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CANADA
DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA
MEMOIR 269

GOLDFIELDS-MARTIN LAKE MAP-AREA, SASKATCHEWAN

BY
A. M. Christie

EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1953

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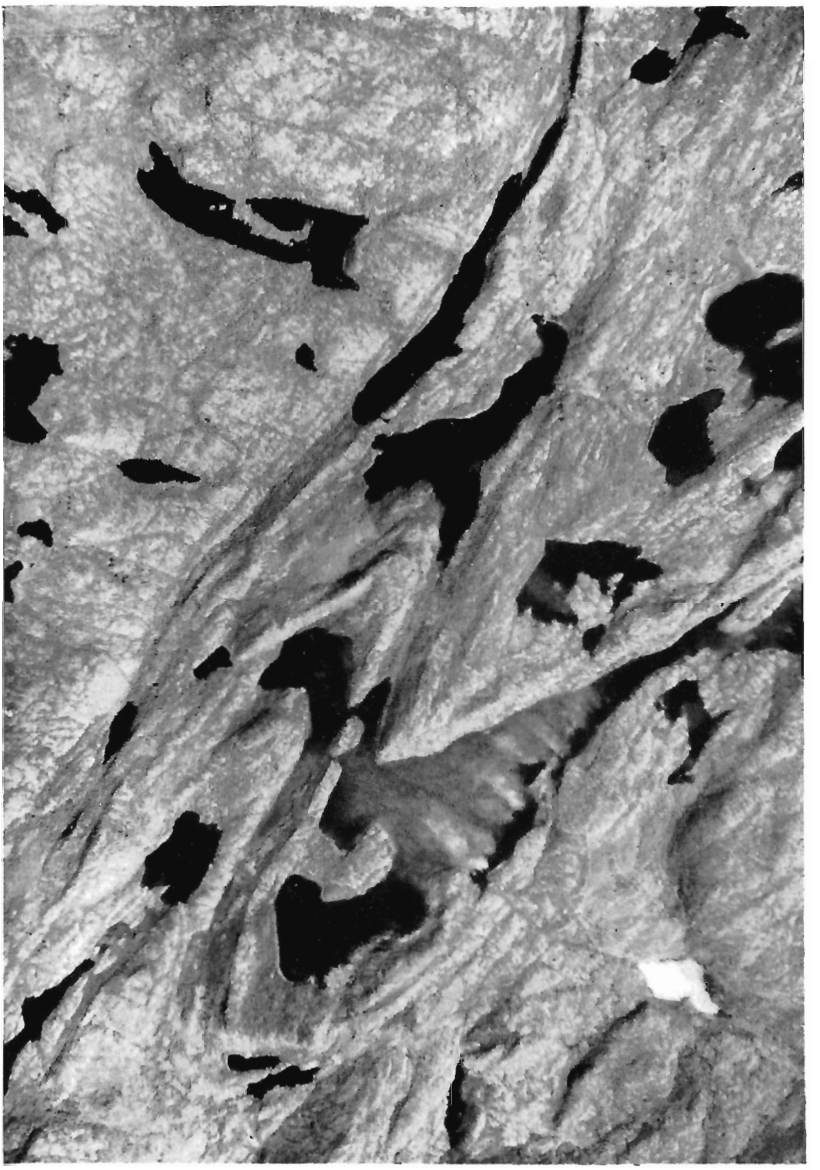

Illustrating complex folds in Tazin formations near Fold Lake (photo A8022-87 by Royal Canadian Air Force). (Page 5.)

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CONTENTS

	Page
Preface	vii

CHAPTER I

Introduction	1
General statement and acknowledgments	1
Location and accessibility	2
Previous geological work	3
Topography	4
Bibliography	5

CHAPTER II

General geology	8
General statement	8
Table of formations	9
Tazin group	8
Introductory statement	8
Sedimentary rocks	10
Quartzite	10
Ferruginous quartzite	10
Quartzite, with minor amounts of dolomitic material	12
Dolomite and dolomitic quartzite	12
Conglomerate	13
Mafic rocks	15
Amphibolites of sedimentary origin	15
Cordierite-amphibolite rocks	16
Garnetiferous biotite schist	17
Andalusite-sericite-biotite schist	17
Sillimanite-cordierite-biotite gneiss	17
Amphibole-epidote-chlorite rocks	17
Chloritic and chlorite-epidote rocks	18
Amphibole-epidote rocks of volcanic origin	18
Amphibolite of intrusive origin	19
Structure	20
Major structures	21
Minor folds	21
Lineation	23
Rock competency	25
Interpretation of structures	26
Bedding foliation	26
Folding	26
Problem of the 'unconformity' between the 'Beaverlodge series' and the Tazin group	28
Granite, granite-gneisses, and granitoid gneisses	30
General statement	30
Granitic rocks west of Lodge Bay	33
Granitic rocks in the vicinity of the Box mine	35
Granitic rocks in the vicinity of the Athona mine	39
Mackintosh Bay granite	41
Granitic rocks in the vicinity of Ace, Eagle, and Melville Lakes	43
Granitic rocks of the Ace Lake-Raggs Lake area	44
Lamprophyre dykes	46
Athabasca series	48
Sedimentary rocks	48
Conglomerate	48
Arkose and sandstone	49
Volcanic rocks	50
Structure	52
Origin and correlation	54
Late basic dykes	55

CONTENTS—*Con.*

CHAPTER III

PAGE

Regional alteration and structural relationships 61
Contact metamorphic effects of granite on amphibolite 61
Discussion of the relative age of the amphibolite and the granite 63
Metamorphism of the Tazin group 64
Major faults and shear zones 65
Mylonites, flaser-gneisses, and crush breccias 67
Granitization 69

CHAPTER IV

Economic geology 73
Iron deposits 73
Gold deposits 73
Characteristics of gold deposits 73
Athona Mines Limited 74
The Consolidated Mining and Smelting Company of Canada Limited 77
Box mine 77
Frontier Trust property 79
Other properties 80
Uranium deposits 80
General statement 80
Characteristics of uranium occurrences 81
Uraninite occurrences 81
Pitchblende occurrences 82
Structure 82
Host rocks 83
Red alteration 84
Vein structure 85
Mineralogy 85
Paragenesis 86
Age determinations 86
Origin 88
Description of properties 89
Amax Athabasca Uranium Mines Limited 89
Concession CC1 89
American Canadian Uranium Company Limited 90
Tom and Paul groups 90
American Yellowknife Gold Mines Limited 90
Concession YY 90
Aurora Yellowknife Mines Limited 91
Concessions CC2 and CC3 91
Beaverlodge Uranium Mines Limited 91
Bar group 91
Cinch Lake Uranium Mines Limited 92
Jam group 92
Clix Athabasca Uranium Mines Limited 92
Concession AA 92
The Consolidated Mining and Smelting Company of Canada Limited 92
Box mine 92
Continental Exploration Limited 93
Axe group 93
Eldorado Mining and Refining (1944) Limited 93
Ace group 93
Beaver group 95
Bolger group 95
Don group 96
Eagle group 96
Emar group 99
Fish Hook Bay group 100
Gil group 102

CONTENTS—*Con.*

PAGE

Hab group 103
R.A. group (Martin Lake mine) 104
Ura group (Fay zone) 105
Goldfields Uranium Mines Limited 106
Concession DD1 106
Concession EE1 106
Concession FF1 107
Concession NN 107
Concession SS 108
Concession TT 108
McIver A. Chum group 109
Millar W.N. Concessions DD2 and DD3 109
Nesbitt Labine Uranium Mines Limited 109
Maj and Jam groups 109
ABC group 111
Nicholson Mines Limited 111
Pitche group 114
Pitch-Ore Uranium Mines Limited 114
Radiore Uranium Mines Limited 114
Rix Athabasca Uranium Mines Limited 115
Concession DD1 115
Strike group 116

Table I. Estimated mineral composition of Lodge Bay granite 34
II. Estimated mineral composition of Mackintosh Bay granite 42
III. Measured modes of granitic rocks, Ace Lake-Raggs Lake area 45
IV. Chemical analyses of volcanic rocks 51
V. Estimated mineral composition of coarse-grained late basic dykes 56
VI. Estimated mineral composition of fine-grained late diabase dykes 58

