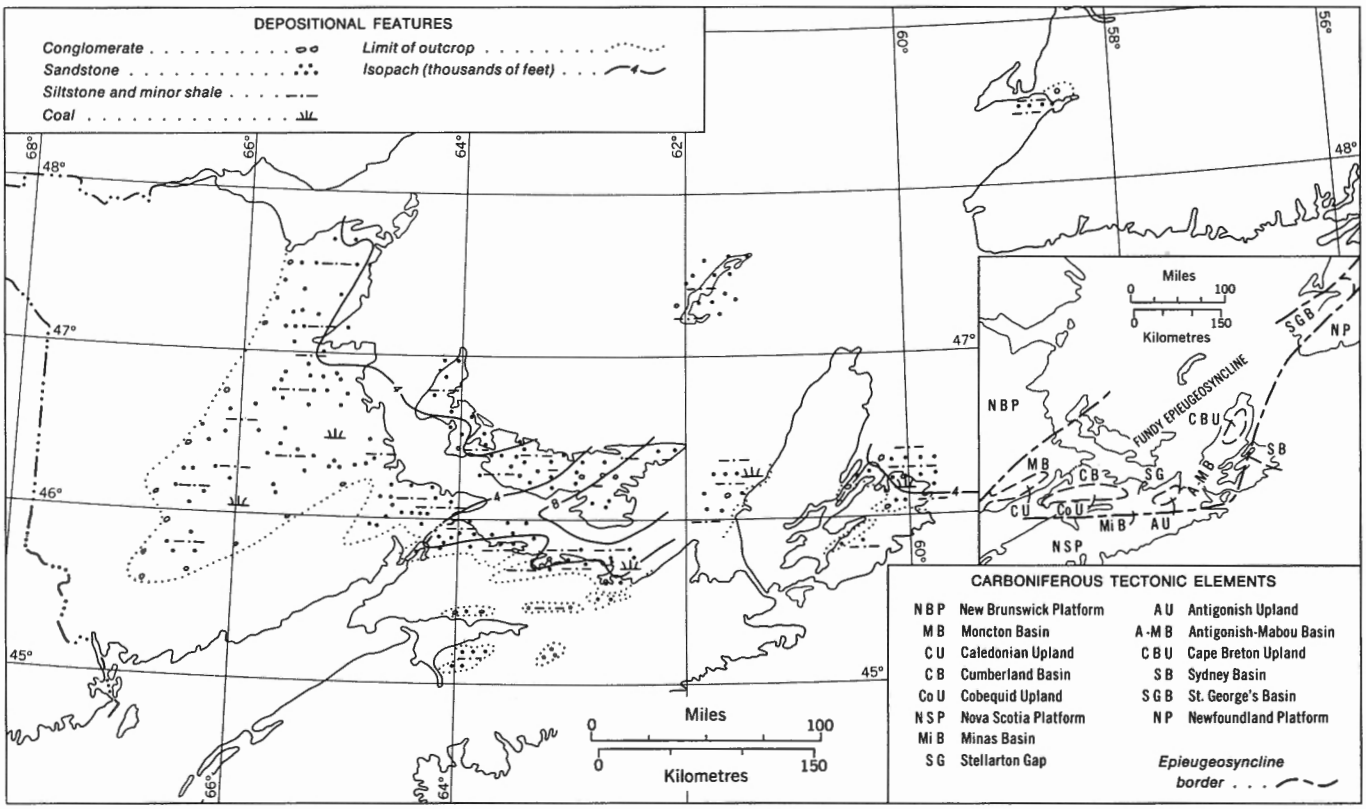

FIGURE VI-28. Carboniferous and Permian, late Westphalian to early Permian (Pictou Group), sedimentation and tectonism in Southeastern Canada.

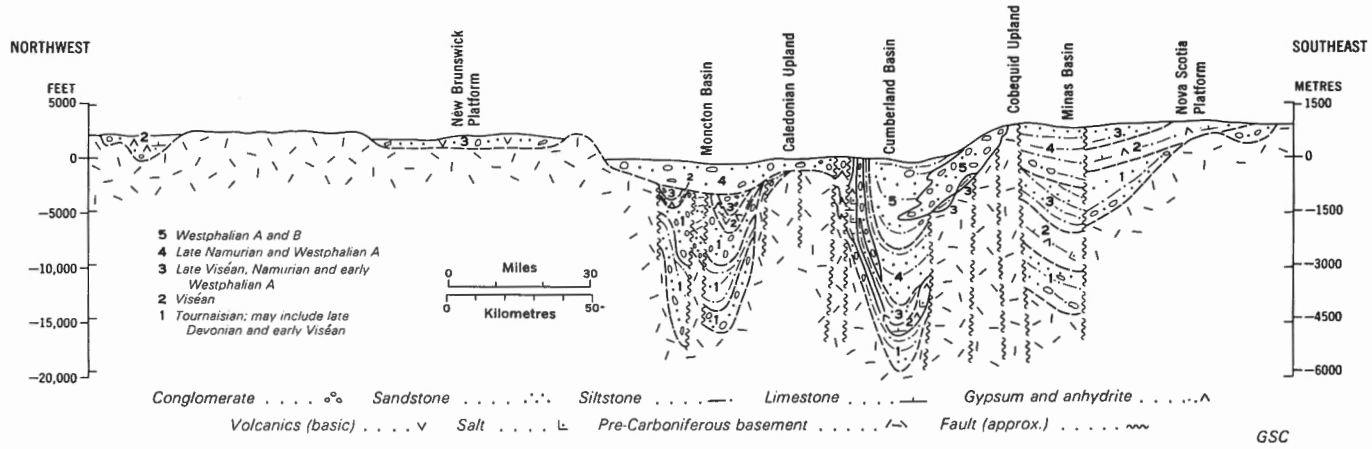

FIGURE VI-29. Diagrammatic restored section of Carboniferous rocks at end of Westphalian B time, New Brunswick and Nova Scotia (by D. G. Kelley).

It has been suggested that the dominant folds are due to gravity sliding, and they may be in part, but evidence of a similar stress pattern in Carboniferous and pre-Carboniferous rocks along the northern boundary of Minas Basin suggests that regional compression played a major role in the development of folds.

The trends of the very broad open folds in Pictou rocks, which essentially blanket earlier rocks, are parallel to the dominant northeast to east-northeast trends in the more intense folds of earlier Carboniferous rocks. Some are overturned. North-trending secondary structures, including folds, were impressed on earlier Carboniferous folds. These cross-folds trend at high angles to the earlier folds and locally are dominant.

A diapiric rise of salt accompanied and accentuated folds that were developed during the Upper Carboniferous. Seismic data tend to confirm that faulting was also a factor in the development of salt structures in the epieugeosyncline.

Metamorphism and igneous intrusion. Metamorphism of Carboniferous and Permian rocks is negligible except for those in a narrow, intermittent zone that extends from the southwest end of Cumberland Basin in southern New Brunswick, east along the southern boundary of Cobequid Upland, and continues out to sea along the same trend. In several places along this zone the Carboniferous rocks have a fracture cleavage. At Cape Spencer near Saint John, New Brunswick, and at several other places in the area underlain by the Carboniferous Mispek Group, there are several granitic stocks and sills. The granite, which is locally miarolitic, intrudes the volcanic and sedimentary rocks of the Mispek Group; both the granite and the intruded rocks are highly fractured, the deformation being late Carboniferous or younger. The granite is probably related genetically to the acidic volcanics of the Mispek Group.

In the Antigonish–Mabou Basin several small stocks and plugs of gabbro cut Lower Windsor strata and may be of Carboniferous age. There are also a number of diabase dykes and sills that cut the lower part of the Horton Group with little visible effect on the enclosing rocks. These dykes are probably Tournaisian.

MESOZOIC AND CENOZOIC

Tectonic Summary

The Mesozoic record of Southeastern Canada is scant (Fig. VI-30). Late Permian to Jurassic rocks are lacking on St. Lawrence Platform and the Appalachian Geosyncline, except for some Upper Triassic non-marine clastics and basalt in the taphrogenic Cape Split Trough of Nova Scotia and southern New Brunswick. The faulting and gentle warping of the trough rocks are referred to the Palisades Disturbance of Late Triassic and possibly younger age. Diabase dykes of Late Triassic and Permo–Triassic age were intruded in southern Nova Scotia and on Prince Edward Island, respectively.

During the Jurassic the entire region, including the Gulf of St. Lawrence and continental shelf, was uplifted and undergoing erosion. In the early Cretaceous and possibly late Jurassic, the basic and alkaline stocks and dykes of the Monteregian Intrusions were intruded along a west-trending zone from within Appalachian Orogen, across St. Lawrence Platform to the Canadian Shield. The platform and Shield were cut by normal faults of similar trend, and some Paleozoic rocks were preserved as outliers in the downfaulted blocks. A diabase dyke intruded lower Paleozoic strata on Anticosti Island, and lamprophyre dykes intruded Acadian-folded

rocks of northeastern Newfoundland and the Canadian Shield at Kirkland Lake.

During the Cretaceous the Paleozoic cover rocks on the Canadian Shield were eroded to about their present distribution. Lower Cretaceous non-marine clastics were deposited unconformably on the Paleozoic strata of Hudson Platform and on Aphebian rocks of Labrador Fold Belt near Schefferville. In the Appalachian Region, Lower Cretaceous fluviatile and lacustrine clastic sediments and lignite, unconsolidated and undeformed, were deposited in a deep river channel cut into an older, possibly Jurassic, upland surface. Upper Cretaceous sediments were deposited on the Scotian Shelf, and possibly also on other parts of the Atlantic Continental Shelf. Marine seismic surveys seem to detect two troughs separated by a ridge—one beneath the shelf and the other beneath the slope and rise. The age of the basement is unknown, but may be Acadian deformed rocks and granites.

The Tertiary record in Southeastern Canada is as meagre as that of the Mesozoic. Tertiary strata have not been recognized, except possibly a conglomerate in Nova Scotia. The entire region may have been low land with thick Tertiary sediments deposited in the troughs of Scotian Shelf and probably also other parts of the continental shelf.

During the Quaternary (*see* Chapter XII), Pleistocene ice sheets advanced southward over the Canadian Shield, St. Lawrence Lowlands, Appalachian Region, and onto the Scotian Shelf, most of which was exposed by the eustatic fall of sea level of at least 400 feet. The island of Newfoundland supported its own ice cap which flowed radially toward the sea. From a glacial maximum about 20,000 years ago, the glaciers began retreating and the sea advanced upon the land, reworked the glacial materials and deposited marine silt and clay along some major river valleys and glacial lake silt and clay in the Great Lakes region. Eustatic fall of sea level and glacial rebound brought Southeastern Canada to its present elevation. Within the last few thousand years, parts of coastal Nova Scotia have subsided.

Triassic

Upper Triassic rocks in the Cape Split Trough outcrop extensively in northern Nova Scotia and southern New Brunswick bordering Bay of Fundy, and locally in Chedabucto Bay. They underlie much of Bay of Fundy and extend southwestward beneath the Gulf of Maine. They are covered by a discontinuous layer of

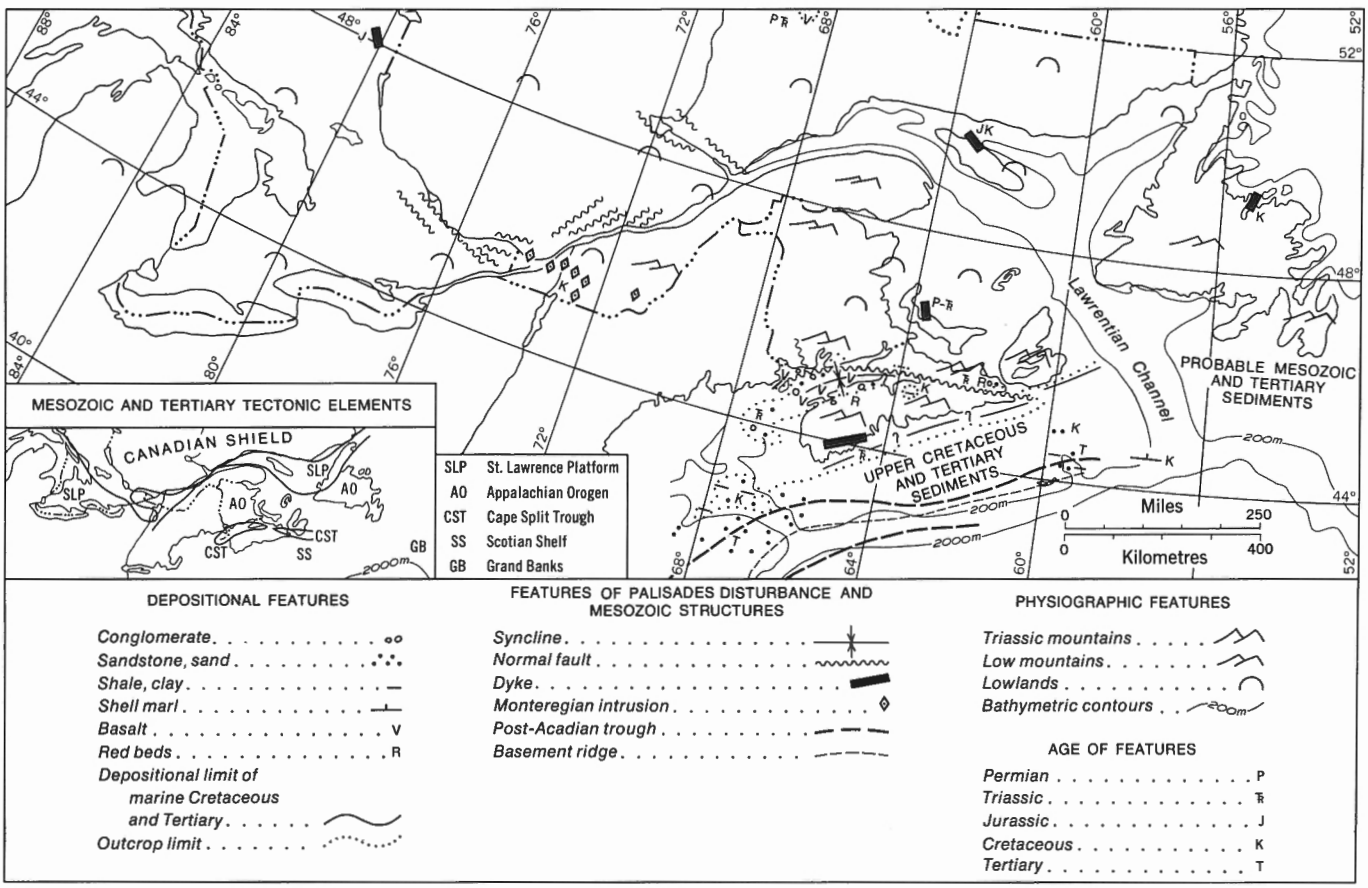

FIGURE VI-30. Mesozoic and Tertiary sedimentation and volcanism in Southeastern Canada, with features of late Triassic Palisades Disturbance and other structures.

Quaternary deposits as much as several hundred feet thick. East of Chedabucto Bay marine seismic and gravity studies suggest that some of the 3,700 feet of consolidated sedimentary rock with a compressional wave velocity about 4.3 km per sec. lies in a trough above possible lower Pennsylvanian strata. Triassic sedimentary rocks may occur in the troughs on Scotian Shelf and elsewhere on the Atlantic Continental Shelf.

In northern Nova Scotia, Upper Triassic rocks of the Fundy Group comprise two sedimentary units separated by basalt flows (Klein, 1962). The lower sedimentary unit, formerly called the Annapolis Formation, consists of the Wolfville and Blomidon Formations. The Wolfville overlies Carboniferous and older rocks with angular unconformity and is made up of 200 to 2,500 feet of red and brown pebble and boulder polymictic conglomerate, greywacke, orthoquartzitic sandstone, and shale. It is of fluviatile origin and exhibits cut-and-fill structures, crossbedding, ripple-marks, current lineation, and pebble imbrication. The conformably overlying, and in part laterally equivalent, Blomidon Formation consists of 25 to 1,200 feet of even-bedded, reddish and greenish grey sandstone and thin-bedded mudstone. Groove casts, salt casts, rain prints, ripple-marks, mudcracks, crossbedding, and tree trunks suggest a mainly lacustrine facies that intertongues with the Wolfville fluviatile facies. The conformably overlying North Mountain Basalt consists of 875 feet or more of tholeiitic flows containing amygdules filled with a varied assemblage of zeolites. Five K–Ar whole-rock dates average 198 m.y., that is, latest Triassic. The upper sedimentary unit, the Scots Bay Formation, occurs at the water's edge of the Bay of Fundy. It consists of 23 feet of grey and brown sandstone, purple and grey mudstone, and limestone with chert and jasperoid nodules, probably of lacustrine origin. Fossils from all the sedimentary formations are non-marine forms, including conchostracan shells, reptillian bones, vertebrate teeth, fish scales, and ferns; they are late Triassic, probably Karnian and Norian. Red sandstone and conglomerate, lithologically similar to the Wolfville, outcrop on Chedabucto Bay and in southern New Brunswick. Basalt outcrops in Minas Basin and on Grand Manan Island.

Two diabase dykes are late Permian or Triassic. The one on Prince Edward Island is a gently dipping dyke or sill, at least 10 feet thick, intrusive into red sandstone of the Pictou Group. The K–Ar whole-rock age is 207±8 m.y. (N. J. Snelling), about Middle Triassic, whereas paleomagnetic pole positions suggest a probable late Permian age. Another diabase dyke, in southern Nova Scotia, is 200 to 500 feet wide and 70 miles long. It has a whole-rock K–Ar date of 197±32 m.y., on or near the Triassic–Jurassic boundary. The paleomagnetic pole position is similar to that of North American Triassic rocks including the North Mountain basalt lavas to which the dyke has been related.

Jurassic and Cretaceous

Northeast-trending lamprophyre dykes cut folded Silurian sedimentary rocks and Devonian granite at Notre Dame Bay, Newfoundland. K–Ar age determinations on biotite and hornblende range from 115 to 144 m.y. and average 133 m.y., which corresponds to earliest Cretaceous. A northwest-trending diabase dyke cuts Upper Ordovician limestone on Anticosti Island and yielded a K–Ar whole-rock date of 138 m.y., that is on or near the Jurassic–Cretaceous boundary.

The Monteregian Intrusions cut folded rocks of the Appalachian Orogen, the gently deformed to flat-lying strata of the St. Lawrence Platform and Precambrian crystalline rocks of the Grenville Province of the Canadian Shield. With related dykes they occur along a west-trending line for about 150 miles. Most are roughly circular plugs with steep walls, but others are considered to be laccoliths. Near Montreal there are diatreme breccias comprising various proportions of igneous material and inclusions of Precambrian to Lower Devonian country rock. The Devonian limestone fragments must have dropped down within the diatreme because no strata younger than Ordovician outcrop in Quebec Basin. The intrusions and dykes consist of a great variety of alkaline rocks among which are nepheline, syenite, essexite, nordmarkite, pulaskite, yamaskite, and rougemontite. Monzonitic and granitic rocks form part of the easternmost intrusion near Lake Megantic. The Oka Intrusion contains abundant carbonatite and is mined for the niobium-bearing mineral pyrochlore. Several K–Ar and Rb–Sr age determinations obtained from minerals and whole-rock samples range from 84 to 123 m.y. with many dates falling in the 100 to 115 m.y. range corresponding to the late Lower Cretaceous. A northwest-striking kimberlite dyke at Kirkland Lake may be related to the Monteregian Intrusions. A K–Ar age determination on phlogopite yielded 151±8 m.y., corresponding to late Jurassic.

Cretaceous sediments occur in Nova Scotia and on the Scotian Shelf. Non-marine Lower Cretaceous sediments, probably pre-Albian, consisting of about 60 feet of red, brown, grey, and black interbedded clay, sand, silt, and lignite containing pollen and spores, are exposed along Musquodoboit River and in an open pit near Shubenacadie in central Nova Scotia (Stevenson, 1959). The sediments are probably of lacustrine and fluviatile origin and fill a valley cut more than 200 feet below the upland surface. They probably lie unconformably on the Windsor Group and are overlain by glacial deposits. The clay has been used in the manufacture of pottery and buff firebrick.

Upper Cretaceous sediments may underlie much of Scotian Shelf and Grand Banks, and perhaps the continental shelf off northeastern Newfoundland and Labrador. They are less likely to occur in Gulf of St. Law-

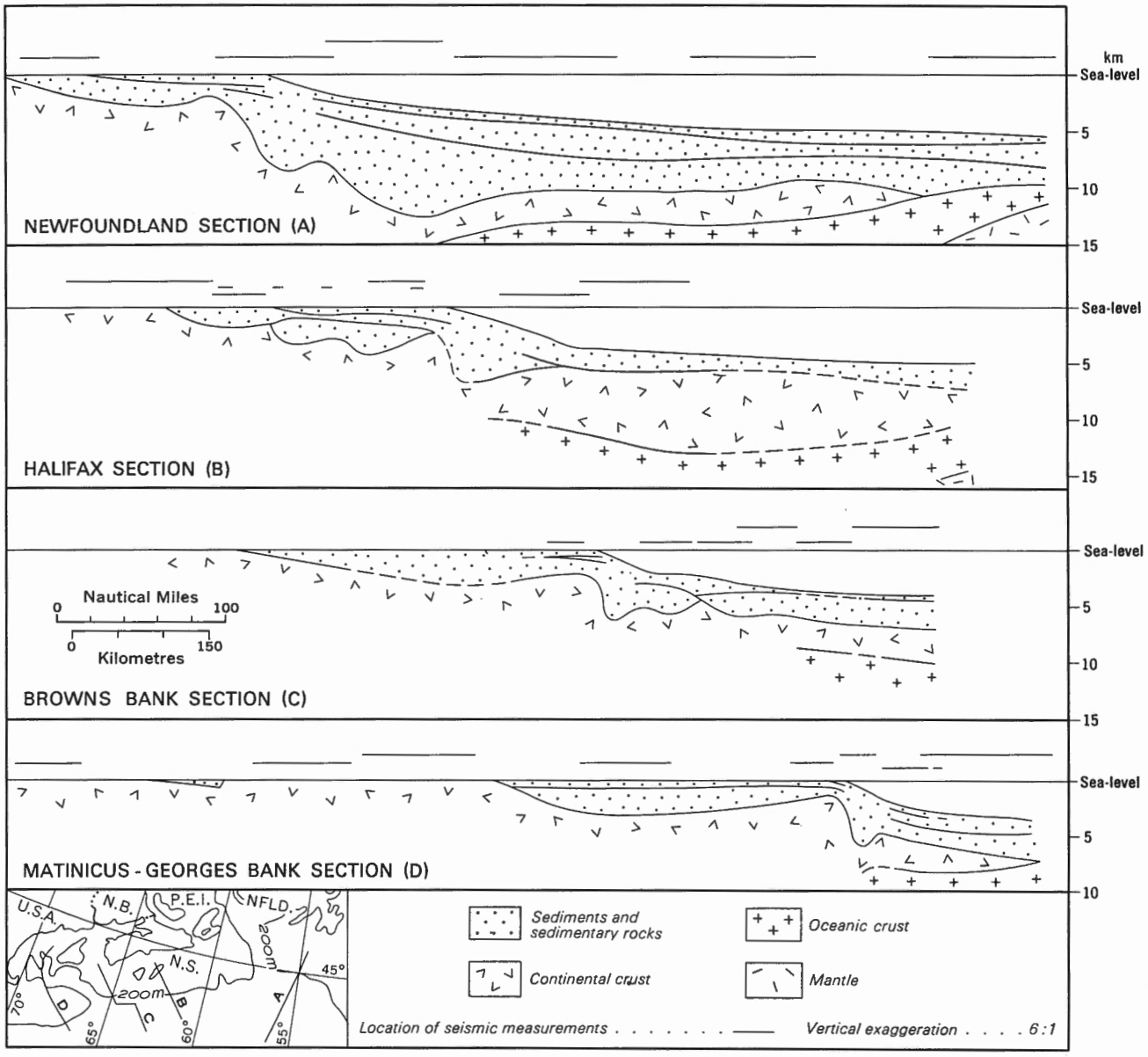

FIGURE VI-31. Structure-sections from seismic refraction measurements, Atlantic Continental Shelf (Drake, et al., 1959).

rence as much of the sea floor between Magdalen Islands and Prince Edward Island is underlain by red sandstone that is probably Carboniferous and Permian. On eastern Banquereau Bank of Scotian Shelf several fragments of indurated, highly fossiliferous, finely arenaceous shell marl were lifted from 200 fathoms of water. The fragments were considered to have fallen from upslope subsea outcrops. The fauna are marine and of Upper Cretaceous age, probably Cenomanian. A greenish grey, impure sandstone was dredged from a subsea peak on central Scotian Shelf north of Sable Island (L. H. King). The fauna are probably Cenomanian (J. A. Jeletzky). The marine late Upper Cretaceous micaceous and glauconitic sandstones dredged from Gulf of Maine probably extend northeastward to the Scotian Shelf and Grand Banks. The Upper Cretaceous could be several thousand feet thick if the strata form part of the troughs that occur beneath the continental shelf, continental slope, and continental rise (Fig. VI-31).

Tertiary

Tertiary sediments have been dredged and cored at 425 to 488 fathoms from the sides of The Gully at the edge of the Scotian Shelf (Marlowe, 1967). They consist of dark brown, hard and fissile silt with foraminifera of late Tertiary, probably Miocene age. A cobble of coarse glauconite sandstone of probable Pliocene age was recovered from the bottom of The Gully. There may be

Tertiary sediments on other shelf areas, including parts of Gulf of St. Lawrence, as the outline of the present land areas seems to be similar to those that could have existed in the Tertiary.

Possible Tertiary stratified grit and gravel deposited by streams and firmly cemented by limonite outcrop in Nova Scotia at Maitland, Greenfield, and between Bridgewater and Halifax. They lie directly on pyritic Halifax slate, and although they underlie the glacial material, they could be Pleistocene outwash deposits.

Quaternary

Pleistocene moraines have been identified in the central part of Scotian Shelf, and abundant igneous and metamorphic clasts of probable glacial origin have been recovered from the southeastern shelf and slope and in canyons like The Gully. Similarly, the floor of Gulf of St. Lawrence is veneered by glacial materials. The Laurentian Channel is a pre-glacial valley that was modified by the glaciers. Retreat of the ice allowed the rising sea to invade main river valleys and deposit marine clays, and lacustrine clay was deposited in the Great Lakes region. In the past few thousand years many coastal parts of Nova Scotia and Prince Edward Island have been depressed, resulting in drowned forests.

In historical times there have been only a few earthquakes in Appalachian Orogen, generally of low intensity. The St. Lawrence Platform and adjacent Canadian Shield are seismically active near Quebec City and along a belt that extends through Montreal to Boston, Massachusetts (Fig. VI-32). The concentrations of earthquake epicentres are apparently not controlled by near-surface geological elements.

Beneath the Appalachian Orogen, approximately along the axial region, a belt of thick crust has been detected by marine refraction seismic surveys (Dainty, *et al.*, 1966). Within the belt (Fig. VI-33), the crust is about 45 km thick and overlies an upper mantle with

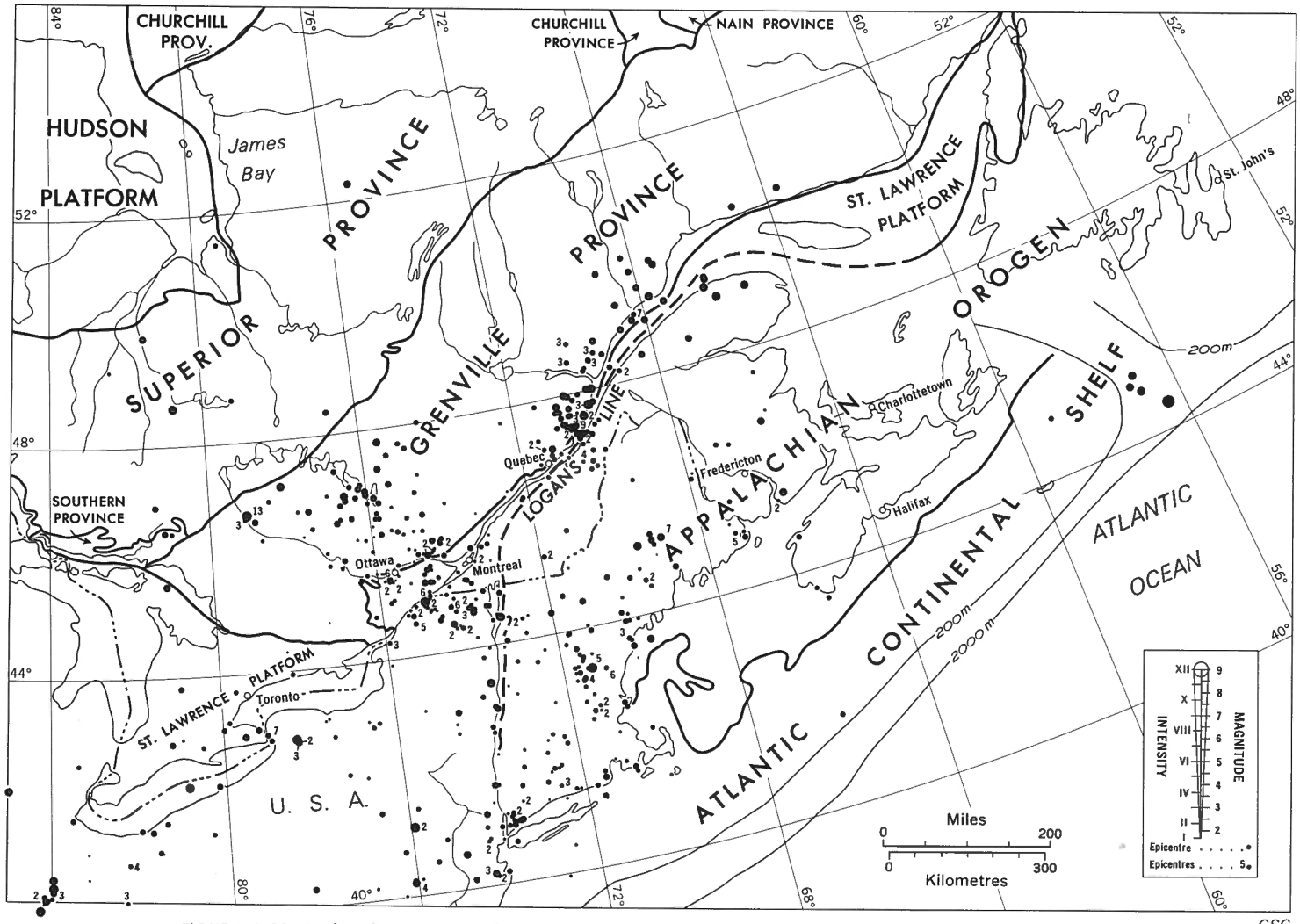

FIGURE VI-32. Earthquake epicentres of eastern Canada and adjacent areas, 1928–59 (modified from Smith, 1967).

high compressional wave velocities of 8.5 to 8.7 km per sec. In the lower part of the crust an intermediate layer has velocities of 7.3 to 7.5 km per sec. The crust flanking the thickened belt is 30 to 40 km thick. It lacks the intermediate layer, and overlies an upper mantle with the usual velocities of about 8.0 km per sec. The thick crustal belt corresponds closely to Notre Dame Trough, a persistently negative tectonic element of Appalachian Geosyncline within which thick eugeosynclinal sedimentary, volcanic, and ultramafic rocks accumulated, and which was intensely deformed during the climactic Acadian Orogeny.

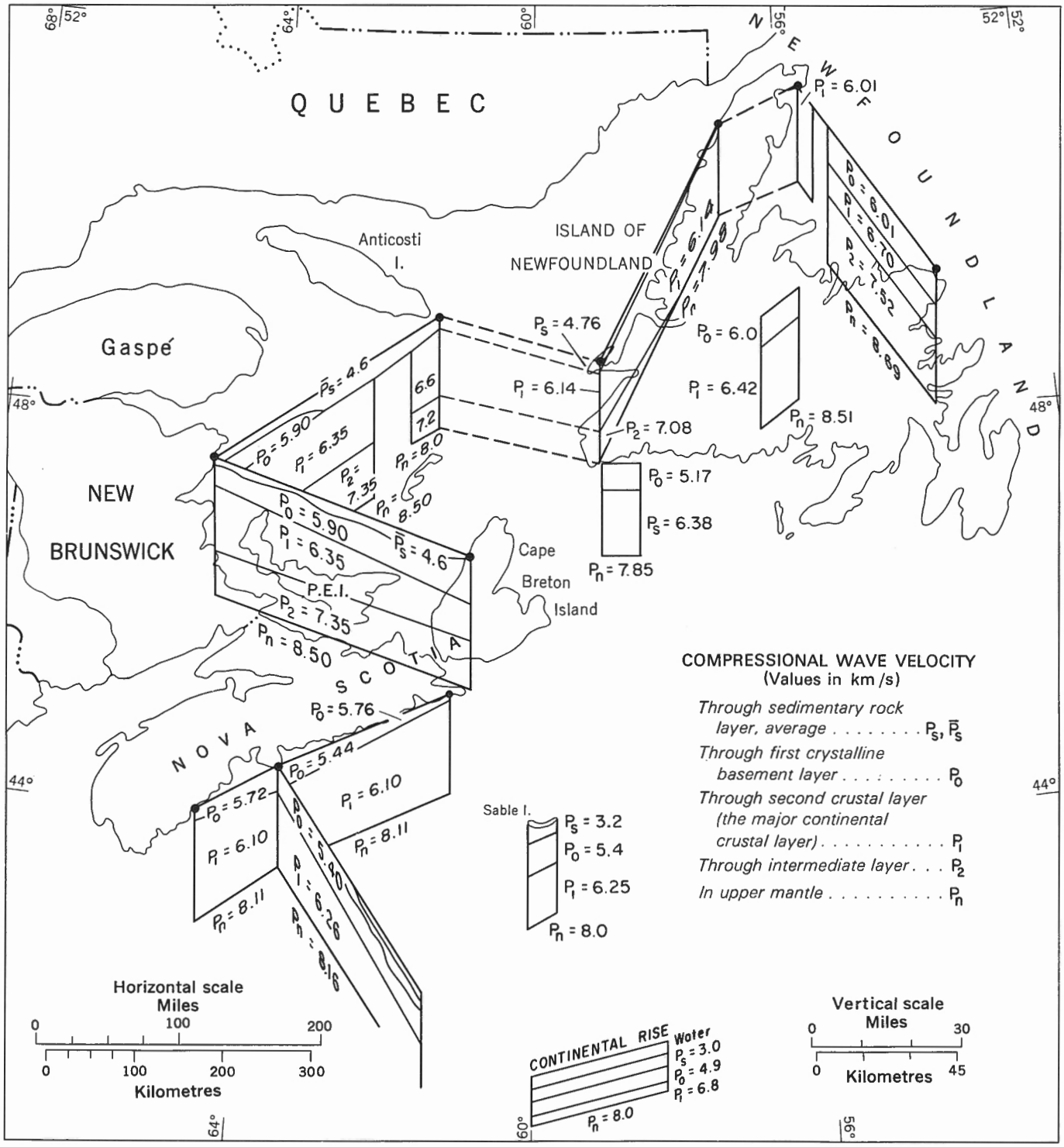

FIGURE VI-33. Fence diagram through crust, Appalachian Orogen (Dainty, et al., 1966).

Alcock, F. J.
1936: Geology of the Chaleur Bay region; *Geol. Surv. Can.*, Mem. 183.
1938: Geology of Saint John region; *Geol. Surv. Can.*, Mem. 216.

Ayrton, W. G.
1967: Chandler–Port-Daniel area; *Quebec Dept. Nat. Resources,* Geol. Rept. 120.

Badgley, P. C.
1956: New Carlisle map-area; *Quebec Dept. Mines,* Geol. Rept. 70.

Baird, D. M., and Cote, P. R.
1964: Lower Carboniferous sedimentary rocks in southwestern Newfoundland and their relations to similar strata in western Cape Breton Island; *Bull. Can. Inst. Mining Met.*, vol. 57, pp. 509-520.

Beards, R. J.
1967: Guide to the subsurface Palaeozoic stratigraphy of southern Ontario; *Ontario Dept. Energy Resources Management,* Paper 67-2.

Béland, J.
1960: Preliminary report on Rimouski–Matapedia areas; *Quebec Dept. Nat. Resources,* Prel. Rept. 430.
1962: Ste-Perpétué area; *Quebec Dept. Nat. Resources,* Geol. Rept. 98.

Bell, W. A.
1927: Outline of Carboniferous stratigraphy and geologic history of the Maritime Provinces of Canada; *Trans. Roy. Soc. Can.*, sect. IV, vol. 31, pp. 75–108.
1929: Horton–Windsor district, Nova Scotia; *Geol. Surv. Can.*, Mem. 155.
1948: Early Carboniferous strata of St. George's Bay area, Newfoundland; *Geol. Surv. Can.*, Bull. 10.
1958: Possibilities for occurrence of petroleum reservoirs in Nova Scotia; *N.S. Dept. Mines.*

Belt, E. S.
1965: Stratigraphy and paleogeography of Mabou Group and related Middle Carboniferous facies, Nova Scotia, Canada; *Bull. Geol. Soc. Am.*, vol. 76, pp. 777–802.

Belyea, H. L.
1952: Deep wells and subsurface stratigraphy of part of the St. Lawrence Lowlands, Quebec; *Geol. Surv. Can.*, Bull. 22.

Betz, F., Jr.
1939: Geology and mineral deposits of the Canada Bay area, northern Newfoundland; *Newfoundland Geol. Surv.*, Bull. 16.

Bolton, T. E.
1957: Silurian stratigraphy and palaeontology of the Niagara escarpment in Ontario; *Geol. Surv. Can.*, Mem. 289.
1961: Ordovician and Silurian Formations of Anticosti Island, Quebec; *Geol. Surv. Can.*, Paper 61-26.

Boucot, A. J., Cumming, L. M., and Jaeger, H.
1967: Contributions to the age of the Gaspé Sandstone and Gaspé Limestone; *Geol. Surv. Can.*, Paper 67-25.

Brückner, W. D.
1966: Stratigraphy and structure of west-central Newfoundland; Guidebook: geology of parts of Atlantic Provinces; *Geol. Assoc. Can.–Mineral. Assoc. Can.*, pp. 137-151.

Burgess, R. J.
1962: Cambrian hydrocarbon traps on the northwest rim of the Appalachian Basin; *Proc. Ontario Petrol. Inst.*, 1st Ann. Conf., pp. 1–24.

Burk, C. F., Jr.
1964: Silurian stratigraphy of Gaspé Peninsula, Quebec; *Bull. Am. Assoc. Petrol. Geol.*, vol. 48, pp. 437–464.

Cady, W. M.
1960: Stratigraphic and geotectonic relationships in northern Vermont and southern Quebec; *Bull. Geol. Soc. Am.*, vol. 71, pp. 531–576.
1967: Geosynclinal setting of the Appalachian mountains in southeastern Quebec and northwestern New England; *Roy. Soc. Can.*, Spec. Publ. 10, Appalachian tectonics, pp. 57–68.

Clark, T. H.
1956: Oil and gas in the St. Lawrence Lowland of Quebec; *Trans. Can. Inst. Mining Met.*, vol. 59, pp. 278–282.
1965: Oil and gas potential of Quebec and the Maritime Provinces; *Proc. Ontario Petrol. Inst.*, 4th Ann. Conf., pp. 1–7.

Clifford, P. M., and Baird, D. M.
1962: Great Northern Peninsula of Newfoundland–Grenville Inlier; *Trans. Can. Inst. Mining Met.*, vol. 65, pp. 95–102.

Cooke, H. C.
1950: Geology of a southwestern part of the Eastern Townships of Quebec; *Geol. Surv. Can.*, Mem. 257.

Cooper, J. R.
1937: Geology and mineral deposits of the Hare Bay area; *Newfoundland Dept. Nat. Resources,* Geol. Sect., Bull. 9.
1954: La Poile – Cinq Cerf map-area, Newfoundland; *Geol. Surv. Can.*, Mem. 276.

Crosby, D. G.
1962: Wolfville map-area, Nova Scotia; *Geol. Surv. Can.*, Mem. 325.

Cumming, L. M.
1959: Silurian and Lower Devonian formations in the eastern part of Gaspé Peninsula, Quebec; *Geol. Surv. Can.*, Mem. 304.

Dainty, A. M., Keen, C. E., Keen, M. J., and Blanchard, J. E.
1966: Review of geophysical evidence on crust and upper-mantle structure on the eastern seaboard of Canada; Geophys. Monograph 10: The earth beneath the continents; *Am. Geophys. Union,* pp. 349–369.

Davies, J. L.
1966: Geology of Bathurst–Newcastle area, N.B.; Guidebook: geology of parts of Atlantic Provinces; *Geol. Assoc. Can.–Mineral. Assoc. Can.*, pp. 33–43.

Drake, C. L., Ewing, M., and Sutton, G. H.
1959: Continental margins and geosynclines: the east coast of North America north of Cape Hatteras; Physical Chemistry of the Earth, London, Pergamon Press, vol. 3, pp. 110–198.

Dresser, J. A., and Denis, T. C.
1944: Geology of Quebec; *Quebec Dept. Mines,* Geol. Rept. 20, vol. 2.

Eakins, P. R.
1964: Sutton map-area, Quebec; *Geol. Surv. Can.*, Paper 63-34.

Espenshade, G. H.
1937: Geology and mineral deposits of the Pilleys Island area; *Newfoundland Dept. Nat. Resources,* Geol. Sect., Bull. 6.

Fairbairn, H. W., Bottino, M. L., Pinson, W. H., Jr., and Hurley, P. M.
1966: Whole rock age and initial $^{87}Sr/^{86}Sr$ of volcanics underlying fossiliferous Lower Cambrian in the Atlantic Provinces of Canada; *Can. J. Earth Sci.,* vol. 3, pp. 509–521.

Fyson, W. K.
1966: Structures in the Lower Paleozoic Meguma Group, Nova Scotia; *Bull. Geol. Soc. Am.,* vol. 77, pp. 931–944.

Greiner, H. R., and Potter, R. R.
1966: Silurian and Devonian stratigraphy, northern New Brunswick; Guidebook: geology of parts of Atlantic Provinces; *Geol. Assoc. Can.–Mineral. Assoc. Can.,* pp. 19–32.

Gussow, W. C.
1953: Carboniferous stratigraphy and structural geology of New Brunswick, Canada; *Bull. Am. Assoc. Petrol. Geol.,* vol. 37, No. 7.

Hacquebard, P. A., and Donaldson, J. R.
1963: Stratigraphy and palynology of the Upper Carboniferous coal measures in the Cumberland Basin of Nova Scotia, Canada; *Cinquième Congr. Inter. Stratigraphique Géol. Carbonifère,* Paris, pp. 1157–1169.

Hamblin, W. K.
1958: The Cambrian sandstones of northern Michigan; *Mich. Geol. Surv.,* Publ. 51.

Hayes, A. O., and Howell, B. F.
1937: Geology of Saint John, New Brunswick; *Geol. Soc. Am.,* Spec. Paper No. 5.

Hayes, A. O., and Johnson, H.
1938: Geology of the Bay St. George Carboniferous area, Newfoundland; *Newfoundland Geol. Surv.,* Bull. 12.

Hubert, C.
1967: Tectonics of part of the Sillery Formation in the Chaudière–Matapédia segment of the Quebec Appalachians; *Roy. Soc. Can.,* Spec. Publ. 10; Appalachian tectonics, pp. 33–40.

Hutchinson, R. D.
1952: The stratigraphy and trilobite faunas of the Cambrian sedimentary rocks of Cape Breton Island, Nova Scotia; *Geol. Surv. Can.,* Mem. 263.
1962: Cambrian stratigraphy and trilobite faunas of southeastern Newfoundland; *Geol. Surv. Can.,* Bull. 88.

Jenness, S. E.
1963: Terra Nova and Bonavista map-areas, Newfoundland; *Geol. Surv. Can.,* Mem. 327.

Kay, G. M.
1966: Newfoundland structures and continental drift; *Bull. Can. Petrol. Geol.,* vol. 14, pp. 613–620.
1967: Stratigraphy and structure of northeastern Newfoundland bearing on drift in North Atlantic; *Bull. Am. Assoc. Petrol. Geol.,* vol. 51, pp. 579–600.