Index 123

Illustrations

Map 1015A. Goldfields-Martin Lake, Saskatchewan ..... In pocket

Plate I. Folded structures in Tazin formations near Fold Lake ..... Frontispiece
II. A. View of Beaverlodge Mountain from the east 117
B. Dolomite, showing typical weathered appearance 117
III. A. Pebble Island conglomerate 118
B. Elliot Bay conglomerate 118
IV. A. Ellipsoidal volcanic rocks near Elliot Bay 119
B. Crenulated or mullion structure, near Goldfields 119
V. A. *Boudinage* or sausage structure 120
B. Granite intrusive into amphibolite 120
VI. A. Basal Athabasca conglomerate on the south shore of Beaverlodge Lake 121
B. Colour banding and crossbedding in Athabasca sandstone, Beaverlodge Lake 121

CONTENTS—*Conc.*

Illustrations—*Conc.*

PAGE

Figure 1. Minor structures in Tazin rocks 22
2. Attitudes of foliation and lineation near Goldfields 24
3. Hypothetical folds 27
4. Surface plan of Box orebody ..... In pocket
5. Pegmatite dykes, showing transition to high-temperature quartz veins.. 37
6. Geological sketch of the Athona mine 76
7. Index map, showing location of uranium deposits ..... In pocket
8. Geological sketch of the Ace mine 94
9. Geological sketch of the Eagle Shaft showings of the Eagle group 97
10. Geological sketch of the Tam South showings of the Eagle group 99
11. Geological sketch of the Fish Hook Bay group 101
12. Geological sketch of the Gil group 103
13. Geological sketch of the Martin Lake mine of the R.A. group 104
14. Geological sketch of the Jam and Maj groups 110
15. Geological sketch of the property of Nicholson Mines Limited 112

PREFACE

The Goldfields-Martin Lake map-area, on the north shore of Lake Athabasca, is the most promising of the newly discovered, uranium-rich areas in Canada. Its exploration was initiated in 1945 by the Crown company, Eldorado Mining and Refining (1944) Limited, who are now preparing to produce from the Ace mine, north of Beaverlodge Lake, and are exploring several other properties. A ban imposed during World War II on exploration for uranium in Canada by private individuals and companies was lifted in 1948; since then prospecting has been active in the area and many discoveries have been made.

The present report is based in large part on the author's field work in 1946, 1947, and 1948, but incorporates much information derived from detailed mapping of properties by company geologists and from special studies on the mineralogy and wall-rock alteration of deposits by other officers of the Geological Survey. The fundamental geological setting of the uranium deposits is dealt with at some length; certain problems relating to the age, sequence, and genesis of the rock formations and to the mineralogy and structural control of the pitchblende ores are resolved; and many of the deposits are described.

The report is illustrated by several figures and plates, and by a geologically coloured map on a scale of 1 inch to 1 mile.

GEORGE HANSON,
Chief Geologist, Geological Survey of Canada

OTTAWA, April 7, 1952

Goldfields-Martin Lake Map-area, Saskatchewan

CHAPTER I

INTRODUCTION

GENERAL STATEMENT AND ACKNOWLEDGMENTS

The presence of radioactive minerals in the Goldfields-Martin Lake area was first recognized in 1935 on what is now the Nicholson property, 2 miles east of the village of Goldfields. Little interest was shown in the occurrence of these minerals until 1944, during World War II, when intensive exploration for uranium minerals was undertaken. The Crown company, Eldorado Mining and Refining (1944) Limited, has been active in the area since that time; between 1945 and 1948 numerous properties were staked and examined. The company has conducted an intensive diamond drilling campaign, and has been exploring its Martin Lake, Ace, Eagle, and Fay properties underground. Production plans have been announced for the combined Ace and Fay properties north of Beaverlodge Lake, a road has been built connecting the Ace mine with Black Bay of Lake Athabasca, and a new townsite has been selected north of the west end of Martin Lake.

In the spring of 1948, the Federal Government repealed the wartime ban on prospecting for uranium by the general public. Subsequently, in March 1949, the Saskatchewan Government established several areas of 25 square miles each, covering all unstaked ground within 20 miles of the north shore of Beaverlodge Lake. Concessions to prospect these areas were then sold to companies and members of the public. Such of these areas as had reverted to the Crown were again thrown open to public prospecting in June 1950. It is planned that all these concessions, as such, will cease to exist in 1952.

Since the 1948 repeal of the ban on private prospecting, many companies and individuals have been active in prospecting the area. Many new discoveries have been made and much diamond drilling has been done. Nicholson Mines Limited, the original discovery in the area, has sunk two prospecting shafts and has done considerable underground work, and underground exploration is progressing on the Rix Athabasca and the Nesbitt-Labine properties.

The Geological Survey of Canada assisted the Crown company in the early work by mapping certain areas and by doing a limited amount of prospecting. In 1945, Jolliffe (38) [1] mapped the Cornwall Bay-Fish Hook Bay area on a scale of 1 inch to 400 feet, and in 1946 the writer mapped the Lodge Bay-Cornwall Bay area on the same scale. During the field seasons of 1947 and 1948, the writer completed the geological mapping of the Goldfields-Martin Lake area on a scale of 1 inch to 1 mile, and a preliminary report, with maps, was issued in 1949 (19). Between 1949 and

[1] Numbers in parentheses refer to Bibliography at end of Chapter I.

1951 S. C. Robinson (45) of the Geological Survey made a special study of the mineralogy of the map-area, and K. R. Dawson (32), also of the Geological Survey, conducted a separate investigation of the wall-rock alteration in the district. The writer is greatly indebted to both for the large amount of information received, which is only partly acknowledged in the text.

The writer has received much assistance from the Crown company; where its geologists did detailed geological work, the results have been incorporated in the present map and report. The company work was done under the supervision of R. F. Murphy, E. B. Gillanders, S. N. Kesten, and, recently, R. B. Allen. W. F. James and B. S. W. Buffam are consulting geologists. C. E. B. Conybeare, R. Edie, E. E. N. Smith, H. C. Norman, S. J. Kidd, J. H. H. Huckle, J. R. Walter, and Iain Bain mapped various areas in detail for the Crown company.

Since 1949, the various companies and individuals prospecting for radioactive minerals throughout Canada have submitted details of their radioactive discoveries and properties to the Geological Survey, where they are kept on a confidential file. The writer has had access to those files that concern the map-area, and from them has made such additions and corrections to the maps and reports as seemed necessary. As the geology of many of the concessions has been mapped on a scale of 400 feet to the inch, it has been possible, in several cases, to correct contacts, and in others to add new faults or shear zones that have been confirmed by detailed mapping and diamond drilling. Differences in interpretation of geological features, and differences in the conception of map-units, was a difficulty in correlating the various company maps. Acknowledgment is hereby made, that much useful information was obtained from reports by the following geologists, who acted for, or were employed by, the various interests engaged in prospecting the area: W. W. Archer, W. J. Bichan, N. W. Byrne, R. W. Edie, J. W. Griffith, W. H. Gross, C. S. Johnston, F. R. Joubin, J. R. Macdonald, J. W. Macleod, G. C. McCartney, L. M. Montgomery, G. W. Moore, H. C. Norman, J. S. Ross, and E. Walli.

In this report the descriptions of properties are concerned mainly with the purely geological features of the deposits; little consideration has been given to their size or possible value, as more of these data are included in the paper by A. H. Lang (42) of the Geological Survey entitled "Canadian Deposits of Uranium and Thorium". S. M. Roscoe, also of the Geological Survey, has examined various properties in the map-area during the 1951 field season and has added many valuable details to the descriptions of properties.

Messrs. Donald A. W. Blake, J. B. Stubbins, J. S. Ross, J. R. Smith, K. Laatsch, E. Hanes, R. C. Heron, Stirling Heron, Roy Heron, Lawrence Heron, and J. E. M. Parker were members of the writer's field parties, and rendered very satisfactory and efficient service. Blake (11) has since mapped the adjoining Forget Lake area to the east.

LOCATION AND ACCESSIBILITY

The Goldfields-Martin Lake map-area is bounded by latitudes 59° 15′ and 59° 45′ north and longitudes 108° 15′ and 108° 45′ west. It may be reached by boat or aircraft from Fort McMurray; by aircraft from Prince Albert; or by aircraft from Fort Smith.