Kelley, D. G.
1967: Some aspects of Carboniferous stratigraphy and depositional history in the Atlantic Provinces of Canada; *Geol. Assoc. Can.,* Spec. Paper No. 4, pp. 213–228.

Kindle, C. H., and Whittington, H. B.
1958: Stratigraphy of the Cow Head region, western Newfoundland; *Bull. Geol. Soc. Am.,* vol. 69, pp. 315–342.

Klein, G. de V.
1962: Triassic sedimentation, Maritime Provinces, Canada; *Bull. Geol. Soc. Am.,* vol. 73, pp. 1127–1146.

Koepke, W. E., and Sanford, B. V.
1965: The Silurian oil and gas fields of southwestern Ontario; *Geol. Surv. Can.,* Paper 65-30.

Lajoie, J., Lespérance, P. J., and Béland, J.
1968: Silurian stratigraphy and paleogeography of Matapedia–Témiscouata region, Quebec; *Bull. Am. Assoc. Petrol. Geol.,* vol. 52, pp. 615–640.

Lilly, H. D.
1963: Geology of Hughes Brook – Goose Arm area, west Newfoundland; *Memorial Univ. Newfoundland,* Geol. Rept. No. 2.
1967: Some notes on stratigraphy and structural style in central west Newfoundland; *Geol. Assoc. Can.,* Spec. Paper No. 4, Collected papers on the geology of the Atlantic Region, pp. 201–211.

Maehl, R. H.
1961: The older Palaeozoic of Pictou County, Nova Scotia; *N.S. Dept. Mines,* Mem. 4.

Marlowe, J. I.
1967: The geology of part of the continental slope near Sable Island, Nova Scotia; *Geol. Surv. Can.,* Paper 65-38.

Mattinson, C. R.
1964: Mount Logan area, Matane and Gaspé–North Counties; *Quebec Dept. Nat. Resources,* Geol. Rept. 118.

McCartney, W. D.
1967: Whitbourne map-area, Newfoundland; *Geol. Surv. Can.,* Mem. 341.

McCartney, W. D., Poole, W. H., Wanless, R. K., Williams, H., and Loveridge, W. D.
1966: Rb/Sr age and geological setting of the Holyrood granite, southeast Newfoundland; *Can. J. Earth Sci.,* vol. 3, pp. 947–957.

McGerrigle, H. W.
1950: The geology of eastern Gaspé; *Quebec Dept. Mines,* Geol. Rept. 35.

Murray, B. C.
1960: Stratigraphy of the Horton Group in parts of Nova Scotia; *N.S. Research Found.,* Halifax.

Neale, E. R. W.
1963: Geology, Pleasant Bay, Nova Scotia; *Geol. Surv. Can.,* Map 1119A.

Neale, E. R. W., Béland, J., Potter, R. R., and Poole, W. H.
1961: Preliminary tectonic map of the Canadian Appalachian Region based on age of folding; *Trans. Can. Inst. Mining Met.,* vol. 64, pp. 405–412.

Neale, E. R. W., and Kennedy, M. J.
1967: Relationship of the Fleur de Lys Group to younger groups of the Burlington Peninsula, Newfoundland; *Roy. Soc. Can.,* Spec. Paper 4, pp. 139–169.

Neale, E. R. W., and Nash, W. A.
1963: Sandy Lake (east half), Newfoundland; *Geol. Surv. Can.,* Paper 62-28.

Oliver, W. A.
1966: The Bois Blanc and Onondaga Formations in western New York and adjacent Ontario; *N. Y. State Geol. Assoc.,* Guidebook: 38th Annual meeting, Buffalo, 1966, pp. 32–43.

Ollerenshaw, N. C.
1967: Cuoq-Langis area; *Quebec Dept. Nat. Resources,* Geol. Rept. 121.

Ollerenshaw, N. C., and MacQueen, R. W.
1960: Ordovician and Silurian of the Lake Timiskaming area; *Proc. Geol. Assoc. Can.*, vol. 12, pp. 105–115.

Osborne, F. F.
1956: Geology near Quebec City; *Naturaliste Can.*, vol. 83, pp. 157–223.

Phinney, W. C.
1963: Phase equilibria in the metamorphic rocks of St. Paul Island and Cape North, Nova Scotia; *J. Petrol.*, vol. 4, pp. 90–130.

Poole, W. H.
1963: Hayesville, New Brunswick; *Geol. Surv. Can.*, Map 6-1963.
1967: Tectonic evolution of Appalachian Region of Canada; geology of the Atlantic Region, *Roy. Soc. Can.*, Spec. Paper 4, pp. 9–51.

Riley, G. C.
1962: Stephenville map-area, Newfoundland; *Geol. Surv. Can.*, Mem. 323.

Rodgers, J.
1965: Long Point and Clam Bank Formations, western Newfoundland; *Proc. Geol. Assoc. Can.*, vol. 16, pp. 83–94.

Rodgers, J., and Neale, E. R. W.
1963: Possible "Taconic" klippen in western Newfoundland; *Am. J. Sci.*, vol. 261, pp. 713–730.

Roliff, W. A.
1962: The Maritime Carboniferous basin of eastern Canada; *Proc. Geol. Assoc. Can.*, vol. 14, pp. 21–41.
1968: Oil and gas exploration—Anticosti Island, Quebec; *Proc. Geol. Assoc. Can.*, vol. 19, pp. 31–36.

Rose, E. R.
1952: Torbay map-area, Newfoundland; *Geol. Surv. Can.*, Mem. 265.

Sage, N. M., Jr.
1954: The stratigraphy of the Windsor Group in the Antigonish quadrangle and the Mahone Bay – St. Margaret Bay area, Nova Scotia; *N.S. Dept. Mines*, Mem. 3.

St-Julien, P.
1967: Tectonics of part of the Appalachian Region of southeastern Quebec (southwest of the Chaudière River); *Roy. Soc. Can.*, Spec. Publ. 10, Appalachian tectonics, pp. 41–47.

Sanford, B. V.
1961: Subsurface stratigraphy of Ordovician rocks in southwestern Ontario; *Geol. Surv. Can.*, Paper 60-26.
1964: Subsurface stratigraphy of Silurian rocks in southwestern Ontario; *Geol. Surv. Can.*, Paper 64-2, pp. 14–19.
1968: Devonian of Ontario and Michigan; *Proc. Internat. Devonian Symposium*, Calgary, 1967, vol. 2, pp. 973–999.

Sanford, B. V., and Quillian, R. G.
1959: Subsurface stratigraphy of Upper Cambrian rocks in southwestern Ontario; *Geol. Surv. Can.*, Paper 58-12.

Schuchert, C., and Dunbar, C. O.
1934: Stratigraphy of western Newfoundland; *Geol. Soc. Am.*, Mem. 1.

Sinclair, G. W.
1965: Succession of Ordovician rocks at Lake Timiskaming; *Geol. Surv. Can.*, Paper 65-34.

Skidmore, W. B.
1965: Honorat–Reboul area; *Quebec Dept. Natural Resources*, Geol. Rept. 107.

Smith, J. C.
1966: Geology of southwestern New Brunswick; Guidebook: geology of parts of Atlantic Provinces; *Geol. Assoc. Can.–Mineral. Assoc. Can.*, pp. 1–18.

Smith, W. E. T.
1967: Some geological and tectonic considerations of eastern Canada earthquakes; *Roy. Soc. Can.*, Spec. Publ. 10, Appalachian tectonics, pp. 84–93.

Smitheringale, W. G.
1960: Geology of Nictaux–Torbrook map-area, Annapolis and Kings counties, Nova Scotia; *Geol. Surv. Can.*, Paper 60-13.

Stacy, M. C.
1953: Stratigraphy and paleontology of the Windsor Group (Upper Mississippian) in parts of Cape Breton Island, Nova Scotia; *N.S. Dept. Mines*, Mem. 2.

Stevenson, I. M.
1959: Shubenacadie and Kennetcook map-areas, Colchester, Hants and Halifax counties, Nova Scotia; *Geol. Surv. Can.*, Mem. 302.

Taylor, F. C.
1965: Silurian stratigraphy and Ordovician–Silurian relationships in southwestern Nova Scotia; *Geol. Surv. Can.*, Paper 64-13.
1967: Reconnaissance geology of Shelburne map-area, Queens, Shelburne and Yarmouth counties, Nova Scotia; *Geol. Surv. Can.*, Mem. 349.

Taylor, F. C., and Schiller, E. A.
1966: Metamorphism of the Meguma Group of Nova Scotia; *Can. J. Earth Sci.*, vol. 3, pp. 959–974.

Twenhofel, W. H.
1909: Geology of Anticosti Island; *Geol. Surv. Can.*, Mem. 154.
1938: Geology and paleontology of the Mingan Islands, Quebec; *Geol. Soc. Am.*, Spec. Paper No. 11.

Webb, G. W.
1963: Occurrence and exploration significance of strike-slip faults in southern New Brunswick, Canada; *Bull. Am. Assoc. Petrol. Geol.*, vol. 47, No. 11, pp. 1904–1927.

Weeks, L. J.
1954: Southeast Cape Breton Island, Nova Scotia; *Geol. Surv. Can.*, Mem. 277.

Whittington, H. B., and Kindle, C. H.
1963: Middle Ordovician Table Head Formation, western Newfoundland; *Bull. Geol. Soc. Am.*, vol. 74.

Williams, H.
1964: The Appalachians in northeastern Newfoundland—a two-sided symmetrical system; *Am. J. Sci.*, vol. 262, pp. 1137–1158.
1967: Silurian rocks of Newfoundland; *Geol. Assoc. Can.*, Spec. Paper No. 4, Collected papers on the geology of the Atlantic region, pp. 93–137.
1969: Pre-Carboniferous development of Newfoundland Appalachians; *Am. Assoc. Petrol. Geol.*, Mem. 12, North Atlantic — geology and continental drift, pp. 32–58.

Williams, M. Y.
1914: Arisaig–Antigonish district, Nova Scotia; *Geol. Surv. Can.*, Mem. 60.

Wilson, A. E.
1946: Geology of the Ottawa – St. Lawrence Lowlands, Ontario and Quebec; *Geol. Surv. Can.*, Mem. 241.

Winder, C. G.
1962: Upper Devonian age of the Kettle Point Shale; *Tran. Roy. Soc. Can.*, vol. 56, 3rd ser., sect. 3, pt. 1, pp. 85–95.

VII. Economic Minerals of Southeastern Canada

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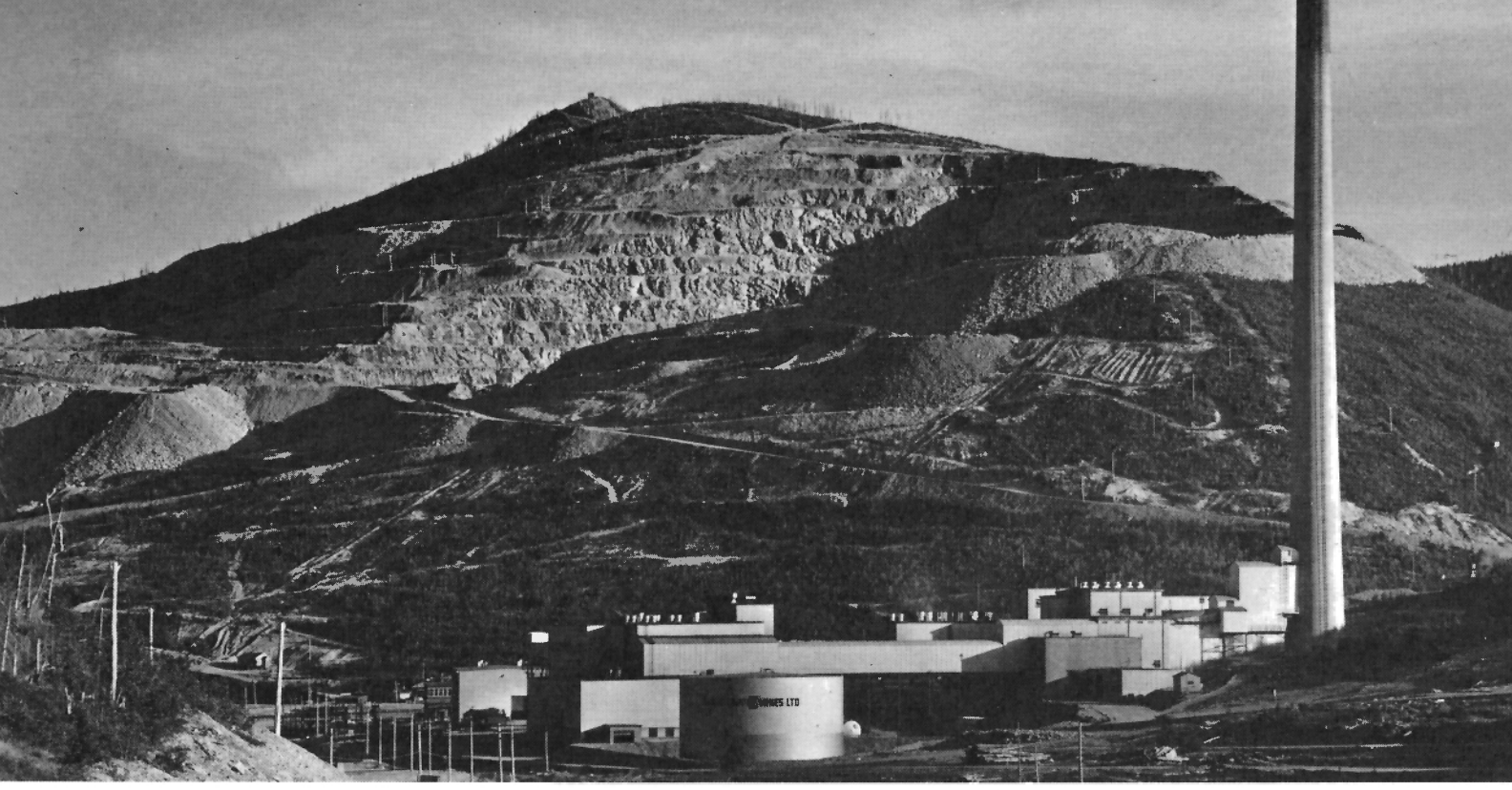


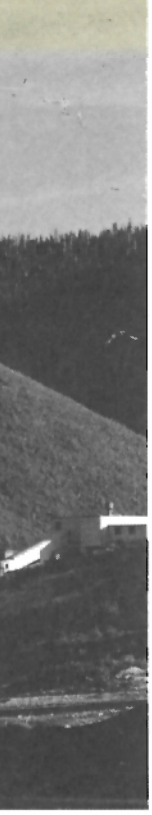
INTRODUCTION

The mineral industry of Southeastern Canada produces several metals, a variety of industrial minerals, structural materials, and fuels—oil, gas, and coal. Their value in 1966 was nearly $702 million, about 18 per cent of the value of the total mineral output of Canada. As shown in Table VII-1, the value of both structural materials and industrial minerals exceeded that of the metals produced. Asbestos was the most valuable economically with a production of 1,401,416 tons of fibre, 94 per cent of the Canadian total, and an estimated value of $152 million. It was followed in order of production value by cement, sand and gravel, stone, coal, zinc, copper, clay products, lead, salt, lime, gypsum, iron ore, silver, natural gas, oil, peat moss, niobium (columbium), fluorspar, gold, and barite; the values of these products ranged from $101 million for cement to $1.8 million for barite. Of the base metals zinc was the most valuable, with a production of 390,490,896 pounds, accounting for 20 per cent of the Canadian total and valued at $57.7 million. It was followed by copper, with 164,976,657 pounds at $40.7 million or 16 per cent of the Canadian total, and by lead, with 144,349,393 pounds at $21.5 million or 20 per cent of the Canadian total; this gives a total of 699,816,946 pounds of copper, lead, and zinc valued at $120 million for the year. Precious metals recovered from these ores contributed an additional $10 million from silver and gold, as well as $1.4 million from molybdenum, cadmium, and bismuth.

The principal mineral deposits are grouped into three main classes—metalliferous deposits, industrial mineral deposits, and fuels. In view of the complex geological history of the metalliferous deposits and of the uncertainties regarding their age, origin, and host rocks, the deposits have been grouped according to the dominant metals and minerals, thus avoiding subjective methods of classification, and enabling comparisons to be made and conclusions to be drawn regarding areas favourable for mineralization.

There is a marked association of mineral deposits with igneous rocks illustrated by the clustering of more than five hundred deposits in centres of igneous activity such as the serpentine belt of the Eastern Townships, the Notre Dame Mountains of Gaspé Peninsula, the central mineral belts of New Brunswick and Newfoundland, and in the roof rocks of the Devonian granite in Nova Scotia (Fig. VII-1). More specific associations are asbestos, chromium, and nickel deposits with the ultrabasic and basic rocks (Fig. VII-4); and gold, molybdenum, antimony, bismuth, tin, and tungsten deposits with granitic rocks (Fig. VII-5).

[1] Authorship responsibilities for sections of this chapter are as follows: Introduction, Mineral Provinces, Metalliferous Deposits, and Non-bedded Industrial Minerals by E. R. Rose; Natural Gas, Oil, and Bedded Industrial Minerals by B. V. Sanford; Coal by P. A. Hacquebard. When acknowledging, reference should be made to individual author and page number.



VII

Economic Minerals of Southeastern Canada

E.R. Rose, B.V. Sanford, and P.A. Hacquebard[1]

Gaspé Copper Mines, Limited, Murdochville, Quebec.

Résumé of Important Mineral Developments

Occurrences of valuable minerals in the early settled parts of Canada were first established by Champlain's discoveries of iron, silver, and copper in 1604 in what is now Nova Scotia. Also, the first coal mined by Europeans in the new world came from Newcastle Creek in the Minto field of New Brunswick. Massachusetts colonial records indicate that coal was shipped to Boston from the Grand Lake coal basin as early as 1639. The coal seams of Cape Breton, subsequently so important to the Canadian economy, were noted in 1672 by Nicholas Denys, a Governor of Acadia, and mined at Port Morien in 1720 to fuel the fortress of Louisbourg, and later the Citadel of Halifax. To date, nearly half a billion tons of coal have been produced.

Early discovery of bog iron in the Eastern Townships of Quebec was followed in 1823 by discovery of placer gold in the Chaudière River valley, and by discoveries of copper and gold in the bedrock schists of the Eastern Townships in 1841. In the period 1843–48, W. E. Logan, Alexander Murray, and James Richardson of the newly formed Geological Survey of Canada investigated the Eastern Townships, and the association of copper, asbestos, and chromite with rocks of the serpentine belt was noted. A number of small copper mines in this belt reached the production stage, stimulated by demands created by the American Civil War in 1865.

In Newfoundland, in 1857, the La Manche Lead mine was opened, and the returns from it are said to have helped finance the laying of the first transatlantic cables. In 1864 the first of Newfoundland's great copper mines, the Union mine at Tilt Cove, was opened with the guidance of Alexander Murray, newly appointed Director of the Geological Survey of Newfoundland. Murray's recognition of the similarity of the rock formations in the two producing areas led to prospecting and the development of many other copper deposits in the Notre Dame Bay area.

The first shipment of asbestos from the serpentine belt of the Thetford area of the Eastern Townships was made in 1876, the prelude to Quebec's subsequent eminence in this field. Asbestos has since become by far the most valuable mineral product of the Appalachian Region. In Ontario, bog iron deposits were discovered at Simcoe (Norfolk county) in 1800, followed by the discovery of gypsum near the present town of Paris in 1822. Crude oil was first produced from seepages in Enniskillen township of Lambton county and refined for use in illumination. This led to the drilling of the first well in 1858 in Lambton county and ultimately the discovery of Devonian oil at Oil Springs and Petrolia in 1861 (Pl. VII-1) and at Bothwell in 1862. Salt was discovered at Goderich in 1866, as a direct result of the search for oil. Natural gas was discovered at opposite extremities of the Niagara Peninsula in 1889 at the Kingsville and Welland fields.

In Nova Scotia iron deposits were developed at Torbrook in 1825, at East River in 1828, and at Londonderry in 1849. Albertite was found in New Brunswick in 1851. In the 1860s the discovery of gold-bearing quartz veins

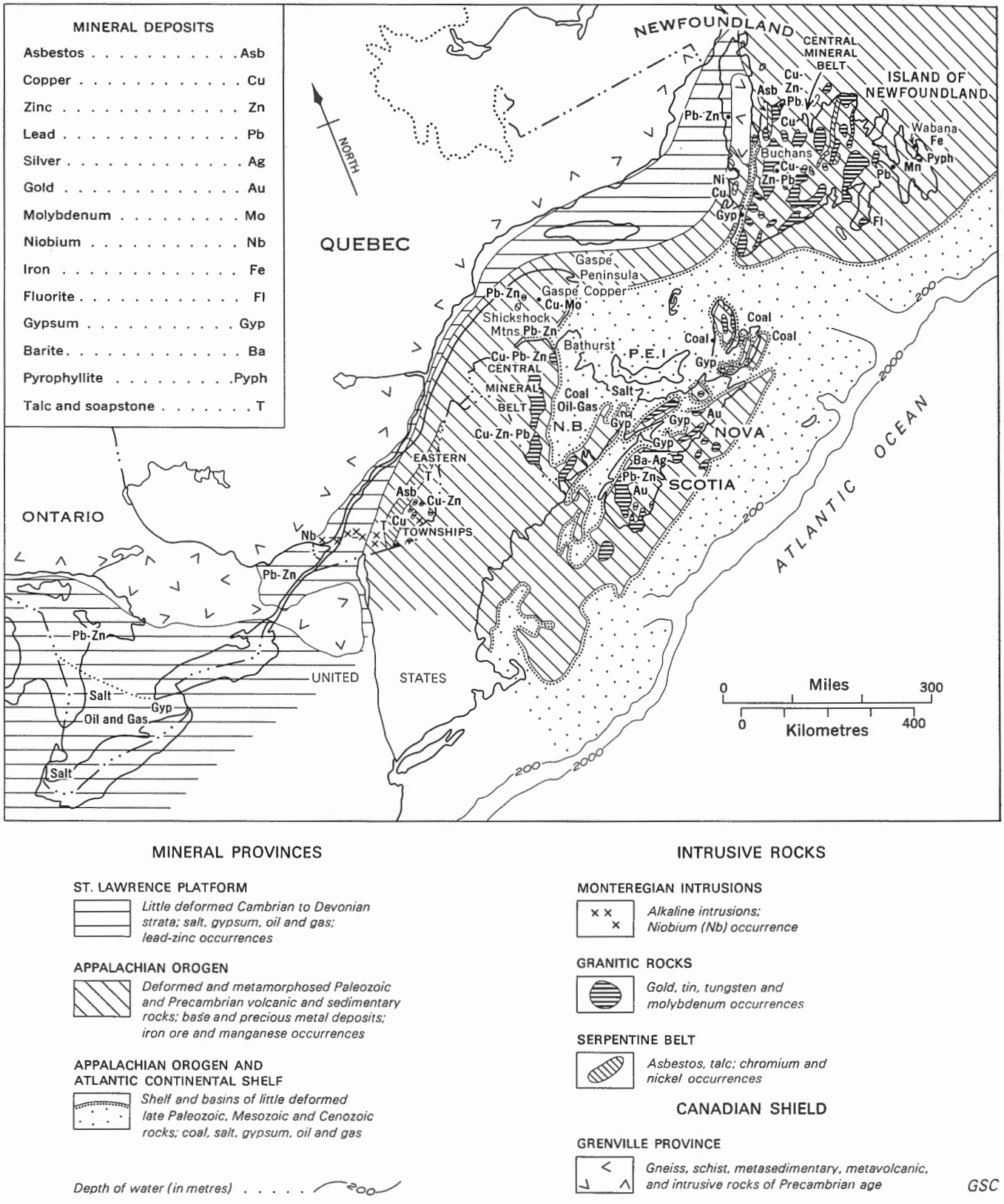


FIGURE VII-1. Mineral provinces of Southeastern Canada, showing principal mineral-producing areas and deposits (by E. R. Rose).

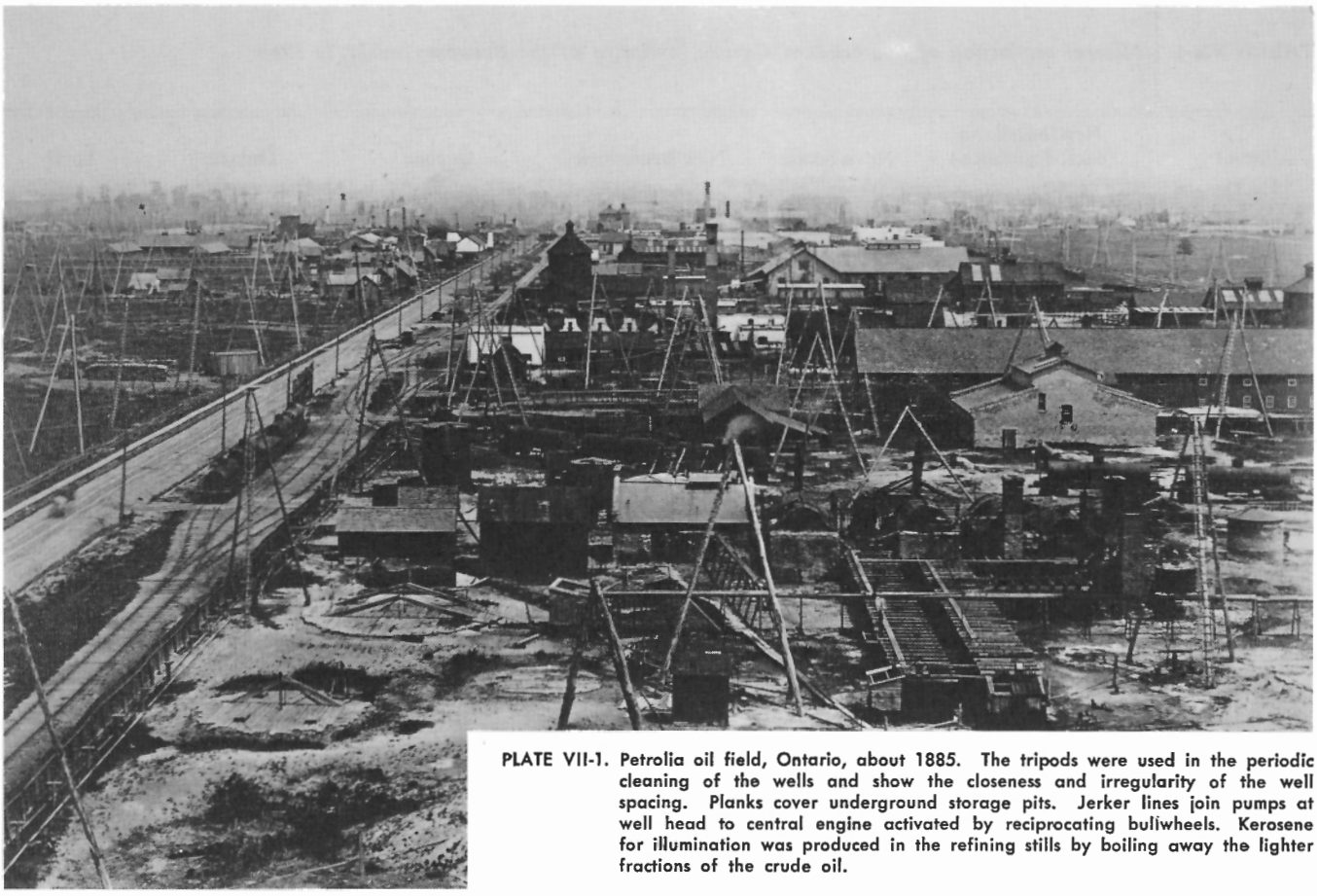


PLATE VII-1. Petrolia oil field, Ontario, about 1885. The tripods were used in the periodic cleaning of the wells and show the closeness and irregularity of the well spacing. Planks cover underground storage pits. Jerker lines join pumps at well head to central engine activated by reciprocating bullwheels. Kerosene for illumination was produced in the refining stills by boiling away the lighter fractions of the crude oil.

led to the development of an important gold mining industry in Nova Scotia. The nineteenth century closed with the discovery in 1892, and first production of iron ore at Wabana on Bell Island, Newfoundland, in 1895. During the next 70 years, until the mines were closed in 1966, the Wabana deposits yielded more than 70 million tons of iron ore, and they are by no means exhausted now. The present century of modern mineral development was ushered in with the establishment of the Dominion Steel and Coal Company steel mill at Sydney, Nova Scotia, in 1900.

Discoveries of this Century

The outstanding discoveries of the present century have been: the Buchans lead–zinc–copper deposit in central Newfoundland discovered in 1905 and brought into production in 1928; the Stony Creek gas and oil field in 1909 near Moncton, New Brunswick; the fluorite veins at St. Lawrence, Newfoundland, brought into production in 1933; the Walton barite deposit and associated lead–zinc–silver ore in Nova Scotia in 1940; the copper deposits in the Gaspé Peninsula discovered in 1921 and brought into production in 1955; natural gas in the Silurian at Tilbury in 1906, which marked the beginning of natural gas production and marketing on a major scale; oil in the Ordovician in 1917, broadening the exploration targets; drilling offshore in 1943, which resulted in the extension of several gas fields into Lake Erie; oil and gas in the Cambrian in 1958; the Advocate asbestos deposits near Baie Verte, Newfoundland in 1963; and recently, the zinc–lead–copper deposits in the Bathurst area of New Brunswick that now are coming into full production with completion of the smelter complex at Belledune.

MINERAL PROVINCES

Southeastern Canada is divisible into three geological provinces, the Appalachian Orogen, St. Lawrence Platform, and Atlantic Continental Shelf. They form parallel, northeasterly trending belts along the eastern margin of the continent and are flanked by the Canadian Shield on the northwest (Fig. VII-1). Differences in the geology and metallogenic history of these provinces permit comparable separation of the region into three mineral

TABLE VII-1 | *Mineral production of Southeastern Canada, exclusive of the Canadian Shield, in 1966*

Mineral	Newfoundland (excl. Labrador)	Nova Scotia	New Brunswick	Quebec	Ontario	Total
METALS						
Bismuth				36,913 lb. $156,880*		$ 156,880
Cadmium			38,902 lb. $93,365	138,202 lb. $380,481*		473,846
Columbium (Niobium)				2,600,000 lb. $3,150,000		3,150,000
Copper	37,338,361 lb. $16,764,924	583,170 lb. $261,843	13,106,548 lb. $5,884,840	113,948,578 lb. $17,800,000*		40,711,607
Gold	24,912 oz. $939,182		1,768 oz. $66,654	24,411 oz. $861,552*		1,867,388
Iron ore	792,000 tons $9,085,000*					9,085,000
Lead	42,223,742 lb. $6,308,227	3,251,914 lb. $485,836	95,998,000 lb. $14,342,101	2,875,737 lb. $420,726*		21,556,890
Molybdenum				531,598 lb. $823,976*		823,976
Silver	1,070,943 oz. $1,498,249	574,505 oz. $803,732	3,025,094 oz. $4,232,107	1,020,446 oz. $1,659,902*		8,193,990
Zinc	68,876,000 lb. $10,400,276	1,090,320 lb. $164,636	292,398,635 lb. $44,152,194	28,125,941 lb. $3,000,000*		57,717,106
Total metals	$44,995,858	$1,716,047	$68,771,261	$28,253,517		$143,736,683
NON-METALLICS						
Asbestos	64,850 tons $10,300,000			1,336,566 tons $141,559,725		$151,859,725
Barite		195,000 tons $1,811,300				1,811,300
Fluorspar	$2,187,500					2,187,500
Grindstone			5 tons $1,500			1,500
Gypsum	459,685 tons $1,173,401	4,502,836 tons $8,140,651	108,207 tons $413,074		565,185 tons $1,581,010	11,308,136
Iron oxide				300 tons $14,000		14,000
Peat moss		3,000 tons $105,000	53,000 tons $1,438,000	110,000 tons $2,500,000		4,043,000
Salt		474,981 tons $4,724,993			3,782,191 tons $15,243,791	19,968,784
Soapstone, talc, pyrophyllite	40,548 tons $608,220			15,100 tons $191,100		799,320
Total non-metallics	$14,269,121	$14,781,944	$1,852,574	$144,264,825	$16,824,801	$191,993,265

FUELS						
Coal		3,854,534 tons $51,518,674	898,315 tons $7,892,427			$59,411,101
Natural gas			97,601 Mcf $92,600	3,000 Mcf $450	15,537,157 Mcf $5,896,662	5,989,712
Petroleum			6,853 bbl. $8,700		1,323,781 bbl. $4,500,000	4,508,700
Total fuels		$51,518,674	$7,993,727	$450	$10,396,662	$69,909,513
STRUCTURAL MATERIALS						
Clay products	$194,102	$1,592,466	$588,625	$5,280,000*	$25,365,409	$33,020,602
Cement	55,441 tons $1,219,700	210,000 tons $3,549,000	260,000 tons $4,290,000	2,381,288 tons $39,488,812*	3,242,591 tons $52,680,630	101,228,142
Lime			3,723 tons $105,650	176,171 tons $1,884,153*	1,077,550 tons $12,210,576	14,200,379
Sand and gravel	3,647,355 tons $3,502,363	7,896,332 tons $10,573,115	6,054,873 tons $3,147,253	39,688,898 tons $18,488,984*	53,534,066 tons $38,612,235	74,323,950
Stone	86,000 tons $108,400	519,005 tons $1,719,465	2,888,579 tons $2,896,080	38,860,131 tons $44,117,616*	21,011,319 tons $24,709,496	73,551,057
Total structural materials	$5,024,565	$17,434,046	$11,027,608	$109,259,565	$153,578,346	$296,324,130
Grand total	$64,289,544	$85,450,711	$89,645,170	$281,778,357	$180,799,809	$701,963,591

Compiled from data supplied mainly by Mineral Resources Division, Dominion Bureau of Statistics, and provincial agencies
* Value calculated at current market price

provinces. The westernmost St. Lawrence Mineral Province includes the relatively undeformed Paleozoic sedimentary cover on the crystalline rocks of the Canadian Shield, and five of the eight known Cretaceous (?) alkaline Monteregian Intrusions. The Appalachian Mineral Province, or middle belt, includes the deformed Paleozoic and Precambrian rocks of the Appalachian Mountains, three of the Monteregian Intrusions, and several more or less undeformed sedimentary basins of Late Paleozoic and Triassic rocks. The rocks of this belt probably extend beneath the Gulf of St. Lawrence and the Atlantic Continental Shelf where younger Mesozoic and Cenozoic sediments occur as a cover on the folded rocks.

St. Lawrence Mineral Province

The St. Lawrence Mineral Province is characterized by unmetamorphosed sedimentary rocks—sandstone, shale, carbonate, and evaporites of Paleozoic age—that were deposited in the epeiric seas covering the Canadian Shield. Here oil and gas accumulated under favourable conditions, and deposits of limestone, salt, and gypsum were precipitated. The strata overlying the Precambrian crystalline basement are relatively undisturbed except along the Logan thrust zone and associated thrusts and tear faults, and near post-orogenic normal faults bordering horst and graben structures formed after the Appalachian orogenies. Igneous activity was mainly restricted to the emplacement of the Cretaceous–Triassic Monteregian alkaline intrusive complexes during which niobium, rare earth, and iron–titanium–vanadium occurrences were formed. Five of these intrusive plugs forming Mount Royal, St. Bruno, Rougemont, and Johnson intrude undeformed Paleozoic rocks in the St. Lawrence Province, and the related Oka stock, from which niobium is now being produced, pierces an inlier of the Precambrian basement complex nearby.

Appalachian Mineral Province

The Appalachian Mineral Province has a complex tectonic and geological history (Fig. VII-2) involving several orogenic disturbances; several episodes of igneous activity including the intrusion of ultrabasic, basic, intermediate, and acidic rocks of diverse ages on a large scale; many epochs of multiform volcanism ranging through the Precambrian, Cambrian, Ordovician, Silurian, and Devonian periods; as well as a host of metalliferous mineral deposits, a variety of industrial minerals, important coal deposits, and a minor amount of oil and gas. This region is particularly noted for copper–zinc–lead deposits (Fig. VII-3) and asbestos (Fig. VII-4), as well as iron, gypsum, salt, barite, fluorite, and coal. Many other metallic elements—antimony, arsenic, bismuth, cadmium, cobalt, chromium, manganese, molybdenum, nickel, tin, tungsten, uranium, vanadium and others—are known in numerous scattered occurrences, some of which have been mined from time to time (Figs. VII-4, VII-5). Bis-

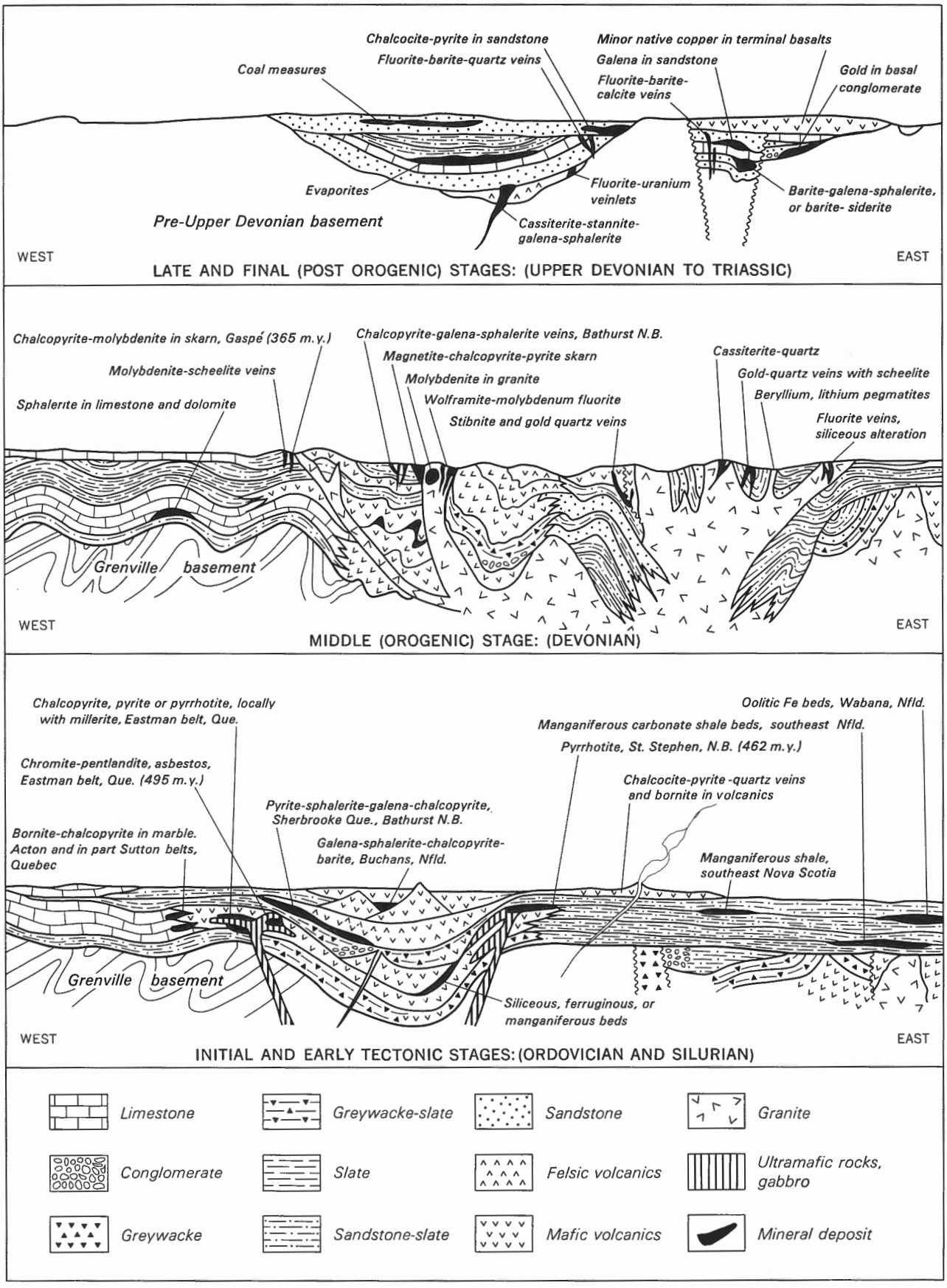


FIGURE VII-2. An idealized metallogenic model of the Appalachian Orogen depicting some known types of mineral occurrences in relation to their tectonic setting and the facies and approximate ages of their wall-rocks (by W. D. McCartney).

muth, cadmium, gold, molybdenum, selenium, silver, and tellurium are also now being recovered as byproducts of some of the mines. Within this province inliers of Precambrian crystalline rocks form the core of the Great Northern Peninsula of Newfoundland, parts of the Long Range Mountains of western Newfoundland, and the highlands of Cape Breton and southeastern New Brunswick. In eastern Newfoundland folded Proterozoic sedimentary and igneous rocks form a platform that probably extends under the Atlantic Continental Shelf. Extrusive and intrusive igneous rocks constitute a major part of the central mineral belts of Newfoundland and New Brunswick, as well as the Eastern Townships and Gaspé Peninsula of Quebec. There is a general association of ore deposits with these belts of igneous rocks.

In parts of the Appalachian Mineral Province Paleozoic and Precambrian strata have been deformed in four orogenies—the Ordovician Taconian Orogeny, a disturbance in the Silurian, the Devonian Acadian Orogeny, and the Appalachian Orogeny or Maritime Disturbance closing the era. The Taconian Orogeny is represented by local unconformities, thrust faults, and the emplacement of large plutons of ultrabasic rock in the Eastern Townships and central Newfoundland that have yielded asbestos, talc, soapstone, chromite, titaniferous magnetite, pyrrhotite, and chalcopyrite. The climactic Acadian Orogeny is represented by widespread folding and faulting, intrusion of granitic rocks, and metamorphism, particularly in southern Nova Scotia, central southern Newfoundland, central New Brunswick, and the Eastern Townships. Mineral deposits produced were gold in quartz veins in the metasedimentary rocks of Nova Scotia, and stibnite, molybdenite, cassiterite, stannite, wolframite, scheelite, bismuthinite, and fluorite in the Eastern Townships of Quebec. The emplacement of the granitic rocks has involved partial assimilation, metamorphism, recrystallization, and re-mobilization of pre-existing wall-rocks and contained mineral deposits in places; elsewhere it has merely resulted in a slight remetamorphism and mineralization. The effects of the Appalachian Orogeny are folding, thrusting, and metamorphism in the United States; in Canada these effects occur mainly in southwestern New Brunswick. Elsewhere, in western Newfoundland and northeastern Nova Scotia, wrench faulting and folding of the Carboniferous coal-bearing beds occurred, partly contemporaneously with their deposition.