During the summer months, boats and barges can reach the map-area from the railhead at Fort McMurray via Athabasca River and Lake Athabasca. The distance from Fort McMurray to Chipewyan, at the west end of Lake Athabasca, is 236 miles by river, and from Chipewyan to Lodge Bay is about 110 miles. Material can be landed from boat or barge, at the north end of Black Bay, at Goldfields, or at the Nicholson property. A new road connects the site of a proposed townsite, and the Eldorado camps north of Beaverlodge Lake, with the wharves at Black Bay. Boats based at Fort McMurray are operated by the Hudson's Bay and Northern Transportation Companies, the latter a subsidiary of Eldorado Mining and Refining (1944) Limited. Due to the ready accessibility of the area by boat, the freight costs are considerably less than in most parts of the north country. McMurray Air Service Limited provides charter service from the railhead.

The Saskatchewan Government Airways maintains bases at the railhead at Prince Albert, at Lac la Ronge, and, in the summer, at Goldfields. Regular flights carry passengers weekly, and mail fortnightly, to Stony Rapids, Fond du Lac, Goldfields, and Camsell Portage, and provide charter service along this route. During the summer of 1950, this Airways based an aircraft at Goldfields to provide charter service in the map-area.

Fort Smith may be reached by air from Edmonton via Canadian Pacific Airlines. Freight is carried to Fort Smith by boat and barge from the railhead at McMurray during the summer season. At Fort Smith, Territories Air Service Limited provides charter flights to all parts of the map-area. The distance from Fort Smith to Beaverlodge is 110 miles by air.

PREVIOUS GEOLOGICAL WORK

The first geological work in the region of Lake Athabasca was done in 1888, when R. G. McConnell (43) traversed the south shore of the lake. There he observed outcrops of a flat-lying sedimentary formation, which he named the Athabasca sandstone. A survey of the entire lake shore was made in 1892 and 1893 by J. B. Tyrrell and D. B. Dowling (52). In 1914, Charles Camsell (16) explored Tazin and Taltson Rivers en route from Lake Athabasca to Great Slave Lake, and gave the name Tazin series to a group of highly metamorphosed sedimentary rocks that he encountered. In 1914 and 1916, F. J. Alcock (1, 2), remapped the north shore of Lake Athabasca and the Beaverlodge Lake area.

Interest in mineral occurrences near Goldfields began in the early 1920s with reports of large bodies of iron ore in the vicinity of Fish Hook Bay. These were investigated during 1922 by J. A. Allan and A. E. Cameron (7), who reported them to be of no commercial value.

In August 1934, two prospectors, Box and Nyman, discovered gold in a granitic rock on what is now the Box property of The Consolidated Mining and Smelting Company of Canada Limited. Following this find, seventeen claims were staked by the company. The surrounding ground, including the Athona property, 1 mile to the east, was staked shortly thereafter. This staking and the subsequent development initiated a period of great activity in the district, and the townsite of Goldfields was laid out and had reached a thriving condition by 1937.

During the summer of 1935, F. J. Alcock (6), with thirty-two assistants, mapped an area of about 7,000 square miles on the north side of Lake Athabasca on a scale of 1 inch to 4 miles, and about 300 square miles in the immediate vicinity of Goldfields on a scale of 1 inch to 1 mile.

The next geological work in the area was done in 1937, when H. C. Cooke (29) mapped two small areas in the vicinity of the Box and Athona mines on a scale of 1 inch to 200 feet.

In 1938, A P. Beavan (9) submitted a doctorate thesis to Princeton University entitled "The Geology and Gold Deposits of Goldfields, Lake Athabaska". This work was not published. The following year C. O. Swanson, geologist for The Consolidated Mining and Smelting Company of Canada Limited, mapped the surface geology of the Box mine. The only descriptive notes available are: (a) three paragraphs in a paper entitled "Probabilities in Estimating the Grade of Gold Deposits", published by Swanson (50) in 1945; and (b) an unpublished Master's thesis by A. F. Killin (40) then a student at the University of British Columbia, who studied material collected from the Box mine by Swanson. Dr. Swanson has kindly permitted the inclusion of his excellent map of the Box orebody in the present report.

In 1940, W. G. Jewitt (37) published a paper on the Box mine, which included a brief note on the geology.

The history of the Box and Athona mines is given in a subsequent section of this report. It will suffice to state here that the grade of these deposits was found to be considerably lower than first estimated. The Athona property closed in 1939, whereas the Box operations were continued until May 1942, when the mine closed due to shortage of manpower. All claims of both properties are in good standing.

In July 1935, pitchblende was found on the property of Mineral Belt Locators Syndicate, now the Nicholson property. In 1945, Eldorado Mining and Refining (1944) Limited commenced an intensive exploration program in the area, which has continued to the present.

TOPOGRAPHY

The topography of Goldfields-Martin Lake map-area is similar to that of most other parts of the Canadian Shield. It is an area of disorganized drainage, with numerous lakes separated by rock, muskeg, and small, drift-covered areas. About 20 per cent of the area underlain by the Athabasca series is exposed bedrock, whereas in those areas underlain by older rocks more than 50 per cent of the bedrock is exposed, or is mantled only by thin lichen or moss.

The lakes drain southward to Lake Athabasca, with the exception of Tazin Lake, which flows via Tazin and Taltson Rivers into Great Slave Lake. None of the streams of the area, except Crackingstone River below Beaverlodge Lake, is navigable by canoe. Lake Athabasca has a mean elevation of 699 feet above sea-level, the maximum difference between high and low water being about 10 feet. Beaverlodge Lake (elevation 797 feet) is 98 feet above Lake Athabasca, and Tazin Lake (elevation 1,135 feet) is 436 feet above it. In detail, the country is rough;

ridges commonly rise 100 to 300 feet above the level of the adjacent lakes, and exceptionally, as near Beaverlodge Mountain, local relief is as much as 700 feet.

Topographic details have depended greatly on differential erosion of the various rock types. Amphibolite most commonly stands out in high relief; it forms a resistant capping above the easily eroded quartzite that underlies Beaverlodge Mountain (*See* Plate II A), and forms the high hills southeast of LeBlanc Lake, where the topography reflects accurately the complicated structure (*See* Plate I). Basalt flows form the prominent ridges in the Athabasca basin about Martin Lake. The one large late basic dyke, north of Neely Lake, forms a prominent ridge. Areas underlain by granite and granite-gneiss are usually characterized by moderate relief, although some high hills near Tazin Lake are composed of these rocks. Quartzites are among the more readily eroded formations because, although they are hard, tough rocks, they commonly exhibit three prominent sets of joints, which aid disintegration. Dolomite and Athabasca arkose underlie low ground.

The two major faults in the area, the St. Louis and Black Bay faults, are marked by prominent lineaments on the ground, which are clearly visible on air photographs and on topographic maps. Numerous other faults and fractures form prominent or noticeable topographic depressions. Where these features cut across structural trends they are readily identified as faults or fractures, but where they parallel the strike of the formations it is not everywhere possible to distinguish a depression due to faulting from one caused only by differential erosion of adjoining rocks.

Widespread glacial striations and *roches moutonnées* show that the ice-cap that covered the area during Pleistocene time advanced from northeast to southwest. The glacial ice left scattered erratics and small areas of drift throughout the area. Sand plains occur in a few places, notably between Beaverlodge and Ace Lakes, west of Cinch Lake, and near Right Lake.

Beach sands occur 100 feet above the shore of Lake Athabasca on the portage from Lodge Bay to Beaverlodge Lake. Many other beach gravel deposits occur at lower elevations.

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CHAPTER II

GENERAL GEOLOGY

GENERAL STATEMENT

The Tazin group of Precambrian age, consisting mainly of sedimentary strata, with minor interbedded volcanic rocks and basic intrusions, is intruded and partly replaced by granite, now generally gneissic. The Athabasca series of conglomerate and arkose, with interbedded basalt flows, rests unconformably on the older rocks. All these rocks are cut by small basic dykes.

TAZIN GROUP

INTRODUCTORY STATEMENT

The term 'Tazin series' was introduced in 1916 by Camsell (16) in his description of the sedimentary and volcanic rocks encountered by him in his traverse along Tazin and Taltson Rivers. As these rocks were probably formed in more than one geological period, Alcock (6), in 1936, proposed the name 'Tazin group' to cover these formations. He divided the older rocks of the Goldfields area into the Tazin group and the Beaverlodge series, which he claimed were separated by an unconformity and a period of granitic intrusion. The writer has grouped Alcock's Tazin and Beaverlodge together in the Tazin group, as no mappable unconformity was recognized between them, and the term Beaverlodge has been abandoned in this report (*See* discussion, pp. 28-30).

The Tazin group consists of sedimentary strata, with subordinate amounts of volcanic rocks. The sedimentary rocks are metamorphosed, and consist of quartzites, crystalline carbonate rocks, diopside and tremolite rocks, amphibolites, cordierite amphibolites, biotite schists, garnetiferous rocks, andalusite schists, and sillimanite gneisses. In places, rocks of the Tazin group have been intimately injected by granite; all gradations exist from comparatively unaltered strata and beds cut by numerous pegmatite and aplite dykes to *lit-par-lit* injection gneisses and gneissic granitoid rocks. As a result, many of the geological boundaries shown represent only gradational zones, or zones in which certain varieties of rocks predominate, rather than abrupt changes in lithology.

TABLE OF FORMATIONS

Era		Formations and lithology	Mixed rocks
Proterozoic		Basic dykes	
	Athabasca series	Basalt flows (a few may be sills) Arkose and sandstone Conglomerate	
		Unconformity	
Archæan or Proterozoic		Lamprophyre dykes	
		Granite and granite-gneiss (commonly contains inclusions of amphibolite)	Granite-gneiss, with bands of diopside or tremolite, believed derived from alteration of dolomite Granite-gneiss, with inclusions of quartzite
		Intrusive contact	
	Tazin group	Mafic rocks[1] Amphibolite Biotite schist or gneiss Garnetiferous gneiss Chlorite-bearing rocks Epidote-bearing rocks Chlorite-epidote rocks grading to more siliceous types	Mafic rocks, with minor added granitic material
		Conglomerate Dolomite and dolomitic quartzite Ferruginous quartzite	Quartzite, with minor amounts of dolomitic material
		Quartzite	Quartzite, with minor added granitic material

[1] These mafic rocks include some intrusive types that have been included with the Tazin group because they are metamorphosed mainly to amphibolite, and could not in all cases be distinguished from metamorphosed Tazin sedimentary or volcanic rocks. Where distinguished from the Tazin group, the intrusive origin is indicated as such on the map. For a definition of the term 'mafic rocks' as used in this report *See* page 15.

Volcanic rocks occur interbedded with sedimentary strata in some places. In one locality, at the head of Elliot Bay, good pillow lavas were observed as described by Alcock (*See* Plate IV A). Elsewhere, definite volcanic structures such as pillows or amygdules are lacking. In places a well-developed fragmental structure may represent original pyroclastic rocks, but in some localities is due to later brecciation.

Basic dykes and sills, which intrude the Tazin group but are older than the granite, are described on page 19.

SEDIMENTARY ROCKS

Quartzite

Quartzite is most common in the south near the shores of Lake Athabasca and in the islands in the lake. The most abundant and typical rock is a pure, white, well-jointed quartzite in which the bedding planes are recognized only with difficulty. In irregular areas, the quartzite is brecciated, and consists of angular to subangular fragments of white quartz, usually less than 1½ inches in diameter, cemented by quartz. The quartzite grades to arkosic quartzite and greywacke, especially in the vicinity of Goldfields and north and west of Milliken Lake, and in some other localities to a highly foliated, white quartzose rock containing abundant sericite. All these varieties have been mapped as quartzite. The quartzite also grades in places to a massive quartzite, with minor amounts of dolomitic material, mapped as a separate unit, or to chloritic schists, biotite schists, and amphibolites.

Narrow and discontinuous pebble-bands, the pebbles in which are composed only of quartz, occur interbedded with the quartzite between Elliot Bay and Lodge Bay of Lake Athabasca. These bands are not wide enough or continuous enough to map separately, and have been included with the quartzite. They are roughly at the same horizon as the conglomerates containing granitic pebbles and pebbles of quartz and lime-silicate minerals, which are shown on the accompanying map.

Ferruginous Quartzite

The ferruginous quartzite of the Tazin group contains notable amounts of hematite and magnetite. Most commonly, the iron is a hematite stain, which has penetrated the quartzite along joint planes or other fractures. Over wide areas the quartzite has been brecciated and recemented by quartz and hematite, forming a ferruginous quartzite breccia. In a few localities the brecciation could be related to recognized fractures, but in many areas the brecciation is widespread and apparently irregular in distribution.

Bands of iron minerals and jasper may occur along the bedding planes of the quartzite. This is the 'banded iron formation' of Allan and Cameron (7) and of Jolliffe (38). The following section, measured on

the peninsula in Fish Hook Bay about 1,000 feet south of the end of the peninsula, is adapted after Jolliffe (38). Here the ferruginous members are interbedded with normal quartzite, dolomite, gneiss, and schist, similar to those found elsewhere in the map-area. The iron minerals occur in bands that average less than ½ inch in thickness, interbedded with quartz, chert, and amphibolitic material.

	Thickness Feet
Base (in conformable contact with massive arkosic quartzite)	
Diopside rock, coarse-grained, probably derived from impure dolomite	6
Dolomite	1
Quartzite, banded and impure	3
Dolomite, with nests of coarse diopside crystals	7
Iron oxides, quartzite, amphibolite, and dolomite, thinly interbanded	9
Ferruginous quartzite, banded	14
Drift-covered	5
Ferruginous quartzite and amphibolite	5
Dolomite	5
Argillite, jasper, and iron oxides, interbanded	10
Dolomite, argillite, jasper, and iron oxides, interbanded	10
Ferruginous jasper and argillite	13
Sulphides and hematite, chiefly introduced	2
Dolomite	5
Amphibolite, ferruginous	15
Total thickness	110

In this vicinity, Jolliffe estimated an exposed 50-foot section of interbanded hematite, magnetite, and quartz, to contain 25 per cent iron. Elsewhere, near Fish Hook Bay, a ferruginous dolomite that is bright scarlet to red-brown on both weathered and fresh surfaces is associated with the normal brown weathering dolomite.

Near the northeast end of the small lake 1¼ miles northeast of the head of Elliot Bay, is a small outcrop of iron formation composed of interbanded hematite and quartzite. Certain of the hematite bands contain large crystals of garnet.

Because the amount of hematite and magnetite in the banded iron formation varies considerably along strike, and because the red colour of many ferruginous dolomites and quartzites is due to introduction of the iron oxides along fractures, Jolliffe (38) and Allan and Cameron (7) suggest that all or most of the iron was introduced. However, because of the fine interbanding of the iron-bearing bands and bands of quartzite, dolomite, amphibolite, and jasper, the writer believes that the iron-bearing bands represent, at least in part, original sedimentary deposits, and that subsequent hydrothermal activity is responsible for the features indicating transportation and redeposition of the iron oxides.

Quartzite, with Minor Amounts of Dolomitic Material

Quartzite, with minor amounts of dolomitic material, grades on the one hand into quartzite and on the other into dolomitic quartzite. It is most commonly represented by a massive quartzite, with, here and there, irregularly shaped aggregates or nests of diopside crystals. In other places, colourless tremolite or light green actinolite crystals may occur in minor amounts along the bedding planes of the quartzite.

Dolomite and Dolomitic Quartzite

Dolomite and dolomitic quartzite as here defined include pure, crystalline carbonate rocks; quartz-diopside, quartz-tremolite, and quartz-actinolite rocks; and quartzite with bands of diopside, tremolite, or actinolite, provided that the dolomite or lime-silicate minerals comprise at least 20 per cent of the rock.

The dolomite commonly weathers rusty brown, but may be buff or grey. Where freshly broken it displays fine- to medium-grained, cream-coloured cleavage surfaces. Analyses of five iron-rich carbonate rocks from Fish Hook Bay (7) show an average content of 25 per cent lime (CaO) and 18 per cent magnesia (MgO), or about in the same proportion as they occur in pure dolomite (30·4 and 21·7 per cent CaO and MgO respectively). These analyses and the invariable alteration of these rocks to the magnesia-rich silicate minerals, diopside, tremolite, and actinolite, leave little doubt that the carbonate of the sedimentary series is mainly dolomite.

The dolomite seldom occurs in large, pure masses, but generally contains bands of pure white quartzite or of silicate minerals alternating with the carbonate bands and indicating the bedding planes. The bands of silicate minerals or of quartzite form prominent, resistant, green or white ridges, standing ½ inch to 2 inches above the softer, rusty weathering carbonate bands (*See* Plate II B).

A study of the silicate bands near Goldfields yielded the following information:

(1) Quartzite bands from ½ inch to hundreds of feet in thickness are common.