Permian red beds unconformably overlie the Carboniferous and show little sign of deformation. Man-

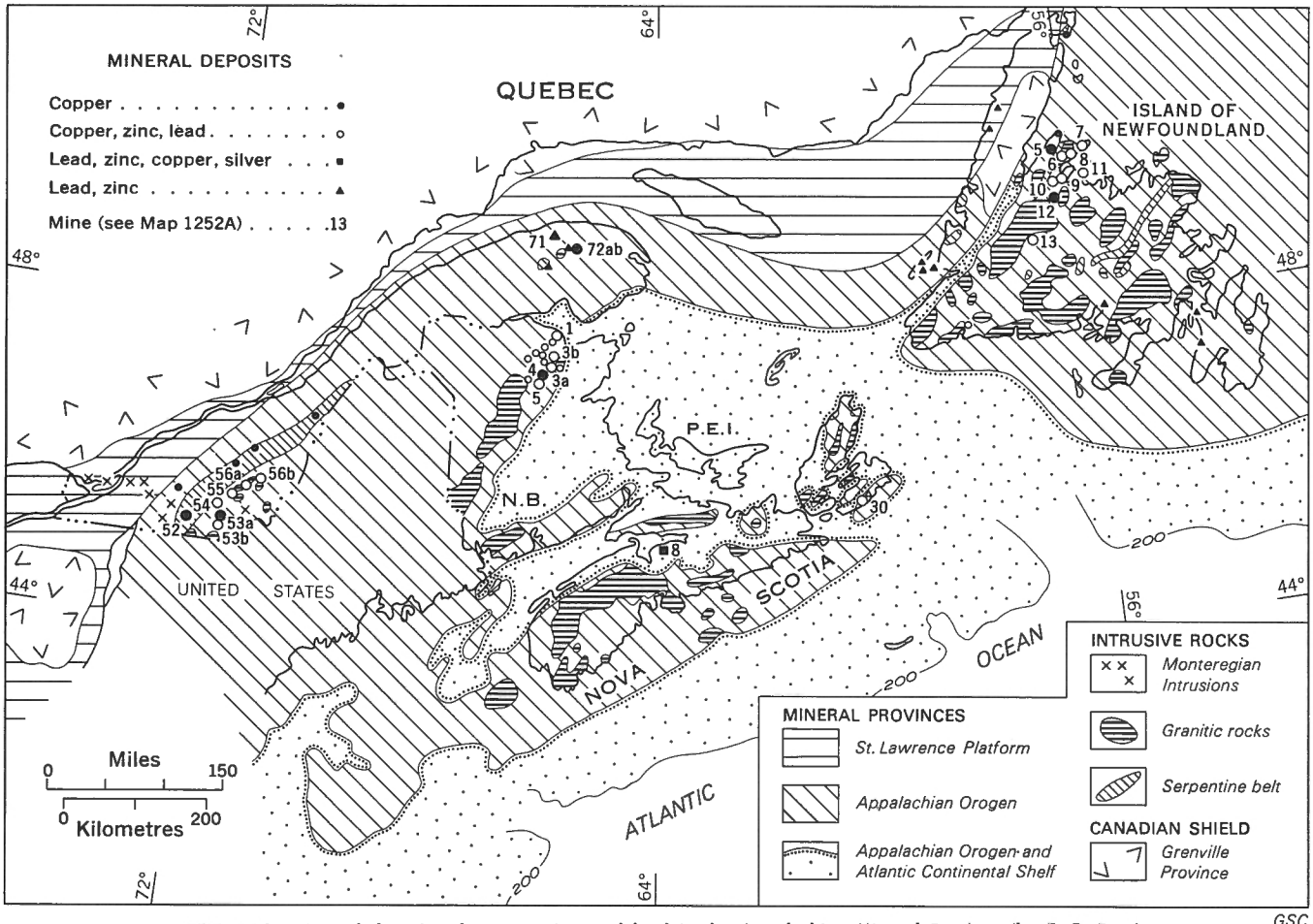


FIGURE VII-3. Principal deposits of copper, zinc, and lead in the Appalachian Mineral Province (by E. R. Rose).

GSC

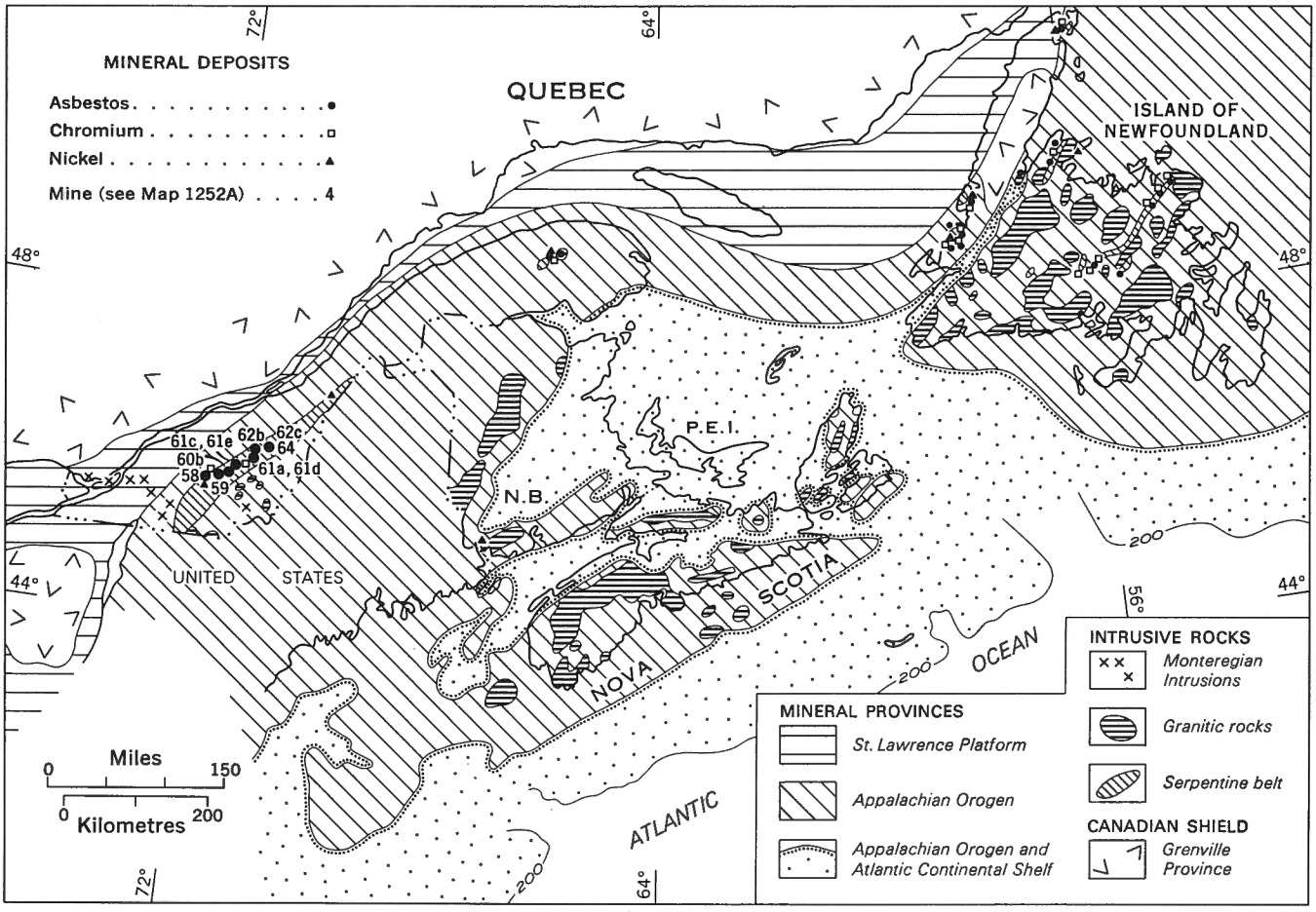


FIGURE VII-4. Principal deposits of asbestos, chromium, and nickel in the Appalachian Mineral Province showing their spatial relationship to ultrabasic and basic rocks (by E. R. Rose).

ganese oxide occurs in the weathered rocks at the unconformity. Igneous activity occurred again in the Triassic. The trap and related rocks produced carry titaniferous magnetite, native copper, amethyst, and zeolites in Nova Scotia and New Brunswick. Three of the Monteregian Hills, Mounts Yamaska, Shefford, and Brome, as well as the nordmarkite ring dykes of Mount Megantic, are formed by intrusion of ovate bodies of alkaline magma into the folded rocks of the Appalachian Province in the southern part of the Eastern Townships. These intrusions probably represent the most recent igneous activity in southeastern Canada.

Atlantic Continental Shelf

The Atlantic Continental Shelf extends seaward for more than 300 miles east of Nova Scotia and Newfoundland forming a belt on the eastern margin of the continent approximately equal in width to the Appalachian Orogen. Although little is known yet about the geology and mineral deposits of this vast submarine area, which undoubtedly has had a varied structural and geological history, it is probably partly underlain by thick deposits of sedimentary rocks ranging from Upper Devonian to Recent. Currently the Atlantic Continental Shelf and the Gulf of St. Lawrence are being investigated by sea- and air-borne geophysical surveys and by drilling. A sedimentary basin, believed to be more than 15,000 feet thick, underlies the Gulf of St. Lawrence, and it is anticipated that equally thick basins of Mesozoic and Cenozoic rocks occupy parts of the continental shelf, possibly including favourable reservoirs for recoverable oil and gas.

METALLIFEROUS DEPOSITS

Metalliferous mineral deposits of the Appalachian Mineral Province contain a variety of elements including the base metals (nickel, copper, zinc, lead, iron, and manganese), the precious metals (gold and silver), and a number of minor metals (antimony, bismuth, cadmium, molybdenum, tin, tungsten, chromium, titanium, and vanadium). The deposits are formed mainly of sulphide and oxide ore minerals, with the sulpharsenides, arsenides, tellurides, carbonates, and native metals being only locally abundant. Many deposits contain a variety of elements,

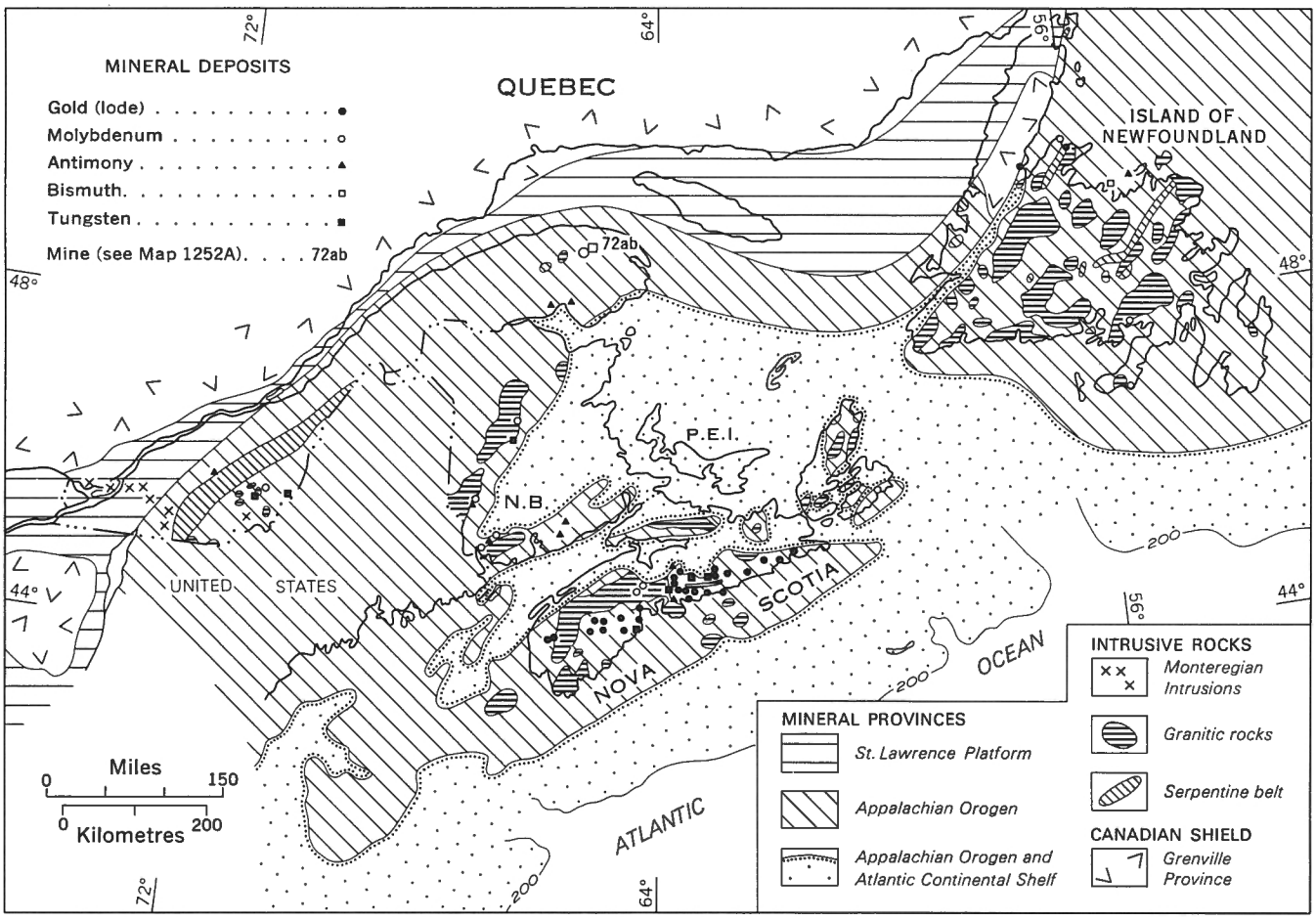


FIGURE VII-5. Principal deposits of gold, molybdenum, antimony, bismuth, tin and tungsten in the Appalachian Mineral Province showing their spatial relationships to granitic rocks (by E. R. Rose).

and commercial recovery of two or more of the contained metals or minerals as byproducts of the main mining operation is now common practice. Only a few deposits are large and rich enough to be mined. Although zinc was the most valuable metal produced in 1966, few mines produce zinc alone. In many, copper is commonly associated with zinc, lead, silver, gold, antimony, arsenic, bismuth, cadmium, and sulphur, and less commonly with nickel or molybdenum, any of which may be recovered. Gangue minerals include pyrite, pyrrhotite, quartz, carbonates, chlorite, and barite. Sulphide ore minerals are mainly chalcopyrite, sphalerite, and galena. They occur in varying proportions to form massive or disseminated sulphide deposits in a variety of host rocks and structures.

Pyrite is the dominant sulphide mineral in most of the base-metal deposits although pyrrhotite predominates in some and nickeliferous pyrrhotite and pentlandite occur in a few. Many of the nickeliferous pyrrhotite–pentlandite deposits are within or closely associated with mafic or ultramafic intrusions and are undoubtedly genetically related to them, as are some of the pyrrhotite–chalcopyrite occurrences. Many of the latter merge into pyrite–chalcopyrite occurrences with sphalerite and galena, forming base-metal sulphide deposits that are either replacements of altered basic to intermediate volcanic rocks, with or without intercalated metasediments, or of the interlayered metasediments. This general association with volcanic rocks suggests a common origin for the contained copper–zinc–lead deposits, many of which are in pre-Devonian rocks, probably Ordovician. According to some investigators these deposits may have formed with the volcanic and sedimentary rocks at or near surface, but according to others they appear to have been introduced at depth. In a few mines, such as Gaspé Copper and Nigadoo, base-metal deposits occur within granitic intrusions and their aureoles of skarn, and there seems little doubt of a genetic association with the intrusions. On the other hand, numerous lead–zinc occurrences are known in undeformed carbonate strata and veins seemingly unrelated to igneous activity.

Antimony

In the Eastern Townships of Quebec, at the *South Ham* mine, native antimony, stibnite (Sb_2S_3), kermesite (Sb_2S_2O), and valentinite (Sb_2O_3) occur as flakes and powder along cleavage planes in sheared arkosic sediments

and schist, and as a vein in a shear zone near or along the contact with an intrusion of serpentinized pyroxenite. The occurrence, about 18 miles east of Asbestos, was first described by Sir William Logan in 1863. It has been traced along strike for half a mile and explored by a shaft 100 feet deep and an adit 380 feet long. About 180 tons of concentrates have been produced. In Gaspé Peninsula stibnite occurs in quartz veins in Ordovician quartzite and conglomerate in New Richmond township and in small pockets in volcanic rocks and limestone in Carleton township.

Stibnite and native antimony occur in quartz veins cutting Ordovician(?) slate and quartzite near masses of diabase and Devonian granite at *Lake George,* about 25 miles west of Fredericton, New Brunswick. At *West Gore,* Nova Scotia, stibnite, kermesite, and native antimony occur with gold, arsenopyrite, and pyrite in small ore shoots in quartz–calcite veins in fissures cutting black slates similar to those of the Ordovician Halifax Formation. One vein has been traced for 2,700 feet and was worked sporadically from 1844 until 1942. Although the nearest exposure of intrusive Devonian granite is several miles distant, specimens from the mine show dykelets of quartz and feldspar cutting the slate (Stevenson, 1958).

In Newfoundland, at *Moretons Harbour* on New World Island, a quartz vein carries arsenopyrite, pyrite, sphalerite, chalcopyrite, galena, stibnite, and calcite. It averages 4 inches in width and has been traced for about half a mile along the sheared footwall contact with a thin rhyolite dyke that is intrusive into chloritized andesite of the Ordovician Moreton volcanics. An assay of a channel sample taken across one foot of vein material and 4 inches of footwall showed 5.39 per cent antimony, 4.39 per cent sulphur, 48.6 per cent silica, and 0.55 ounce of both gold and silver per ton. The deposit was mined sporadically around 1890, 1906, and 1915 (Baird and Snelgrove, 1953).

Bismuth

On *Pond Island* in the Bay of Exploits, Newfoundland, three quartz veins, each several inches wide, carry pyrite, bismuthinite (Bi_2S_3), chalcopyrite, sphalerite, tetrahedrite, and calcite; they follow joint planes in Silurian(?) granodiorite near a stock of rhyolite porphyry. A selected sample yielded 1.5 per cent bismuth, 13.92 per cent antimony, 0.5 per cent zinc, 3.65 per cent copper, 12.6 per cent sulphur, and 5 ounces per ton silver.

In 1966, at Gaspé Copper Mines Limited, Quebec, 36,913 pounds of bismuth valued at $156,880 was recovered from smelter flue dust. The native bismuth is a rare constituent of the complex copper ores mined at Copper Mountain and Needle Mountain.

Cadmium

In 1966, 38,902 pounds of cadmium valued at $93,365 was recovered from zinc concentrates produced from zinc–lead–copper ores in the *Bathurst* area of New Brunswick. The cadmium occurs in solid solution in sphalerite, and probably also as greenockite (CdS).

Nickel

Nickeliferous Pyrrhotite–Pentlandite

Nickeliferous pyrrhotite is a common constituent of relatively unaltered basic and ultrabasic igneous rocks of Appalachian Region, as at Mount Albert in Gaspé; St. Stephen, New Brunswick; and in Rope Cove Canyon, Gregory River, Hare Bay, and Chapel Cove all in Newfoundland. Pyrrhotite-rich sulphide disseminations, segregations, and veins are associated with basic and ultrabasic intrusions. Nickel occurs as strong traces, and in some, pentlandite may be intergrown with nickeliferous pyrrhotite and chalcopyrite. Not all the pyrrhotite is nickeliferous, particularly that in deposits within highly altered rocks, such as those at Gullbridge mine in Newfoundland and Huntingdon mine in the Eastern Townships. On Sugarloaf Island in Bay of Exploits, Newfoundland, however, nickeliferous pyrrhotite, pyrite, magnetite, and chalcopyrite form part of a recrystallized carbonate lens that is intercalated with altered basic Ordovician volcanics and shale.

South of *Bay of Islands,* Newfoundland, a zone of disseminated nickeliferous–pyrrhotite–chalcopyrite 10 feet wide was discovered in 1936 near the base of the Ordovician(?) Bay of Islands Complex (Cooper, 1936). The sulphides occur interstitially to silicate minerals in a zone of interbanded troctolitic anorthosite, serpentine, and diallagic pegmatite. Pyrrhotite, pentlandite, and chalcopyrite, with secondary marcasite and violarite(?), average about 2 per cent of the zone, and representative samples show as much as 1 per cent nickel and 0.32 per cent copper. The mineralized zone was observed at two places a quarter mile apart. In the *Hare Bay* area of northern Newfoundland, dissemination of nickeliferous pyrrhotite in hornblendite and in peridotite near hornblendite intrusions is reported. Pyrrhotite, pentlandite, chalcopyrite, magnetite, and ilmenite, along with biotite and chlorite, occur interstitially to silicates. Pentlandite grains are veined by fine-grained pyrrhotite. At Goose Cove, also on Hare Bay, a copper mine was opened to a depth of 100 feet in 1908 on small sulphide deposits in Goose Cove schist of Ordovician age. Pyrite, pyrrhotite, chalcopyrite, and small amounts of sphalerite, magnetite, and copper–nickel–iron arsenides occur in a gangue of hornblende, epidote, calcite, and quartz as irregular lenticular bodies along the crests of drag-folds in the schists. The ore ranged from 2 to 12 per cent copper.

Nickeliferous Pyrite–Millerite

About 400 tons of high-grade nickel ore was produced prior to 1876 from lenses within talc–carbonate rocks associated with serpentinized peridotite in the Tilt Cove copper mine. The deposit is described in the section on copper–zinc–lead. Minor occurrences of a similar nature have been reported from time to time in talc–carbonate rocks elsewhere in the Appalachian serpentinite belts.

The *Eastern Metals* deposit was found in 1949 in Rolette township, Quebec, in carbonate–talc schist along the contact of serpentinite and slate, both of which are intruded by granodiorite dykes. A small tabular body of massive pyrite averaging 0.91 per cent nickel occurs within a larger mineralized zone that averages 0.15 per cent nickel and 1.52 per cent copper. Small amounts of millerite, gersdorffite, siegenite, pyrrhotite, and pentlandite are present. Pentlandite veinlets and patches occur in the serpentinite nearby. The ore minerals within the larger zone are mainly fine-grained pyrite, chalcopyrite, chalcocite, bornite, sphalerite, galena, and rare arsenopyrite. A potential orebody of about a million tons of low-grade material has been outlined in which the nickel and zinc minerals are found mainly in irregular stringers in brecciated masses of fine-grained pyrite.

Copper

Native Copper

Numerous occurrences of native copper are known in igneous rocks of various ages in the Appalachian Region, but none has been of sufficient importance to mine. The native copper is found as disseminations, thin sheets, amygdules, and calcite veins. It has been noted in association with cuprite and minor amounts of chalcopyrite, chalcocite, melaconite, tenorite, and malachite in serpentinized Ordovician(?) dunite.

At the *Gregory River* copper lodes in Newfoundland (Smith, 1958) copper minerals occur as: pyrite–chalcopyrite–arsenopyrite–sphalerite–quartz veins; chalcopyrite–nickeliferous pyrrhotite veins and disseminations associated with fracture zones in basic intrusive rocks of the Ordovician Bay of Islands Igneous Complex or their intrusive contacts with basic volcanic rocks; native copper in calcite veins in the basic volcanic rocks of the Ordovician Humber Arm Group. In the Mount St. Gregory area south of Bonne Bay, the occurrences, which were discovered in 1921, were drilled in 1953 and the known limits of the Court A zones extended for 1,000 feet along strike. The sulphide minerals, pyrite, chalcopyrite, and arsenopyrite, occur in quartz veins and disseminated through the metavolcanic host rocks that form the roof of the intrusive gabbro, and along the Court A tear fault.

Pyrrhotite–Chalcopyrite

Pyrrhotite, rather than pyrite, is an important constituent of a few of the chalcopyrite deposits such as the Lake Memphremagog, Huntingdon, and Ives mines in the serpentine belt of the Eastern Townships; and the Sugarloaf Island, Gullbridge, and Hodder deposits in Newfoundland. The predominance of pyrrhotite over pyrite in these deposits suggests an environment of higher temperatures and pressures, either within or near an igneous source. In this regard they are similar to the Ducktown-type copper deposits of the southern Appalachian Mountains. The occurrences of pyrrhotite are commonly nickeliferous, and in places may also carry millerite, as at Orford, Quebec, and Tilt Cove, Newfoundland; or pentlandite, as at St. Stephen, New Brunswick. Many are low in nickel, however, and do not show the customary relationship with a basic igneous source.

The *Huntingdon mine* (52)[1], near Lake Memphremagog, Quebec, has been worked to a depth of 1,000 feet. Chalcopyrite and pyrrhotite occur as four lenticular ore zones flanking serpentine and steatite bands within sheared, silicified, mafic volcanic rocks. The largest ore zone is 100 feet wide, 300 feet long, and 1,300 feet deep. The mine has produced more than a million tons of ore. The deposit at nearby Ives mine is similar.

Gaspé Copper Mines, Quebec (72). Pyrrhotite and chalcopyrite are important constituents of the skarn ore at *Needle Mountain* near Murdochville, in Gaspé Peninsula (Fig. VII-6). Since the mine opened in 1955, 25 million tons of copper ore has been produced, about half the original reserves. Molybdenite, silver, bismuth, selenium, and gold are also recovered. The ore occurs along several faults within a skarn zone in altered calcareous shales and limestones of the Lower Devonian Grand Grève and underlying Cape Bon Ami Formations, and as a stockwork of fracture fillings (Ford, 1959). Ore minerals comprise chalcopyrite, molybdenite, and native bismuth. Scheelite, sphalerite, and pyrite are rare and occur partly as small exsolved crystals in the chalcopyrite. Late quartz veins carrying bornite, chalcopyrite, chalcocite, tennantite, and fluorite cut the normal ore. Wallrocks are well-bedded argillaceous limestone or calcareous shales, and siliceous limestones that have been altered respectively to diopside–andradite, porcellanite, and wollastonite–diopside skarn.

At *Copper Mountain* nearby, chalcopyrite and pyrite, with minor molybdenite, chalcocite, sphalerite, galena, and bornite, and secondary limonite, azurite, and malachite, are present in skarn beneath an oxidized capping and above a biotite granite intrusion within which minor veinlets of quartz locally carry chalcopyrite and molybdenite. This deposit came into production by open pit early in 1968. Quartz–feldspar porphyry dykes are abundant, the feldspars being highly altered to fine-grained

[1] Number is that assigned the deposit on Mineral Deposits of Canada, Map 1252A.

sericite and clay. Potassium–argon dates of 350 m.y. and 395 m.y. have been obtained from the granite and porphyry dykes, respectively, suggesting that they are Devonian, intruded during the Acadian Orogeny.

The pyrite–chalcopyrite–molybdenite deposit and occurrences in granite underlying Copper Mountain show marked similarity to the porphyry copper–molybdenum-type deposits of the western Cordillera as exemplified by Climax, Colorado and Bingham, the Utah deposits, as well as the Copper Mountain, Bethlehem, and Endako deposits in British Columbia. They are, however, of much younger geological age, but there can be little doubt that these large, low-grade skarn and disseminated deposits are all genetically related to intrusive granitic rocks. The Bingham district is also a large producer of lead, zinc, and silver from fissure veins and replacement lodes that lie in a zonal arrangement in metamorphosed Pennsylvanian limestone beds peripheral to the central core of the copper- and molybdenum-bearing Utah Copper stock. An interesting analogy is that quartz–calcite fissure veins carrying sphalerite and galena with minor chalcopyrite have been found in the Cascapedia River area within Devonian limestones and other rocks to the south and north peripheral to the Shickshock and Copper Mountain granite bodies (Fig. VII-7). Silver-bearing galena also occurs in fractures in Devonian rocks at Cross Point on the Bay of Chaleur.

The *Hodder* copper prospect was found half a mile northwest of Fleur de Lys, Newfoundland in 1913. The main ore mineral is chalcopyrite; it occurs in bands or veins parallel to the foliation, and as disseminations in two bands of impure silicated marble (skarn?) each about 5 feet thick. The marble lies within black calcareous gneiss between garnetiferous gneiss on the west and garnet-free gneiss on the east. The upper marble band is more mineralized than the lower and carries as much as 17 per cent copper with traces of gold and silver. Pyrrhotite is slightly more abundant than pyrite; magnetite, bornite, and marcasite are also present. Quartz gangue fills fractures in all of these minerals. According to Fuller (1941): "Mineralizing solutions penetrated the calcareous gneiss and apparently replaced the relatively pure marble lenses. The solutions were probably derived from a subjacent granitic magma and are believed to be related to those which deposited the minerals at the molybdenite and lead prospects". There is some similarity in type of mineralization between this occurrence and the Gaspé Copper Mines deposits which are indeed related to an underlying, probably Devonian, granitic intrusion.

The *Terra Nova* (5) deposit at Baie Verte, Newfoundland, lies within the zone of ultramafic rocks of the serpentine belt. It is a steeply dipping sulphide lens about 30 feet wide lying along the contact of serpentinized peridotite and Ordovician chlorite schist. The deposit is believed to have been worked to a depth of 300 feet and to have yielded ore which averaged 2.41 per cent copper, 37.23 per cent sulphur, and $2.50 per ton each of gold and silver. As at the Huntingdon mine in Quebec, pyrite

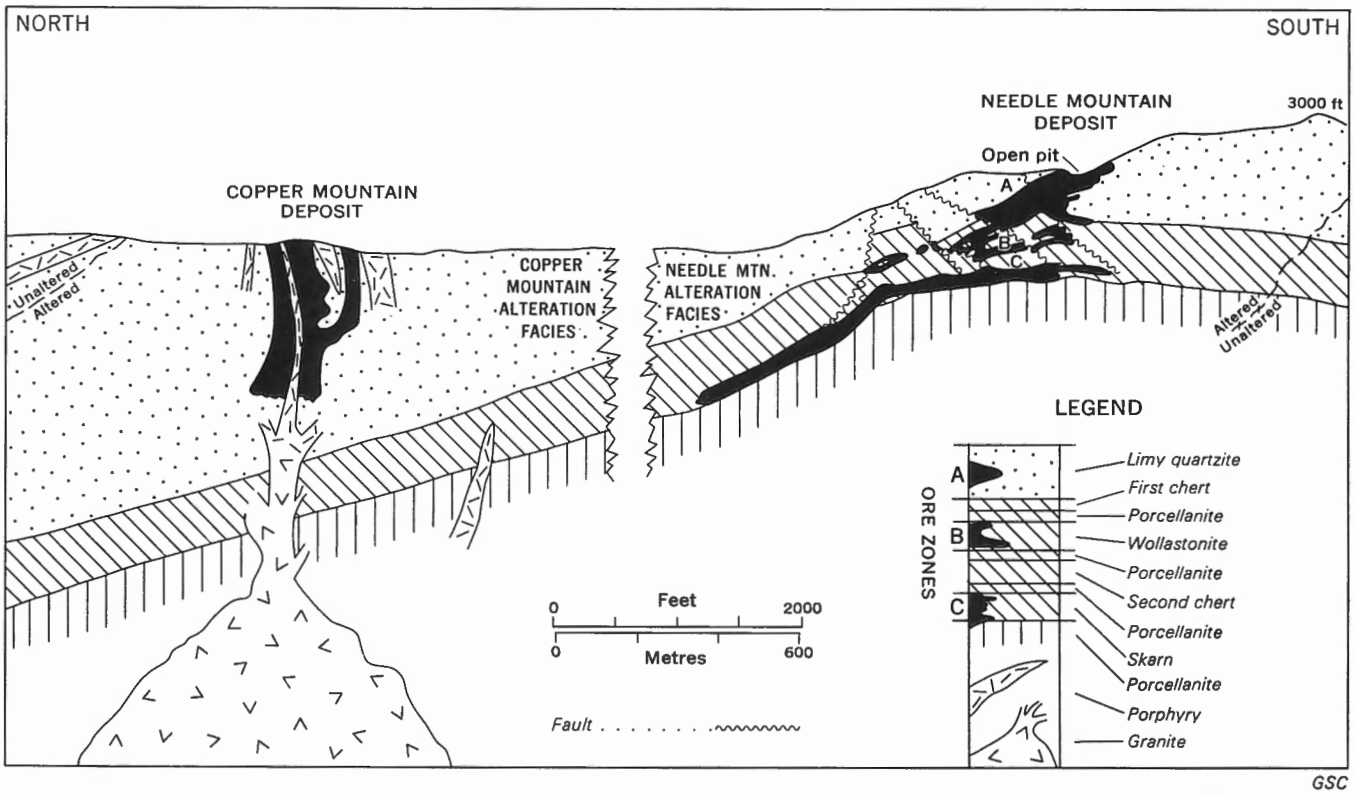


FIGURE VII-6. Generalized cross-section, Needle Mountain and Copper Mountain deposits, Quebec (courtesy of Gaspé Copper Mines Ltd.).

is the predominant sulphide mineral with considerable pyrrhotite and chalcopyrite, minor sphalerite, and rare specks of native copper.

Gullbridge mine (12). An occurrence of sulphide minerals on Gull Pond, near Badger in central Newfoundland, has been known since 1905. A four-compartment shaft has now been sunk to a depth of 1,050 feet, and the mine is being prepared for production. Pyrrhotite, pyrite, chalcopyrite, and magnetite, along with quartz, chlorite, sericite, biotite, cordierite, and tremolite–actinolite, occur in lenticular masses along sheared zones in andesitic or dacitic lavas, cherts, and siliceous tuffs of the Ordovician or Silurian Roberts Arm Group. The possible Silurian age of these rocks suggests that mineralization may not be confined to Ordovician rocks in Newfoundland. The group is flanked by intrusive diorite on the east and by the Silurian Springdale sandstone and Devonian granite on the west. It is intruded by swarms of dykes of acidic and basic composition. An aureole of pyrite surrounds the ore. Reserves of 4 million tons averaging more than one per cent copper are reported.

Copper–Zinc–Lead

Pyrite–Chalcopyrite–Sphalerite–Galena

Pyrite is the predominant sulphide mineral in most producing base-metal mines in the Appalachian Mineral Province. Together with sphalerite, galena, and chalcopyrite, with minor or rare tetrahedrite–tennantite, bornite, molybdenite, magnetite, pyrrhotite, arsenopyrite, and native bismuth, the pyrite forms irregular lenticular, massive and disseminated ore deposits. They characteristically occur in zones of sheared, folded, and brecciated rocks and most commonly in sequences of basic volcanics with intercalated siliceous sediments. Many occurrences are in eugeosynclinal Cambrian, Ordovician, and Silurian rocks that have been intruded and metamorphosed by igneous rock of acidic to basic composition, but few of the deposits show a sufficiently close association to any particular rock type to establish a clear-cut genetic relationship for this sub-type. Logan and Murray placed great emphasis on the association of these deposits with the serpentines and limestones, but most later geologists

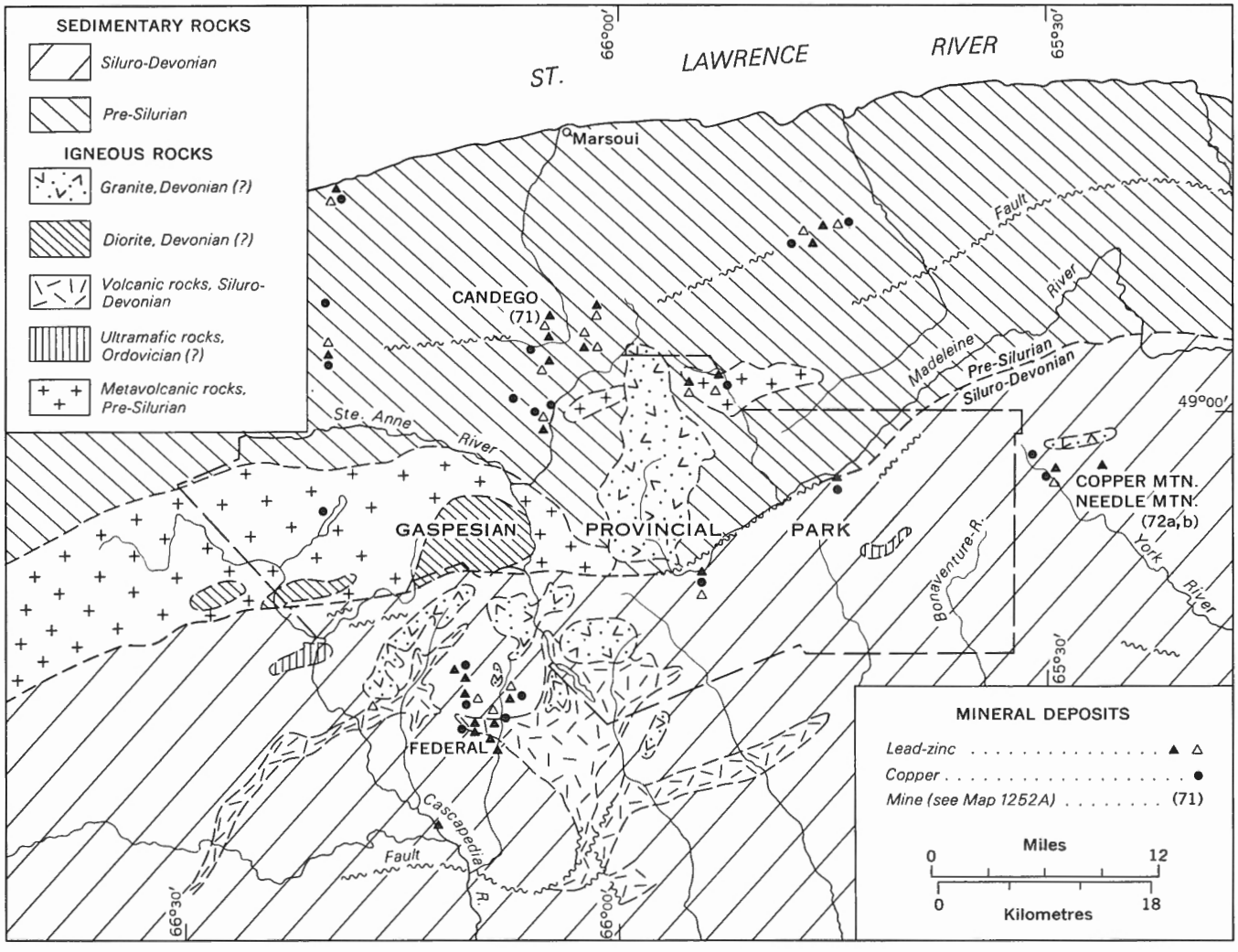


FIGURE VII-7. Relationship of copper and lead–zinc deposits to Devonian granite in Shickshock Mountains, Gaspé, Quebec (by E. R. Rose).

believed them to be replacement deposits probably associated with the emplacement of Devonian granitic intrusions. Many geologists now consider them to be stratiform deposits related to volcanic extrusion, gaseous exhalation, or to attendant sedimentation; others regard them as of metamorphic or multiple origin.

The *Harvey Hill* mine, Quebec, is a pyrite–chalcopyrite–bornite–chalcocite deposit in slaty schists of the Cambrian(?) Sutton Group. The ore occurs in transverse veins and lenticular bands that parallel the schistosity. An intrusion of pyroxenite, now altered to talc or soapstone, passes beneath the main workings and may have been the source rock. The deposit was mined sporadically for about 30 years; for 10 years it was mined along with the richer but smaller deposits of the Acton mine near Acton Vale. The latter orebodies occur in three lenses of brecciated, cherty, dolomitic limestone resting on deformed Ordovician black slate and shale. Intrusive greenstone (diabase) dykes and sills may have been source rocks for the mineralization.

Eustis–Capelton mines (53b). Two similar pyrite-chalcopyrite deposits in greenschists and green carbonate rock occur 7 miles south of Sherbrooke, Quebec. Pyritic lenses, 2 to 25 feet wide, arranged *en echelon* and carrying 0.05 to 1.25 per cent copper, were mined along strike for 250 feet and to a depth of about 1,000 feet. Below, a lens much richer in chalcopyrite was mined to a depth of 4,800 to 5,200 feet. The lens varied in width from 6 to 40 feet and averaged 110 feet along strike. At the southwest end it assayed 1.5 per cent copper and 40 per cent iron, and at the northeast end, 16 per cent copper and 26 per cent iron. About 2.5 million tons of pyritic copper ore was produced, mainly from the Eustis mine.

The *Suffield* or *Ascot* (53c) mine and the nearby *Albert* mine (53a), a few miles northeast of Sherbrooke, Quebec, were operated intermittently from 1865 to 1958. Pyrite, chalcopyrite, and sphalerite, with a little galena and traces of silver and gold, were produced from two flat lenses in green chloritic tuff on the footwall of a band of Ordovician or Cambrian quartzite. The largest lens was 200 feet wide by 1,500 feet long. About a million tons of ore was produced.

The *Moulton Hill–Aldermac mine* (54) northeast of Sherbrooke, Quebec, was developed as a pyrite and copper producer. A new deposit was found in 1942, with the aid of geophysical surveys, along a shear zone a quarter mile south of the old mine at the contact of sheared rhyolite and sedimentary schists. It consisted of pyrite, sphalerite, galena, chalcopyrite, and tetrahedrite with a gangue of barite, quartz, and calcite. The mine was operated intermittently for several years, producing about 350,000 tons of pyritic copper–zinc–lead ore.

Weedon mine (55), a pyrite–chalcopyrite deposit discovered in 1908, 40 miles northeast of Sherbrooke, Quebec, was mined for 20 years to a depth of 1,150 feet. The ore, consisting of granular pyrite with chalcopyrite and minor pyrrhotite, sphalerite and galena, formed a lenticular deposit about 50 feet wide and 570 feet long, mainly along the contact of sericite (hanging-wall) and chlorite (footwall) schists. The ore follows folds in the schists, which are similar to those in the Eustis and Capelton mines, about 50 miles to the southwest. These schists are now believed to represent altered rhyolitic pyroclastic rocks, greywackes, and mafic volcanics. They are intruded by albite or bluish grey porphyries. An intrusion of Devonian granite forms the hanging-wall of the deposit in the lower levels of the mine, but its precise relationship to the ore deposit is not certain. The mine was an important pyrite and copper producer during the periods 1909–21 and 1951–59, and has produced more than a million tons of copper–zinc–lead ore, as well as 200,000 tons of pyrite for the manufacture of sulphuric acid.

At *Cupra* and *Solbec mines* (56a, b) two deposits of pyrite–chalcopyrite–sphalerite ore were found recently along the contact between Ordovician(?) sericite and chlorite schists northeast of Sherbrooke, Quebec. Production began at Solbec copper mines in 1962 and at Cupra mines in 1965. The combined mill feed in 1966 was half a million tons. Combined reserves are about 3 million tons, averaging 3.5 per cent copper, 3.5 per cent zinc, 0.5 per cent lead, and 1.3 ounces of silver and 0.02 ounce of gold per ton. The ore consists mainly of granular pyrite with interstitial chalcopyrite, sphalerite, bornite, galena, and minor tennantite. The Cupra deposit forms a tabular mass about 10 feet thick and more than 250 feet long that extends for more than 5,000 feet down dip. Bornite is abundant in the upper levels but has not been found in the Solbec deposit. A very thin siliceous iron-formation is present in parts of the Solbec ore zone.

Bathurst–Newcastle area, New Brunswick (1 to 5). The *Brunswick No. 6* (3a) and *No. 12* (3b) sulphide deposits were discovered in 1952 by diamond drilling on magnetic anomalies near the Austin Brook magnetite iron-formations and an associated pyritic sulphide body. The association between the iron-formation and sulphide deposits subsequently led to intensive exploration of magnetic anomalies and the use of other geophysical and geochemical methods of prospecting by which twenty-five or more sulphide deposits were discovered in the Bathurst–Newcastle area (Fig. VII-8). Some fifteen of these deposits, listed in Table VII-2, held reserves in excess of 120 million tons of copper–lead–zinc ore (Davies and Smith, 1966).