(2) Quartz-diopside bands and lenses may be as much as several hundred feet thick. In places, diopside crystals up to 6 inches long form isolated clusters in the quartzite; elsewhere the rock may be largely diopside with very little interstitial quartz. Locally the diopside crystals are fractured; a thin section of such a crystal shows fresh unaltered diopside veined along fractures by a mixture of tremolite, carbonate, and a little quartz showing strain lamellæ.

(3) Narrow bands and lenses containing green amphibole, commonly 5 mm. long, are seen under the microscope to consist mainly of actinolite close to tremolite in composition. A little diopside, carbonate, and quartz also occur in these bands.

(4) Narrow bands of light green, fine-grained material show in thin section 80 per cent diopside in grains averaging 1·5 mm. across, 10 per cent untwinned potash feldspar, 5 per cent tremolite, 1 per cent carbonate, and traces of iron oxide minerals and epidote. Most of the feldspar and tremolite is interstitial; some is included in the diopside.

(5) Still finer grained (0·1 mm.) bands of light grey-green rock consist of about 80 per cent tremolite, 10 per cent carbonate, 7 per cent relict diopside, and 3 per cent sphene and iron oxide minerals. The tremolite forms an imperfectly alined felt showing rude augen structures around diopside crystals. The latter are largely replaced by carbonate along cleavage planes, but the remaining islands of diopside are fresh, with sharp boundaries against the enclosing minerals, and extinguish as a unit.

(6) Very fine-grained bands, weathering light green to white and in places having a chalky appearance, consist of more than 95 per cent tremolite with minor amounts of carbonate, iron oxide minerals, and a little fine-grained sericite or talc.

In other places the dolomite contains alumina or iron, which give rise to other rock types that in the general mapping were included with the dolomite. Thus, red garnet crystals up to 10 mm. in diameter occur in a quartzose actinolite-tremolite-diopside rock. Other aluminous, carbonaceous rocks may contain a little brown biotite close to phlogopite in composition. As, however, most of such rocks alter to the various types of amphibolites and biotite schists they have been mapped as 'mafic rocks'.

Another, ferruginous type of dolomite has been included in the 'banded iron formation' of Allan and Cameron (7), Jolliffe (38), and the Eldorado geologists, in the vicinity of Fish Hook Bay. This ferruginous dolomite is most commonly bright red on both weathered and fresh surfaces; in places it is interbedded with jasper, iron oxide minerals, ferruginous quartzite, and ferruginous amphibolite. The red hematite stain in the dolomite appears to replace the latter along crystal boundaries, along cleavage planes, and in other irregular areas (7).

In a few localities, small veinlets of serpentine cut dolomitic rocks. Near Fish Hook Bay a mass of serpentine may represent an altered dolomite.

Conglomerate

Three occurrences of conglomerate containing pebbles of quartz and lime-silicate minerals, and pebbles of acidic igneous rocks, were observed.

The *Pebble Island conglomerate* in Lodge Bay of Lake Athabasca is the most accessible and best exposed of these. A photograph of this conglomerate is shown in Plate III A. Cobbles and pebbles, up to 12 inches in diameter, but mostly 2 to 6 inches or less, are set in an abundant, fine-grained, light green groundmass. The pebbles in the conglomerate are subangular to rounded, and consist of quartz, a quartz-diopside-actinolite-epidote rock, apparently derived from a metamorphosed dolomitic quartzite, granite porphyry, a fine-grained, light-coloured rock resembling rhyolite, and a few greenstone pebbles. The matrix is arkosic, consisting of quartz, microcline, epidote, penninite, muscovite, and sphene, and is similar to

that of the underlying quartzite. Detrital zircons and apatite are present. The epidote occurs in well-formed euhedral crystals in the groundmass, and as veinlets cutting the rock.

The granite porphyry pebbles consist of well-formed crystals of microcline and quartz (usually rhombohedral in cross-section), commonly 3 mm. in diameter, set in a fine-grained groundmass of microcline, quartz, epidote, muscovite, sphene, and chlorite.

The conglomerate strikes north 20 degrees east and dips easterly at 20 degrees. It is conformable with the underlying, impure, cherty-looking quartzite, which greatly resembles that of the Box property. Under the microscope, the quartzite is seen to consist of quartz, microcline, epidote, and minor amounts of amphibole and sillimanite. Elsewhere on Pebble Island the quartzite is dolomitic. The quartzite and conglomerate are cut by pegmatite and aplite dykes and sills composed of quartz and microcline, with accessory apatite, hematite, and chlorite. Both formations are also cut by quartz veins striking north 20 degrees west, which are common in the vicinity of Goldfields, and by a later, less prominent set striking north 75 degrees east.

The *Frontier Lake conglomerate,* 1 mile north of the Box mine, was first described by Beavan (9). It is very similar to the Pebble Island conglomerate, containing pebbles of white quartz, diopside-, tremolite-, and actinolite-bearing quartzite, rhyolite porphyry, and granite porphyry set in an arkosic matrix of quartz, microcline, epidote, sericite, and chlorite. The rhyolite porphyry and granite porphyry consist of phenocrysts of pink microcline and quartz, set in a very fine-grained (0·03 mm.) groundmass of microcline and quartz. The rhyolite porphyry contains scattered phenocrysts in an abundant groundmass, and the quartz commonly shows rhombohedral outline; the granite porphyry consists mainly of phenocrysts of microcline and quartz, with relatively little groundmass. Small veinlets of epidote, quartz, and carbonate cut the rock. On the steep scarp face at the northwest side of the conglomerate outcrop, a band of this conglomerate was seen to be underlain conformably by white quartzite, and overlain conformably by a quartzite containing minor amounts of dolomitic material. To the northeast is a mass of granite-gneiss.

The *Elliot Bay conglomerate* was first described by Alcock (6). It contains rounded and lens-shaped masses of quartz and granitic material in a sheared matrix, the shearing being parallel with the bedding. Rounded masses of lime-silicate minerals also occur in the matrix. Some of the quartz occurs as vein material in elongate lenses parallel with the bedding, and some of the granitic or pegmatitic material occurs in similar fashion. Elsewhere, more rounded granitic or quartz masses occur, and these commonly carry a small, tail-like appendage of quartz or pegmatitic material (*See* Plate III B). Under the microscope the groundmass of this conglomerate is seen to consist of mosaics of quartz crystals, in places containing numerous tiny needles of rutile, and areas of fine-grained material in which biotite, sericite, microcline, and quartz were recognized. Two specimens of granitic material from the lenses were found to consist of quartz, albite (much sericitized), relatively fresh microcline, and a little chlorite. Carbonate veinlets intersect the granitic material. In one specimen, grey-blue tourmaline occurs, apparently as a replacement, in the altered albite.

This rock is interpreted as a sheared conglomerate that has suffered hydrothermal alteration and probably injection of some pegmatitic material. Its contact with the underlying ellipsoidal volcanic rocks is not exposed, but as attitudes on either side are the same there is no evidence of an angular unconformity. The conglomerate is overlain conformably by white quartzite. The ellipsoidal volcanic rocks that underlie the conglomerate are intruded by a granitoid gneiss, and this granitoid gneiss, or some fraction of it, is considered to be intrusive into the conglomerate.

MAFIC ROCKS

Mafic rocks[1] of the Tazin group comprise all the basic or dark-coloured rocks of the map-area, such as the amphibolites, biotite schists, epidote- and chlorite-bearing rocks, and the dark-coloured, aluminous metamorphic rocks such as sillimanite-biotite gneisses, cordierite-amphibole rocks, etc. They may be either of igneous or sedimentary origin. Because of the frequent difficulty experienced in distinguishing the mode of origin of these rocks they have been mapped as a unit and differentiated according to their mineralogical composition and origin or postulated origin. A description of the more important and more interesting of these rock types follows.

Amphibolites of Sedimentary Origin

The amphibolites of sedimentary origin are of variable composition, and grade into chlorite schists, biotite schists, quartzites, dolomitic quartzites, and cordierite-amphibole rocks. They are dark grey to green, banded, amphibole-bearing schists or gneisses containing variable quantities of feldspar and quartz. The amphibole crystals may have a random orientation or may show a preferred orientation, being alined parallel with the fold axes. More rarely the amphiboles have a feathery habit, occurring as sheaves or forming rosettes about 10 mm. in diameter in the rock.

A common type of amphibolite is a black to grey-green, gneissose rock containing a considerable quantity of feldspar. Minor amounts of brown biotite (or phlogopite) may be present in these rocks and certain phases are garnetiferous. Under the microscope the black to dark green amphibole is seen to be a pleochroic blue to green to yellow variety, and a less common light green amphibole is nearly colourless in thin section. The feldspar is much altered to a fine-grained, sericitic aggregate. The composition of the feldspar, although difficult to determine accurately because of alteration, varies from andesine to albite. Common accessory minerals are sphene, zircon, ilmenite, and hematite.

Many of the amphibolites of sedimentary origin contain quartz, which may occur sparingly in scattered crystals throughout the rock or may comprise a large part of it, commonly as quartz bands intercalated with amphibole-bearing bands. With increase in quartz, these rocks grade to

[1] A. Holmes in "The Nomenclature of Petrology" defines mafic as "a mnemonic term for the ferromagnesian and other non-felsic minerals actually present in an igneous rock, and also applied to rocks in which those minerals predominate...". In this report the term 'mafic rocks' includes all dark-coloured rocks whether of igneous or sedimentary origin. This extension of the meaning of an established term is not intended as a recommendation that this general usage be adopted by geologists; it is employed here in this sense only because it appears to be the term best fitted to the map-unit. The writer has not called this group 'greenstones' because the latter term commonly implies an igneous origin, and most of these rocks are believed to be altered sediments; also, coarse-grained amphibolites are included in this unit.

dolomitic quartzites and quartzites. The dominant amphibole of these rocks is the dark grey-green variety, which is pleochroic blue to green to yellow. In some specimens this amphibole appears to be altered to the lighter green variety, which is almost colourless in thin section, in other specimens the amphibole is partly altered to chlorite. The plagioclase of these rocks is much altered to an aggregate of sericite and, more rarely, to clinozoisite. In composition it is either albite or a sodic oligoclase. Accessory minerals are epidote, sphene, apatite, zircon, and iron oxides.

Cordierite-Amphibolite Rocks

Cordierite-amphibolite rocks are considered to represent original argillaceous beds in the Tazin group. The most common type consists of radiating sheaves of light grey to brownish amphibole crystals up to 10 mm. long enclosed in what appears to be a light grey, fine-grained, vitreous groundmass. Under the microscope the 'groundmass' is seen to consist, in most slides, of a single, slightly fractured crystal of cordierite poikilitically enclosing sheaves of amphibole crystals, irregular biotite flakes of various sizes, small rounded blebs of quartz, iron oxide minerals, pyrite, and apatite.

Most of the cordierite seen under the microscope is fresh, with good cleavages and close to parallel extinction. No pleochroism or pleochroic haloes were noted. The mineral alters in irregular areas to a light greenish yellow chloritic material, which is nearly isotropic, and colourless mica may occur along certain of the cleavage planes.

The associated amphibole, which is light brown to grey in hand specimen, is colourless in thin section and shows good amphibole cleavages. It is optically positive, and in this and other optical properties corresponds with the properties given by Winchell (53) for cummingtonite. A prominent feature in some of these crystals is the multiple twinning on the orthopinacoid (100).

The biotite is a light brown variety containing numerous black pleochroic haloes about minute zircons, and is close to phlogopite in composition.

A chemical analysis of a specimen of the cordierite-cummingtonite rock, made by R. J. C. Fabry of the Geological Survey of Canada, is given below, together with the mode of the specimen as determined by Rosiwal analysis.

Chemical analysis		Rosiwal analysis	
	Per cent		Per cent
SiO_2 —	49·37	Cordierite —	37·9
Al_2O_3 —	18·70	Cummingtonite —	23·8
Fe_2O_3 —	9·80	Biotite —	26·9
FeO —	4·04	Chlorite —	7·7
MgO —	12·62	Opaque iron minerals (mainly pyrite) —	3·7
CaO —	1·33		
Na_2O —	0·58		
K_2O —	1·15		
H_2O —	2·88		
	100·47		

Narrow bands of this cordierite-cummingtonite rock are persistent along strike, but across the strike the rocks show marked changes in mineral composition and may, for example, vary in a short distance to a garnetiferous biotite schist or to a normal amphibolite with hornblende and altered feldspar. The appearance of the rock, too, may change as a result of partial or complete alteration of the cordierite to a fine-grained chloritic aggregate.

Garnetiferous Biotite Schist

Well-formed crystals of wine-coloured garnet, commonly 4 mm. in diameter, occur in medium- to coarse-grained biotite schist. Under the microscope, a typical specimen contained: garnet, 5 per cent; dark green-brown biotite, 46 per cent; quartz, showing strain shadows, 35 per cent; oligoclase, 8 per cent; chlorite (var. penninite), 5 per cent; and accessory sphene, apatite, and iron oxide minerals. The biotite contains black haloes about zircon crystals.

Andalusite-Sericite-Biotite Schist

An occurrence of andalusite-sericite-biotite schist is exposed near the shore of Beaverlodge Lake about ¾ mile north and west of the portage to Lake Athabasca. The rock is a contorted, sericite-biotite schist containing fractured and twisted porphyroblasts of andalusite commonly 15 mm. long. Under the microscope, the crystals of andalusite are seen to be greatly altered, containing trains of crystals of white mica along the prismatic cleavages, and abundant fine-grained quartz. Large, corroded porphyroblasts of biotite are also present, and many small crystals of deep grey-blue tourmaline. The fine-grained groundmass is composed largely of sericite and quartz, with chlorite occurring as an alteration product of the biotite. Accessory minerals are sphene, iron ores, and zircon, the last surrounded by black haloes in the biotite porphyroblasts. Smith (48) reports an andalusite-sericite-chlorite schist northeast of Melville Lake.

Sillimanite-Cordierite-Biotite Gneiss

A biotite-sericite gneiss east of the north end of Milliken Lake contains flat ovoids of a white material about 10 mm. in diameter along the foliation planes. These ovoids stand out on the weathered surface. Under the microscope they are seen to consist of a matte of slender sillimanite needles rudely alined in one direction and set in a matrix of quartz. On the edges of the ovoids the rock is composed of biotite and quartz with rarer needles of sillimanite; between the ovoids it is composed of cordierite, brown biotite, quartz, muscovite, and garnet. The cordierite is in large crystals, with poikilitically enclosed quartz and biotite. Muscovite appears to be secondary, as it cuts across the biotite flakes and occurs in irregular patches in the ovoids. The garnet is partly altered to chlorite.

Amphibole-Epidote-Chlorite Rocks

Amphibole-epidote-chlorite rocks are commonly dark green and pistachio green on fresh surfaces and are fine grained. They may be banded or almost massive. Small, dark green amphibole crystals are visible, and

the rock contains narrow bands or veinlets rich in epidote. In thin section, the amphibole crystals are seen to be from 0·1 to 2 mm. in length, and are moderately strongly pleochroic blue-green to green to yellow. The feldspar is commonly oligoclase, is not twinned, and may be fresh or considerably altered to sericite. Epidote or clinozoisite occurs along the foliation planes and in veinlets cutting the rock, and carbonate is common in some specimens. Chlorite occurs mainly as an alteration product of the amphibole. Quartz may form narrow bands parallel with the foliation, and hematite, sphene, and ilmenite are accessory minerals.

Chloritic and Chlorite-Epidote Rocks

The chloritic and chlorite-epidote rocks are green to black, fine grained, and finely banded to massive; they are most abundant near Beaverlodge Lake. The well-foliated rocks are best called chlorite-sericite schists or chloritic schists. A typical, chlorite-sericite schist is seen under the microscope to consist of very fine grains, roughly 30 per cent chlorite, 30 per cent sericite, 20 per cent oligoclase feldspar, and 10 per cent quartz, with some larger grains of quartz. Small veinlets of epidote, close to clinozoisite in composition, cut the rock. Another common rock is a chloritic schist consisting of about 45 per cent chlorite, 35 per cent sericitized oligoclase, and lesser amounts of quartz and epidote. Crystals of pyrite are common, and carbonate occurs both in minute stringers and as small, disseminated particles. Locally the schists are graphitic, contain abundant specular hematite, or may be red, due to a fine-grained impregnation of hematite.