The sulphide deposits occur mainly in sedimentary rocks, iron-formation, and schists of Ordovician and Silurian age that are highly deformed and metamorphosed, commonly interlayered with volcanic rocks, and intruded by igneous rocks ranging from gabbro to granite. The deposits are usually overlain by thick sooty gossans with zones of secondary enrichment (Boyle and Davies, 1964). The deposits are fine-grained assemblages of: (1) pyrite with sphalerite, galena, minor chalcopyrite and pyrrhotite, rare arsenopyrite and tetrahedrite–tennantite, and a gangue

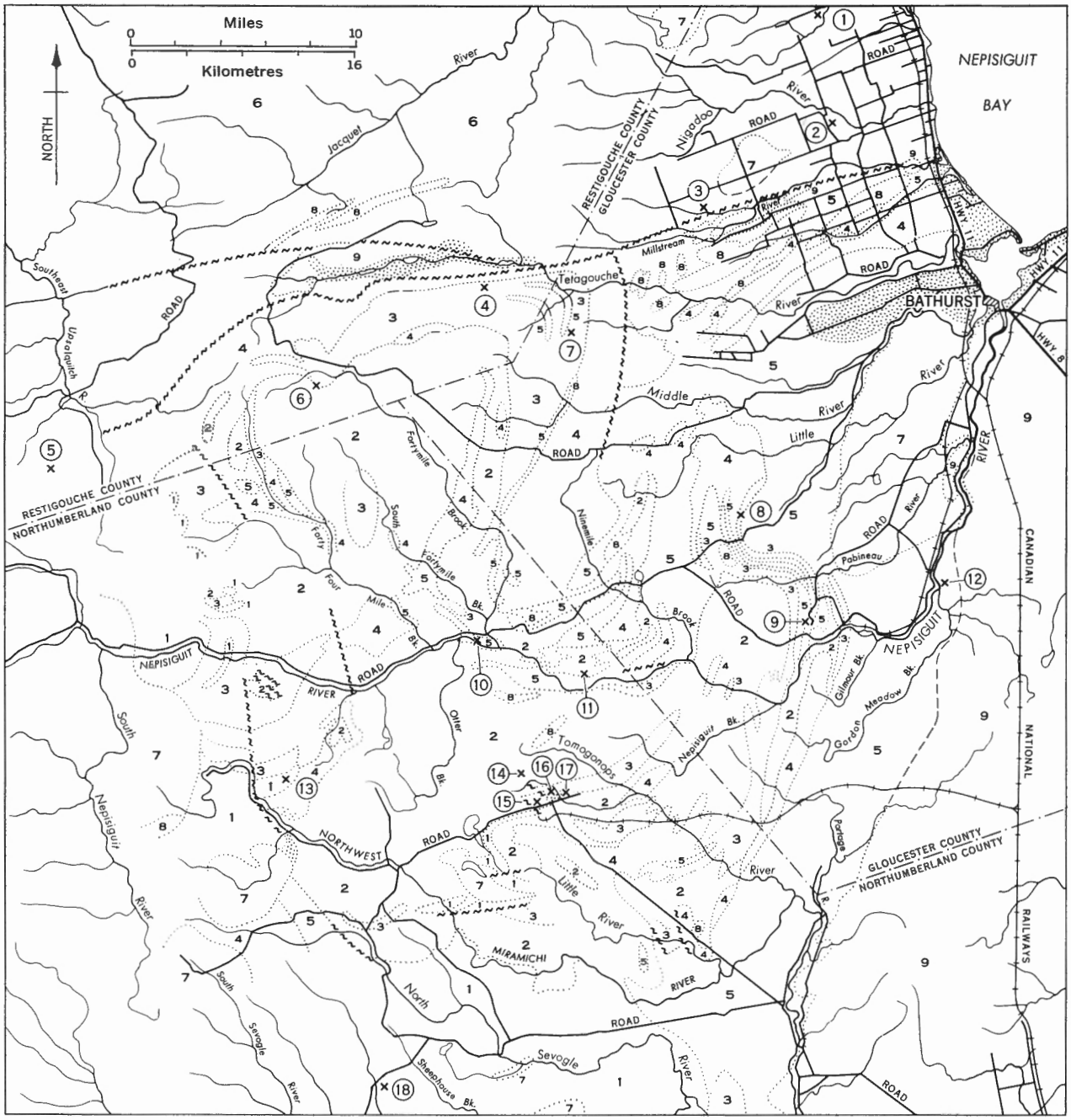
of quartz, sericite, chlorite, magnetite, biotite, calcite, siderite, and in places, barite; (2) pyrrhotite with chalcopyrite, in a gangue of chlorite and quartz. The latter type transects both schistosity in the host rocks and the massive pyrite-type ore. Other metallic minerals in the sulphide deposits are: magnetite, hematite, stannite, cassiterite, boulangerite, enargite, native silver, domeykite, marcasite, acanthite, argentite, gold, cubanite, covellite, chalcocite, bornite, native bismuth, limonite, beudantite, freibergite, anglesite, cerussite, and pyromorphite. Trace elements are silver, arsenic, bismuth, cadmium, germanium, indium, manganese, molybdenum, tin, titanium, and vanadium.

The massive pyritic sulphide deposits form lenticular, pipe-like, or sheet-like bodies, that are partly banded, folded, brecciated, and perhaps recrystallized. Some appear to be localized or thickened in places around the crests of folds; others do not. Some of the deposits are rudely zoned into zinc–lead-rich portions, copper-rich parts, and barren pyrite, but generally the zones are erratic and intermixed. The deposits are regarded by some as epigenetic replacement bodies in places possibly directly related to intrusive rocks, and by others as chemically precipitated sedimentary deposits. Evidence for a sedimentary mode of origin is largely inferred.

TABLE VII-2 *Size, tonnage, and grade of some sulphide deposits of the Bathurst area, New Brunswick (Davies and Smith, 1966; modified after McAllister, 1960)*

Deposit	Location (approx.)	Size (Feet)			Thousand tons	Grade			
		Length	Width	Depth		% Cu	% Pb	% Zn	Ag oz./ton
Anaconda (Caribou)	47° 34′ N	3800	20–130	1200	28,000		2	5	1
Anaconda (Armstrong Brook)	47° 36′ N 66° 17′ W	A—450 B—450	50 (max) 150 (max)	800 800					
Brunswick No. 6	47° 28′ N 65° 53′ W	1000	200	1000	22,278 4,350 1,684	0.4 0.5 0.8	1.9 0.4 0.5	5.0 1.0 0.5	1.6 0.7 0.3
Brunswick No. 12	47° 28′ N 65° 53′W	1200	200	1400	15,787 13,500	0.3 0.7	3.6 1.0	9.5 3.2	2.6 1.6
Captain mines	47° 17′ N 62° 52′W	500	80	800	802	1.15			
Canoe Landing Lake	47° 25′ N 66° 12′ W	3200	30	700	3,500	0.5	0.5	1.5	1.5
Chesterville mines (massive zone only)	47° 07′ N 66° 12′ W	650	650	30	650	0.92	1.62	3.4	
C.M. and S. (Nepisiquit A)	47° 22′ N 66° 03′ W	700 700	75 50	350 500					
C.M. and S. (Nepisiquit B)	47° 22′ N 66° 03′ W	900	75	300					
C.M. and S. (Wedge mine)	47° 24′ N 66° 08′ W	850	50	500					
Heath Steele mines	47° 17′ N 66° 05′ W	400–600	50	400–800	4,700	1.1 1.4	3.0 1.3	7.2 3.6	3.3 2.0
Kennco (Murray Brook)	47° 32′ N 66° 27′ W	1000	300	800	23,000	0.44	0.86	1.95	0.91
Key Anacon mines	47° 36′ N 65° 42′ W	1200[1]		1500	3,000		2.35	6.4	2.16
Middle River Mining Co. (Texas Gulf Sulphur)	47° 17′ N 66° 19′ W	1000	75	1000	5,000	1.0	2	5	
New Calumet (Orvan Brook)	47° 38′ N 66° 08′ W	6000 800[3]	14[2] 14[2]	500 500	200		3.25	6.3	1.0
New Jersey Zinc (Teck Corp.)	47° 38′ N 66° 08′ W	1500	100	500	3,000		5	9	3.0
Stratmat (C.M. and S.)	47° 19′ N 66° 06′ W	600	100	500					

1 Several lenses along zone 1,200 feet long
2 Maximum width
3 Ore zone



PENNSYLVANIAN

9 *Undivided*

DEVONIAN

8 *Mafic intrusive rocks*

7 *Felsic intrusive rocks*

SILURIAN

MIDDLE SILURIAN

CHALEURS BAY GROUP

6 *Undivided*

ORDOVICIAN

MIDDLE ORDOVICIAN

TETAGOUCHE GROUP (1–5)

5 *Slate division*

4 *Greenstone division*

3 *Porphyry division*

2 *Felsic volcanic division*

1 *Siliceous metasedimentary rocks*

MINING PROPERTIES

(1) Keymet
(2) Nigadoo Mines Ltd.
(3) Sturgeon River Mines
(4) New Calumet
(5) New Jersey Zinc
(6) Anaconda Co. (Caribou)
(7) Anaconda Co.
(8) Brunswick No. 12
(9) Brunswick No. 6
(10) Consolidated Mining and Smelting Co.
(11) Consolidated Mining and Smelting Co.
(12) Anacon Lead Mines (New Larder "U")
(13) Middle River Mining Co. Ltd.
(14) Stratmat
(15) Heath Steele
(16) Heath Steele Mines Ltd.
(17) Heath Steele Mines Ltd.
(18) Kennco Explorations (Canada) Ltd. (Clearwater)

Drift-covered area . . . . . *Sulphide deposit* . . . . . × *Fault (assumed)* . . . . . ~~~~

GSC

FIGURE VII-8. Principal base-metal deposit, Bathurst–Newcastle district, New Brunswick (Roy, 1961).

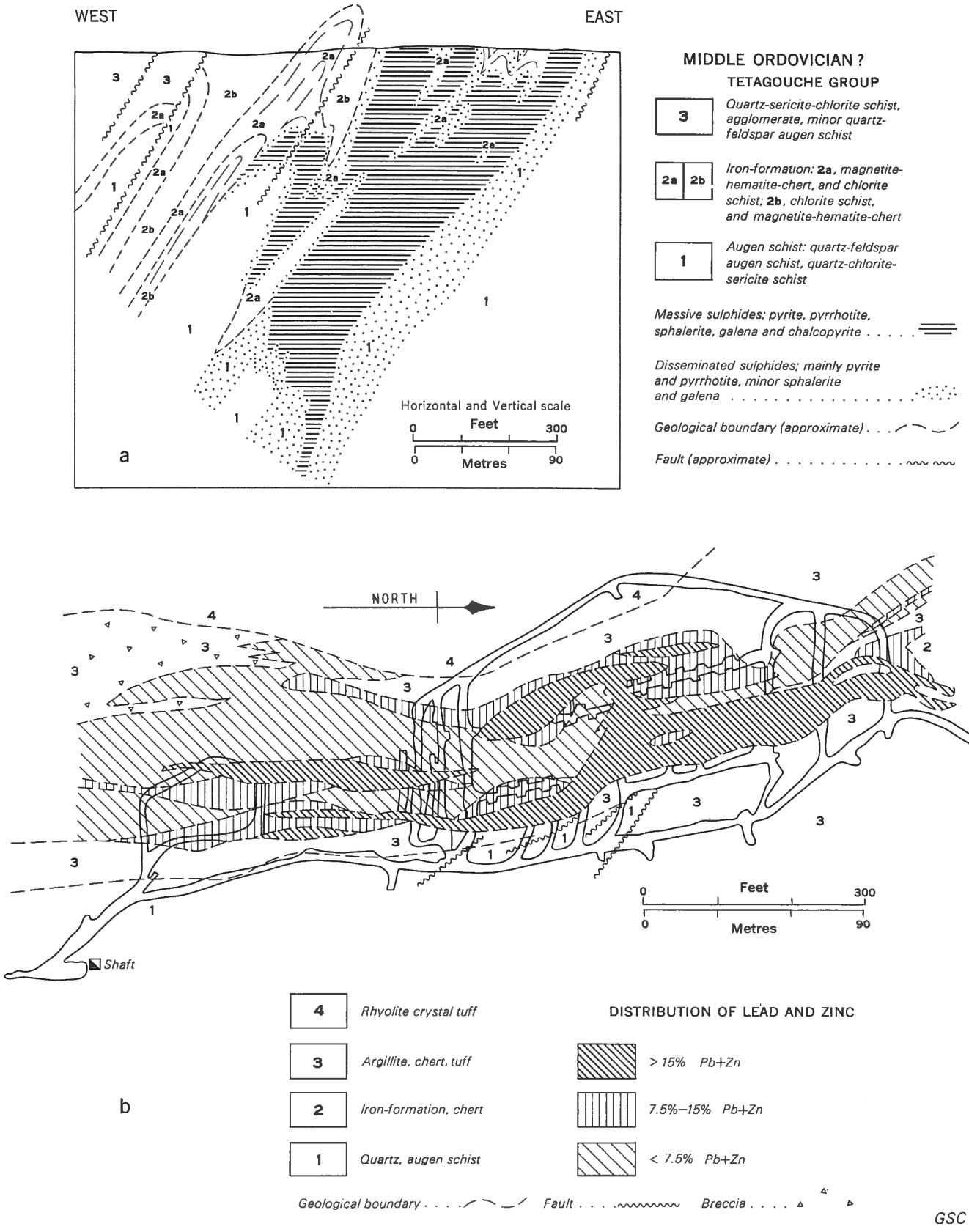


FIGURE VII-9. Bathurst sulphide deposits, New Brunswick (Davies and Smith, 1966). (a) Cross-section through the Brunswick No. 6 deposit. (b) Geology of the 650 level, Brunswick No. 12 deposit showing distribution of lead and zinc.

The Brunswick No. 6 ore deposit occurs in complexly folded, regionally metamorphosed acid volcanic and sedimentary rocks of the Tetagouche Group that have been intruded by sills of diabase and gabbro (Fig. VII-9a). Near surface the central part of the large massive sulphide lens, which is being developed by open-cut, contains a well-mineralized and replaced core of iron-formation of which only the more siliceous parts have resisted replacement. The lens is 400 feet thick and 1,000 feet long. A smaller, saddle-shaped, massive pyrite body, at most 100 feet thick, merges with the main lens. A third lens about 35 feet thick, formed of pyrite, pyrrhotite, and chalcopyrite, follows a sheared zone in the footwall schist. The deposits hold more than 28 million tons averaging 4.1 per cent zinc, 1.6 per cent lead, 0.4 per cent copper, and 1.4 ounces per ton of silver.

Brunswick No. 12 deposit (Fig. VII-9b) also consists of three parts: a large, irregular, massive pyrite lens with sphalerite, galena, and chalcopyrite; a large irregular body of pyrite; and a chalcopyrite–pyrrhotite-rich zone. The deposit held more than 28 million tons above the 2,500-foot level averaging about 9 per cent zinc, 3 per cent lead, 0.3 per cent copper, and 2.3 ounces of silver per ton. The chalcopyrite–pyrrhotite zone contains about 2,700,000 tons averaging 1.33 per cent copper. The high-grade zinc–lead part of the deposit shows an intimate association with a reverse S-shaped fold in iron-formation at the northern end of the body.

The *Wedge mine* (4) sulphide orebody lies concordantly between a porphyritic and tuffaceous rhyolite and overlying argillaceous fragmental rock on the south limb of a complex fold in the Tetagouche Group. The ore consists of 95–100 per cent sulphides, averaging 3 per cent copper and 1.75 per cent zinc. It forms a fishhook-shaped lens, 15 to 150 feet wide, 1,200 feet long, and 500 feet deep, controlled by an east-plunging drag-fold. Pyrite is the main mineral, with varying amounts of chalcopyrite, sphalerite, galena with associated silver, and minor tennantite. The relatively high copper content is unusual for deposits in this area. Chalcopyrite, the copper-carrying mineral, is concentrated within coarser grained pyrite along the hanging-wall in the wider eastern part of the deposit, along the northern rhyolite contact, and near the footwall in the eastern part. Local bands of sphalerite and galena within fine-grained barren pyrite also occur near the footwall and in the eastern part of the deposit.

At the *Heath Steele mine* (5) twelve irregular and pipe-like sulphide bodies occur in the minor folds in siliceous and basic volcanic and sedimentary rocks of the Tetagouche Group, at or near the contact between quartz–feldspar augen schist and a mixed assemblage of chlorite schist, quartz–sericite schist, iron-formation, and feldspathic sedimentary rocks (Fig. VII-10). Pyrite, sphalerite, and galena are the main sulphide minerals in most of the deposits, but chalcopyrite and pyrrhotite predominate in one and are important in three others. One of the orebodies was partly covered by a gossan 45 feet thick, the basal 2 to 6 inches of which was black mud rich in the silver minerals acanthite and argentite. The upper 80 feet of the orebody contained disseminated secondary chalcocite.

The *Keymet* (1) deposit, 15 miles northwest of Bathurst, occurs in a fault zone in sedimentary rocks of the Chaleurs Bay Group of probable Silurian age, north

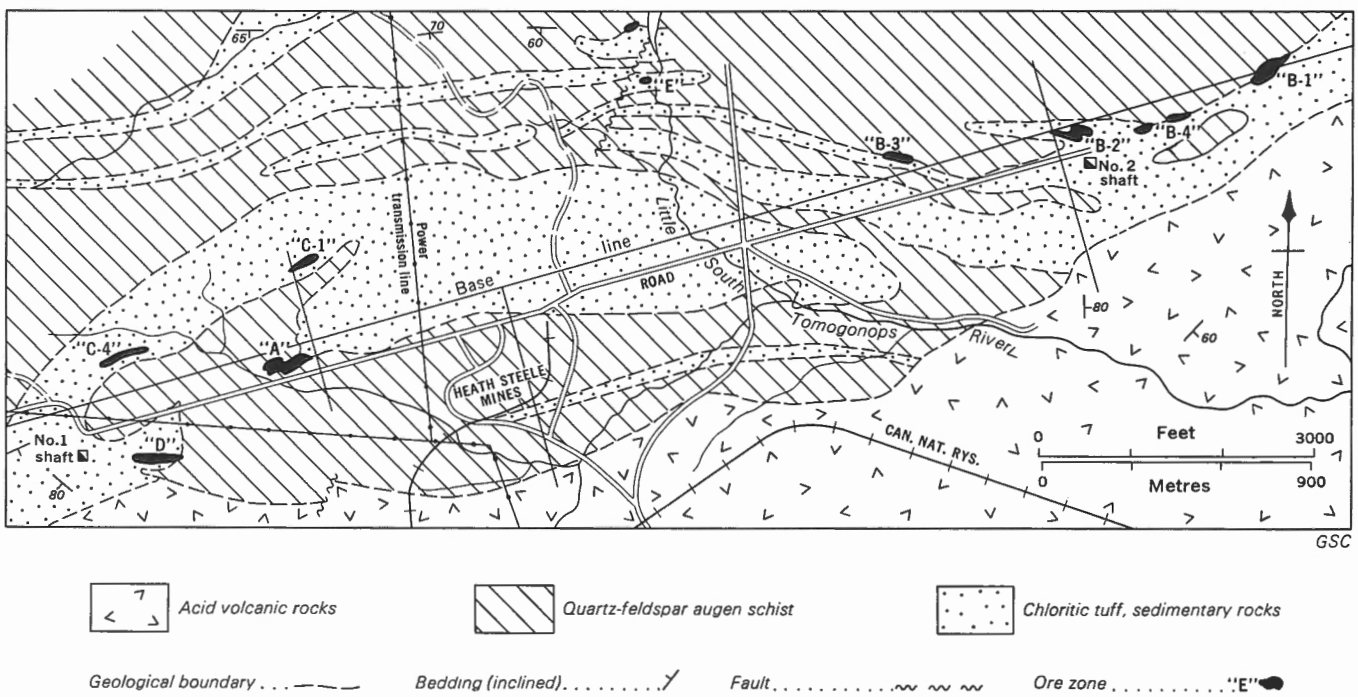


FIGURE VII-10. Geology and ore zones, Heath Steele mine, New Brunswick (McFarlane and Gates, 1966).

of the Rocky Brook – Millstream fault (Fig. VII-8). Lenses and veins of sulphides penetrate shale, conglomerate, and argillite along a crosscutting fault and fracture zone. The ore consists mainly of pyrite, arsenopyrite, pyrrhotite, sphalerite, galena, and chalcopyrite, with minor tetrahedrite and marcasite, in a gangue of calcite, quartz, and a little fluorite. Reserves at the mine were estimated to be 112,000 tons averaging 4.41 per cent lead, 4.31 per cent zinc, 0.55 per cent copper, and 1.42 ounces of silver per ton.

The *Nigadoo* (2) deposits, 2½ miles north of the Rocky Brook – Millstream fault, occur as lenses and veins along a fault zone within green and graphitic schists, shales, and argillites of the Elmtree Group in the contact zone of a differentiated intrusive porphyry stock of probable Devonian age and also within the intrusive itself. The best ore is mainly within the porphyry or in the argillite a short distance from the contact. The ore minerals are similar to those at the Keymet deposit, and they extend to a depth of at least 900 feet.

Mindamar (Stirling) mine (30). The Stirling zinc mine on Cape Breton Island was first opened as a copper prospect in 1904, and developed as a zinc mine in the period 1927–36. It was reopened in 1950 as a lead–zinc–copper mine, the Mindamar mine, and produced about a million tons of ore before closing again in 1956. Pyrite, sphalerite, galena, chalcopyrite, and minor tennantite form lenses of massive, fine-grained, banded sulphides in a zone of talc–carbonate–sericite schist within rhyolitic flows, tuffs, and interbanded minor sediments similar to those of the Middle Cambrian Bourinot Group. Banding in the ore is parallel to the strike of the deposits and to the schistosity of the enclosing volcanic rocks and schists. A variety of igneous rocks intrude the group in the vicinity, and a major fault zone intersects these rocks near Stirling.

Central mineral belt, Newfoundland. The mines producing base metals in Newfoundland in 1966—the Buchans, Tilt Cove, Gullbridge, Little Bay, Whalesback, and Rambler mines—are all in sulphide bodies within metavolcanic rocks that are invaded by a variety of intrusive rocks ranging from ultrabasic to acidic. The volcanic rocks, for the most part now chloritic schists of basic composition, are intercalated with graptolitic slates in places, and are considered to be mainly Ordovician, although some may be Silurian. Many past producers, such as the Terra Nova, Betts Cove, Little Bay, and Pilley's Island mines in the same geological environment and region, have made Newfoundland an important copper, zinc, and lead producer. In 1966 the combined output of copper, zinc, and lead from these mines was valued at more than $30 million, mainly from the Buchans mines.

Buchans mines, Newfoundland (13). The first Buchans River deposit, "Old Buchans", was found in 1905 (Fig. VII-11). A body of 100,000 tons of very fine grained zinc–lead–copper sulphides was indicated. The mine was closed in 1911 because of metallurgical difficulties in processing the ore, but these difficulties were subsequently overcome in 1925. The Lucky Strike and the Oriental deposits, discovered in 1926, are now largely mined out. After mining and milling began in 1928 they produced more than 9 million tons, averaging 16.5 per cent zinc, 8.1 per cent lead, 1.54 per cent copper, 3.37 ounces silver, and 0.54 ounce gold per ton.

The Rothermere and Maclean orebodies outlined in 1947 and 1950 are presently producing. They form irregular, massive, gently pitching replacement lenses, mainly within tuff and breccia in the basic volcanic rocks of the Buchans Group (George, 1937). These rocks are intruded by diabase, granite, andesite, dacite, and quartz porphyry dykes. The deposits lie in the loop of a sigmoid curve in the Buchans Group in a re-entrant into a Devonian granite batholith to the west, and between two northeast trending diorite plutons along strike. The orebodies are both about 2,000 feet long, as much as 750 feet wide, and from 20 to 200 feet thick. They are intersected by zones of soft schist. Smaller zones of low-grade, disseminated sulphides occur below and marginal to the high-grade orebodies (Fig. VII-11b). The ore is of three main types: breccia ore containing numerous rock fragments, baritic ore containing as much as 35 per cent barite, and normal ore consisting of massive sulphides with a few rock fragments and minor barite. The normal ore is a fine-grained mixture of sphalerite, galena, pyrite, chalcopyrite, and a little tetrahedrite. The gangue consists mainly of barite with some quartz and calcite. Minor amounts of bornite, native silver, gold and silver tellurides, hematite, and sulphates of zinc, copper, iron, and lead are present.

Tilt Cove mines (7). The old Tilt Cove (Union) mine (Pl. VII-2), discovered in 1857, produced about 1½ million tons of high-grade copper ore from 1864 to 1917. It was reopened in 1957 and yielded an additional 6 million tons of lower grade ore. Between 1869 and 1876 small shipments of selected ore contained 24 per cent nickel and some gold. Two separate deposits, the East and West, occurred in chloritic schist and altered pillow lava of the Ordovician Headland Group at or near the contact of dykes and sills of intrusive, serpentinized, and steatitized pyroxenite. Dykes of quartz porphyry or granite cut the pyroxenite. They formed the footwall of the ore in the West mine and separated the ore masses in the East mine, the massive sulphides following both contacts of the dyke. The dykes are believed to be related to the intrusive Burlington granite that has been dated as Devonian.

The East mine deposits were irregular, massive, fine-grained pyritic lenses with abundant chalcopyrite and some sphalerite. Large masses of magnetite that were partly brecciated and cemented by sulphides were encountered locally. Some specular hematite occurred in vugs in the magnetite. The West mine deposit was

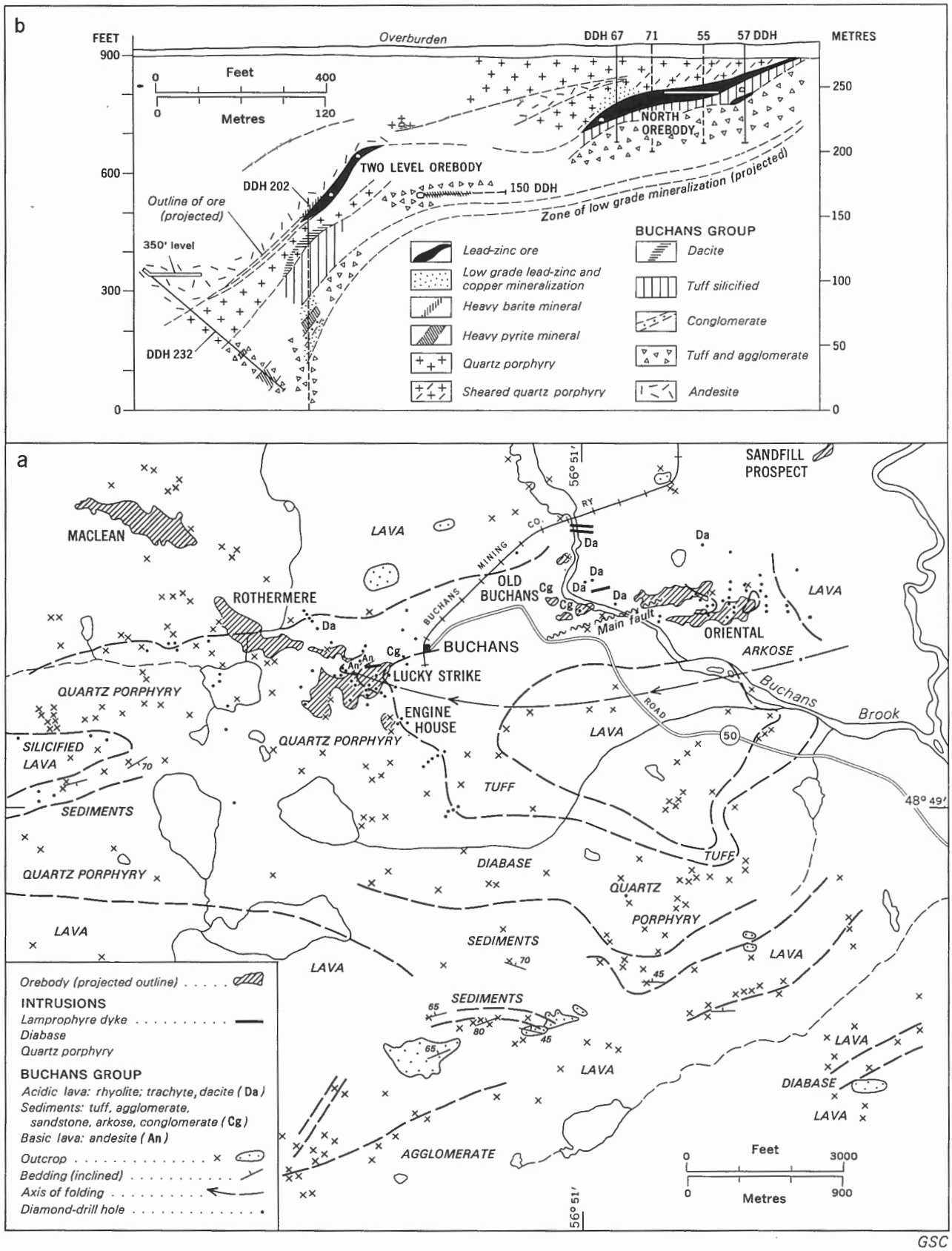


FIGURE VII-11. Buchans copper-zinc-lead deposits, Newfoundland (George, 1937). (a) Geology in vicinity of Buchans orebodies. (b) Cross-section through Lucky Strike North deposit.

PLATE VII-2. First Maritime Mining Corporation Limited copper–zinc–lead mine at Tilt Cove, Newfoundland.

formed of veins and disseminations of chalcopyrite, pyrite, pyrrhotite, quartz, and ankerite within altered chloritic andesite. Nickel- and cobalt-bearing minerals, including maucherite, niccolite, chloanthite, gersdorffite, rammelsbergite, arsenopyrite, violarite, and millerite, were found in the West mine as lenses of breccia or veins of dense grey dolomite in a talc–carbonate zone that was formed where serpentinite is intruded by a quartz porphyry dyke. Rare calcite veins in the quartz porphyry carry niccolite, maucherite, gersdorffite, and rammelsbergite.

Betts Cove (8) mine. In 1875 lenticular deposits of massive sulphides were opened in chloritic schist within pillow lava of the Ordovician Headland Group on Burlington Peninsula, Newfoundland. The group is intruded by a serpentinite sill or dyke and by bodies of diorite and quartz diorite that almost engulf the older rocks west of the mine. All Betts Cove copper deposits are less than 500 feet from exposed diorite, which is itself slightly mineralized in places. Olivine diabase dykes cut one of the ore zones, and small basalt dykes are common in both the lavas and diorite. The ore consists mainly of pyrite and chalcopyrite with bands of sphalerite and jasper. The mine produced 130,682 tons of high-grade copper ore carrying traces of gold, as well as several thousand tons of material that was rejected because of its zinc content. Several attempts to reactivate the mine have failed.

The *Little Bay* (9) deposit on Notre Dame Bay was discovered in 1877 in a fault zone in pillow lavas of probable Ordovician age. It produced about 200,000 tons of high-grade copper ore prior to 1900, and more than a million tons of gold-bearing copper ore since it was reopened in 1961. The ore occurs as veins and disseminations of pyrite, chalcopyrite, sphalerite, and magnetite with considerable quartz gangue in lenticular zones of chloritic schist within altered basic lava. The main ore lens, 30 feet wide and 900 feet long, strikes easterly, dips steeply south, and extends more than 1,000 feet down dip. Diorite intrudes the lavas about half a mile west of the mine, and numerous barren diabase dykes, as thick as 25 feet, occur within the ore zone. At *Whalesback Pond mine* (10), in similar chloritic schists about 3 miles to the west, the main lenticular pyrite–chalcopyrite ore zone is 40 feet wide and 1,200 feet long; it strikes easterly and dips steeply south. It extends below the 850-foot level and averages 1.75 per cent copper. A second ore zone, known as the Little Deer Pond deposit, has been found near by.

Consolidated Rambler mines (6). The Rambler prospect was found in 1905 on Burlington Peninsula and developed for production in 1964. There are two main ore zones, the "Rambler" and the "East". Both occur in chlorite–sericite schists north of a salient of the Devonian Burlington granite that intrudes the Ordovician Baie Verte volcanic rocks. A host of minor intrusions of basic to acidic composition intersects the volcanic rocks. The Rambler orebody is 5 to 25 feet thick and 450 feet long, dipping 40 degrees to the north. It consists of pyrite, chalcopyrite, and sphalerite impregnations in silicified, sericitized, chloritic schist, and has a high gold and silver content in places. The Rambler deposit averages 1.4 per cent copper, 2 per cent zinc, 0.12 ounce gold, and 1 ounce silver per ton. The East orebody about 5,000 feet to the east comprises heavily pyritized chlorite schist with some chalcopyrite. The deposit does not outcrop. It is reported to hold 2 million tons averaging 1.65 per cent copper.

Pilley's Island (11) mines. A pyritic deposit on Pilley's Island in Notre Dame Bay, carrying chalcopyrite, minor sphalerite, rare galena, and abundant quartz, was mined sporadically from 1889 to 1908 for the pyrite, from which sulphur was recovered; about 600,000 tons of ore were produced. In 1920 diamond drilling revealed that part of the deposit had been offset by faulting and was estimated to hold a similar tonnage of pyrite–chalcopyrite ore. The occurrence is unusual in that the ore is found within green rhyolite flows of the Ordovician and Silurian Roberts Arm volcanics, whereas all other copper occurrences in this part of Newfoundland are in basic volcanic rocks.

Lead–Zinc–Copper–Silver

Galena–Sphalerite–Chalcopyrite–Silver

The *Magnet Cove* (8) barite quarry and underlying lead–zinc–copper–silver mine near Walton, Nova Scotia (Fig. VII-12), lie in an area of faulted Carboniferous sedimentary rocks—red sandstone, shale, anhydrite, and

gypsum (Boyle and Jambor, 1966). In 1956 diamond drilling at the site of the barite quarry disclosed a lead–zinc–copper–silver orebody below, at a depth of 250 feet, lying mainly within a breccia zone along the footwall fault contact of the barite deposit (Fig. VII-13). Since its opening in 1961 the sulphide deposit has yielded more than 10 million pounds of lead, 5 million pounds of zinc, 2 million pounds of copper, and 2 million ounces of silver. The ore is reported to average 10 per cent lead, 4 per cent zinc, 1 per cent copper, 15.7 per cent iron, 30 ounces per ton silver, and traces of gold, cadmium, nickel, cobalt, arsenic, antimony, and bismuth. The principal minerals in the deposit are siderite, barite, hematite, nickeliferous and cobaltiferous pyrite, marcasite, galena, sphalerite, chalcopyrite, tennantite, acanthite, proustite, and pearcite. Although similar, this assemblage differs from that in Bathurst, New Brunswick, mainly in its higher barium, lead, and silver content and its framboidal texture.

Boyle and Jambor (1966) suggested that the source of the elements in the barite and sulphide deposits at Walton is the enclosing sedimentary rocks. They look to the Cheverie sandstones which have higher-than-average contents of barium over large areas, and to the Horton Bluff Formation of black pyritiferous shales that are moderately enriched in sulphur, copper, and silver, and in which the pyrite is particularly high in nickel, cobalt, and arsenic. The method of concentration is uncertain. Circulating brines may have been the medium of deposition. On the other hand, an igneous source of Triassic or younger age may underlie the area.

Lead–Zinc

In Gaspé Peninsula, Quebec, attempts were made as early as 1665 to obtain lead and silver from occurrences along the shore of Gaspé Bay. The occurrences are essentially small fissure veins, mineralized with calcite, quartz, galena, sphalerite, and a little chalcopyrite. They are found in fractured Lower Devonian Gaspé Limestone at Percé, in the overlying Middle Devonian Gaspé Sandstone at Indian Cove, and with a little fluorite in the Ordovician Trenton limestone at Baie St. Paul. In central Gaspé on the flanks of the Devonian intrusives there are numerous occurrences of sphalerite and galena. At the Candego mine, on the north flank, galena and sphalerite with minor pyrite occur in quartz veins in faults and fractures in silicified shale. During 1948–51 about 14,000 tons of ore averaging 3–6 per cent lead, 1–6 per cent zinc, and 3–5 ounces per ton of silver was

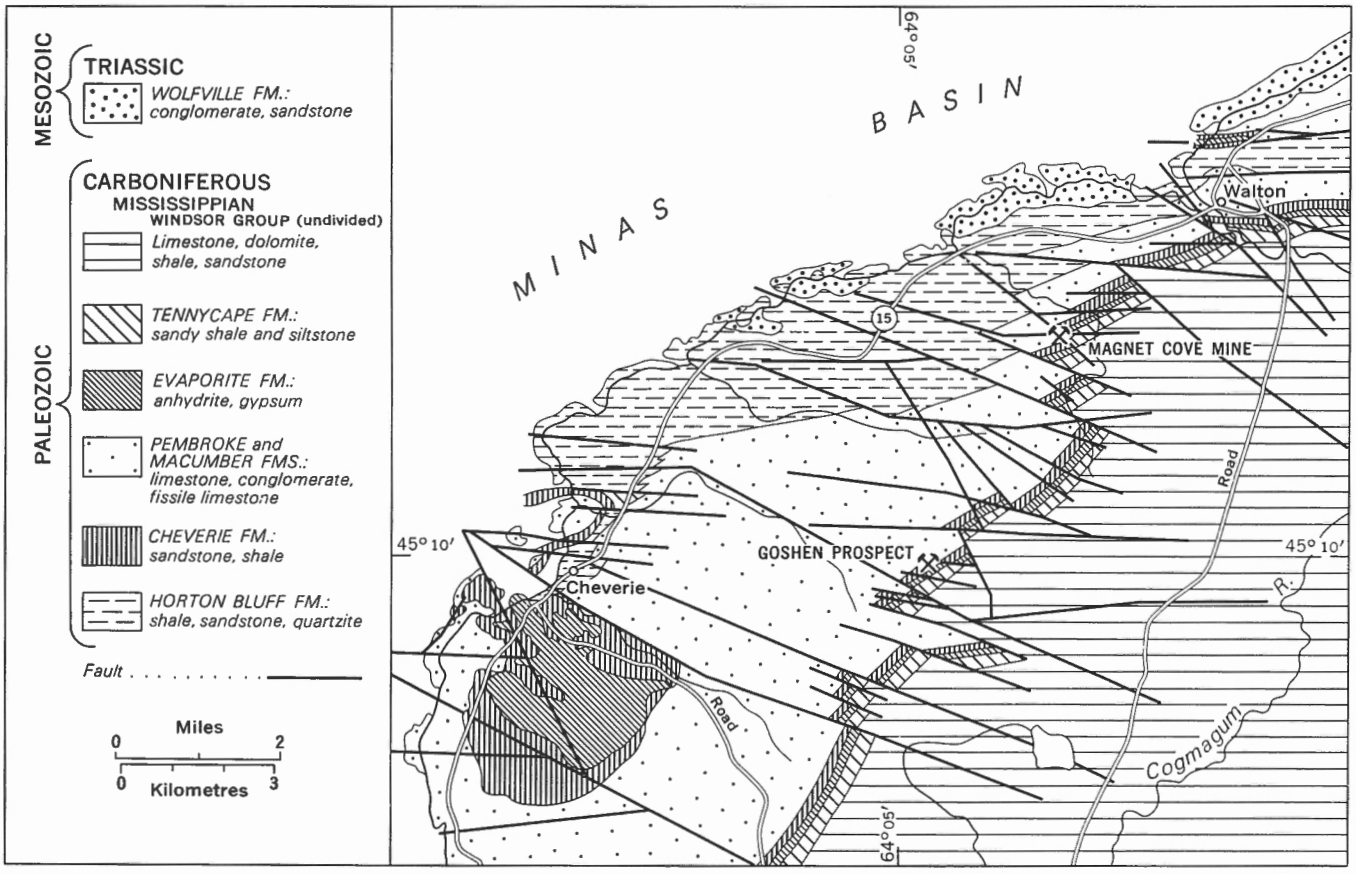


FIGURE VII-12. Geology of the Walton–Cheverie area, Nova Scotia (Boyle and Jambor, 1966).

milled. At the Federal mine, on the south flank, lead–zinc minerals occur in the form of veins and breccia zones in Lower Devonian limestone, argillite, and tuff. The veins there also cut syenite that is intrusive into the Lower Devonian rocks, but not the Gaspé Sandstone.

In Nova Scotia, numerous lead–zinc occurrences have been noted in fissures and disseminations in Carboniferous limestones and dolomites, notably at Jubilee and Smithfield, and associated with barite at Magnet Cove. At Leadville, galena, sphalerite, and some barite occur as replacements in grey limestone breccia at or near its contact with Horton shale and sandstone. The breccia, containing blocks of galena–sphalerite, is exposed over a width of 25 feet for a length of 220 feet.

On the west coast of Newfoundland galena and sphalerite occur in small vertical fissure veins with barite and celestite in places, in Ordovician Table Head limestone, and in grabens of brecciated Mississippian rocks. Extensive occurrences of disseminated sphalerite have recently been found within a zone 200 feet thick of brecciated, gently dipping beds of dolomitic limestone of the Ordovician St. George Formation north of Daniels Harbour. Reserves of 3.7 million tons averaging 7.3 per cent zinc are indicated. Lead–zinc occurrences are also reported on the north coast at Bear Cove and Fleur de Lys and in metasedimentary rocks that are invaded by granite batholiths on the south coast of Newfoundland, particularly in the La Poile Bay and Bay d'Espoir areas.

At the *Talisman (Silver) mine*, Cape Breton Island, pyrite and argentiferous galena are disseminated through Mississippian Windsor limestone and Devonian rhyolite, and fine-grained galena is disseminated through a sandstone bed—a basal member of the Pennsylvanian Canso Group. Diamond drilling has shown this bed to be 37 feet thick with an average grade of 3 per cent lead. It has been traced along strike for 6,900 feet and down dip for 1,000 feet.

The *La Manche* vein on Placentia Bay in the Avalon

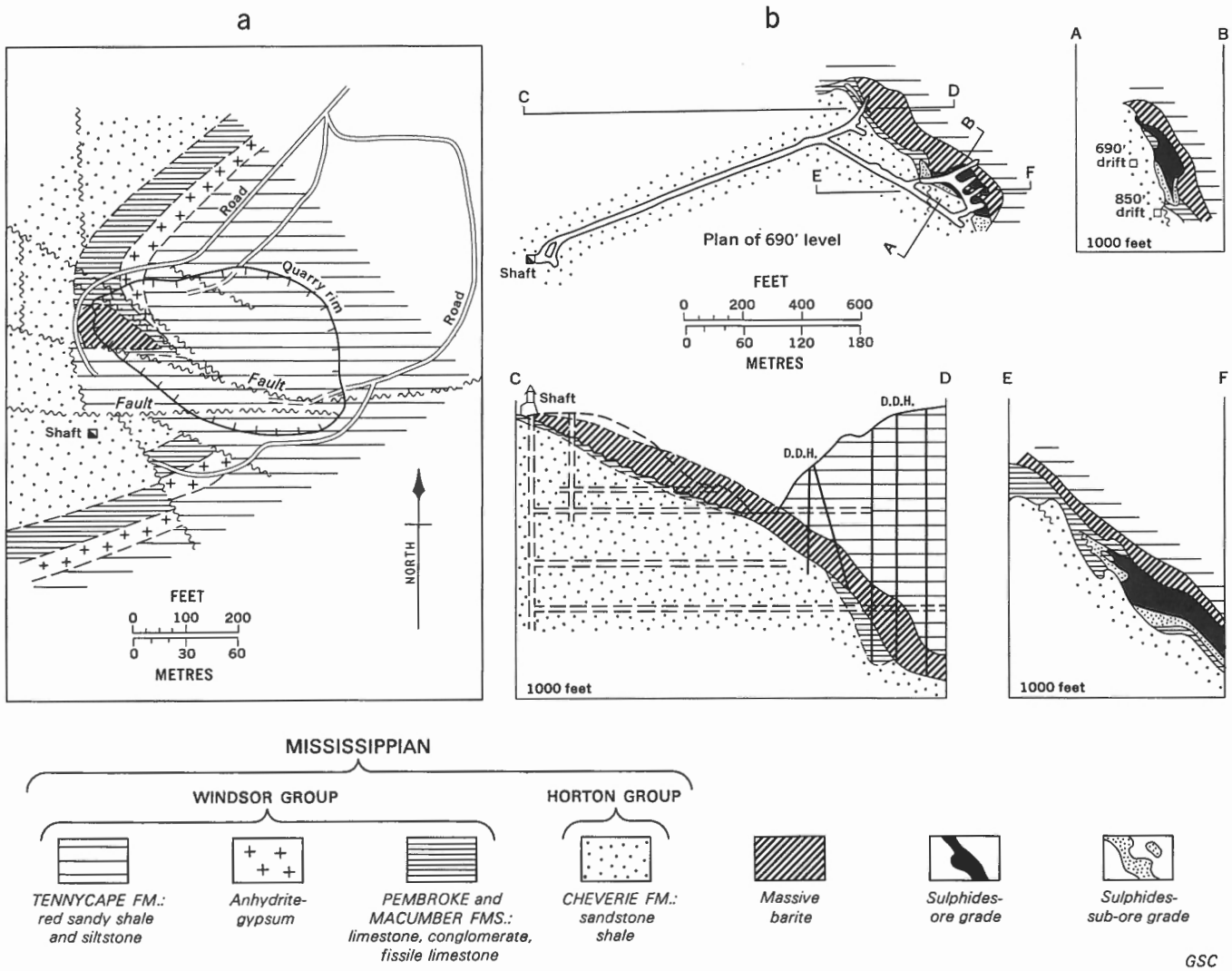


FIGURE VII-13. Magnet Cove barite–sulphide mine, Walton, Nova Scotia (Boyle and Jambor, 1966). (a) Geological map of quarry and mine. (b) Plan of 690 level and cross-sections A–B, C–D, and E–F.