The origin of the chloritic and chlorite-epidote rocks is not everywhere certain. Southwest of Eagle Lake, they are finely banded and are associated with andalusite-, cordierite-, and garnet-bearing schists, which are assumed to be of sedimentary origin. The metamorphic minerals andalusite, cordierite, and garnet are much altered to sericite and chlorite, indicating that this part of the map-area has been strongly affected by a period of retrograde metamorphism. The fine compositional banding of the chloritic and chlorite-epidote rocks and their association with metasedimentary rocks strongly suggests a sedimentary origin.

Elsewhere, however, as immediately south of Eagle Lake, fine-grained chlorite-epidote rocks are massive and may be of volcanic origin. No volcanic structures, however, such as amygdules or pillows have been observed. Under the microscope, these rocks are seen to be completely recrystallized.

Near the Eagle shaft, numerous, dark-coloured, fine-grained bands in the gneisses have been mapped as chlorite-epidote rocks. Some of these are remnants of older rocks in the gneisses; others are considered to be mylonitized granite-gneisses impregnated with chlorite. The latter commonly have a banded appearance, and may be difficult to distinguish from chloritic or chlorite-epidote rocks of sedimentary or volcanic origin.

Amphibole-Epidote Rocks of Volcanic Origin

Near Elliot Bay, pillow lavas (*See* Plate IV A) occur at the base of the conglomerate band mapped in that area, as described by Alcock (6). The pillow structure is, in a few places, clearly defined; the dark green to black

material composing the pillows is partly outlined by lighter green epidote-bearing bands, and by occasional bands of light-coloured quartz believed to be a recrystallized chert. The angular spaces between the pillows are filled with an aggregate of relatively coarse-grained amphibole crystals, diopside, carbonate, and quartz. No amygdaloidal or vesicular structures were noted in these volcanic rocks.

In thin section, 42 per cent of the rock comprising the pillows is seen to be composed of blue-green pleochroic amphibole crystals up to 1 to 2 mm. in length; 43 per cent consists of fresh untwinned andesine feldspar (An_{45}); 14 per cent, of iron oxide minerals, mainly ilmenite; and less than 1 per cent, of green biotite. Quartz and epidote-bearing veinlets cut the pillows.

Along strike, both to the north and south, these rocks grade into more coarsely crystalline amphibolite.

The band of amphibolite striking northwestward from Elliot Bay to the Athabasca series contact near Beaverlodge Lake is also believed to be of volcanic origin because of its predominantly fine grain and because narrow bands of cherty material up to 20 or 30 feet long, similar to those in the Elliot Bay volcanic rocks (*See* Plate IV A), occur within it. However, no definite volcanic structures were noted in it or, indeed, within the Tazin group in any part of the map-area other than at the base of the conglomerate near Elliot Bay.

Amphibolite of Intrusive Origin

Basic intrusive rocks, now mainly amphibolites, form extensive sill-like masses in the map-area, and in a few places cut across the bedding of the sedimentary rocks. Some are multiple intrusions.

The amphibolite weathers dark brown or green. The grain is commonly coarse, with crystals of dark green amphibole up to 10 mm. long in a fine-grained, brown to light green groundmass. The rock is rarely massive and commonly shows a weak foliation and a lineation, the foliation being particularly well marked at the contacts. Most outcrops are crossed by interlacing irregular stringers containing one or more of epidote, calcite, dolomite, quartz, zeolite, serpentine, chlorite, and hematite.

An average Rosiwal analysis of four thin sections of this rock showed 43 per cent amphibole, 41 per cent andesine feldspar (An_{40}), commonly much altered to sericite; 7 per cent penninite; 2 per cent biotite; 4 per cent iron oxide minerals, mainly ilmenite; 2 per cent apatite; 1 per cent sphene; and lesser amounts of zeolite, carbonate, and quartz.

The amphibole commonly has a sieve-structure, the larger crystals containing numerous inclusions of feldspar, apatite, and iron oxide minerals. In all sections examined, it is the pleochroic blue-green to green to yellow type referred to previously. The andesine feldspar (An_{40}) occurs in small, commonly untwinned grains, many of which are altered to fine-grained sericite. The biotite is pleochroic (yellow-brown to faint yellow), and invariably contains small, well-formed grains of sphene. The penninite occurs in well-formed flakes that are weakly pleochroic and show straight extinction and positive elongation. Berlin blue interference colours are common. The penninite occurs near ilmenite, or replacing biotite, or in and adjacent to narrow veinlets in the rock. The black, opaque grains all

show white leucoxene alteration in reflected light, and are associated with sphene; they are, therefore, considered to be ilmenite. Apatite is scattered throughout the rock, and quartz, carbonates, and zeolites form small cross-cutting veinlets.

One thin section of amphibolite from the Athona property near Goldfields contains a few crystals of a pyroxene believed to be augite. The pyroxene is altered on the edges, and more rarely in the interior of the crystals, to blue-green pleochroic amphibole and to biotite. Numerous, well-formed crystals of sphene occur in the alteration products, suggesting that the pyroxene is a titaniferous variety. Alcock (6) states that, in a few thin sections of these basic intrusive rocks, remains of diallage crystals were recognized associated with an amphibole, pleochroic in shades of green and greenish blue, that is apparently secondary.

Beavan (9), reports that, at the Athona property, a light green amphibole, with higher birefringence than the amphibole referred to above, forms the core of largish crystals of amphibole, and is bordered by, and in optical continuity with, the blue-green pleochroic amphibole.

It appears certain that the bulk of the blue-green pleochroic amphibole in these basic intrusive rocks is a recrystallized metamorphic mineral, rather than an original igneous constituent, for the following reasons: (1) the mineral has commonly a pronounced sieve-structure typical of recrystallized minerals; (2) relict structures have been noted, showing that this amphibole has formed by alteration of pyroxene or by alteration of a different amphibole; (3) the amphibole crystals commonly show a preferred alinement parallel with the axes of the folds, which strongly suggests that they were formed during the period of folding. Probably this folding, and the period of maximum metamorphism, are related to the granitic intrusions; and (4) the amphibole in these rocks appears to be the same as some commonly found in amphibolites considered to be of sedimentary origin.

It is probable that many of the amphibolites of intrusive origin were originally gabbroic in composition, and were altered to amphibolite during a period of metamorphism. This hypothesis requires the alteration of the original pyroxene to amphibole, of labradorite to intermediate or sodic feldspar, and the introduction of soda (Na_2O) in large amounts for the alteration of the plagioclase and for the formation of amphibole from pyroxene, if the blue-green, pleochroic amphibole contains considerable soda, as suggested by Beavan (9) and the writer (18). It is also possible that some of these amphibolites were originally dioritic in composition.

STRUCTURE

The Tazin group of sedimentary and volcanic rocks is a bedded series in which no unconformities have been found. As nearly as could be estimated, 30,000 feet of these rocks are exposed in the map-area. The Tazin group is composed of foliated, highly metamorphosed rocks, in which the foliation of the sedimentary strata parallels the bedding. Commonly the bedding foliation dips at a flat angle, but locally it may be steep or vertical. Lineations are prominent, and are useful as an aid in working out the structure. They comprise: alinement of fold axes, alinement of amphibole crystals, mullion structure or fluting, and rodding.

Major Structures

The strike of the Tazin beds is predominantly northeasterly. The largest single structure is the synclinorium centred about Goldfields on the shore of Lake Athabasca from Elliot Bay on the west to Elto and Bigfowl Islands on the east. This synclinorium plunges southwest at about 25 degrees. Flanking this structure on the west, and separated from it by an area of granite, is an anticline in the vicinity of Milliken Lake, which plunges northeast at 20 degrees. On the east the Goldfields synclinorium is bounded by an anticlinal structure south of the Mackintosh Bay granite, the axial trace of the anticline passing southeast through Bigfowl Island. East of this again is a narrow syncline at the entrance to Mackintosh Bay that plunges southwest at 30 to 35 degrees. North of Mackintosh Bay the beds strike easterly, with numerous minor variations, whereas farther north the beds swing to the northeast to where they disappear in the gneiss.