Isthmus, Newfoundland, was opened in 1857 and mined until 1873 (later sporadically) for a length of 1,685 feet and to a depth of 400 feet. Although the mine is now flooded the ore is not exhausted. The vein extends inland for 10,000 feet and beneath the bay for an unknown distance. It is formed of coarse calcite with aggregates of galena and minor amounts of sphalerite, chalcopyrite, quartz, barite, and pyrite. It follows steeply inclined, northeast-trending, parallel fissures within and along the contact of a trap dyke that intersects thinly bedded, westerly dipping green siltstones of the Hadrynian Connecting Point Group. The vein shows no sign of pinching out, but varies in width from a few inches to 5 feet. It averages 5 per cent lead over an average width of 2½ feet for at least 700 feet and carries traces of gold and silver. The vein was formed by repeated opening and filling of the fissure and is characterized by banding and abundant vugs. The presence of so much calcite as well as galena is difficult to account for in these rocks. The nearest limestones are those of Lower Cambrian age some 10 miles away. They once overlapped the La Manche area, and conceivably may have contributed calcite as well as barite to the vein.

Lead–zinc–silver occurrences with associated quartz calcite, and barite gangue were once mined at the *Silver Cliff* mine near Argentia. There small veins and breccia cements in the Hadrynian Bull Arm Formation carry auriferous pyrite, argentiferous galena, sphalerite, chalcopyrite, quartz, carbonates, and barite. Similar occurrences have been noted near Placentia, in Southeast Arm (Strouter adit), in Northeast Arm southeast of Seven Islands in Placentia Bay, and at Jerseyside.

Gold–Silver

The most recent production of gold and silver has come as a byproduct of smelting of base-metal ores in Newfoundland, New Brunswick, and Quebec. Silver appears to be associated with the galena-rich deposits, and the gold with the chalcopyrite–pyrite occurrences. In 1966 more than $8 million in silver and $1.8 million in gold were recovered from base-metal ores.

Gold nuggets found in 1823 in gravel in the Chaudière River valley near the mouth of the Gilbert River led to placer mining in the Eastern Townships of Quebec in the period 1847–85 when about $3 million in gold was recovered. Many rough angular nuggets weighing from 1 ounce to 30 ounces were found, some with bits of quartz attached as if they were not far removed from their quartz vein source. Most gold was obtained from the older, preglacial gravels. Prospecting for the bedrock source was rewarded by discoveries of several precious metal-bearing copper deposits and many quartz veins, but no high-grade lode gold deposit has yet been found in the region.

In Nova Scotia lode gold mining began in 1862, and production reached a high of more than a million dollars in 1939. Scores of small mines produced gold from quartz veins that intersect slate and quartzite of the Ordovician Meguma Group. The veins follow or cut across the bedding planes and become more numerous and wider on the anticlines and domes where they form 'saddle reefs'. Free gold is commonly concentrated in shoots within the quartz veins along with pyrite, arsenopyrite, calcite, and galena. The deposits show a spatial relationship to intrusive Devonian granites and appear to have been deposited from solutions generated by them. On Middle River in Cape Breton Island, gold has also been found in quartz veins in altered sedimentary rocks of Precambrian or early Paleozoic age and in the granitic rocks that intrude them. Some has been recovered from the gravels derived from them.

In Newfoundland small amounts of gold have been produced at Ming's Bight and Sop's Arm from metamorphosed Ordovician rocks.

Iron

The Appalachian Mineral Province has a great number and variety of iron occurrences including titaniferous magnetite lodes of magmatic origin in anorthositic rocks, magnetite replacement deposits of hydrothermal origin in basic volcanic rocks and sediments, magnetite–hematite–chert iron-formations of volcanic–sedimentary aspect, replacement hematite–siderite–ankerite masses, primary sedimentary oölitic hematite–chamosite–siderite beds, and manganiferous bog iron. Early mining was from relatively small deposits of the various types of iron ore in Nova Scotia and New Brunswick, but after World War I production was from the oölitic deposits at Wabana, Newfoundland, which closed in 1966 because of increasing competition.

Oölitic Hematite

Nictaux–Torbrook deposits (9). Iron deposits were discovered in 1820 and 1825 near Annapolis, Nova Scotia, and were mined from 1825 to 1916. The hematite–greenalite–magnetite ore is locally oölitic, and in places carries brachiopod and cephalopod shells. It forms thin beds in zones as thick as 18 feet that are intercalated with early Devonian slates and quartzites. The ore lies in two zones each more than 4 miles long and about a mile apart on opposite limbs of a syncline. Most of the ore has come from three bands that are 4 to 9 feet thick. The lean sedimentary iron-formation in which the ore occurs has been partly metamorphosed by intrusions of granite and gabbro, and magnetite has formed at the expense of some of the other iron minerals. The deposit is credited with a production of 350,000 tons of iron ore.

Similar but smaller deposits of this type have been noted in Middle Cambrian beds on Gillis Brook at Grand Mira South on Cape Breton Island. Near Arisaig, beds of oölitic hematite occur in the Lower Ordovician Browns Mountain Group, and can be correlated with the Wabana beds.

Wabana Iron mines (16). The Wabana iron deposits were discovered on Bell Island in Conception Bay, Newfoundland, in 1892 and have produced oölitic hematite ore from surface cuts and submarine mines. Five main bands and many thin seams of oölitic hematite are intercalated with fossiliferous Lower Ordovician sandstones and dark shales. They dip gently beneath Conception Bay where they lie conformably above the Cambrian exposed along the south shore of Conception Bay, and form part of an outlying basin, truncated by faults, underlying the bay. Three of the oölitic hematite bands, separated by 240 feet and 58 feet of strata, have been mined—the Lower (Dominion), Middle (Scotia), and Upper (Little Upper) beds. The possible extent and form of these deposits as they may exist beneath Conception Bay is shown on Figure VII-14. It is evident that large tonnages of potential ore, some of which may never be recovered, underlie the bay. Most production has come from the Lower bed that attains a thickness of 40 feet in places and has been mined down dip for a distance of almost 2 miles (Fig. VII-15). The Lower and Middle beds average 61 and 55 per cent hematite, respectively, and yield iron ore that ranges from 45 to 57 per cent iron; the average is about 52 per cent iron. Silica at 12 per cent, and phosphorus at 0.85 per cent are the most objectionable impurities in the ore. Sulphur is less than 0.03 per cent, and calcium less than 2 per cent. The silica occurs mainly as chamosite and detrital quartz, the phosphorus and calcium in the shell fragments, and the sulphur as pyrite.

The ore beds are composed essentially of sand-like grains of concentrically banded hematite, siderite, chamosite, quartz, and an occasional shell fragment set in a matrix of siderite and a paste of comminuted quartz, chamosite, hematite, shell fragments, manganese oxides, and carbonates—a mixture of chemically precipitated and subordinate clastic material (Pl. VII-3). The oölites are formed by direct chemical precipitation and accretion of hematite about nuclear clastic grains. Penecontemporaneous erosion, transportation, and deposition of oölites are shown by crossbedding, interformational conglomerate beds carrying oölitic hematite, and the off-shore bar arrangement within the ore zones. The ore zones are remarkable for their continuity. They include lenses of dark shale and sandstone. Variations in thickness suggest deposition as near-shore sand bars (Fig. VII-16). The beds show many features such as ripple-marks, rain drop impressions, cut and fill structures, algal structures, worm burrows, and abraded clastic materials—also suggestive of shallow-water deposition. The top of the Lower bed is eroded and overlain by a persistent conglomerate carrying pieces of hematite and shale. The overlying bed of

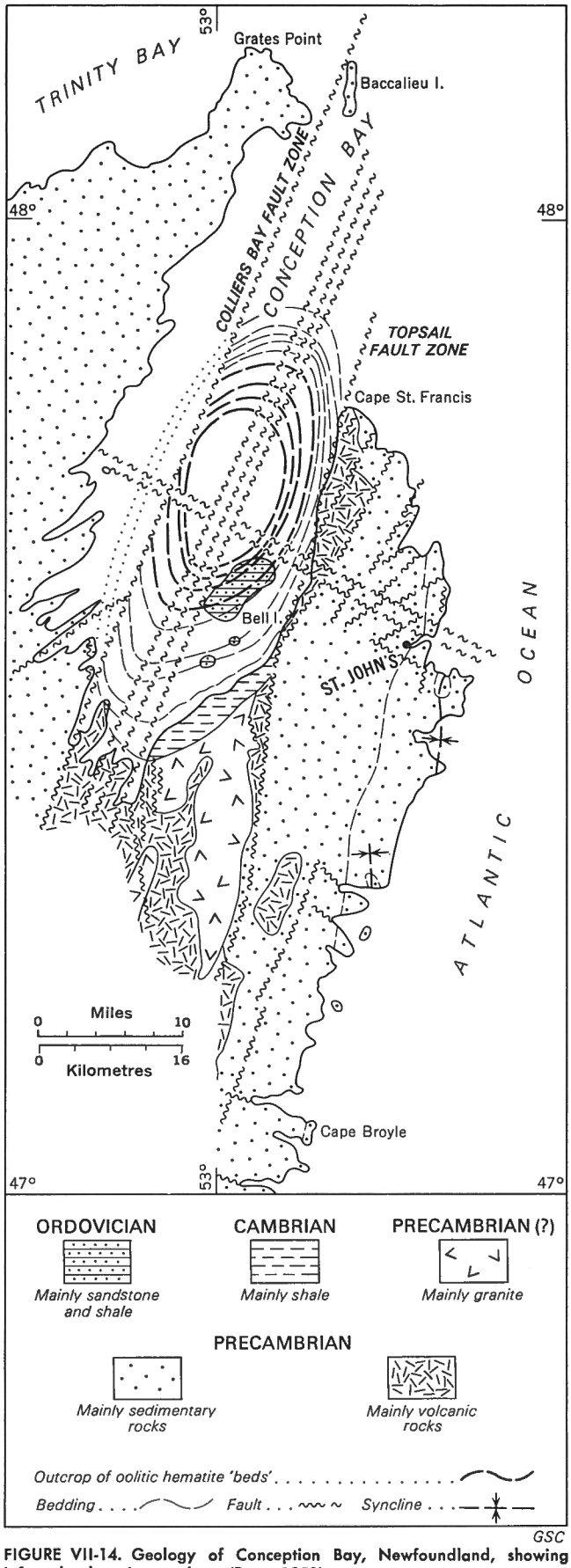


FIGURE VII-14. Geology of Conception Bay, Newfoundland, showing inferred submarine geology (Rose, 1952).

granular oölitic pyrite, as much as 1½ feet thick, carries graptolites and is succeeded by dark shale with dolomite nodules. The texture of the oölitic pyrite is remarkably similar to that of the ore beds and suggests deposition in a reducing environment. Thin nodular phosphatic beds composed of shell fragments, nodules, and oölites of calcium phosphate, siderite, and pyrite occur above the Middle bed.

Siderite–Hematite

Londonderry iron deposits (3). From 1849 to 1908 about 2 million tons of siderite and hematite ore were produced from one of the earliest known iron deposits in Canada, that of the Londonderry area in the Cobequid Mountains of Nova Scotia. The deposits are hematite–limonite-rich zones that resulted from surficial enrichment of irregular lenticular masses of ankerite–siderite that

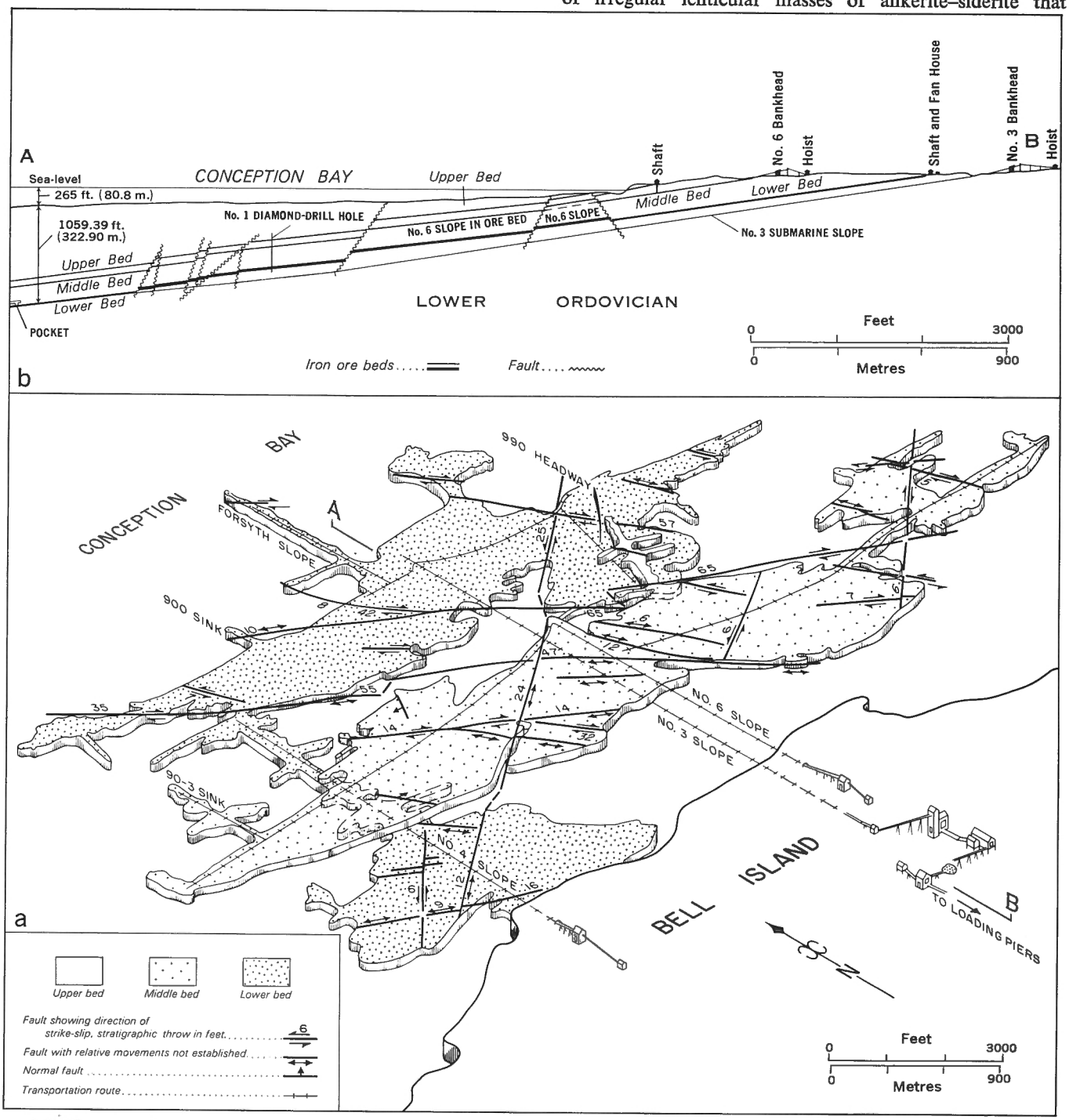


FIGURE VII-15. Wabana iron mines, Newfoundland. (a) Schematic drawing of workings in Lower, Middle and Upper beds (Norris, 1956). (b) Section along line of No. 3 slope (by J. B. Gilliatt).

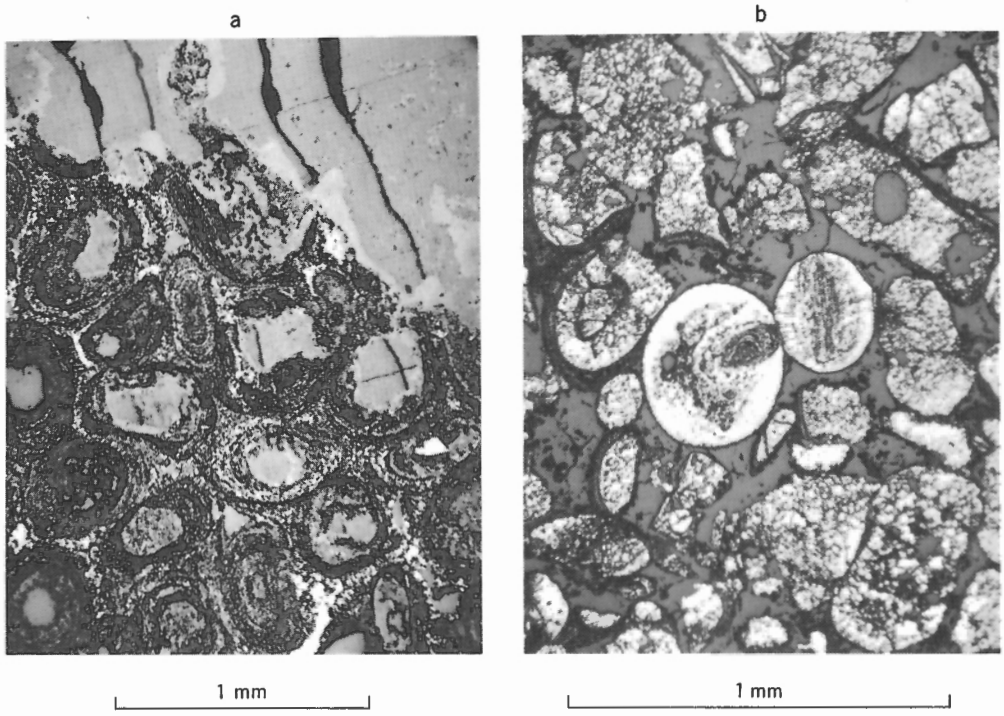


PLATE VII-3
Photomicrographs of Ordovician iron deposits at Wabana, Newfoundland; (a) Hematite oöliths with cores of detrital quartz and shell fragments; (b) Oölitic pyrite.

occur *en echelon* in a belt about 12 miles long parallel to a fault zone in pre-Carboniferous altered volcanic and sedimentary rocks. The carbonate bodies are as much as 100 feet wide and several thousand feet long; they contain irregular pockets of enriched oxide ore 100 feet wide and 300 feet deep underlain by unaltered carbonate. The enriched ore is reported to have carried from 47 to 57 per cent iron, and the unaltered carbonate material about 4 to 10 per cent iron. The origin of the carbonate masses is believed to have been connected with the emplacement of granitic intrusions into rocks of the pre-Carboniferous Cobequid complex.

Magnetite

Bathurst iron mine (6). Magnetite concentrations in iron-formation at the Drummond pit near Bathurst, New Brunswick, produced 200,000 tons of ore between 1910 and 1915. The magnetite results from the intrusion of quartz porphyry into Ordovician banded iron-formation. As noted in the section on Copper–Lead–Zinc, many of the large base-metal sulphide deposits of the Bathurst area are spatially related to magnetite bodies and iron-formations within the Tetagouche Group. Samples from the deposit have 42 to 49 per cent iron, 1 to 16 per cent manganese, 20 to 26 per cent silica, 0.6 to 0.7 per cent phosphorus, and 0.05 to 0.12 per cent sulphur.

Titaniferous Magnetite

Titaniferous magnetite and associated minor hematite and ilmenite occurrences have been explored sporadically in western Newfoundland. Disseminations and massive segregations occur within a gneissic, banded gabbro phase of the Indian Head anorthosite intrusion near Stephenville on St. George's Bay. Pegmatite dykes cutting these deposits have been dated by K–Ar methods at 910 m.y. The mass is therefore considered to be an inlier of anorthosite, part of the underlying Grenville basement. Segregated bands and disseminations of massive, hard, dark hematite intergrown with magnetite and ilmenite, appear in granitic rocks and gneiss to the north. At Steel Mountain, in the interior of the Flat Bay Brook anorthosite intrusion to the east, several dyke-like deposits of titaniferous magnetite cut the anorthosite. All these titaniferous magnetite occurrences carry strong traces of vanadium.

Manganese

Manganese is common in the Appalachian Mineral Province where it forms deposits of several types, and although some have been mined on a small scale from time to time, none is productive at present (Johnston and McCartney, 1965). The most numerous and important deposits are of replacement and secondary origin occurring within Carboniferous beds, particularly the limestones of the Windsor Group. They include deposits at Markhamville, Turtle Creek, and Shepody Mountain in New Brunswick; Tennycape in Nova Scotia; and the Magdalen Islands in the Gulf of St. Lawrence. A second, related type occurs within fissures in pre-Carboniferous rocks where solution and concentration has been effected by circulating groundwaters. Examples of this type have been found at Gowland Mountain, Jordan Mountain, and

Tetagouche Falls in New Brunswick; and at New Ross, Nova Scotia. A third type, potentially the most important source of manganese in the region, is of a primary sedimentary nature, found interbedded with sedimentary rocks of Cambrian age in Newfoundland, and Ordovician age in New Brunswick. A fourth type, bog manganese, is common throughout the region, but most occurrences are of limited extent and of insufficient purity to be worked at present. Bog manganese occurs near Moncton and on Renour River, in New Brunswick; and on Terra Nova River in Newfoundland.

Low-grade manganiferous hematite iron-formation near *Jacksonville* (7), northwest of Woodstock, New Brunswick, was mined for iron from 1848 to 1884; about 70,000 tons of ore was smelted. The iron-formation is interbedded with folded and metamorphosed red and green slates of Silurian age. The deposits carry from 9 to 22 per cent manganese in places.

Manganese-bearing beds occur in Cambrian limestone, breccia, and shale mainly within a zone at the contact of Lower and Middle Cambrian beds, at numerous localities in the Avalon Peninsula, and around *Conception Bay*, Newfoundland. Manganese carbonates and oxides occur as nodules, disseminated lenticles, and bands in the dark shales. The manganese rocks are essentially calcareous or dolomitic argillites with carbonates and oxides or carbonate–oxides of manganese, hematite, barite, and tri-calcium phosphate as the chief accessories. The primary manganese and barium-bearing carbonates in these beds are more or less surficially altered to pyrolusite, and in some places secondary enrichment in manganese oxides has occurred; for the most part, however, the manganiferous zone seldom exceeds 12 feet in thickness or 12 per cent manganese. At Manuels, samples across widths of 5.8, 7.8, 13.4, and 5.9 feet of the gently dipping beds contained 11.5, 10.73, 8.29, and 10.35 per cent manganese, respectively. Similar thicknesses and grades are indicated at Kelligrews Brook. At Brigus South Head on the west side of Conception Bay, a bulk sample from the central 1.5 feet of a manganiferous zone, 15 feet thick in steeply dipping Cambrian beds, carried 33.35 per cent manganese, 3.80 per cent iron, and 18.69 per cent silica. According to Johnston and McCartney (1965) this untreated material yielded silico-manganese in a single-stage electric smelting test, and in other tests was concentrated

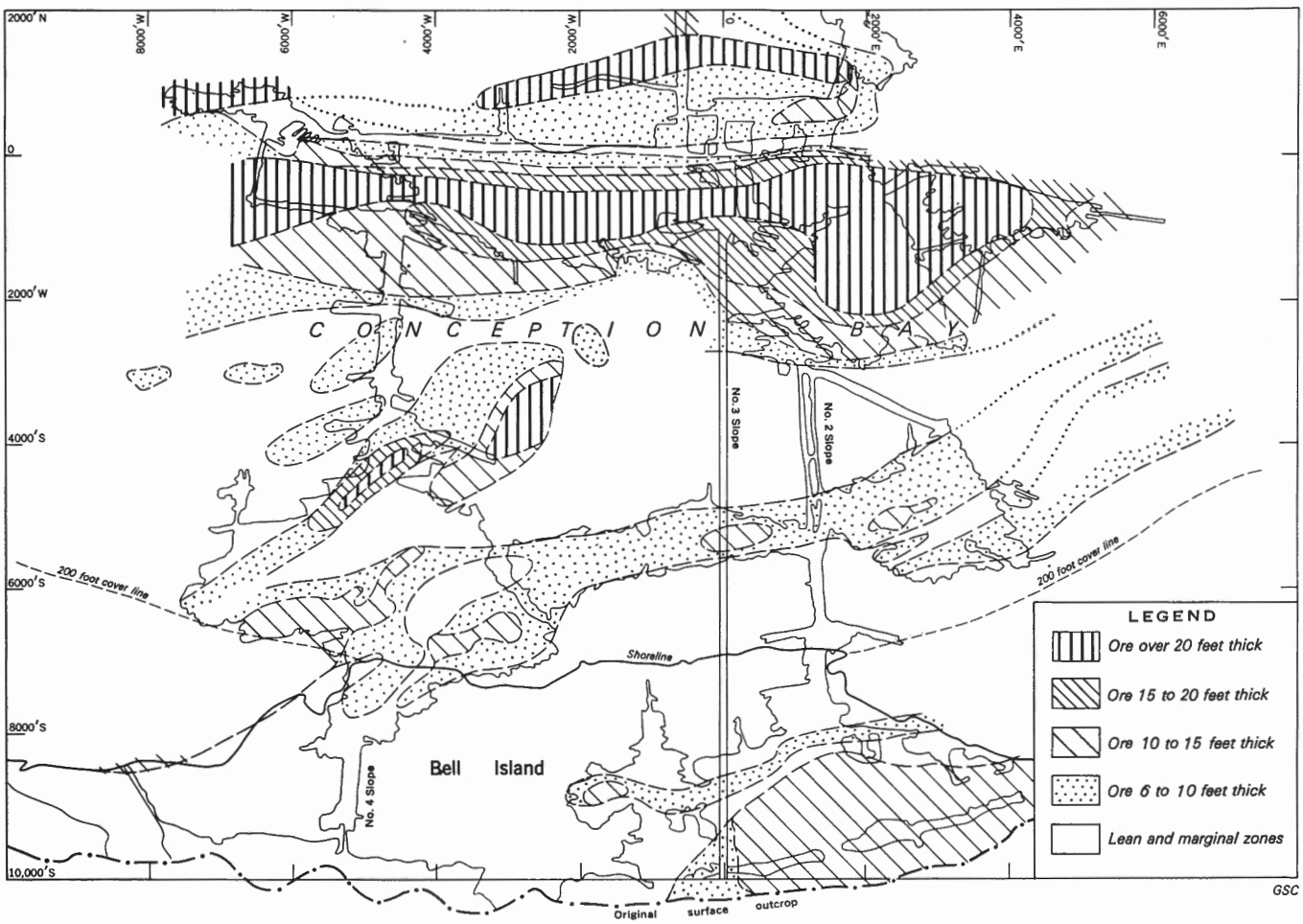


FIGURE VII-16. Ore trends and thickness of the Lower Bed, Wabana iron mines, Newfoundland (Lyons, 1957).

by a sink–float process to yield a roasted sink product containing 57.06 per cent manganese.

Molybdenum

As mentioned in the section on Copper, molybdenite is a byproduct of the Needle Mountain and Copper Mountain deposits at Gaspé, Quebec. In 1966, 531,598 pounds of molybdenum valued at $832,976 was recovered from these ores.

Numerous occurrences of molybdenite in quartz veins, aplite, and pegmatite, associated with granitic intrusions, are known at Gabarus Bay on Cape Breton Island, and near Jordan Falls, Nova Scotia. Small, high-grade molybdenite occurrences are reported in serpentine and gneiss intruded by granite pegmatite near Fleur de Lys, northern Newfoundland. Disseminations of molybdenite occur within a granitic intrusion and along its contact with the Belle Bay volcanics at Rencontre Lake near Fortune Bay, Newfoundland. The disseminated pyrite and molybdenite, and molybdenite in quartz veinlets, occupy a large, almost circular area in a fluorite-bearing alaskite granite, the Ackley granite, of probable Devonian age. Small occurrences are known at Lawn on the Burin Peninsula.

Niobium (Columbium)

The first and only producer of niobium in Canada is the deposit at *Oka* (49), Quebec. Pyrochlore, a dark brown mineral of complex composition carrying niobium, titanium, thorium, uranium, and rare earths, along with perovskite, magnetite, and some other minerals with radioactive and rare elements, are disseminated through a complex, multiple, circular stock of alkaline syenite that penetrates a Precambrian inlier of anorthosite, granite, gneiss, and crystalline limestone as well as the marginal remnants of brecciated Paleozoic limestone around it (Rowe, 1958). The niobium-bearing syenite is believed to be Triassic and is probably related to the Monteregian Intrusions that penetrate Paleozoic sediments in the St. Lawrence and Appalachian Provinces near by. As suggested in Chapter V it may be distantly related to a suite of niobium-bearing Precambrian alkaline intrusions that occur in the Canadian Shield. In 1966, 2,637,997 pounds of niobium oxide valued at $3,182,170 were contained in pyrochlore concentrates recovered from the deposit.

Tin

Tin is a minor constituent of the base-metal ores of the Bathurst area in New Brunswick and of the pegmatites and greisen zones in a muscovite-bearing leuco-granite near New Ross, Nova Scotia. At the Reeves mine in Lunenburg county, Nova Scotia, a pegmatite dyke in granite carries cassiterite, amblygonite, lepidolite, topaz, tourmaline, fluorite, monazite, and columbite–tantalite, rare beryl, and quartz crystals as much as 3 feet long.

At *Pleasant Mountain* north of St. George, New Brunswick, a low-grade tin deposit occurs in fractures in a complex of altered volcanic, pyroclastic, and metasedimentary rocks that are mainly Mississippian. The volcanic rocks at the mine are silicified and chloritized, in places replaced by fluorite, topaz, sericite, and kaolin, and impregnated with varying amounts of cassiterite, sphalerite, arsenopyrite, pyrite, chalcopyrite, galena, stannite, molybdenite, wolframite, and other minerals (Mulligan, 1966). Two zones of potential ore 4,000 feet apart, controlled by a complex fracture system, lie in the general line of several small granite stocks that outcrop in a belt north of the main batholith of Devonian(?) granite. The ore is reported to carry 0.6 per cent tin, 2.3 per cent zinc, 0.30 per cent copper, and 0.36 per cent lead.

Titanium

Titaniferous magnetite in anorthositic rocks of the Indian Head and Steel Mountain areas of Newfoundland, and elsewhere in the Appalachian Mineral Province, form disseminations and dyke-like bodies of iron and titanium oxide minerals, mainly vanadiferous titanomagnetite and ilmenite. Most occurrences have not been developed. Low-grade deposits of titaniferous magnetite may be concentrated magnetically and pelletized. Pelletized iron ore now commands premium prices in the steel industry, and recovery of the byproducts of titanium and vanadium, as well as iron, may also be feasible.

Tungsten

At *Burnt Hill,* 35 miles northwest of Fredericton, New Brunswick, Devonian granite intrudes thick Silurian beds of grey argillite and quartzite that are altered to hornfels over wide areas. The metasediments are also cut by basic dykes, aplite dykes, and greisenized granites that grade into quartz veins. Some greisens and quartz veins contain wolframite, molybdenite, and cassiterite. Numerous vertical quartz fissure veins, as much as 6 feet wide and 100 feet long, cut across the beds and carry pyrrhotite, chalcopyrite, pyrite, fluorite, chalcocite, locally abundant clusters of wolframite, sparse cassiterite and molybdenite, and abundant topaz. The deposit was opened in 1916 and about 200 tons of ore was milled (Little, 1959). The deposit was reopened in 1939 and 1953, but only limited production has ensued. The Square Lake occurrence, 20 miles northwest of Saint John, also consists of zones of wolframite–molybdenite–topaz-bearing greisen zones and quartz veins in a Devonian biotite granite. The quartz veins carry bismuthinite and native bismuth as

well, and crystals of wolframite as much as a half inch or more long.

In Nova Scotia, numerous occurrences of scheelite, cassiterite, and wolframite have been found in quartz veins, gold–quartz–antimony veins, and greisenized zones associated with the emplacement of the central Devonian granitic batholith in Lunenburg and Halifax counties. Wolframite and chalcopyrite occur in quartz veins in the Grey River area of the south coast of Newfoundland. Scheelite and tungstite were discovered in a large quartz vein near Charles Cove on the west side of Gander Bay, Newfoundland. The quartz vein, from 2 to 15 feet wide, intersects the contact of granodiorite and Silurian(?) slates and has been traced for a length of three-quarters of a mile.

Chromium

Chromite deposits are confined to the belts of serpentinized ultrabasic rocks that contain the asbestos and nickel occurrences in the Eastern Townships of Quebec, the Mount Albert intrusion in the Gaspé Peninsula, the Bay of Islands and Hare Bay Complex in western Newfoundland, and two belts in northern and central Newfoundland. There has been sporadic production from a number of these deposits, mainly during times of war, but none have produced since 1947. Most of the higher grade occurrences are irregular pockets, but a few are tabular. The orebodies consist of disseminated chromite and segregations or veins of massive chromite, mainly in dunite and peridotite that form lower layers of partly differentiated ultrabasic rocks (Stockwell, 1944). Some deposits, such as the *Reed-Belanger (Chromeraine)* deposit in Coleraine township, are as much as 500 feet long, 8 to 60 feet wide, and more than 300 feet deep. Workable ore consists of a series of irregular lenses in a zone 1,500 feet long and 100 feet wide. Some of the ore mined was as low as 10 per cent Cr_2O_3. Shipments averaged about 35 per cent Cr_2O_3, with a chromium to iron ratio of 2.6:1. Small tonnages of chromite with a 3:1 ratio have been produced from the deformed serpentinites of the Eastern Townships, but the known deposits with this ratio are too small to compete with foreign sources.

Chromite occurrences in the deformed serpentinite belts of central Newfoundland show a ratio slightly higher than 3:1, but these deposits are rather small. Thin layers and bands of chromite are found in the relatively undeformed, stratiform Bay of Islands Complex. The chromite is concentrated in the upper horizons of the ultrabasic rocks immediately below the overlying gabbro (Smith, 1958). The Stowbridge deposit is the largest known concentration in the North Arm Mountain pluton. The chromite is reported to be a magnesium-rich variety, carrying about 40 per cent Cr_2O_3 and having a maximum chromium to iron ratio of 1.70:1.

Vanadium

Vanadium is a common trace element in deposits of titaniferous magnetite, oölitic hematite, chromite, copper, and uranium-bearing sandstones of the red bed type. It has been found in the titaniferous magnetite of St. George's Bay in Newfoundland in amounts ranging from 0.02 to 1.1 per cent; in Wabana hematite from 0.007 to 0.093 per cent; in Coleraine chromite at 0.2 per cent; and in red Carboniferous sandstone beds north of Fredericton at 0.04 per cent (Rose, 1967). Vanadium is also commonly associated with dark shales, lignite, coal, and hydrocarbons, and has been detected in oil shale from Newfoundland and New Brunswick, from soft coal at New Glasgow, Nova Scotia, and from the albertite at Albert mines, New Brunswick.

INDUSTRIAL MINERAL DEPOSITS

The industrial mineral output of the Appalachian Mineral Province includes asbestos, salt, gypsum, fluorite, barite, soapstone, talc, and pyrophyllite. The value of asbestos alone exceeds that of the metals produced in 1966. Exclusive of asbestos, however, the value of the industrial mineral production of the region is but a third of that of the metals. This is true also for Newfoundland, New Brunswick, and Quebec, but not for Nova Scotia where the industrial mineral output exceeds that of the metals. In the St. Lawrence Mineral Province bedded sedimentary deposits of salt, gypsum–anhydrite, limestone, dolomite, quartz sandstone, and shale are produced, as well as structural materials such as sand, gravel, crushed stone, and building stone (Table VII-1).

Asbestos

Chrysotile asbestos was first mined near Thetford, Quebec, in 1876. Since that time many large deposits of asbestos have been found within the elongated, sill-like, differentiated intrusions of serpentinized ultrabasic rock that spread through the Eastern Townships and Gaspé Peninsula into northern Newfoundland. The most productive part of the belt is 55 miles long, extending from Asbestos to Broughton township. Nine mines are currently active, and thirteen deposits have been mined out. Production from Quebec in 1966 was 1,336,566 tons valued at $141,559,725. Important deposits were developed in 1963 near Baie Verte in Newfoundland. In

1966, this mine produced 64,850 tons of fibre valued at $10,300,000.

Eastern Townships, Quebec. Serpentinized peridotite and pyroxenite occur as sheet-like stocks, dykes, and sills in what is known as the serpentine belt in Quebec. The belt actually extends along almost the entire length of the Appalachian fold belt in North America. The ultrabasic rocks invade, for the most part concordantly, stratified metasedimentary and metavolcanic host rocks that range from Cambrian to Ordovician. The emplacement of the ultrabasic intrusions at Mount Albert has been dated at 495 m.y. (Lower Ordovician), but they are generally believed to have been emplaced during either the Taconian or Acadian Orogeny. They are intruded in many places by granitic bodies of probable Devonian age. The formation of asbestos has been ascribed by Hess to autometamorphism within the cooling ultrabasic magma. The asbestos in the Eastern Townships is regarded as a product of later orogeny and invasion by granite (Cooke, 1937; Riordon, *in* Convey, *et al.*, 1957).

Two types of asbestos are common—cross-fibre and slip-fibre chrysotile. The former occurs in veins as wide as 4 inches, but most production is from veins less than ⅜ inch wide. The ore is crushed and screened and the asbestos fibre is lifted off by suction. With the split-fibre veins a separation may occur in the central part of the vein where grains of serpentinized peridotite, magnetite, and chromite may be found. Ribbon veins fill parallel fractures in serpentinized peridotite and in places these form parts of larger, composite veins. In a few places asbestos veins grade into picrolite (harsh fibre) veins.

Extensive zones of soapstone and talc–carbonate rocks occur near or along the contacts of the serpentinized ultrabasic rocks. Magnetite, in places titaniferous, and chromite, in both disseminated and massive, segregated form are also commonly associated with these rocks. Nickeliferous pyrrhotite and nickeliferous pyrite also appear to be related to the ultrabasic rocks.

During the past decade many of the producing mines have been consolidated as pits converged, and much of the production during these years has come from the following mines: *Carey-Canadian Mines Limited* (64): a company formed in 1955 to mine a series of four chrysotile deposits located about 20 miles northeast of Thetford Mines. Open-pit mining began in 1958. About 4,000 tons per day are milled. *King–Bell–Johnson–Beaver mine* (61d): a series of deposits extending over 7,000 feet in length, 2,500 feet in width, and 1,300 feet in depth, worked from the earliest days of asbestos mining in the area, is being mined by block-caving methods underground and by open pit (Figs. VII-17, 18). The mill processes up to 8,000 tons of ore daily. *The British Canadian mine* (61a): the British Canadian mine (Fig. VII-19) located in Black Lake, opened in 1885, has now been merged with the Megantic mine of Johnson's Company Limited. From the pit, which is over a mile long and half a mile wide, about 40,000 tons is mined daily. *Normandie mine* (60b): this open-cut mine, located 4 miles west of Black Lake, was opened in 1955; its annual production is about 85,000 tons of asbestos. *Nicolet Asbestos mines* (59): an open-cut asbestos mine opened recently at Norbestos, in Tingwick township, about 10 miles northeast of Asbestos. The Nicolet cross-fibre chrysotile deposit is 3,300 feet long and 500 feet wide. It has been developed to a depth of 100 feet. *National Asbestos mines* (62a): an open-pit asbestos mine 4 miles east of Thetford Mines was brought into production in 1958. It is producing at the rate of 3,600 tons daily. *Flintkote Mines Limited* (62b): this company began an open-pit asbestos operation 3 miles east of Thetford Mines in 1946. About 2,000 tons is mined daily. The deposit is within a band of serpentinized peridotite known as the Pennington dyke. *Lake Asbestos mine* (61e): an asbestos deposit beneath the waters of Black Lake was prepared for mining during the period

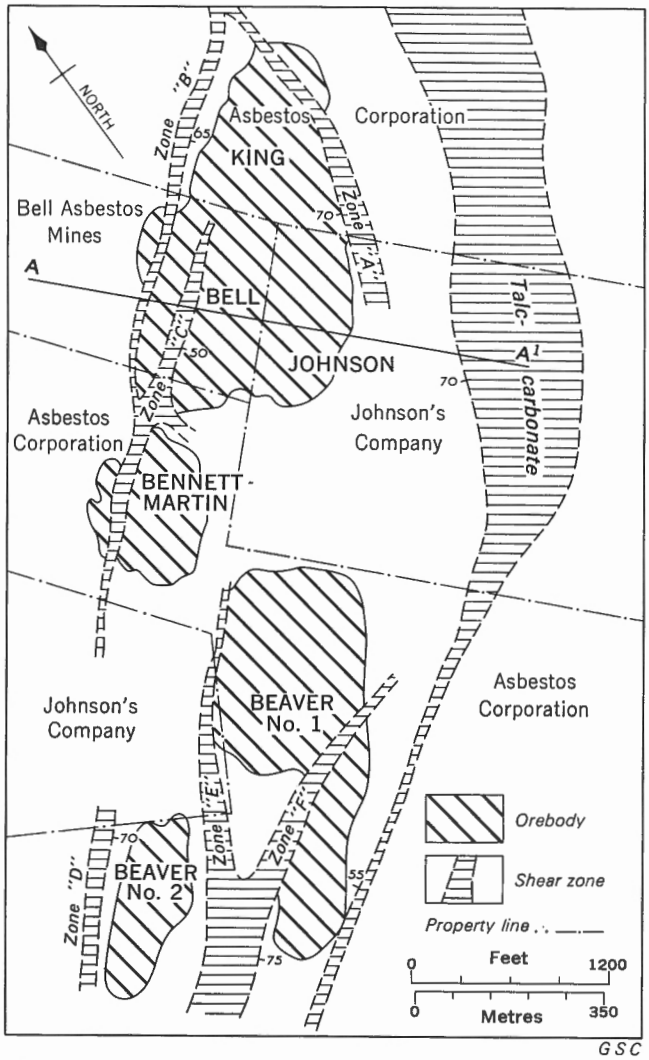


FIGURE VII-17. Asbestos deposits at Thetford Mines, Quebec, showing relationships with shear zones and talc–carbonate, or Thetford fault zone (Riordon, 1957).

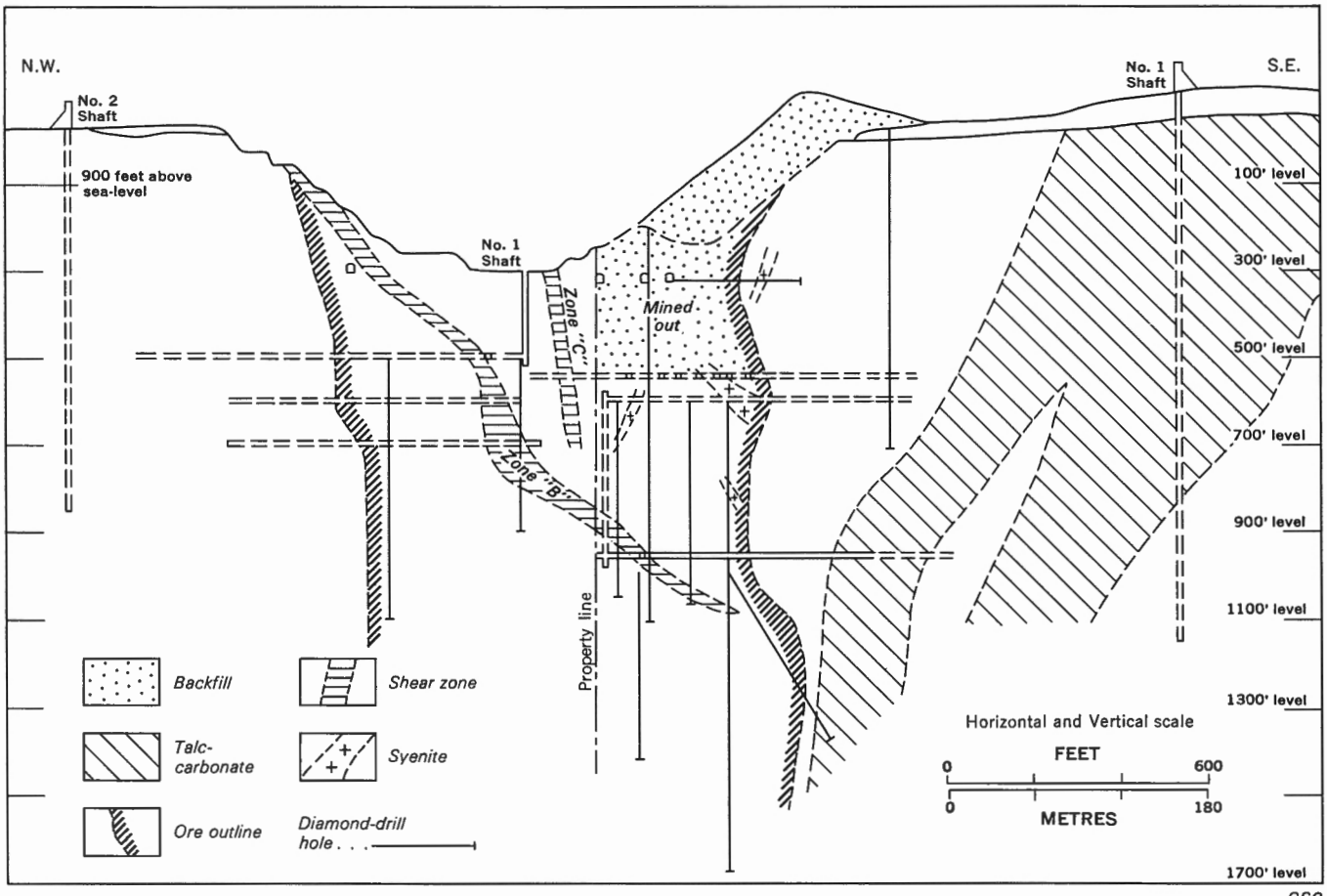


FIGURE VII-18. Cross-section through the Bell–Johnson deposit, Thetford Mines, Quebec; along line A–A[1] of Figure VII-17 (Riordon, 1957).

1955–58, by draining most of the lake and diverting the Bécancour River. About 31 million cubic yards of alluvium was dredged from a 483-acre area of the lake bottom. Production capacity of the mill is rated at 125,000 tons of asbestos per year.

The *Jeffrey mine* (58) at Asbestos, Quebec, is one of the largest open-cut mines in Canada. In 1966 this mine produced 610,305 tons of fibre, 45 per cent of the country's total. The open pit measures 3,500 feet by 3,800 feet, and is 590 feet deep. About 32,000 tons of "ore" and 16,000 tons of waste are mined per day. The pit is being extended to increase annual production by 1971 to more than 10 million tons. Black slates, interbedded with impure quartzite and quartz–actinolite schist, form the north or footwall side of a sill 4,800 feet thick consisting of serpentinized peridotite, dunite, and pyroxenite. The beds, believed to be Cambrian or younger, strike N60°E and dip 65° southeast. Several feet beyond the contact the slate is crumpled and altered to phyllite. Andesitic lava and volcanic (explosion) breccias form the south or hanging-wall side of the sill. Gabbro intrudes pyroxenite along the hanging-wall contact. Small granitic intrusions occur within the deposits. The most favourable host rock for asbestos is the massive peridotite. The deposit forms an elliptical cylinder raking 60° south.

Newfoundland. Ultrabasic intrusions of the same type as those in Quebec occur in two belts in central Newfoundland. They have long been known to carry serpentine, chromite, and talc–carbonate, but it was not until 1963 that commercial deposits of asbestos were located. At *Advocate mine* (4) near Baie Verte, asbestos-bearing rock forms a mass about 1 mile long and ¼ mile wide within a sill-like body of highly serpentinized peridotite that intrudes chloritic schists of the Ordovician Baie Verte Formation. In 1966, 65,201 tons of fibre was produced from 2,006,735 tons of ore. The stratiform, serpentinized, ultrabasic intrusions of the Bay of Islands Igneous Complex of western Newfoundland also carry small deposits of asbestos, and similar intrusions at Hare Bay on the Northern Peninsula have narrow veins of asbestos. Six occurrences are known in the eastern (Gander River) belt.

Barite

Walton, Nova Scotia (6). This great pipe-like barite deposit, one of the largest in the world, yields most of Canada's barite. The Magnet Cove deposit has been described previously in the section on lead–zinc–copper; it is an argentiferous massive sulphide orebody that was

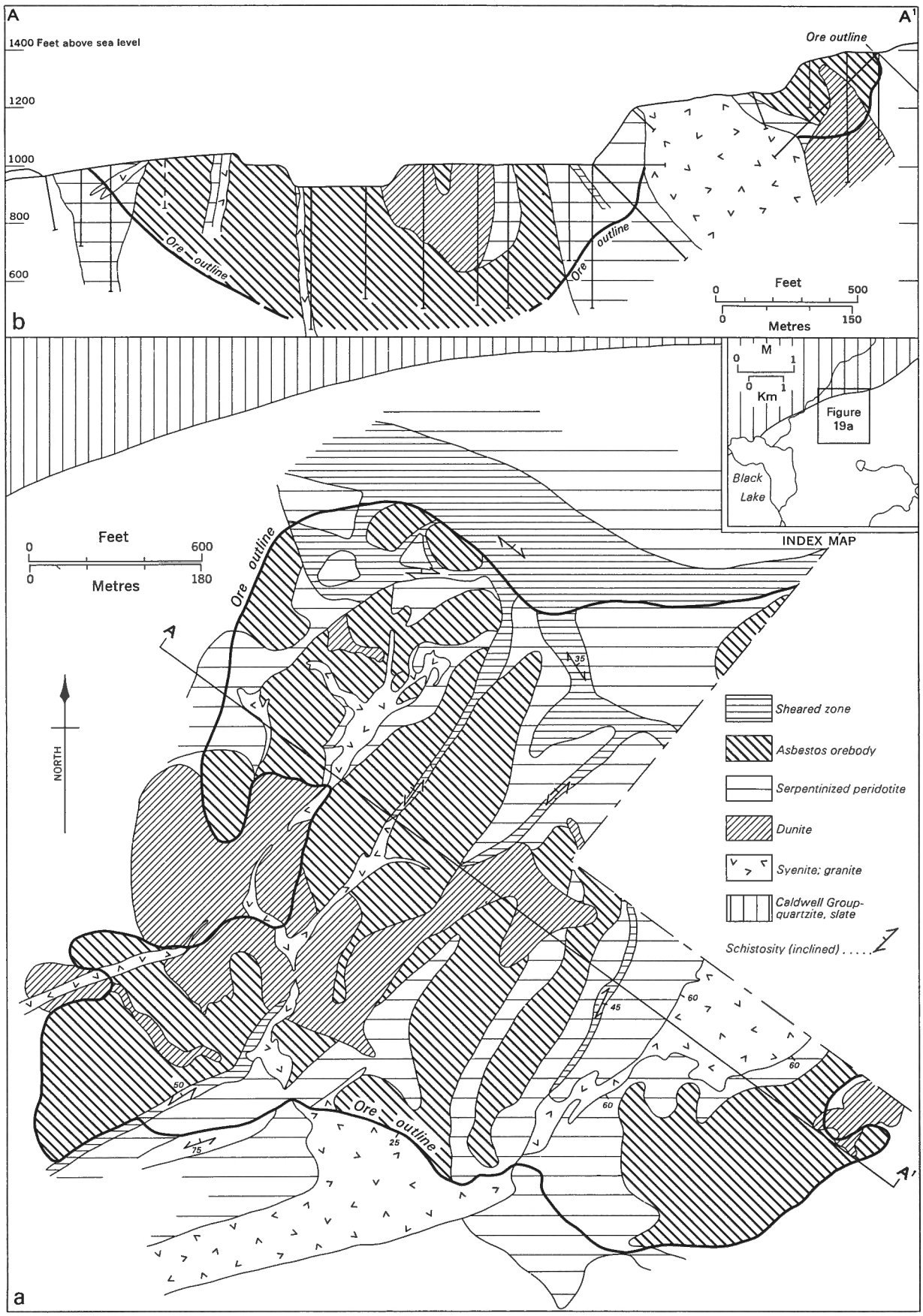


FIGURE VII-19. British Canadian orebody, Black Lake, Quebec (Riordon, 1957). (a) Geology. (b) Cross-section along line A–A[1].

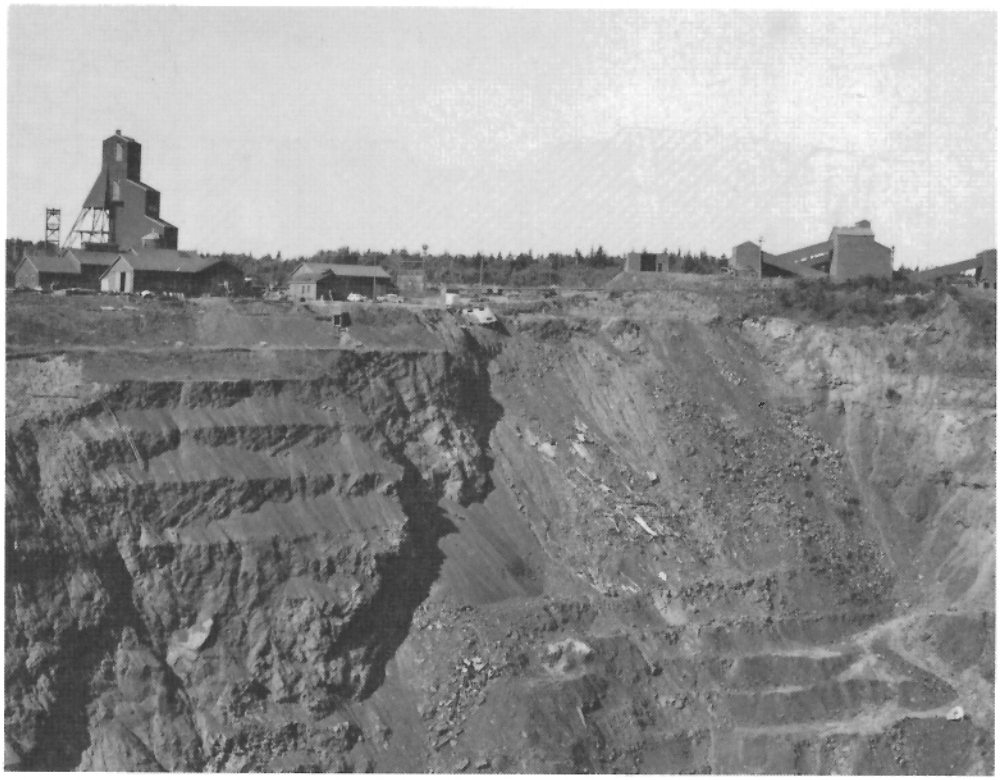


PLATE VII-4

Magnet Cove Barium Corporation, Walton, Nova Scotia. Open pit is in the barite deposit and headframe covers shaft leading to underlying lead–zinc–silver orebody.

found beneath the barite (Pl. VII-4). More than 4 million tons of barite valued at about $50 million has been produced to the end of 1966. The orebody, 90 per cent barium sulphate ($BaSO_4$), appears to be a replacement body localized by a fold and intersecting faults in the gypsum and limestone-bearing sediments of the Windsor Group. Triassic trap and diabase intrusions occur within 15 miles of the deposit. Barite deposits in the United States from Missouri to New York are believed to be associated with deep faulting and folding accompanying late Triassic igneous activity, and this may also be true at Walton. Boyle and Jambor (1966) suggested that the enclosing sedimentary rocks are the source of the elements in the deposits at Walton.

Fluorite

The *Director mine* (15b) at St. Lawrence, Newfoundland, is the only fluorspar mine currently in operation in the district (Fig. VII-20). More than forty fluorite-bearing veins are known, but only a few have been mined. The fluorite occurs as fracture fillings within alaskite granite and rhyolite porphyry of probable Devonian age that have intruded Ordovician and older volcanic and sedimentary rocks. The Director vein has been traced for more than 6,000 feet, mainly in the granite and at the contact between granite and wall-rock. Three ore lenses occur along the vein; the main lens is 90 feet wide in one place, but is generally less than 50 feet wide and more than 1,000 feet deep. Fluorite forms most of the vein, along with some quartz, calcite, barite, pyrite, chalcopyrite, galena, and sphalerite. It also forms stringers or cements breccia adjacent to the veins. The veins are banded parallel to their walls (Pl. VII-5), and locally the fluorite forms concentrically banded nodules around granite fragments. Locally, comminuted fluorite is cemented by silica and is called "blastonite", a material undesirably high in silica.

Steatite, Talc, and Pyrophyllite

Soapstone (steatite) and talc, the hydrous silicates of magnesium, occur in serpentinized peridotite and associated zones of talc–carbonate rock in the serpentine belt of the Appalachian Mineral Province. Some of these occurrences in the Eastern Townships of Quebec were worked as early as 1871. Products of the *Baker Talc* mines (50, 51) and *Broughton Soapstone and Quarry* (63a) include soapstone blocks, talc crayons, and pulverized talc or soapstone for use as dry carriers in insecticides, fillers in paint, paper, rubber, linoleum, tile, soap, plastics, and cosmetics.

Pyrophyllite, the hydrous aluminum silicate resembling talc, has been found at *Manuels* (17), Newfoundland. It occurs along with quartz in irregular silicified zones in the Harbour Main volcanic rocks near the intrusive Holyrood granite contact. The deposits were opened in 1904, sporadically worked, and reopened in 1956 to supply markets in the ceramics industry.

Salt

Salt deposits occur in the Upper Silurian of southwestern Ontario, and are known in Mississippian strata in various parts of Nova Scotia, New Brunswick, and Prince Edward Island. Salt springs have also been noted at the margin of Mississippian basins in western Newfoundland, Nova Scotia, and New Brunswick. Recovery operations currently conducted in Ontario and Nova Scotia are by artificial brine and conventional mining methods. The former method has been in use for more than 100 years in Ontario. Wells are drilled into the salt beds, cased, then tubing of smaller diameter placed inside the casing. Fresh water forced into the well through the outer tube dissolves rock salt to form a brine which is pumped to surface through the inner tube and then the salt is removed by evaporation.

The largest consumers of salt are the chemical industries in the manufacture of soda ash and chlorine. Other major uses are the food processing industries such as meat packing, fish processing, baking, canning, brewing, and the manufacture of confectionary and dairy products. Large quantities are also used for tanning and in the metallurgical and oil refining industries; it is also being used during the winter months in ever increasing quantities for de-icing streets and highways.

Ontario. Salt was discovered in Ontario in 1866 when a company was formed at Goderich for the purpose of drilling for oil. The first well was drilled on the north side of the Maitland River at Goderich, but instead of striking oil, a bed of rock salt was encountered at a depth of 964 feet, and thus a new industry was initiated. Drilling for salt quickly spread to neighbouring centres, and a

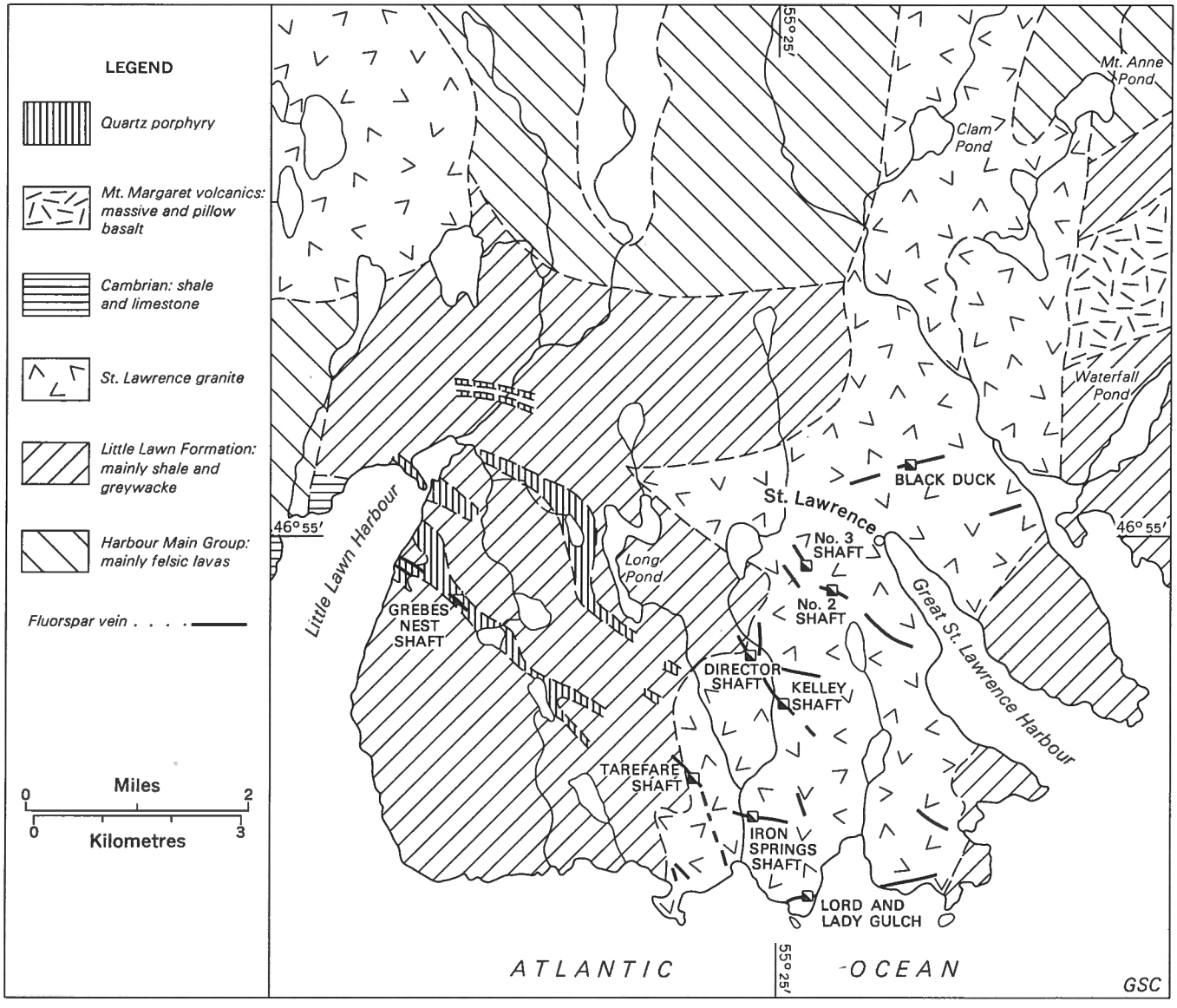


FIGURE VII-20. Geology of the St. Lawrence fluorspar area, Newfoundland (van Alstine, 1948).

PLATE VII-5. Banded fluorite vein, Director mine, Newfoundland Fluorspar Limited, St. Lawrence, Newfoundland. Vein is a fissure filling in Devonian alaskite granite.

number of artificial brine fields came into production throughout the western part of the Ontario Peninsula. Brine fields in operation in 1966 were at *Goderich* (116), *Sarnia* (117), *Windsor* (118), and *Amherstburg* (119a). The brine is taken from the B, D, and F salt zones of the Upper Silurian Salina Formation (Fig. VII-21). In recent years, salt mines at *Ojibway* (119b) and *Goderich* have come into production in Ontario. The Ojibway (Pl. VII-6) produces from one of the F unit salts at a depth of 948 feet. The mine at Goderich is producing from an 80-foot salt zone in the A-2 unit at a depth of 1,675 feet. These operations have greatly increased the annual salt production in Ontario, and have added considerably to the versatility of the industry. Although salt has been produced continually since its discovery, production figures are only reliable for the years 1895 to 1966 inclusive when 48,560,299 tons valued at $241,578,079 was recovered. Production during 1966 was 3,782,191 tons valued at $15,243,791.

Nova Scotia. For many years, the *Malagash* rock salt mine on Northumberland Strait was the chief source of salt in Nova Scotia, but it has gradually become exhausted and a new property has been developed at *Pugwash* (2). In addition, production is obtained from an artificial brine field at *Nappan* (1). Drillholes in the Malagash, Pugwash, and Nappan areas have penetrated salts as thick as 1,500 feet at depths of from 85 to 3,500 feet. These deposits are Mississippian and occur in the Windsor Group. Salt production in Nova Scotia during 1966 was 474,981 tons valued at $4,724,993.

Gypsum

Large deposits of gypsum occur in Ontario, Newfoundland, New Brunswick, and Nova Scotia. During the early development of the industry gypsum was utilized solely for fertilizer and the market was local. It now has many other uses, principally in the construction industry for the manufacture of plaster of paris, gypsum lath, and wall board, and is also used as a control in the setting of portland cement or as filler in paint and paper.

Ontario. Gypsum occurrences have been known in Ontario for 145 years; the first mine was opened about 1822 near the site of the present city of Paris. Since then, about 15 deposits, all located along the Grand River valley, have been worked intermittently. The most important occurrences are in Seneca, Oneida, and North Cayuga townships of Haldimand county. The deposits are lenticular, as much as 11 feet thick, and occur sporadically at various horizons interdigitating with dolomites and shales within the Upper Silurian Salina Formation.

In 1966 two mines were operating in Ontario, one at *Caledonia* (114) the other near *Hagersville* (115), both in Haldimand county. Their combined output during that year totalled 565,185 tons valued at $1,581,010.

Nova Scotia and New Brunswick. Gypsum occurs in central and eastern Nova Scotia, southern New Brunswick, and on the Magdalen Islands. All the deposits are in Mississippian beds of the Windsor Group. The main gypsum deposits of Nova Scotia are near *Windsor* (7) in Cape Breton Island. In New Brunswick production is confined to the *Hillsborough* (9) area of Albert county. In 1966, Nova Scotia produced 4,502,836 tons valued at $8,140,651, and New Brunswick produced 108,207 tons ($413,074).

Newfoundland. In Newfoundland, strata of the Mississippian Codroy Group underlie the lowland bordering St. George's Bay, and gypsum is found at a number of places, the largest producer being *Flat Bay* (14). Production in 1966 was 459,685 tons valued at $1,173,401.

Limestone and Dolomite

The relatively undisturbed Paleozoic strata of Southeastern Canada provide an adequate supply of limestone and dolomite for the manufacture of a wide variety of structural products. These include crushed stone for road construction, concrete aggregate, railway ballast, fluxstone, building stone, terrazzo, stucco dash, riprap (armourstone), and pulverized stone as an asphalt filler, cement, and chemical lime. Although more commonly used in the

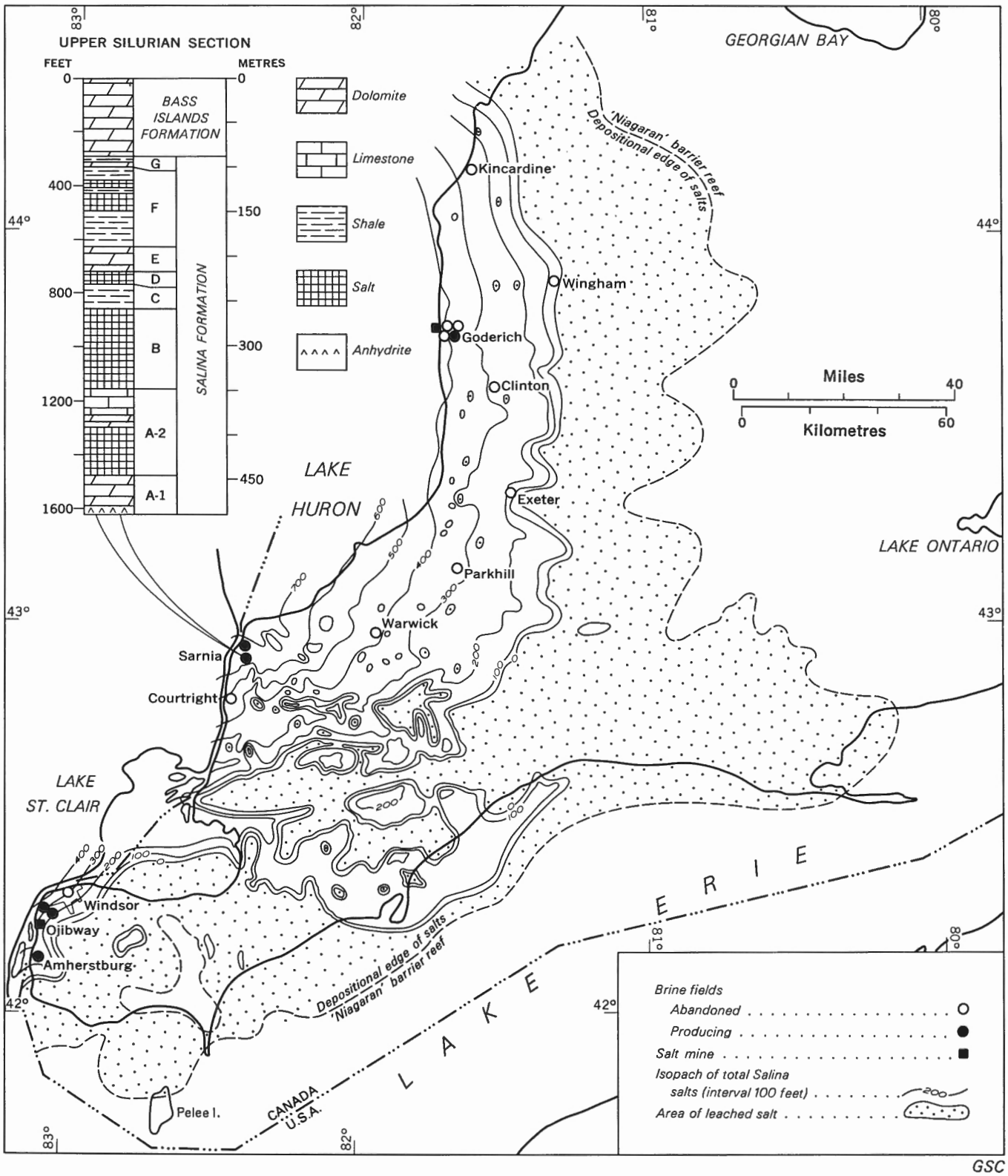


FIGURE VII-21. Salt mines and brine fields in the Silurian Salina Formation of southwestern Ontario (Sanford, 1965).

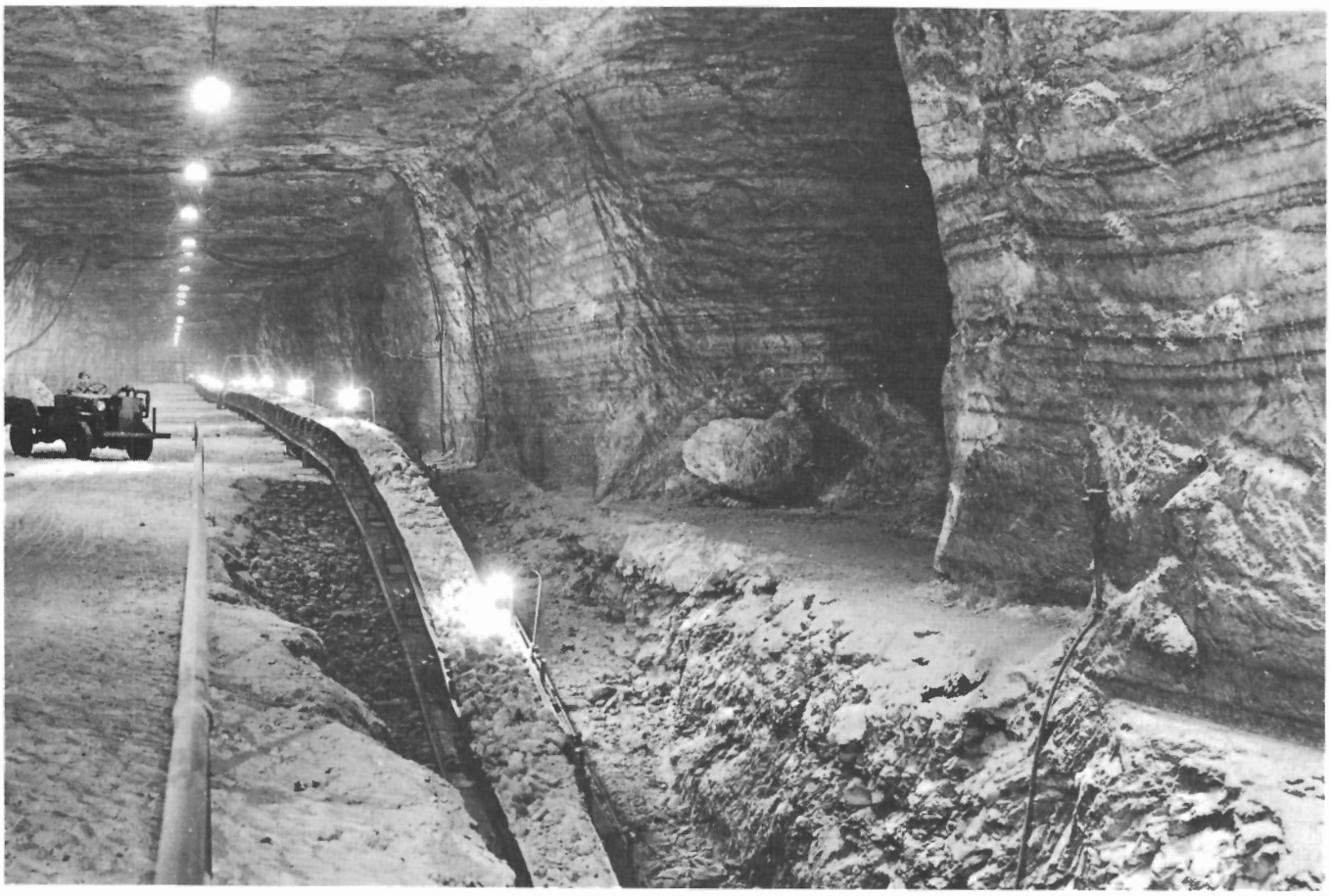


PLATE VII-6. Salt mine of Canadian Rock Salt Company Limited at Ojibway, Ontario, in F unit of the Upper Silurian, Salina Formation.

building trades, chemical lime is an important ingredient in the manufacture of iron and steel, uranium processing, pulp and paper, glass making, gold milling, refining of sugar, smelting, tanning, and as a soil conditioner.

Approximately 68.5 million tons valued at nearly $68 million was quarried in various parts of Ontario, Quebec, and western Newfoundland, and utilized for one or more of the foregoing products. More than half of this production is from the Ottawa–Montreal–Quebec region, and is derived from the Beekmantown, Chazy, Black River, and Trenton Groups, all of Ordovician age; most of the remaining production is quarried in southwestern Ontario. Many of the carbonate formations are utilized, particularly the Ordovician Black River and Trenton Groups; the Silurian Guelph, Lockport, and Amabel Groups; and the Devonian Dundee, Lucas, and Amherstburg Formations. Approximately 250,000 tons of limestone was quarried in western Newfoundland during 1966; production is from the Middle Ordovician Table Head Formation. Much of the limestone in Nova Scotia and New Brunswick is derived from the Mississippian Windsor Group. In 1966 the two provinces had a combined limestone production of about 1.5 million tons valued at $2,235,000.

Sandstone and Shale

The sandstones of Ontario and Quebec have long been utilized as building stone. In southwestern Ontario the Lower Silurian Whirlpool and the Lower Devonian Oriskany beds have been used most. The Upper Cambrian Nepean sandstone in the region of Ottawa and the Quebec Lowland is famous for its durability and pleasing qualities as a building and ornamental stone. The Parliament Buildings in Ottawa are constructed of this sandstone obtained from a local quarry. Because of their exceptional purity, the sandstones are also used in glass making, the manufacture of silicon carbide, the processing of alloys, for foundry purposes, as a filler in asbestos cement, and in various cleaners.

Brick and tile are the chief products manufactured from the shales of Ontario and Quebec, particularly the Upper Ordovician Meaford, Dundas, and Queenston strata below the Niagara Escarpment in Ontario, and equivalent beds in the Ottawa and St. Lawrence Valleys. In addition, the late Middle Devonian shales of the Hamilton Group in southwestern Ontario are excellent for the manufacture of brick and tile.

Petroleum and Natural Gas

Petroleum and natural gas are produced from the Cambrian, Ordovician, Silurian, and Devonian rocks of southwestern Ontario and from Mississippian strata in New Brunswick (Fig. VII-1). The fields in southwestern Ontario occur along Algonquin and Findlay Arches and the flanks of the adjoining Michigan and Allegheny Basins. Other sedimentary basins of St. Lawrence Platform—the Quebec Basin, Ottawa Embayment, and Anticosti Basin—contain similar, little deformed Paleozoic strata that rest on a basement of Precambrian crystalline rocks and are generally considered to be potentially productive of oil and gas. The Silurian and Devonian strata of Gaspé Trough have been explored from time to time without success. The strata were folded in the Devonian Acadian Orogeny and rest on Ordovician and Cambrian low-grade metamorphic rocks deformed in the Taconian Orogeny. The Maritime sedimentary basins of Carboniferous, Permian, and Triassic strata that rest on a basement of older Paleozoic and Late Proterozoic rocks presumably also underlie parts of the Gulf of St. Lawrence and Atlantic Continental Shelf. Currently, there is moderate exploration activity, mainly offshore.

In Ontario the oil industry began with the utilization of oil from seepages occurring in glacial deposits along Black Creek in Lambton county. The first wells that were drilled into bedrock formations at Oil Springs were highly successful and many flowing wells were soon completed. After the discoveries at Petrolia in 1861 and Bothwell in 1862, the output of oil steadily increased until a peak of 829,000 barrels was recorded in 1894. The annual yield then declined to 113,000 barrels in 1945, but recent discoveries have increased production to 1,323,781 barrels during 1966 valued at $4.5 million (Table VII-1).

In 1889, the natural gas industry was initiated in Ontario with discovery of the Kingsville field in Essex county. Since then numerous gas fields have been discovered and these now occur over a wide area extending from southern Lake Huron to Niagara River. Several fields also extend for considerable distance beneath the waters of Lake Erie. In 1966 a total 15,537,157 Mcf of gas was produced, having a wholesale value in excess of $5,896,662.

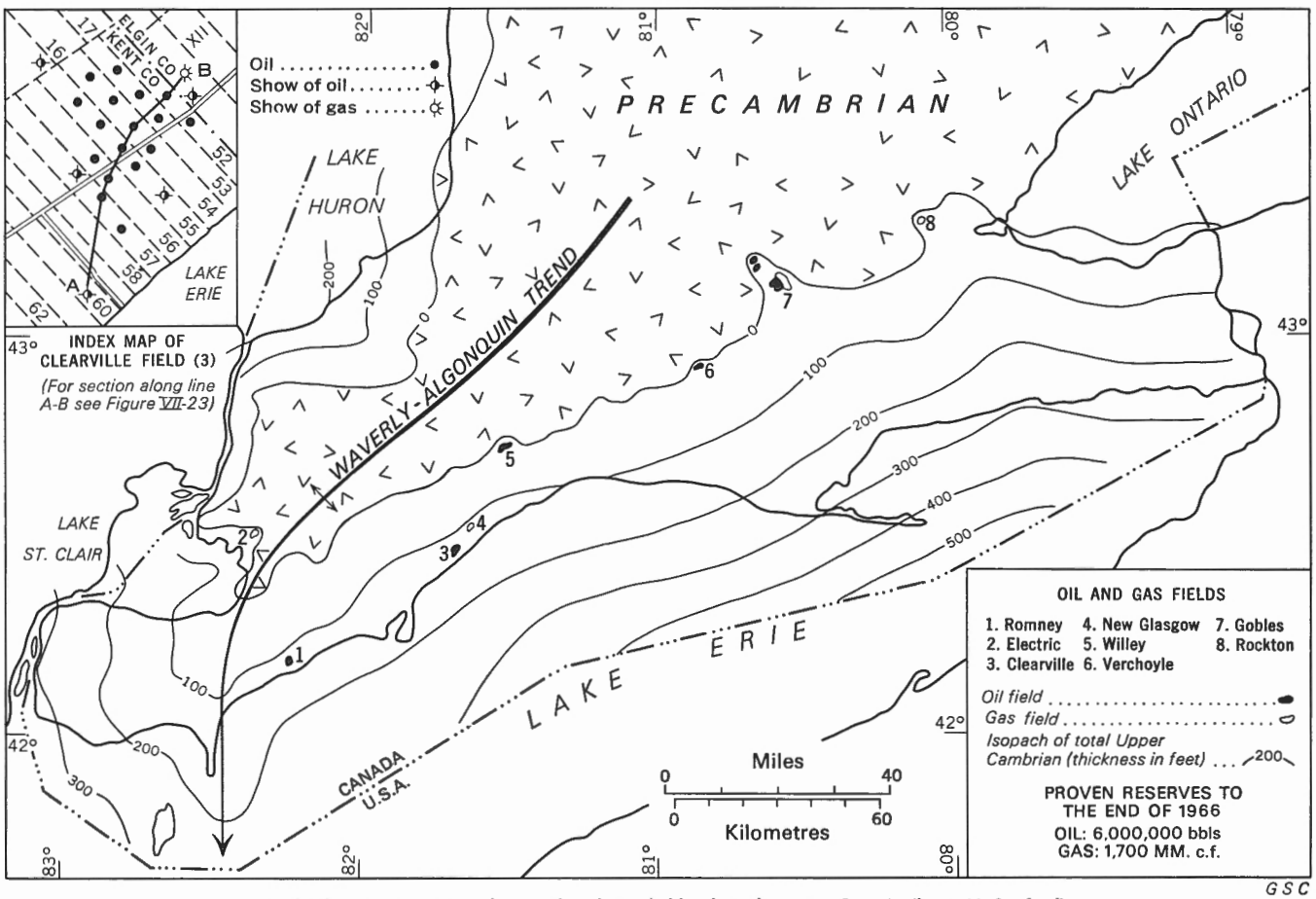


FIGURE VII-22. Upper Cambrian oil and gas fields of southwestern Ontario (by B. V. Sanford).

In New Brunswick drilling for oil commenced about the year 1858, but it was not until 1909 that the Stony Creek field was discovered near Moncton. During the peak years of 1913 and 1941 the field produced 856,156 Mcf of gas, and 33,359 barrels of oil, respectively. It has gradually declined to 97,403 Mcf of gas and 6,836 barrels of oil in 1966.

Southwestern Ontario Oil and Gas Fields

As of the end of 1966, a total of 58,400,000 barrels of oil and 858,150,000 Mcf of gas have been discovered. The first oil production was obtained from the Devonian and these rocks have continued to be the most important. Of lesser importance, although accounting for an appreciable percentage of the ultimate reserves, are rocks of Silurian and Cambrian age. Most gas is from the Silurian but some is produced from Cambrian and Ordovician rocks as well.

Cambrian Oil and Gas Fields

The Cambrian rocks of southwestern Ontario are potential oil and gas reservoirs throughout their entire area of distribution, but discoveries to date are confined to the southern flank of the Algonquin Arch bordering Allegheny Basin (Fig. VII-22). Deep drilling has delineated eight oil and gas fields with estimated ultimate reserves of 6 million barrels of 38° API gravity oil and 1.7 billion cubic feet of gas. The most favoured exploration target is the erosional edge of the sandstones and dolomites of the Potsdam and Theresa Formations, respectively, where the fields lie in embayments on the irregular surface of the Precambrian basement and are overlapped by Middle Ordovician limestones. Five accumulations have been discovered so far in such traps: the Electric, Willey, Verchoyle, Gobles, and Rockton fields. In addition, three fields, the Romney, Clearville, and New Glasgow, have been discovered downdip from the Cambrian edge in the interbedded dolomites and sandstones of the Theresa Formation. Marginal accumulations such as at Romney and New Glasgow occur in sandstone remnants on topographic highs on the Upper Cambrian erosion surface. Accumulation in the Clearville field is controlled largely by normal faults (Fig. VII-23).

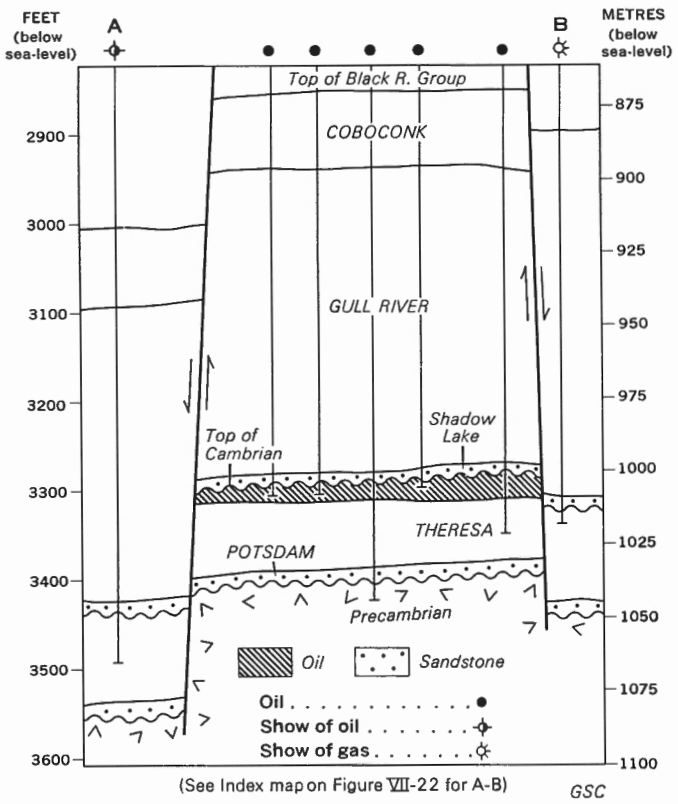


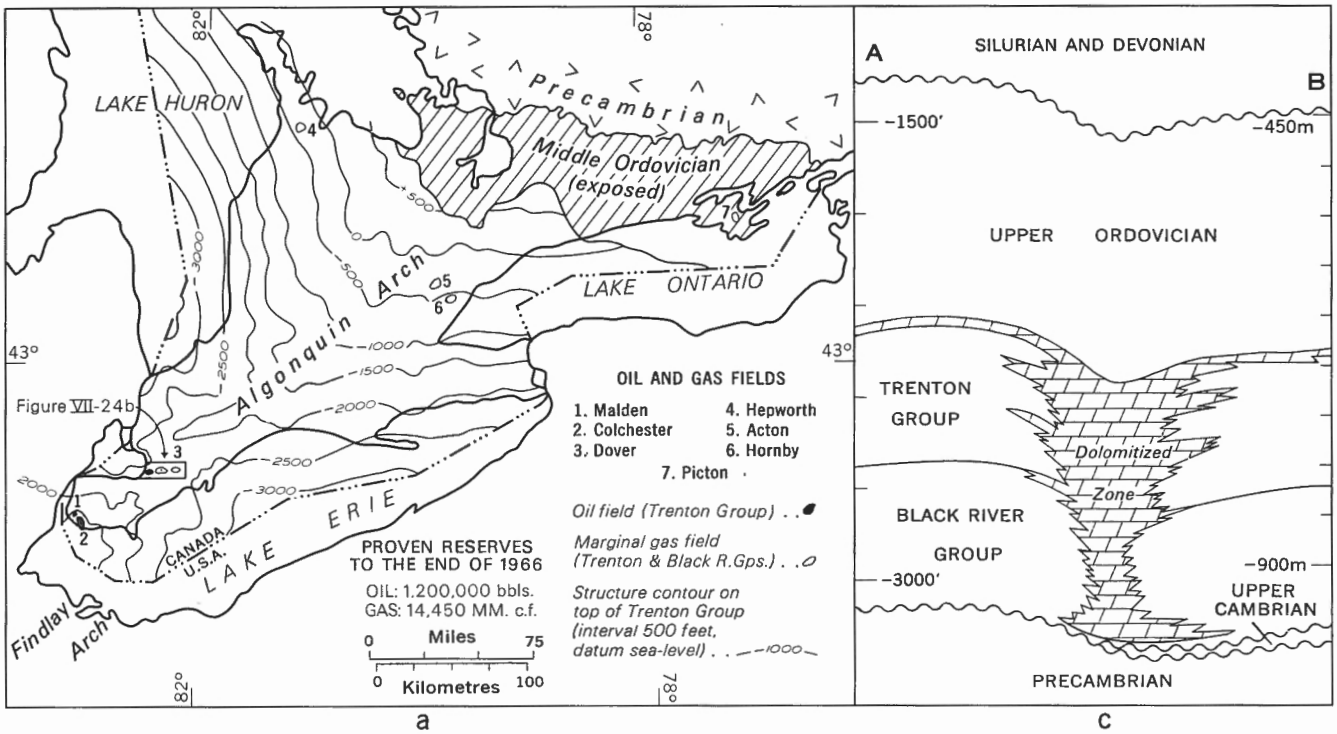
FIGURE VII-23. Upper Cambrian, Clearville oil field, Ontario (after W. E. Koepke).

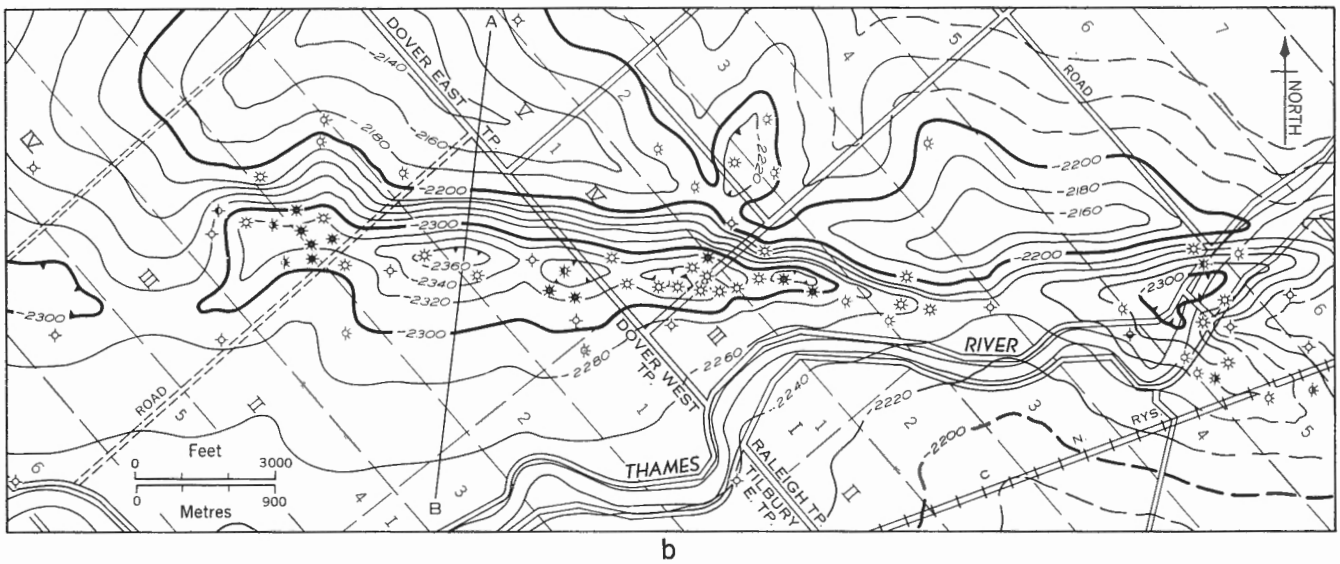
Oil was initially discovered in Cambrian rocks in 1923 at the Romney field, but it was the Gobles field, discovered in 1960, that provided the stimulus for the current deep-drilling program in Ontario. The Gobles field and subsequent discoveries such as Clearville had a combined output of 329,970 barrels of oil in 1966. This constituted 25 per cent of the total Ontario production during that year. In addition, 82,816 Mcf of gas was produced from the Gobles field.

Ordovician Oil and Gas Fields

Middle Ordovician carbonates of the Trenton and Black River Groups have long been regarded as potential oil and gas reservoirs in Ontario, but to date only three fields have been developed (Fig. VII-24a). These have an ultimate yield of 1.2 million barrels of 39° API gravity oil, and 14,450,000 Mcf of gas. Small quantities of oil and gas have been encountered in Middle Ordovician limestones on Manitoulin Island, and in Bruce, Halton, and Picton counties.

The Malden, Colchester, and Dover oil fields are unique structurally in that oil accumulation has taken place along the axis of an elongated syncline. The Dover oil and gas field discovered in 1917 is typical (Fig. VII-24b, c). The structure contours show the configuration of the top of the Trenton Group, and the typical elongated depression that coincides with the dolomitized sequence that extends the length of the field. In the structural depression the Black River and Trenton limestones are intensively dolomitized, a feature that has resulted from mass migration of magnesium-bearing solutions upward through fracture zones in the limestones and thence laterally along the base of the overlying Collingwood shale. The synclinal structure, although partly attributable to faulting, is due primarily to subsidence following the leaching effects of the interstitial moving water. The accumulation of the oil and gas, which coincides with the synclinal structure, is controlled by the porosity development in the dolomitized zones; these are considerably more developed in the bioclastic units of the Trenton Group, particularly the Sherman Fall Formation. To date all the Trenton production in Ontario is confined to dolomitized fracture systems that were induced by uplift





Well, oil and gas producer

Well, gas producer

Well, gas producer with show of oil

Well, with show of gas

Well, with show of oil

Well, with show of gas and show of oil

Well, non-productive

Structure contour on Cobourg Formation (interval 20 feet, datum sea-level)

Lot and concession number. . . . . 4, III

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FIGURE VII-24. Middle Ordovician oil and gas fields of southwestern Ontario (by B. V. Sanford). (a) Distribution. (b) Structure contours on Middle Ordovician Trenton limestones in the Dover field. (c) Cross-section along line A–B through Dover field.

of the Findlay Arch. Consequently those areas of western Lake Erie, Essex, and Kent counties that are in close proximity to this arch are most favoured for future exploration.

During 1966, 42,008 barrels of oil and 34,263 Mcf of gas were recovered from Middle Ordovician strata, representing 3 per cent and 0.3 per cent, respectively, of the total annual yield.

Silurian Oil and Gas Fields

More than sixty Silurian oil and gas fields have so far been discovered in Ontario (Figs. VII-25, VII-29), and these will ultimately yield 842 billion cubic feet of gas and 8.7 million barrels of 36° API gravity oil. The most important reservoirs are the Guelph bioherm reefs that have a wide distribution along the eastern margin of Michigan Basin (Fig. VII-26). The largest and most productive of these are patch reefs such as those at the Kingsville, Mersea-Leamington, Tilbury, and D'Clute fields. They occur along the inner margins of the Guelph barrier reef complex. The largest of this group, the Tilbury reef (Fig. VII-27), was discovered in 1906, and accounts for nearly half of all the gas produced in Ontario from all sources. Although structural closure on the field is only about 160 feet, the reef is productive throughout an area of 38,000 acres, nearly half of which underlies Lake Erie.

In the lower part of Michigan Basin, pinnacle reefs account for a substantial percentage of the rest of the Ontario oil and gas reserves. These reservoirs have a gross pay section of as much as 300 feet, and are productive over areas varying from 300 to 500 acres. Of the forty-three pinnacle reefs so far discovered, some twenty-five are productive, most of which are located in Lambton county. Of these, twenty contain commercial volumes of gas, three contain oil, and two contain both oil and gas. The non-productive reefs are either filled with salt water or have no effective porosity, because they are plugged by salt and anhydrite. A typical reef is the Dawn 156 field (Fig. VII-28); discovered in 1956, it will ultimately yield a total of 26 billion cubic feet of gas. Also within the pinnacle reef belt are a number of low relief biohermal structures that generally have less than 100 feet of structural closure. Several of these contain commercial volumes of oil and gas, but most have proven to be non-productive.

Closely associated with the Guelph bioherm reefs are the oil and gas fields in the carbonates of the A-1 and A-2 units of the Upper Silurian Salina Formation. These beds are locally productive where they formed with synchronous drape over the patch reefs. They are considerably more productive (the A-1 unit in particular) in the lower part of the Michigan Basin where they flank the pinnacle reefs. The Salina A unit carbonates are also locally pro-

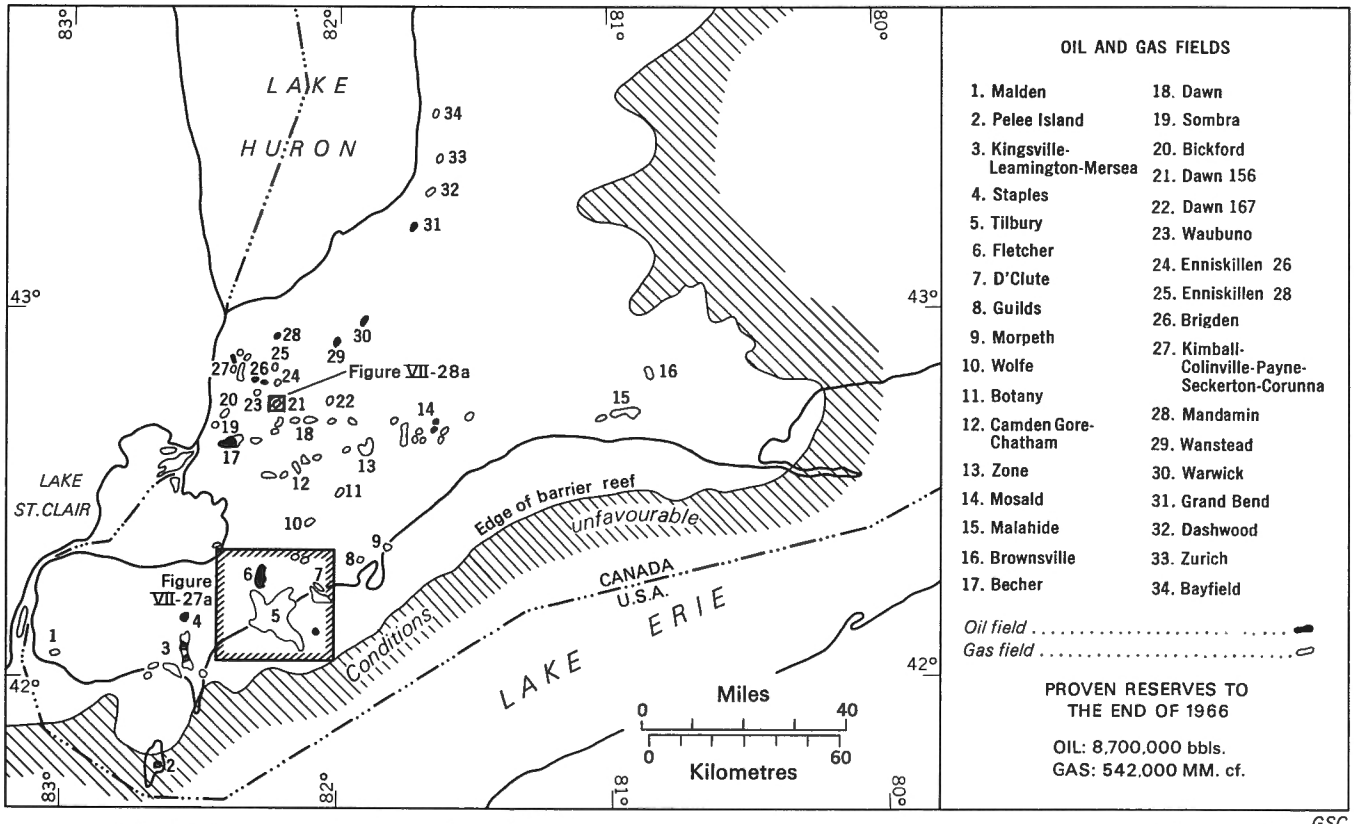


FIGURE VII-25. Principal oil and gas fields in the Silurian, Salina, and Guelph Formations of southwestern Ontario (by B. V. Sanford).

ductive in anticlines and domes that have resulted from normal faulting. Salina and Guelph production in 1966 was 11,441,937 Mcf of gas and 353,909 barrels of oil. This represents 74 per cent and 27 per cent, respectively, of the total gas and oil production in the province during that year.

The Silurian reefs of southwestern Ontario have a twofold importance, for once depleted of their primary production they are utilized as gas storage reservoirs. The storage reservoirs are filled during the summer, and are drawn upon in the winter months when requirements in Ontario and western Quebec exceed the combined local

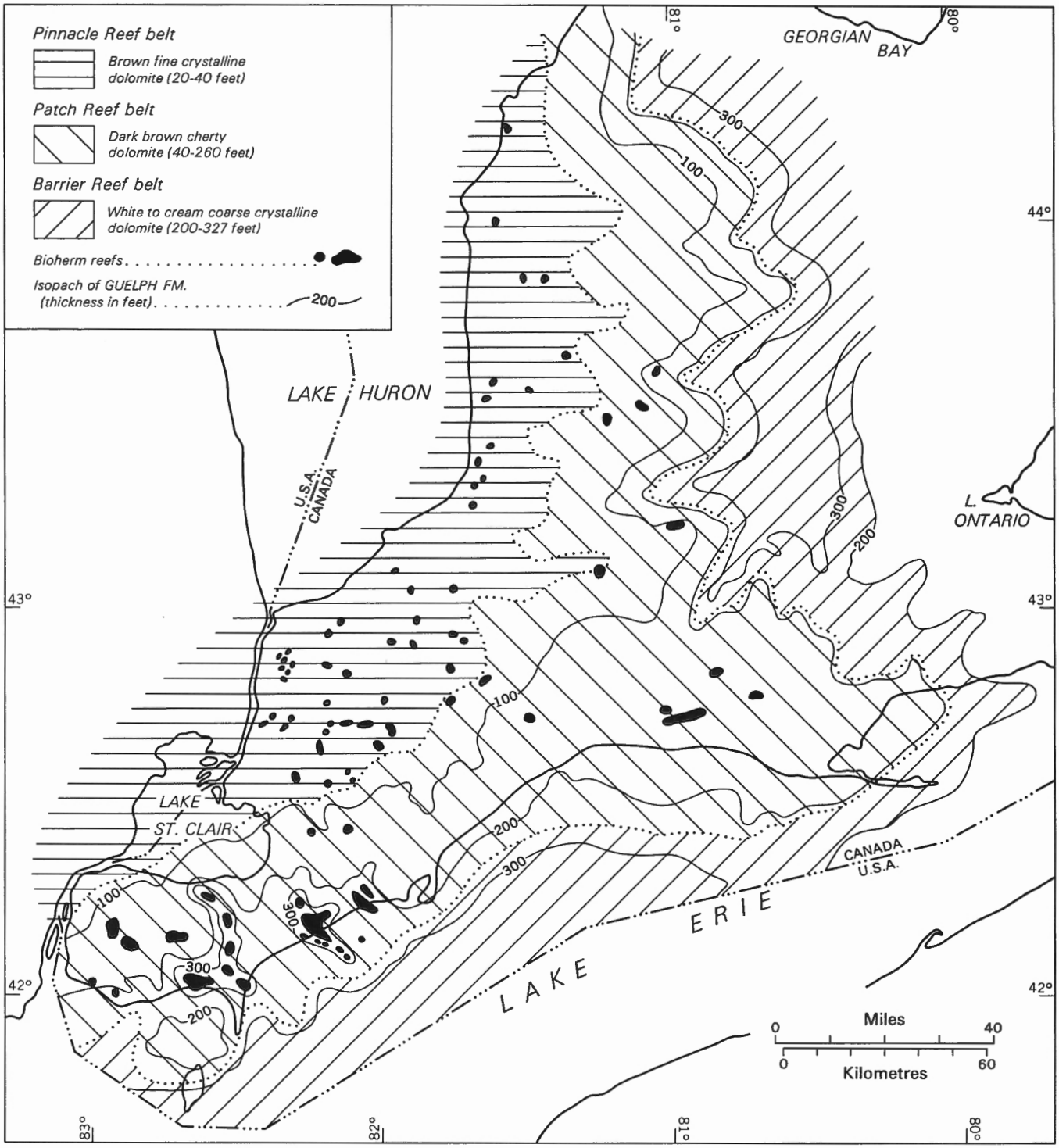


FIGURE VII-26. Facies of the Silurian Guelph Formation, southwestern Ontario (by B. V. Sanford).

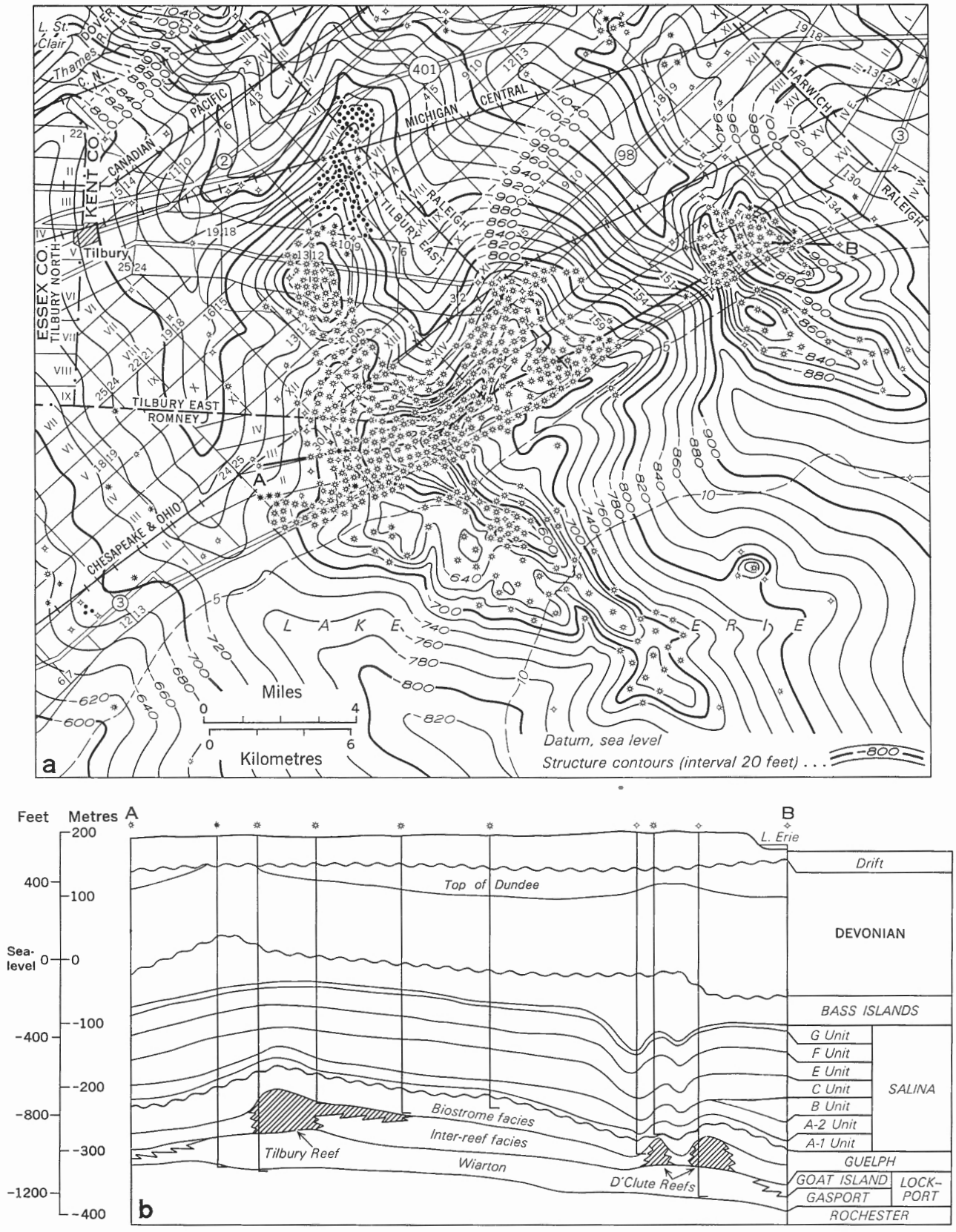


FIGURE VII-27. The Tilbury and D'Clute reefs in the Silurian Guelph Formation, Ontario (by B. V. Sanford). (a) Structure contours on top of the Guelph Formation. (b) Cross-section along line A–B.

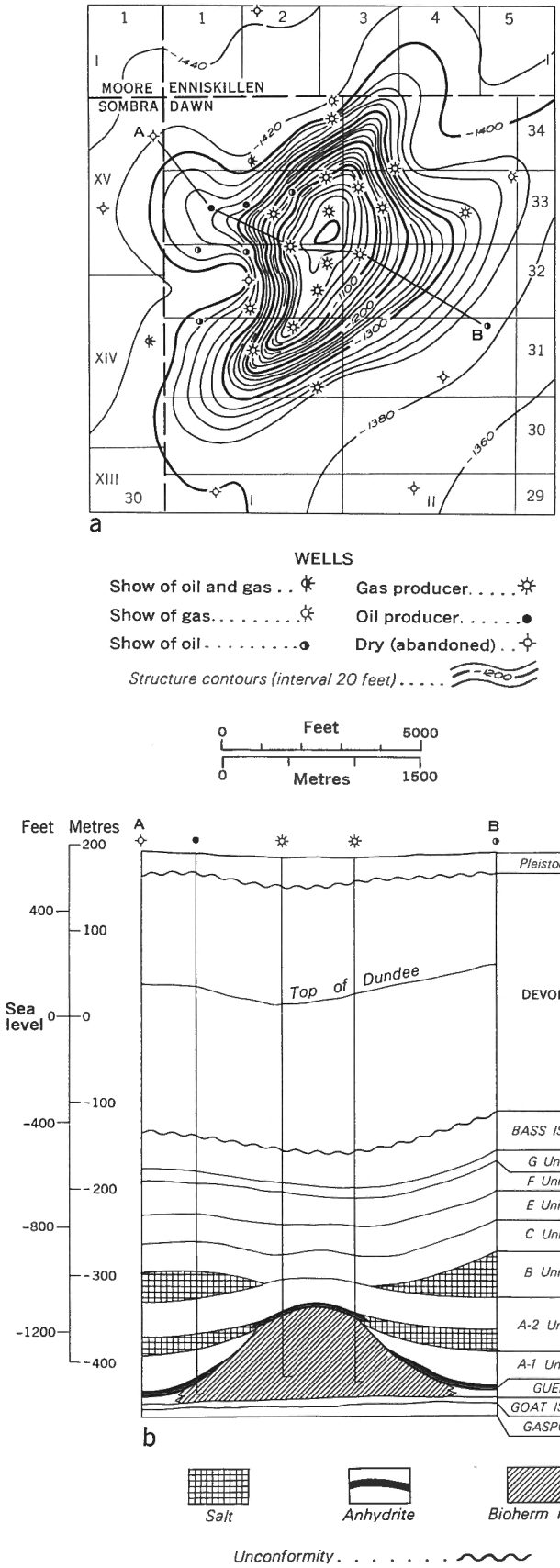


FIGURE VII-28. The Silurian Dawn 156 reef, southwestern Ontario (by B. V. Sanford). (a) Structure contours on top of the Guelph Formation. (b) Cross-section along line A–B.

production and throughput of the pipeline from western Canada. So far, nine pinnacle reefs and two Salina pools have been designated as storage reservoirs, providing a capacity of about 100 million cubic feet of natural gas.

Accounting for an appreciable percentage of current gas production are the sandstone reservoirs of the Whirlpool, Grimsby, and Thorold Formations in the Niagara Peninsula (Fig. VII-29). Four large fields have been developed gradually since the first discovery in this region in 1889: the Bayham, Norfolk, Haldimand, and Welland fields. Their combined area totals 356,460 acres on land and an additional 32,560 acres are now proven productive offshore in Lake Erie adjacent to the Haldimand and Norfolk fields (Pl. VII-7). The fields lie on the south-dipping, northern flank of the Allegheny Basin. Accumulation of the gas is mainly the result of permeability pinchout and is in no way related to local variations in regional dip. The producing formations consist of orthoquartzitic sandstones, and for the most part are rather poor reservoirs. They are extremely fine grained, and due to the advanced state of secondary quartz overgrowths their primary porosities and permeabilities have been considerably reduced. These fields yielded 3,977,142 Mcf of gas in 1966 which represents 26 per cent of the total Ontario production for that year.

Devonian Oil Fields

The distribution of Middle Devonian oil fields in Ontario is confined to an area of about 1,000 square miles extending from the southern extremity of Lake Huron to Lake Erie (Fig. VII-30). The eighteen principal fields discovered to date have an ultimate yield of 42,500,000 barrels of 33° API gravity oil. Accumulation is confined to domes in which the reservoir rocks of the Dundee and Lucas Formations have been locally dolomitized and deformed because of the solution and removal of the underlying Upper Silurian Salina salts. The series of dome structures that underlie the Petrolia region of Lambton county provide good examples of post-Devonian salt leaching. In this area, due to solution collapse, the northwestward regional dip of Middle Devonian carbonate rocks has been reversed along the southern and eastern margins of the field, resulting in structural closure. The Petrolia and Oil Springs fields have produced continuously since their discovery and account for more than half the oil produced to date in Ontario. These fields combined with the more recently discovered Rodney field produced 606,242 barrels of oil in 1966; this represents 45 per cent of the total annual yield during that year.

Quebec Sedimentary Basins

Quebec Basin and Ottawa Embayment

Approximately one hundred and eighty-five exploratory wells have been drilled at widely separated localities

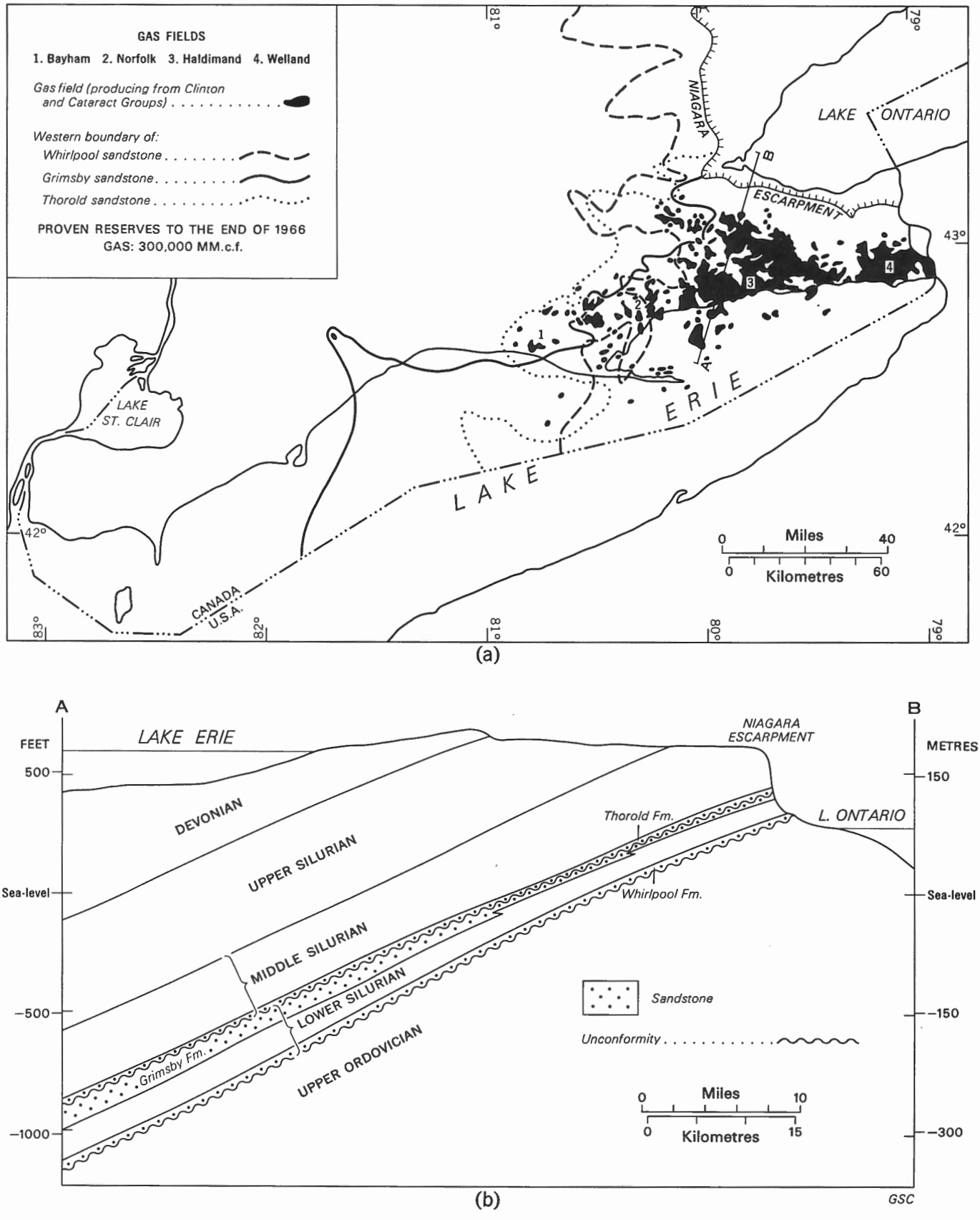


FIGURE VII-29. Gas fields in the Silurian Clinton and Cataract Groups (by B. V. Sanford). (a) Distribution of fields and limits of producing sandstones. (b) Cross-section along line A–B.

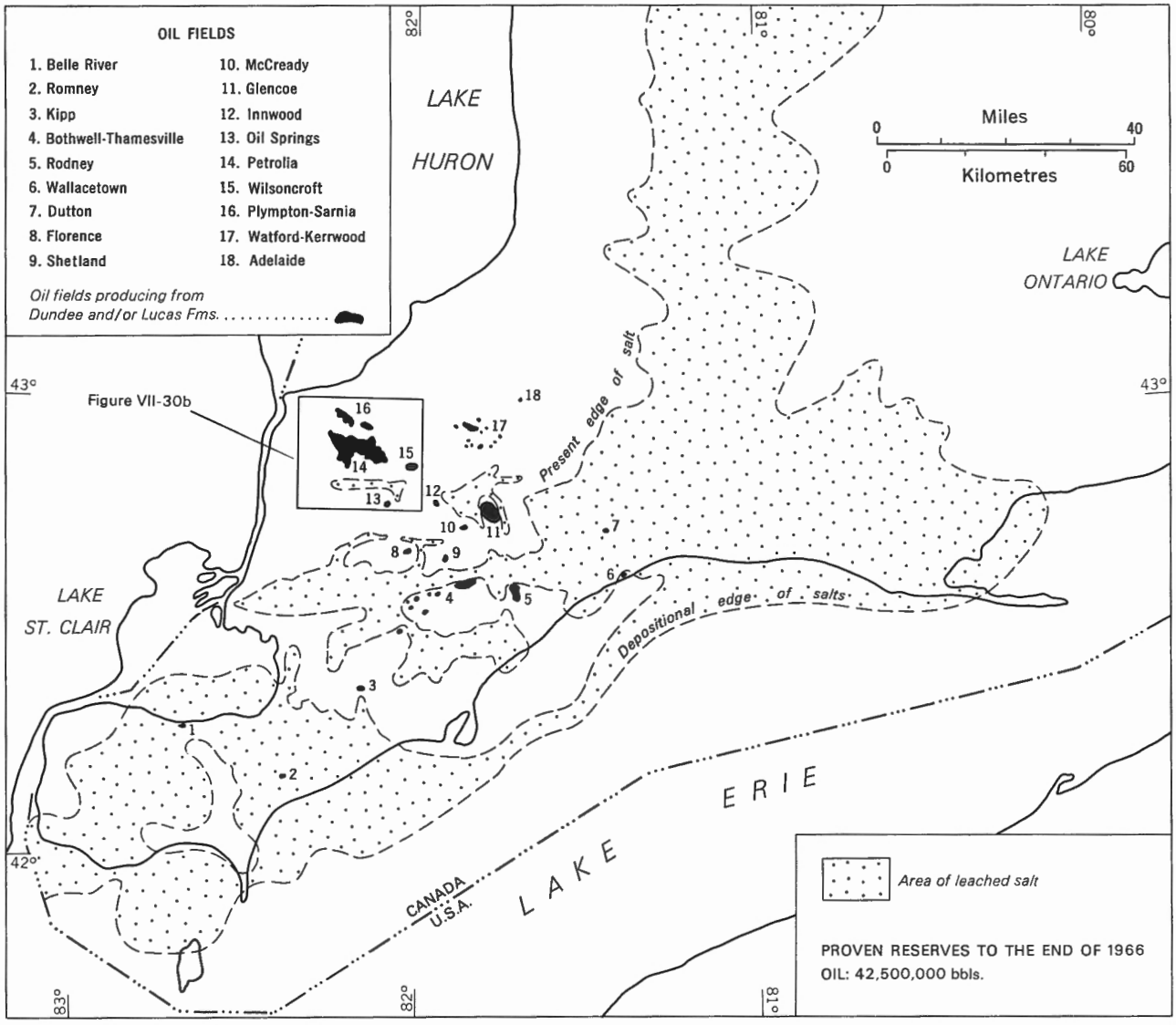


FIGURE VII-30. Devonian oil fields of southwestern Ontario (by B. V. Sanford). (a) Distribution of fields and relationship to areas of leached Silurian salt. (b) Structure contours on top of the Middle Devonian Dundee Formation, Oil Springs and Petrolia fields. (c) Cross-section along line A–B.

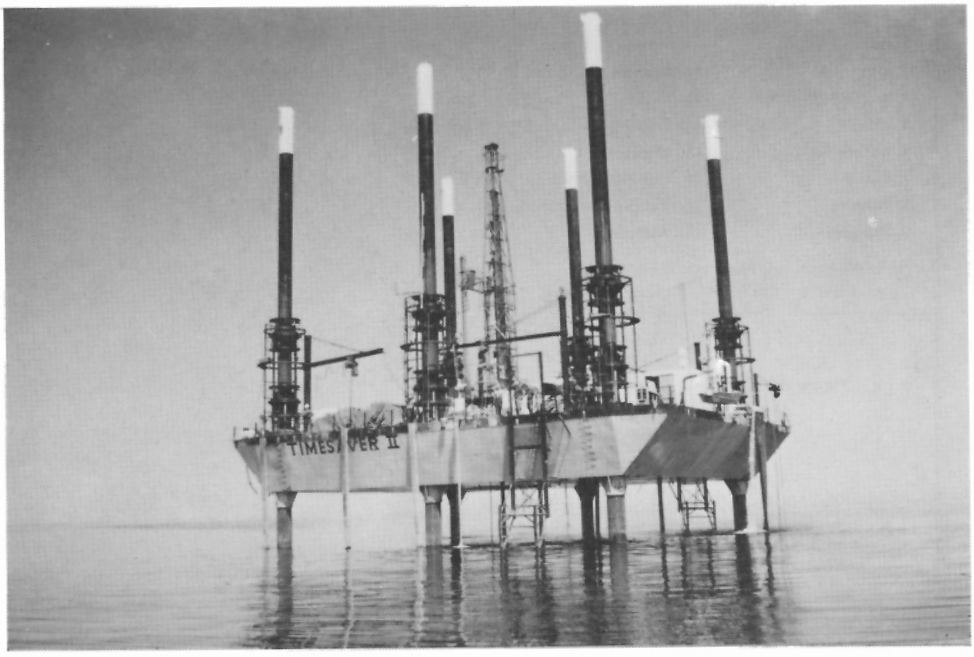


PLATE VII-7

Drilling barge 'Timesaver II' on location in eastern Lake Ontario (offshore extension of Silurian Haldimand gas field). The six hydraulic jacks lift barge above wave level to serve as a drilling platform.

in the Ottawa Embayment and Quebec Basin, none of which was successful in finding commercial quantities of petroleum or natural gas. Of the twenty wells drilled in the Ottawa Embayment, four were completed in basement rocks and ten tested only the Trenton and Black River Groups. Showings of gas have been reported in various parts of the stratigraphic column, mainly the Trenton Group, and in the overlying marine shales of the Billings and Carlsbad Formations. Showings of gas were also locally encountered in surficial deposits in an area underlain by bituminous shales. In the Quebec Basin, more than one hundred wells have been completed to depths in excess of 750 feet; only twelve of these were completed to basement. Much of the deep drilling is concentrated along the St. Lawrence River, and as yet no tests to the basement have been drilled in the deeper parts of the basin. Oil and gas shows have been recorded from the Upper Cambrian Potsdam sandstone; the Ordovician, Beekmantown, Black River, and Trenton carbonates; and from sandstones in the Upper Ordovician marine shales. Many shallow holes drilled for water have encountered substantial gas flows. The gas is commonly found at the contact between the surficial deposits and bedrock surface, generally shales of the Utica or Nicolet River Formations. It also occurs in porous layers of sand within marine clay.

Anticosti Basin

Petroleum seepages were known as early as 1812 on the west coast of Newfoundland in the vicinity of Parsons Pond, St. Paul's Inlet, and on Port au Port Peninsula. Approximately forty wells have been drilled since 1867, ranging from 300 to 4,000 feet in depth. Production was reported at 1 to 6 barrels of 33° API gravity. The reservoirs in the Port au Port wells were porous limestone intercalated with the intricately folded shales of the Lower Ordovician Humber Arm Group. The oil-bearing strata at Parsons Pond and St. Paul's Inlet were the steeply dipping dolomites of the Lower Ordovician St. George Group.

Since 1963, five stratigraphic test holes have been completed on Anticosti Island to depths of 3,239 to 6,146 feet. All are in the northwestern part of the island, and with one exception terminated in crystalline rocks of the Precambrian basement. Shows of oil and gas were encountered in dolomites of the Lower Ordovician Romaine Formation in one well.

Gaspé Trough

The Gaspé Peninsula has long attracted attention as a potential oil-producing province. Seepages of oil were recorded as early as 1836 and about eighty-five wells were drilled between 1860 and 1966. Many are reported to have encountered small quantities of oil varying in specific gravity from 20° to 47° API, but no production of commercial significance has been obtained. Potential reservoir rocks are Silurian bioherm reefs and Lower and Middle Devonian limestones and sandstones. These strata were folded in the Acadian Orogeny and rest on a folded and metamorphosed sedimentary basement complex of Ordovician and Cambrian age deformed mainly by the Taconian Orogeny.

New Brunswick Oil and Gas Fields

The Stony Creek oil and gas field near Moncton is the only commercially productive field in the Appalachian Region of Canada. The field was discovered in 1909, and to the end of 1966 had yielded 697,251 barrels of 42° to 57° API gravity oil and 26,038,162 Mcf of gas. Production in 1966 was 6,836 barrels of oil and 97,403

Mcf of gas. Production is obtained from the early Mississippian Albert Formation (Fig. VII-31). The reservoir rocks consist of sandstone interbedded with grey, grey-green, and black shale; bituminous or calcareous shale; and some siltstone and limestone. The sandstone occurs in zones that vary in number from well to well and reach a maximum of about thirty. The zones are present in groups separated by 50 to 350 feet of predominantly non-bituminous shale. Six groups occur, but the main oil production is from the lower four. The field lies on a gently dipping monocline, the north limb of a syncline, and has a proven area of about 1,600 acres. Of approximately one hundred and forty-five wells drilled, one hundred and fifteen were successful. Although initial production of gas was as much as 5 million cubic feet a day, initial production of oil was small, averaging less than 3 barrels a day.

The Albert Formation contains oil shales at Rosevale and Albert mines in Albert county, and at Taylor village in Westmorland county. Diamond drilling was carried out in 1942 and more than three thousand analyses have been made of the oil content of the shale. The results obtained at Albert mines were the most encouraging. The shales assayed an average of 10.6 gallons to the ton to a depth of 400 feet. Locally the Albert Formation also contains the solid hydrocarbon albertite. The largest deposit at Albert mines was discovered in 1851 and mining was carried on for some 15 years. The material was originally thought to be coal, but subsequently it was found to occur as a vein injected into a fracture crossing the bedding of enclosing shales. The vein had an irregular strike, a steep dip, and was as wide as 28 feet, averaging 8 feet. It was followed underground to a depth of 1,400 feet and for a length of 3,000 feet. Over 200,000 tons of albertite was shipped to the United States, where it was used for the enrichment of coal gas, the yield being 14,500 cubic feet a ton.

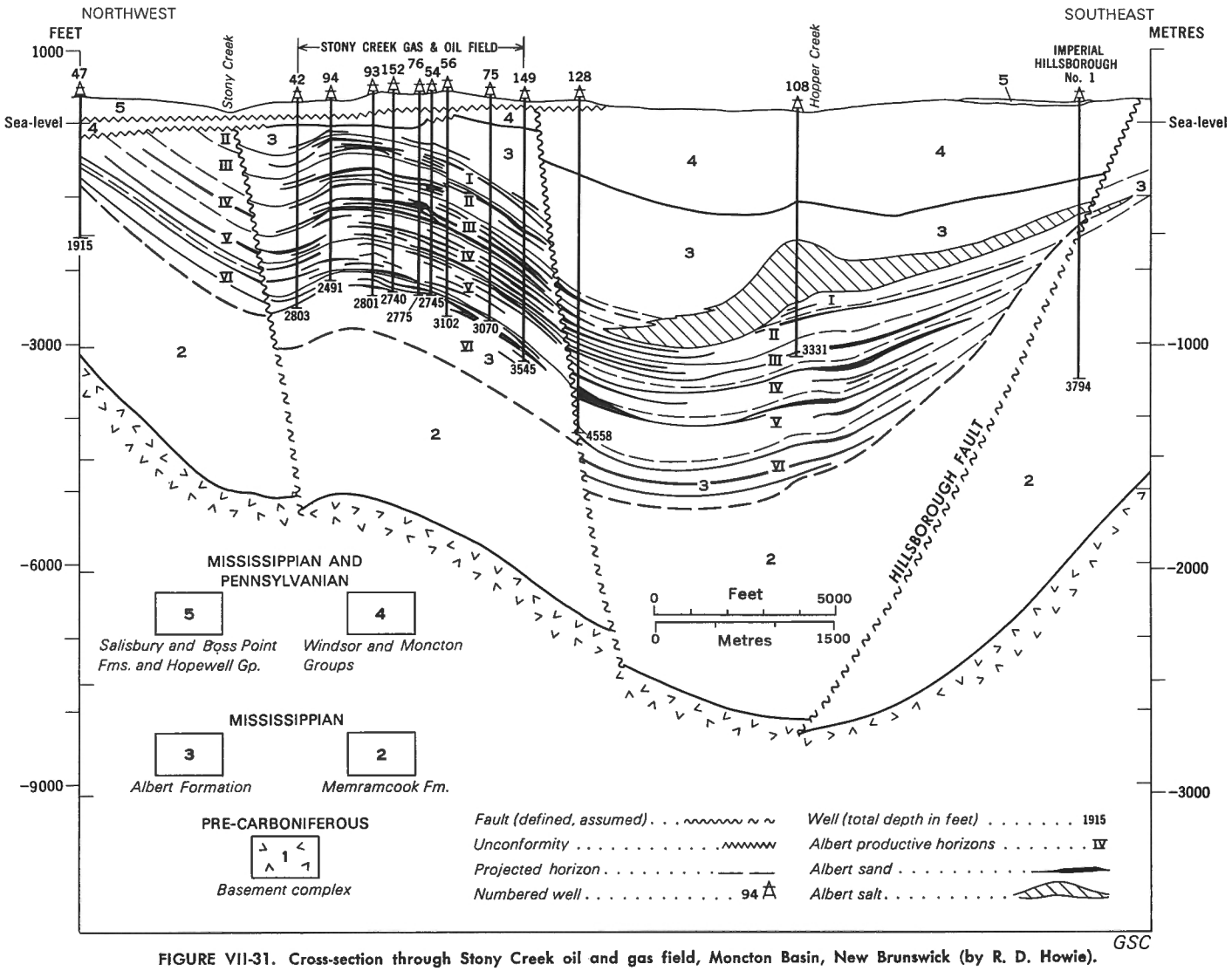


FIGURE VII-31. Cross-section through Stony Creek oil and gas field, Moncton Basin, New Brunswick (by R. D. Howie).

Coal

Coal has long been one of the most important mineral products of the Appalachian Region, and in 180 years of mining a grand total of 482 million tons has been extracted (Fig. VII-32). Although production has declined considerably during the past 25 years, in 1966 it amounted to 4,752,849 tons with a value of $59,411,101 (Table VII-1). The production from Nova Scotia declined from a near record output of 7,735,783 tons in 1940 to 4,391,832 tons in 1959, and has remained at about this figure until now. During the top production years coal was extensively mined in seven separate coalfields of Nova Scotia, with the largest field at Sydney contributing 76 per cent. In 1966, however, this field produced 88 per cent of the total output, largely because of the greatly reduced scale of mining operations in nearly all the other six fields. On the other hand the output from the only producing field in New Brunswick has been almost doubled since 1940, from 530,468 tons to 1,003,362 in 1964, but it decreased to 898,315 tons in 1966. During the past 10 years Appalachian coal production has generally accounted for about 45 per cent of the total annual output in Canada. The coal is Pennsylvanian and of high volatile A or high volatile C bituminous rank. Only in the Pictou coalfield are some medium volatile bituminous coals also represented. The coal is used to manufacture metallurgical coke and gas, as a steam coal in industrial plants, for domestic heating, and for thermal power generation. About half the annual production is consumed in the Atlantic Provinces and the rest is shipped to Quebec and Ontario. The Sydney coalfield on Cape Breton Island and the Minto coalfield in New Brunswick are the main producers. Other main fields are those of Pictou and Springhill on the mainland of Nova Scotia, but their output has greatly diminished since 1956.

Coalfields of the Riversdale Group

The oldest productive coal measures belong to the Riversdale Group and are of Westphalian A age. They occur in the St. George's coalfield of southwest Newfoundland and in the St. Rose – Chimney Corner and Port Hood coalfields of Nova Scotia.

The *St. George's* field occupies a small saucer shaped basin with a diameter of about 10 miles. The coal-bearing section is 2,200 feet thick and contains four seams. These seams, which are not more than 4 feet thick, are dirty and contain shale partings. The strata are strongly faulted, resulting in truncated, steeply dipping seams with shattered coal; commercial exploitation has not been undertaken.

Near *Chimney Corner* on the west coast of Cape Breton Island, two seams of possible economic value lie near the top of a 500-foot-thick coal-bearing member of the Riversdale Group. The seams, which have been mined very little, are only 3 to 3½ feet thick at the outcrop, dip steeply seaward, and their reserves are largely confined to an area under the sea.

The *St. Rose* field, 2 miles south of Chimney Corner, contains the same seams, but a small down-faulted block separates the two areas. The seams are 5 and 8 feet thick and occupy a land basin that measures only 1 mile by 2 miles. A small, but efficient and continuous operation has been in progress on the 8-foot seam since 1950.

The coalfield with the largest potential reserves in the Riversdale Group is situated at *Port Hood* on the west coast of Cape Breton Island. A syncline, striking parallel to the coast for about 5 miles, contains a coal-bearing section 2,000 feet thick. Two economical seams, 6 feet and 3½ feet thick, underlie 400 feet of coal measures that are concealed by the waters of Port Hood Harbour. Relatively small scale operations, on the "Six-Foot" or "Main" seam only have been carried out to date.

Coalfields of the Cumberland Group

The productive coal measures of the Cumberland Group are Westphalian B. They occur in the northern part of the Cumberland Basin of Nova Scotia and are mined at the Joggins, River Hebert, Springhill coalfields.

Near *Joggins,* in the seacliffs along the eastern shore of the Bay of Fundy, 5,000 feet of coal measures with no less than sixty-five separate coal horizons are exposed (Fig. VII-33). This section was first described in 1845 by Sir William Logan who pointed out the phenomenon of cyclic sedimentation so well displayed in these rocks. The coals are thin; only five seams attain mineable thickness; most average 3 feet or less. Inland the seams have been traced for a distance of about 19 miles, but they decrease in number and deteriorate in quality. At *River Hebert* only four seams are present, and two seams outcrop at Maccan and Chignecto. All seams have been mined at various times during the past 120 years, especially in the Joggins area where nearly all readily accessible coal has been extracted. By 1962 virtually all mining came to an end, except at River Hebert where one small mine is still operating.

The *Springhill* coalfield lies on the southern limb of the syncline that separates it from the Joggins–Chignecto coal area, but the exact stratigraphic relationship between the coal-bearing members of the two fields is not known with certainty. As a result of recent studies based on correlations made with fossil plant spores, they are considered to be contemporaneous, although individual seams may be different (Fig. VII-33). At Springhill the section is 2,600 feet thick and contains thirty-nine coal horizons, five of which attain an economical thickness of between

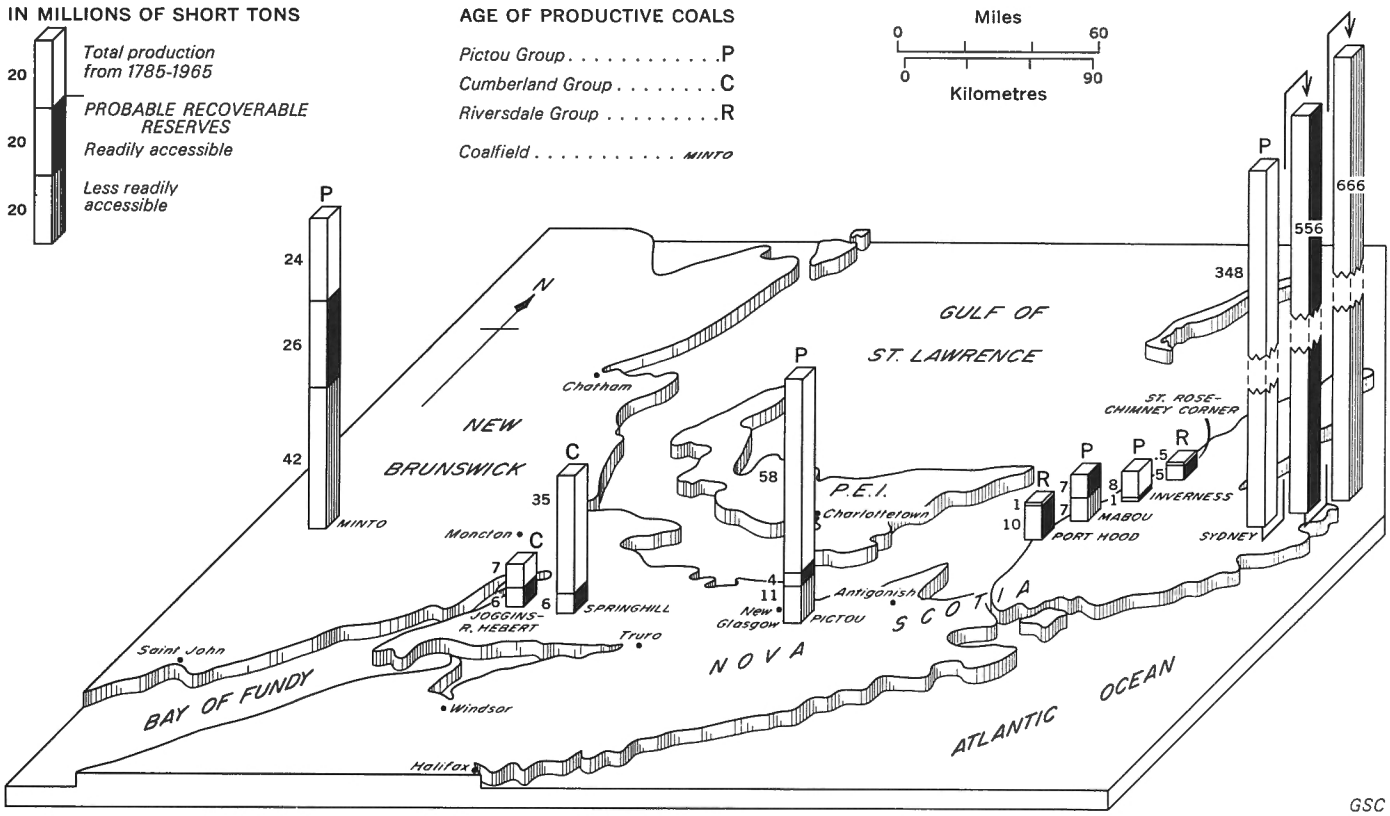


FIGURE VII-32. Location, production, and recoverable reserves of the coalfields of Southeastern Canada (by P. A. Hacquebard).

4½ and 10 feet in the area of good coal. This area is restricted to the centre of the field and extends westward from the outcrop. Along strike the seams deteriorate rapidly and become unworkable to the north and south. Coal has been mined in the area since 1870, and reached a maximum annual production of 733,329 tons in 1942. The largest producer was the No. 2 mine, which had the distinction of being one of the deepest coal mines in the world. It eventually reached a vertical depth of 4,340 feet below the surface. Production declined abruptly in 1957 and 1958 when the last two remaining collieries were closed after disastrous rock outbursts. In 1960 a small mine was opened in a hitherto unexploited part of the field. This part, however, has reserves of only a few million tons. Other large reserves still remain in the area of good coal, but these lie at a depth where extraction would be hazardous because of the outbursts or bumps. In the now-abandoned mines the bumps occurred below a depth of 1,000 feet and increased in magnitude in direct proportion to the increase in depth of overburden.

Coalfields of the Pictou Group

The youngest productive coal measures of the Appalachian Region belong to the Pictou Group and are Westphalian C and D. They occur in the Sydney, Inverness, and Mabou coalfields of Cape Breton Island; the Pictou coalfield of the mainland of Nova Scotia; and the Minto coalfield of New Brunswick.

The *Sydney* coalfield underlies a narrow fringe of lowland extending 31 miles along the coast of the Atlantic Ocean. It covers a land area of about 200 square miles and a large area where mining is carried out beneath the sea. The extent of this area is not known, but the farthest mine workings now extend nearly 4 miles from the shore. Nearly all the reserves lie in the submarine area and amount to 1,222 million tons of recoverable coal when calculated to a 5-mile limit from shore. These reserves represent 90 per cent of the total remaining reserves of the entire Appalachian Region (Fig. VII-32). The Pictou (Morien) Group in the Sydney coalfield reaches a maximum thickness of about 6,450 feet and contains twelve productive seams in the upper half of the section. The seams, 4 to 7½ feet thick, are thrown into broad open folds that trend northeasterly to easterly and pitch seaward at low angles. The prevailing dips throughout the field vary from 4 to 15 degrees, and serious structural difficulties have not been encountered in mining. Coal has been recovered at this field since 1720 when it was utilized by the French during the construction of the fortress of Louisbourg. Continuous, large-scale mining has been in progress during the past 140 years, reaching a peak annual production of 5,875,038 tons in 1940.

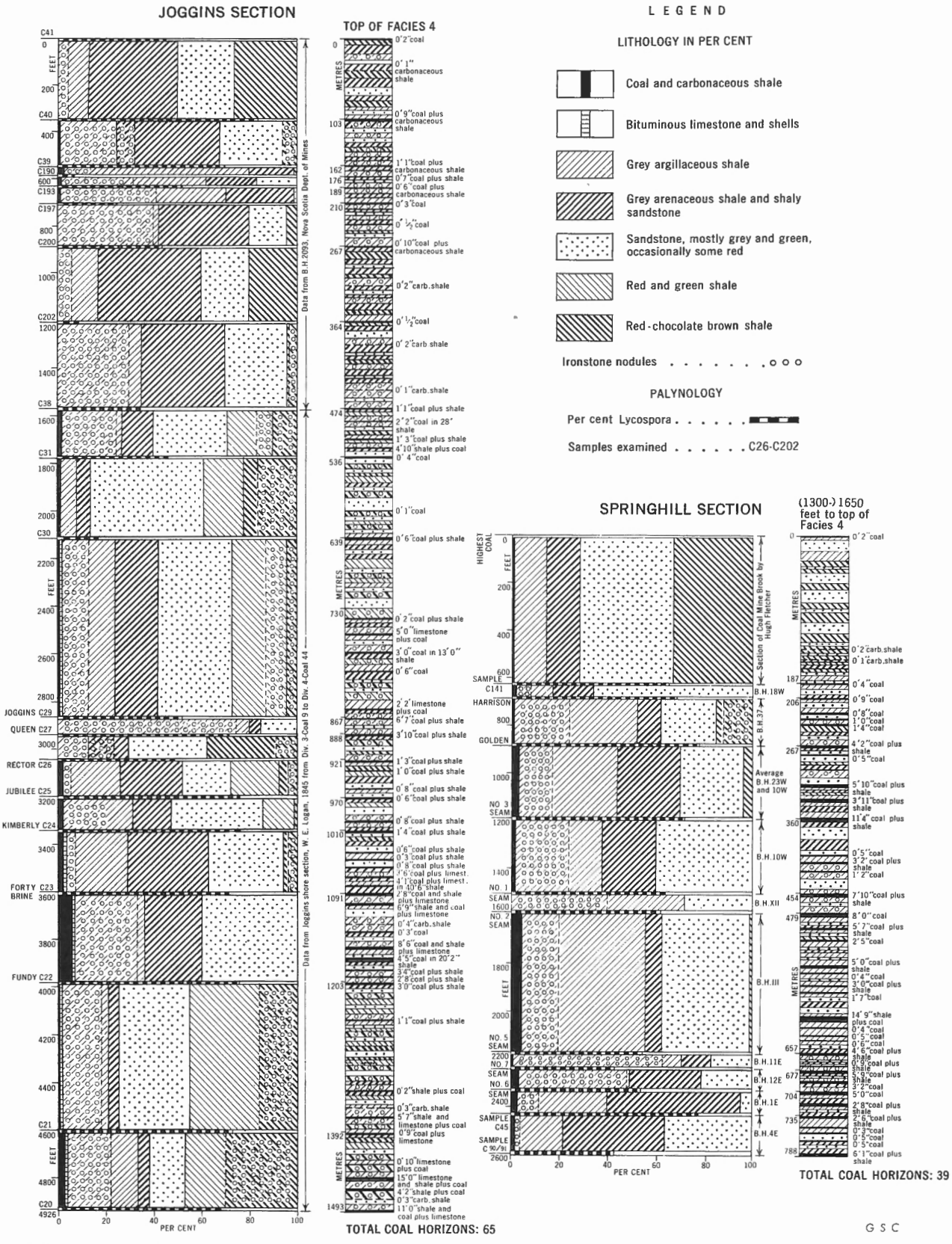
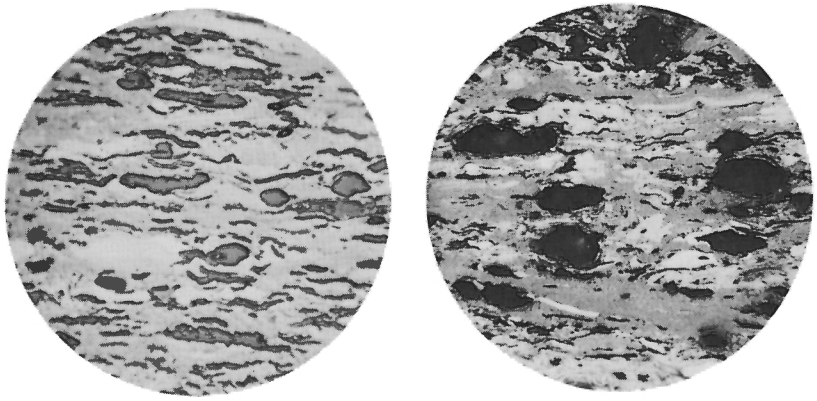


FIGURE VII-33. Lycospora distribution in several coal seams, and the lithology and stratigraphy of the coal-bearing sections at Joggins and Springhill, Nova Scotia (Hacquebard and Donaldson, 1964).



a b

PLATE VII-8

Photomicrographs of Carboniferous coal. (a) Well-preserved plant spores (dark grey, elongated bodies) in autochthonous coal from the Sydney coalfield. (Polished section perpendicular to bedding plane; magnification ×300; dry objective.) (b) Poorly preserved plant spores (thin, dark grey, linear forms) and detrital quartz grains (black, oval areas) in hypautochthonous coal from Pictou coalfield. (Polished section perpendicular to bedding plane; magnification ×215; oil-immersion objective.)

The deposition of the coal seams and accompanying fluvial and fluviolacustrine sediments of the Sydney coalfield took place in a valley-flat or flood-plain environment (Fig. VII-34). Normal-banded autochthonous coals accumulated in extensive peat bogs that were formed and buried where the vegetation grew. In such coals the plant entities are usually well preserved (Pl. VII-8a). The coal seams all rest on underclays with *Stigmaria* and persist for long distances with little variation in the thickness of individual coal benches. There is typical splitting and digitation of the coal by partings of clastic rocks that result from the interaction of fluviatile and peat bog depositional environments. Figure VII-34a shows the widespread distribution of five successive seams and their termination by splitting and gradual pinching out of individual coal benches. Changes in the groundwater table also had a pronounced effect on the type of peat that was formed because it affected the kind of vegetation that grew and the mode of its preservation. This is now evident in the vertical changes of petrographic composition and spore distribution within each seam (Fig. VII-34b). The presence of thin layers of durain (dull coal) that can be traced over long distances is considered a characteristic feature of coal seams that were laid down in a flood-plain environment.

The coals of *Inverness* and *Mabou mines* belong to two successive zones of the Pictou Group, those of Mabou mines being the oldest. In both fields the coal measures occupy small land areas but continue underneath the waters of the Gulf of St. Lawrence. The submarine areas may be continuous and may belong to one larger coal basin that extends along the coast for at least 13 miles. The section at Inverness measures 2,400 feet in the land area and contains four commercial seams that are from 3 to 13 feet thick; these seams have been largely depleted of recoverable coal. In only one seam hitherto not mined to any extent is a small reserve thought to be present. In 1961 virtually all mining came to an end. Peak annual production of 154,628 tons was reached in 1936. The known section at Mabou mines is 1,200 feet thick and contains six seams that are from 3 to 15 feet thick. There are also five seams, from 3½ to 11 feet thick, present in a faulted block that underlies the known portion. The land portion of this field is only a tenth of a square mile, but considerable reserves may occur offshore because of the great number of seams present. Only two seams are known that can provide ready access to this area. The workings of one seam were flooded in 1909 after only about 60,000 tons of coal had been extracted, although much development work had been carried out. On the other seam, which is 15 feet thick, very minor operations have been in progress from time to time; it constitutes the most important accessible reserve of the field.

The *Pictou* coalfield underlies an area of about 3 by 10 miles near New Glasgow, Nova Scotia, and in relation to its size, has been the most extensively exploited coalfield in Canada. Some 58 million tons have been mined over a period of about 150 years. A peak annual production of 828,368 tons was obtained in 1940. This has dropped considerably since 1956, and because of depletion the field has now reached its final stage of commercial operation. Structurally the Pictou coalfield is confined to a graben that is bounded by faults of large displacement. Within this fault block the coal measures lie in a number of open folds and become progressively younger from west to east. They reach a total thickness that is probably in excess of 8,500 feet. The section has as many as forty-five coal seams, eleven of which have been mined in three separate coal-producing districts; they range from 3 to 44 feet thick.

The Pictou coalfield is an excellent example of coal deposition in a narrow, intermontane lake basin. In this basin the fine clastic rocks with finely dispersed organic debris, such as the black shales, occupy a central position. They are flanked by areas of grey shales, which in turn are bordered by more sandy sediments. The coal seams reveal a similar picture, with clean, low-ash coal in the centre, and coarse high-ash coal at the periphery. The seams reach a great thickness, but are of limited extent

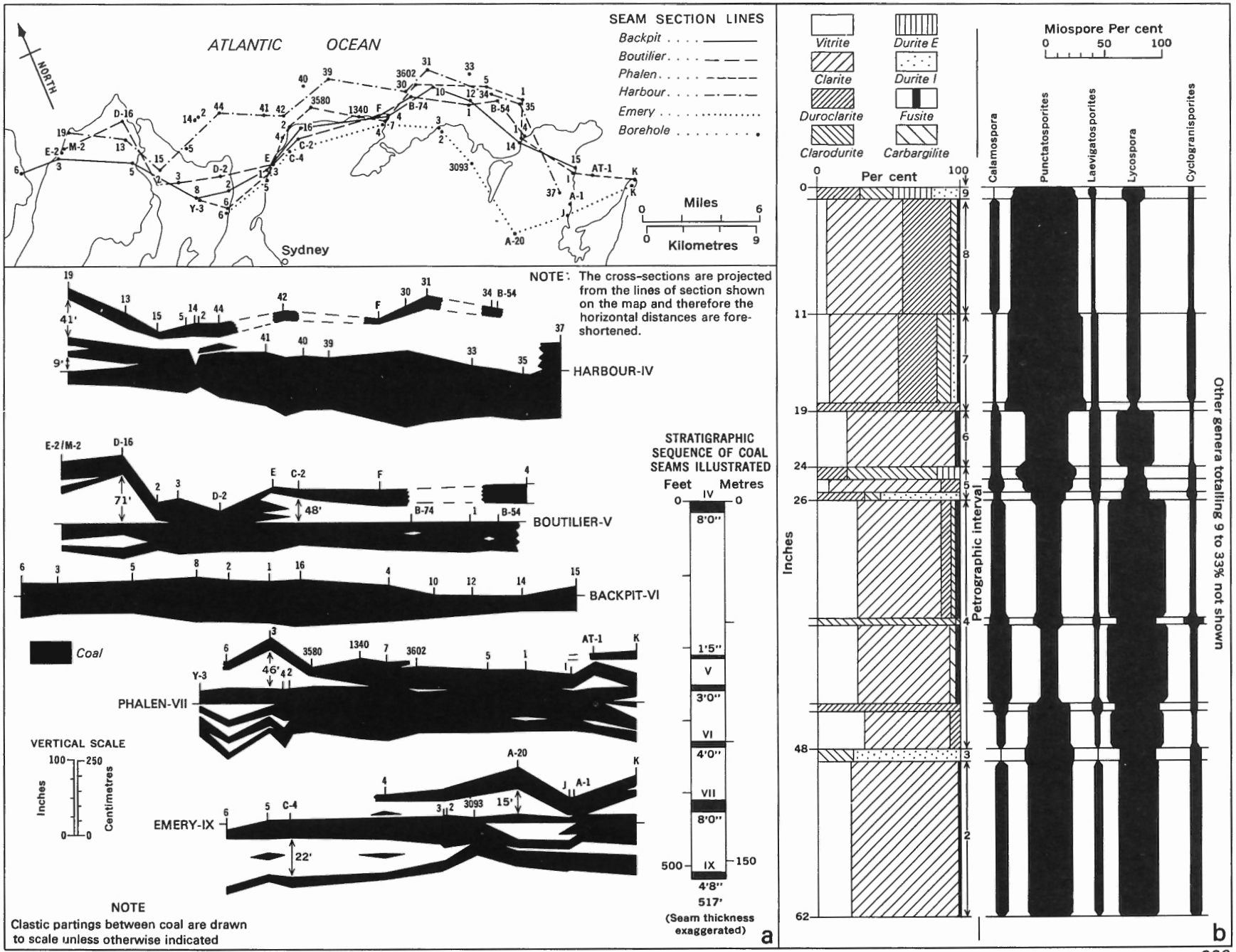


FIGURE VII-34. Flood-plain environment of coal deposition (by P. A. Hacquebard). (a) Cross-sections through five successive seams of the Sydney coalfield. (b) Palyno-petrographic seam profile, typical of the Sydney coalfield.

and terminate by lateral transition of coal into shale through zones of shaly coal and coaly shale (Fig. VII-35a). This type of facies change is typical of a limnic environment of coal deposition and is in marked contrast to the termination by splitting and digitation characteristic of a flood-plain environment. The Pictou coals are probably of drift origin, but the movement of the vegetal matter was likely restricted to the general area of plant growth, rather than being transported from outside the lake basin. Such coals are classed as hypautochthonous. They usually contain plant entities that are not well preserved and that often occur in association with detrital mineral matter (Pl. VII-8b). They are typically micro-banded, and apart from the pronounced variations in mineral matter, are of uniform petrographic composition between roof and pavement. Distinct durain bands, such as occur in the Sydney coals, are not present. The mode of preservation of the vegetal matter remained uniform throughout the life of the peat bog signifying that there were no long-lasting variations in the groundwater table. That the ecological conditions remained the same is also reflected in the remarkable constancy of the spore florules of successive benches of the same seam (Fig. VII-35b).

The *Minto* coalfield of New Brunswick occupies an area about 20 miles long and 8 miles wide. There are two coal-bearing members present; only the lower one, 100 feet thick, contains one productive seam. The mineable thickness of this seam varies from 12 to 36 inches, averaging about 18 inches; it is thickest in the southwestern section of the field and thins out in the northern and eastern parts. It occurs at shallow depth over much

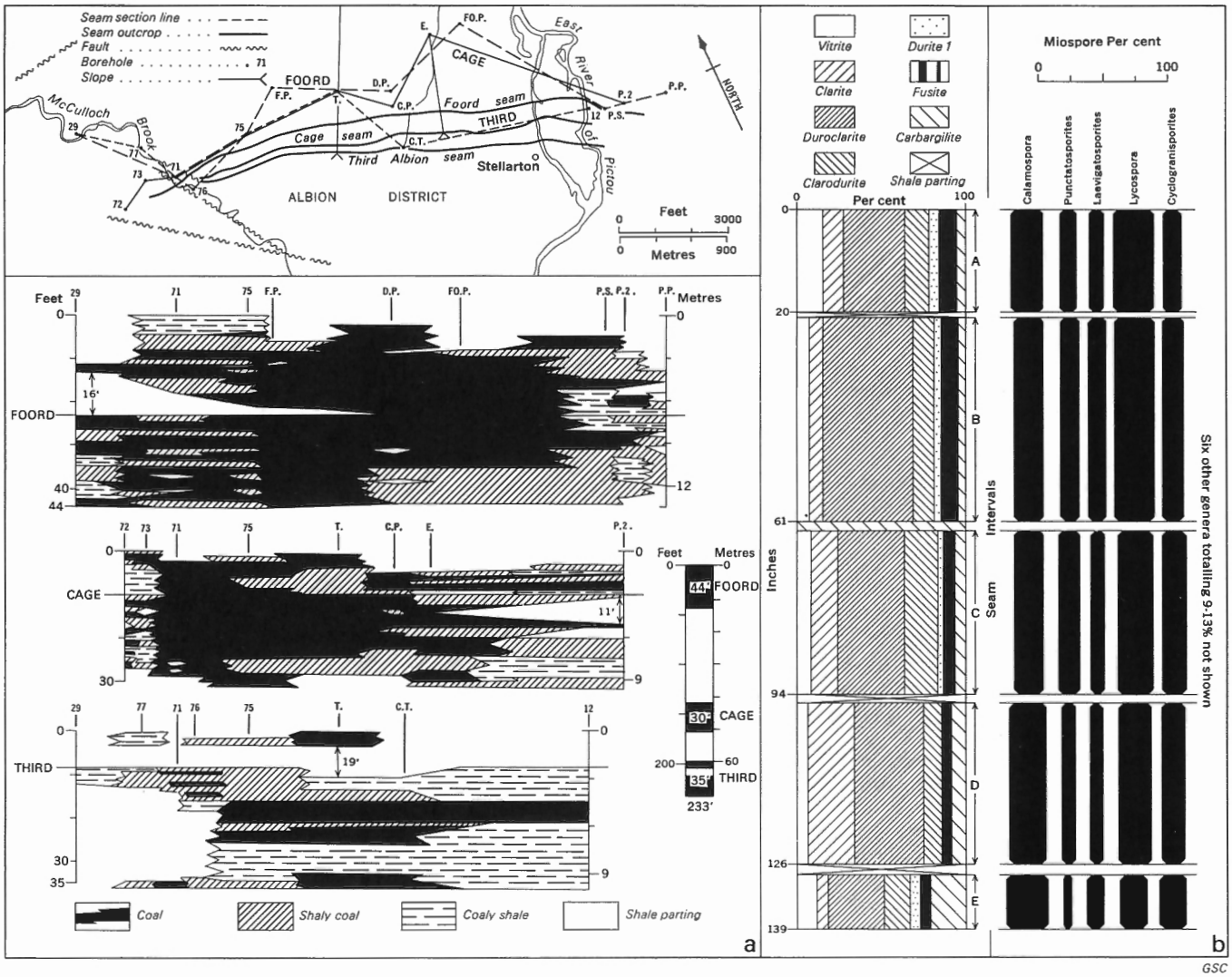


FIGURE VII-35. Limnic environment of coal deposition (by P. A. Hacquebard). (a) Cross-sections through three successive seams of Pictou coalfield. (b) Palyno-petrographic seam profile, typical of the Pictou coalfield.

of the area and is nearly flat lying. Approximately 85 per cent of the present production is by strip mining to a depth of about 70 feet. The remaining 15 per cent is extracted in underground workings to a depth of 125 feet. Since 1955 the annual output has remained fairly steady at between 800,000 and 1 million tons.

SELECTED REFERENCES

General

Abbott, D.
1965: The occurrence of economic minerals, rocks and fuels in New Brunswick—industrial and non-metallic, part A; metallic, part B; *N.B. Res. Productivity Council,* Record 2.

Baird, D. M., and Snelgrove, A. K.
1953: Mines and mineral resources of Newfoundland; *Geol. Surv. Nfld.,* Inform. Circ. No. 4 (revised).

Beland, J., Marleau, R., Perusse, J., and Duquette, G.
1962: Metallic mineralization in the Appalachians of southern Quebec; *Can. Mining J.,* vol. 83, No. 4, pp. 97–100.

Convey, J.
1957: The geology of Canadian industrial mineral deposits; *Commonwealth Mining Met. Congr., 6th,* Canada.

Dresser, John A., and Denis, J. C.
1949: Geology of Quebec; *Que. Dept. Mines,* Econ. Geol. Rept. 20, vol. III.

Fogwill, W. D.
1965: Mines and mineral occurrences map of the Island of Newfoundland; *Nfld. Dept. Mines, Agric. Resources,* Inform. Circ. No. 11.

Goudge, M. G., and Slater, R.
1966: Metallic mineral occurrences recorded in the province of Nova Scotia (to accompany mineral map of Nova Scotia); *N.S. Dept. Mines.*

Grenier, P. E., *et al.*
1963: Annotated bibliography of metallic mineralization in the Quebec Appalachians; *Quebec Dept. Nat. Resources,* Mineral Deposits Branch, Spec. Rept. S-72.

Toombs, R. B., and Janes, T. H.
1966: Canadian minerals yearbook—general review, 100 years of progress; *Can. Dept. Energy, Mines Resources, Mineral Resources Div.*

Metalliferous Deposits

Alcock, F. J.
1930: Zinc and lead deposits of Canada; *Geol. Surv. Can.,* Econ. Geol. Rept. No. 8.

Baird, D. M.
1954: The magnetite and gypsum deposits of the Sheep Brook–Lookout Brook area, Newfoundland; *Geol. Surv. Can.,* Bull. 27.
1960: Massive sulphide deposits in Newfoundland; *Trans. Can. Inst. Mining Met.,* vol. 53, pp. 39–42.

Boyle, R. W.
1963: Geology of the barite, gypsum, manganese, and lead–zinc–copper–silver deposits of the Walton–Cheverie area, Nova Scotia; *Geol. Surv. Can.,* Paper 62-25.

Boyle, R. W., and Davies, J. L.
1964: Geology of the Austin Brook and Brunswick No. 6 sulphide deposits, Gloucester county, New Brunswick; *Geol. Surv. Can.,* Paper 63-24.

Boyle, R. W., and Jambor, J. L.
1966: Mineralogy, geochemistry and origin of the Magnet Cove barite–sulphide deposit, Walton, Nova Scotia; *Trans. Can. Inst. Mining Met.,* vol. 49, pp. 394–413.

Cooper, J. R.
1936: Geology of the southern half of the Bay of Islands igneous complex; *Geol. Surv. Nfld.,* Bull. 4.
1937: Geology and mineral deposits of the Hare Bay area; *Geol. Surv. Nfld.,* Bull. 9.
1954: La Poile–Cinq Cerf map-area, Newfoundland; *Geol. Surv. Can.,* Mem. 276.

Davies, J. L., and Smith, R. N.
1966: Geology of the Brunswick No. 6 and No. 12 sulphide deposits: *In* Poole, *et al.,* Geology of parts of Atlantic Provinces; *Geol. Assoc. Can. – Mineral Assoc. Can. Guidebook,* Halifax, Nova Scotia, pp. 45–57.

Deschow, E.
1960: Geology, sulphur isotopes and the origin of the Heath Steele ore deposits, Newcastle, New Brunswick; *Econ. Geol.,* vol. 55, pp. 539–556.

Douglas, G. V., *et al.*
1940: Copper deposits of Newfoundland; *Geol. Surv. Nfld.,* Bull. 20.

Espenshade, G. H.
1937: Geology and mineral deposits of the Pilleys Island area; *Geol. Surv. Nfld.,* Bull. 6.

Ford, R. E.
1959: Geology of Gaspé Copper mine; *Can. Inst. Mining Met.,* Bull. 52, No. 567, pp. 425–429.

Fuller, J. O.
1941: Geology and mineral deposits of the Fleur de Lys area; *Geol. Surv. Nfld.,* Bull. 15.

George, P. W.
1937: Geology of lead–zinc–copper deposits at Buchans, Newfoundland; *Am. Inst. Mining Met. Engrs.,* Tech. Publ. No. 816, *In* Mining Technology, vol. 1, No. 3, pp. 1–23.

Johnson, Helgi
1954: The strontium deposits of Port au Port Peninsula, Newfoundland; *Geol. Surv. Can.,* Bull. 27.

Johnston, A. G., and McCartney, W. D.
1965: Manganese occurrences in Canada; *Geol. Surv. Can.,* Paper 64-37.

Keating, B. J.
1960: Massive sulphide deposits in Nova Scotia; *Trans. Can. Inst. Mining Met.,* vol. 53, pp. 43–49.

Little, H. W.
1959: Tungsten deposits of Canada; *Geol. Surv. Can.,* Econ. Geol. Ser. No. 17.

Lyons, J. C.
1957: Wabana iron ore deposits; structural geology of Canadian ore deposits; *Commonwealth Mining Met. Congr., 6th,* Canada, 1957, Can. Inst. Min. Met. Symp.

McAllister, A. L.
1960: Massive sulphide deposition in New Brunswick; *Trans. Can. Inst. Mining Met.,* vol. 53, No. 574, pp. 88–98.

McCartney, W. D., and Potter, R. R.
1962: Mineralization as related to structural deformation, igneous activity and sedimentation in folded geosynclines; *Can. Mining J.*, vol. 83, No. 4, pp. 83–87.

McFarlane, P., and Gates, W. J.
1966: Geology of Heath Steele sulphide deposits: *in* Poole, *et al.*, Geology of parts of Atlantic Provinces; *Geol. Assoc. Can. – Mineral Assoc. Can. Guidebook*, Halifax, Nova Scotia, pp. 59–62.

Mulligan, R.
1966: Geology of Canadian tin occurrences; *Geol. Surv. Can.*, Paper 64-54.

Norris, D. K.
1956: Structural conditions at Wabana Iron Mines, Newfoundland, with reference to increased ore recovery; *Geol. Surv. Can.*, Topical Rept. No. 5.

Riordon, P. H.
1957: The asbestos belt of southern Quebec; *in* The geology of Canadian industrial mineral deposits, *Commonwealth Mining Met. Congr., 6th*, Canada.

Rose, E. R.
1952: Torbay map-area, Newfoundland; *Geol. Surv. Can.*, Mem. 265.
1967: Vanadium occurrences in Canada; *Geol. Surv. Can.*, Paper 66-57.

Rowe, R. B.
1958: Niobium (columbium) deposits of Canada; *Geol. Surv. Can.*, Econ. Geol. Ser. No. 18.

Roy, S.
1961: Mineralogy and paragenesis of lead–zinc–copper ores of the Bathurst–Newcastle district, New Brunswick; *Geol. Surv. Can.*, Bull. 72.

Smith, C. H.
1958: Bay of Islands igneous complex, western Newfoundland; *Geol. Surv. Can.*, Mem. 290.

Snelgrove, A. K.
1934: Chromite deposits of Newfoundland; *Geol. Surv. Nfld.*, Bull. 1.

Stevenson, I. M.
1958: Shubenacadie and Kennetcook map-areas, Colchester, Hants, and Halifax counties, Nova Scotia; *Geol. Surv. Can.*, Mem. 302.

Stockwell, C. H.
1944: Chromite deposits of the Eastern Townships, Quebec; *Trans. Can. Inst. Mining Met.*, vol. 47, pp. 71–86.

Swanson, E. A., and Brown, R. L.
1962: Geology of Buchans orebodies; *Trans. Can. Inst. Mining Met.*, vol. 65, pp. 284–292.

White, D. E.
1940: The molybdenite deposits of the Rencontre East area, Newfoundland; *Econ. Geol.*, vol. 35, p. 967.

Williams, H.
1963: Relationship between base metal mineralization and volcanic rocks in northeastern Newfoundland; *Can. Mining J.*, vol. 84, No. 8, pp. 39–42.

Industrial Minerals

Allen, C. C., *et al.*
1957: The Jeffrey Mine of Canadian Johns-Manville Company Limited; *in* The geology of Canadian industrial mineral deposits, *Commonwealth Mining Met. Congr., 6th*, Canada, pp. 27–36.

Baird, D. M.
1959: Development of gypsum deposits in southern Newfoundland; *Trans. Can. Inst. Mining Met.*, vol. 62, pp. 257–264.

Carr, G. F.
1958: The industrial minerals of Newfoundland; *Can. Dept. Mines Tech. Surv.*, Mines Br., No. 855.

Cooke, H. C.
1937: Thetford, Disraeli, and eastern half of Warwick map-areas, Quebec; *Geol. Surv. Can.*, Mem. 211.

Goudge, M. F.
1938: Limestones of Canada, Part IV; *Ont. Dept. Mines*, Mines Br., No. 781.

Guillet, G. R.
1964: Gypsum in Ontario; *Ont. Dept. Mines*, Ind. Mineral Rept. 18.
1966: Principal shale areas of southern Ontario, and the clay products industry dependent on shale; *Ont. Dept. Mines*, Map 2131.

Hamilton, J. B.
1961: Salt in New Brunswick; *New Brunswick Dept. Lands Mines*, Mines Br. Mineral Resources Rept. 1.
1965: Limestone in New Brunswick; *New Brunswick Dept. Lands Mines*, Mines Br. Mineral Resources Rept. 2.

Hewitt, D. F.
1962: Salt in Ontario; *Ont. Dept. Mines*, Ind. Mineral Rept. 6.
1964: The limestone industries of Ontario, 1958–1963; *Ont. Dept. Mines*, Ind. Mineral Rept. 13.

Hewitt, D. F., and Karrow, P. F.
1963: Sand and gravel in southern Ontario; *Ont. Dept. Mines*, Ind. Mineral Rept. 11.

Hume, C. B.
1954: Mining Nova Scotia gypsum; *Can. Inst. Mining Met.*, Bull. 504, vol. 47, pp. 263–274.

McKillop, J. H.
1959: Gypsum in Newfoundland; *Nfld. Dept. Mines Resources*, Mines Br. Mineral Resources Rept. 1.

van Alstine, R. E.
1948: Geology and mineral deposits of the St. Lawrence area, Burin Peninsula, Newfoundland; *Geol. Surv. Nfld.*, Bull. 23.

Fuels

Barss, M. S., and Hacquebard, P. A.
1967: Age and stratigraphy of the Pictou Group in the Maritime Provinces as revealed by fossil spores; *Geol. Assoc. Can.*, Spec. Paper No. 4, pp. 267–282.

Bell, W. A.
1940: The Pictou coalfield, Nova Scotia; *Geol. Surv. Can.*, Mem. 225.

Bell, W. A., Goranson, E. A., and Hayes, A. O.
1938: Geological sheets of Sydney coalfield, with marginal notes; *Geol. Surv. Can.*, Maps 359A to 362A.

Belyea, H. R.
1952: Deep wells and subsurface stratigraphy of part of the St. Lawrence Lowlands, Quebec; *Geol. Surv. Can.*, Bull. 22.

Caley, J. F.
1940: Palaeozoic geology of the Toronto–Hamilton area, Ontario; *Geol. Surv. Can.*, Mem. 224.
1941: Palaeozoic geology of the Brantford area, Ontario; *Geol. Surv. Can.*, Mem. 226.
1943: Palaeozoic geology of the London area, Ontario; *Geol. Surv. Can.*, Mem. 237.
1945: Palaeozoic geology of the Windsor–Sarnia area, Ontario; *Geol. Surv. Can.*, Mem. 240.

Clark, T. H.
1956: Oil and gas in the St. Lawrence Lowlands of Quebec; *Can. Inst. Mining Met.*, Bull. 531, pp. 480–484.

Clark, T. H. *(cont.)*
1965: Oil and gas potential of Quebec and the Maritime Provinces; *Ont. Petrol. Inst.*, 4th Ann. Conf., Tech. Paper 11.

Copeland, M. J.
1959: Coalfields, west-half Cumberland County, Nova Scotia; *Geol. Surv. Can.*, Mem. 298.

Hacquebard, P. A.
1951: The correlation, by petrographic analyses, of No. 5 seam in the St. Rose and Chimney Corner coalfields, Nova Scotia; *Geol. Surv. Can.*, Bull. 19.
1956: Palynological studies of some Upper and Lower Carboniferous strata in Nova Scotia. Part I: The Mabou coal area; *Proc. 3rd Coal Conf.*, Crystal Cliffs, N.S., pp. 227–253.

Hacquebard, P. A., Cameron, A. R., and Donaldson, J. R.
1965: A depositional study of the Harbour seam, Sydney coalfield, Nova Scotia; *Geol. Surv. Can.*, Paper 65–15.

Hacquebard, P. A., and Donaldson, J. R.
1964: Stratigraphy and palynology of the Upper Carboniferous coal measures in the Cumberland Basin of Nova Scotia; *Proc. 5th Carboniferous Congr.*, Paris, France, vol. III, pp. 1157–1169.

Haites, T. B.
1951: Some geological aspects of the Sydney coalfield with reference to their influence on mining operations; *Trans. Can. Inst. Mining Met.*, vol. 54, pp. 215–225.
1952: Some geological aspects of the Inverness County coalfields in comparison with those of the Sydney coalfield; *Proc. 2nd Coal Conf.*, Crystal Cliffs, N.S., pp. 112–134.
1956: Some geological aspects of the Pictou coalfield with reference to their influence on mining operations; *Proc. 3rd Coal Conf.*, Crystal Cliffs, N.S., pp. 39–74.

Hayes, A. O., and Bell, W. A.
1923: The southern part of the Sydney coalfield, Nova Scotia; *Geol. Surv. Can.*, Mem. 133.

Hayes, A. O., and Johnson, H.
1938: Geology of the Bay St. George Carboniferous area; *Nfld. Geol. Surv.*, Bull. 12.

Howie, R. D.
1965: Structure and stratigraphy of the Stony Creek field, New Brunswick; *Geol. Surv. Can.*, Paper 65–2, pt. II, p. 71.

Jones, I. W.
1962: Sedimentary basins and petroleum possibilities of Quebec; *Proc. Geol. Assoc. Can.*, vol. 14.

Koepke, W. E., and Sanford, B. V.
1965: Oil and gas fields of southwestern Ontario; *Geol. Surv. Can.*, Map 6-1965.
1965: The Silurian oil and gas fields of southwestern Ontario; *Geol. Surv. Can.*, Paper 65-30.

Latour, B. A.
1960: Coal reserves of Canada, prepared for the Royal Commission on Coal (1959); *Geol. Surv. Can.*, Topical Rept. 17.

MacKay, B. R.
1947: Coal reserves of Canada; *Geol. Surv. Can.*, Reprint of Chapter 1 and Appendix A of report of the Royal Commission on Coal, 1946.

Milne, J. E. S., and Howie, R. D.
1967: Developments in eastern Canada in 1966; *Am. Assoc. Petrol. Geol.*, Bull. 6, vol. 51 (June, 1967), pp. 1163–1173.

Muller, J. E.
1952: Geology and coal deposits of Minto and Chipman map-areas, New Brunswick; *Geol. Surv. Can.*, Mem. 260.

Norman, G. W. H.
1935: Lake Ainslie map-area, Nova Scotia; *Geol. Surv. Can.*, Mem. 177.

Ontario Dept. of Energy and Resources Management
1967: Oil and gas exploration, drilling and petroleum summary 1966; *Ont. Dept. Energy Resources Management*, Paper 67-1.

Roliff, W. A.
1955: Explorations for oil and gas in eastern Canada; *Proc. Geol. Assoc. Can.*, vol. 7, pp. 61–81.
1962: The Maritime Carboniferous basin of eastern Canada; *Proc. Geol. Assoc. Can.*, vol. 14, pp. 21–41.

Sanford, B. V.
1958a: Geological map of southwestern Ontario, showing oil and gas producing areas; *Geol. Surv. Can.*, Map 1062A.
1958b: Subsurface stratigraphy of Upper Cambrian rocks in southwestern Ontario; *Geol. Surv. Can.*, Paper 58-12.
1961: Subsurface stratigraphy of Ordovician rocks in southwestern Ontario; *Geol. Surv. Can.*, Paper 60-26.
1962: Sources and occurrences of oil and gas in the sedimentary basins of Ontario; *Proc. Geol. Assoc. Can.*, vol. 14, pp. 59–89.
1965: Salina salt beds, southwestern Ontario; *Geol. Surv. Can.*, Paper 65-9.

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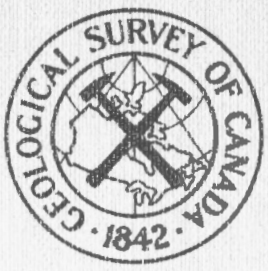

Economic Geology Series No. 1
Fifth Edition
Geological Survey of Canada

DEPARTMENT OF ENERGY, MINES AND RESOURCES,
OTTAWA, CANADA, 1970