North and east of Beaverlodge Lake, the Tazin group formations dip to the south, but to the north, between Beaverlodge and Eagle Lakes, lineations indicate a northeasterly plunge of the folds of 20 to 30 degrees. Two miles west of Cinch Lake, sedimentary inclusions in the gneiss are arranged so as to form a gentle anticline plunging about 15 degrees to the northeast. Strong lineations occur on the nose of the anticline. Southeast of LeBlanc Lake, a large remnant of the Tazin group in the gneiss has a very complicated, folded structure. At its northern end, the folds plunge northeast, but the plunge appears to be essentially horizontal to the south of Fold Lake. It is considered that the sedimentary bands southwest of Fold Lake, at least as far as the first transverse fault, occupy a syncline. Southeast of Charlot Lake, an inclusion in the gneiss also has the form of an anticline, plunging northeast at 30 degrees, and another of these structures occurs north of Right Lake. The lowest horizon of Tazin rocks in the western part of the map-area (*See* Map No. 1015A) is exposed in the core of the anticline west of Milliken Lake. Southeastward, the rocks become progressively younger to the shores of Lake Athabasca. The anticline west of Milliken Lake plunges northeastward at about 25 degrees. Farther north and east, the northeasterly plunge of the folds in inclusions in the granite indicates that higher horizons are exposed as far as the northern boundary of the map-area. In the central part of the map-area, the lowest exposed Tazin formations are north of Murmac Bay of Beaverlodge Lake. Southward, the beds represent progressively higher horizons to where the centre of the Goldfields synclinorium is reached. The estimate of the exposed thickness of the Tazin group (30,000 feet) was made across the sections from west of Milliken Lake to the centre of the Goldfields synclinorium, and from there to north of Murmac Bay, on the assumption that the strata are not repeated by faulting.

Minor Folds

In the southern part of the map-area, many minor folds occur within larger folds and plunge south with them and at about the same angle. These folds are open, and are of variable dimensions from $\frac{1}{2}$ mile across to crenulations an inch or less wide that occur particularly near the noses of the folds.

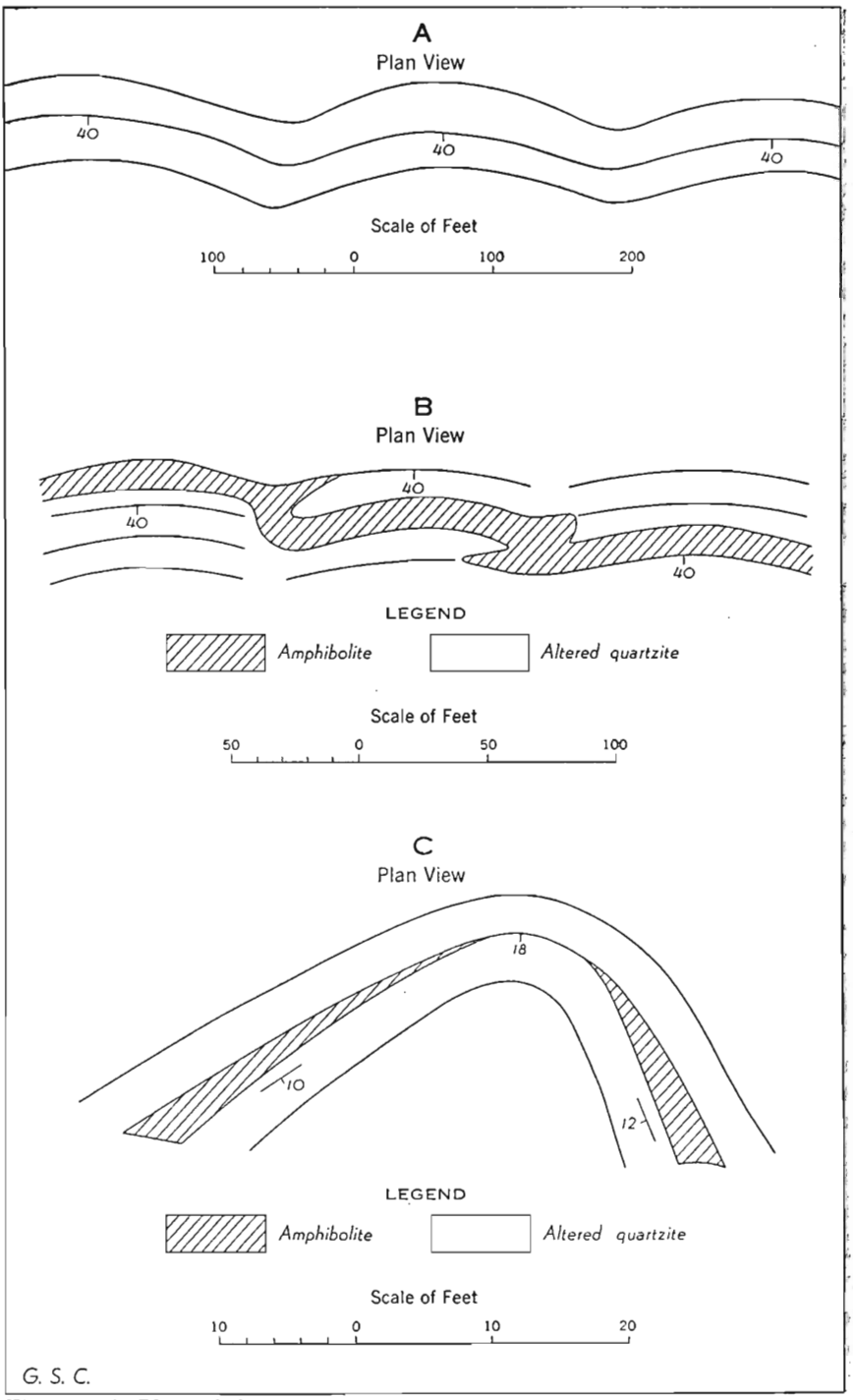


Figure 1. A. Plan of bedding foliation, showing broad synclines and narrower anticlines.
B. Sketch to show the relation of an amphibolite dyke to the minor folds.
C. Sketch to illustrate thinning of less competent beds at the nose of a syncline and thickening on the limbs.

Figure 1a shows a characteristic arrangement of folds in which numerous, well-formed, open synclines are joined by sharp anticlines; in places the anticlinal structure is missing, its place being taken by a fracture or occupied by intrusive material. Figure 1b is a sketch of an amphibolite dyke, showing its relations to banded gneiss (believed to be a granitized quartzite) northeast of No. 2 shaft of the Box mine. It will be noted that the adjacent rock is folded into broad open synclines similar to those shown in Figure 1a. The anticlines appear to be zones of weakness, as the amphibolite intrusions, which conform with the bedding-foliation in the synclinal parts of the folds, commonly thicken at the anticlines and cut across the beds to follow a different horizon in the adjacent syncline, commonly extending short tongues between other beds.

Close to the nose of the synclinorium near Goldfields, where hornblende or biotite schist or cordierite-amphibolite rocks occur interbedded with the more competent quartzose or granitic rocks in small synclinal folds, most commonly the less competent rock thins or is lacking at the nose of the synclines and thickens on the limbs (*See* Figure 1c), in contrast with most described types of folds.

Folding on a very small scale, which may be referred to as mullion or crenulated structure, is well developed in the minor folds and especially around the noses of these folds. This structure is discussed under 'Lineation'.

Lineation

Most of the Tazin rocks display a prominent lineation, which invariably parallels or nearly parallels the axes of the folds. The lineation is expressed in the alinement of amphibole crystals in the amphibolite, in the alinement of the axes of minute corrugations[1] in the schists, mullion structures[1] in the quartzites and granitized quartzites, and 'rodding' (an imperfect pencil structure) in the quartzites.

The perfection of the alinement of the amphibole crystals in the amphibolite varies greatly throughout the area. In a few places all the amphibole crystals appear to be parallel; in others no lineation is apparent. Near their borders, however, most amphibolite bodies show a foliation and at least a faint lineation.

The axes of the mullion structures or corrugations (*See* Plate IV B) also parallel the axes of the folds. On some surfaces the corrugations have the appearance of slickensides. However, an examination of sections across these structures shows that the foliation of the rock is not interrupted by the corrugations but follows around them, and that, furthermore, they are not restricted to one surface but commonly appear in equal strength throughout a succession of bedding-foliation surfaces. For these reasons the corrugations are not considered to be slickensides, although minor movements (probably later than the folding) may have occurred along some of them. The individual corrugations are essentially symmetrical; they exhibit no regular asymmetry such as would be expected if the corrugations were drag-folds. Moreover, unlike the distribution of drag-folds, they are more common around the noses of small synclines than on the adjacent limbs.

[1] Corrugations and mullion structures are here considered to be minor folds differing from each other only in scale, corrugations being less than 2 inches across and mullion structures more than 2 inches.

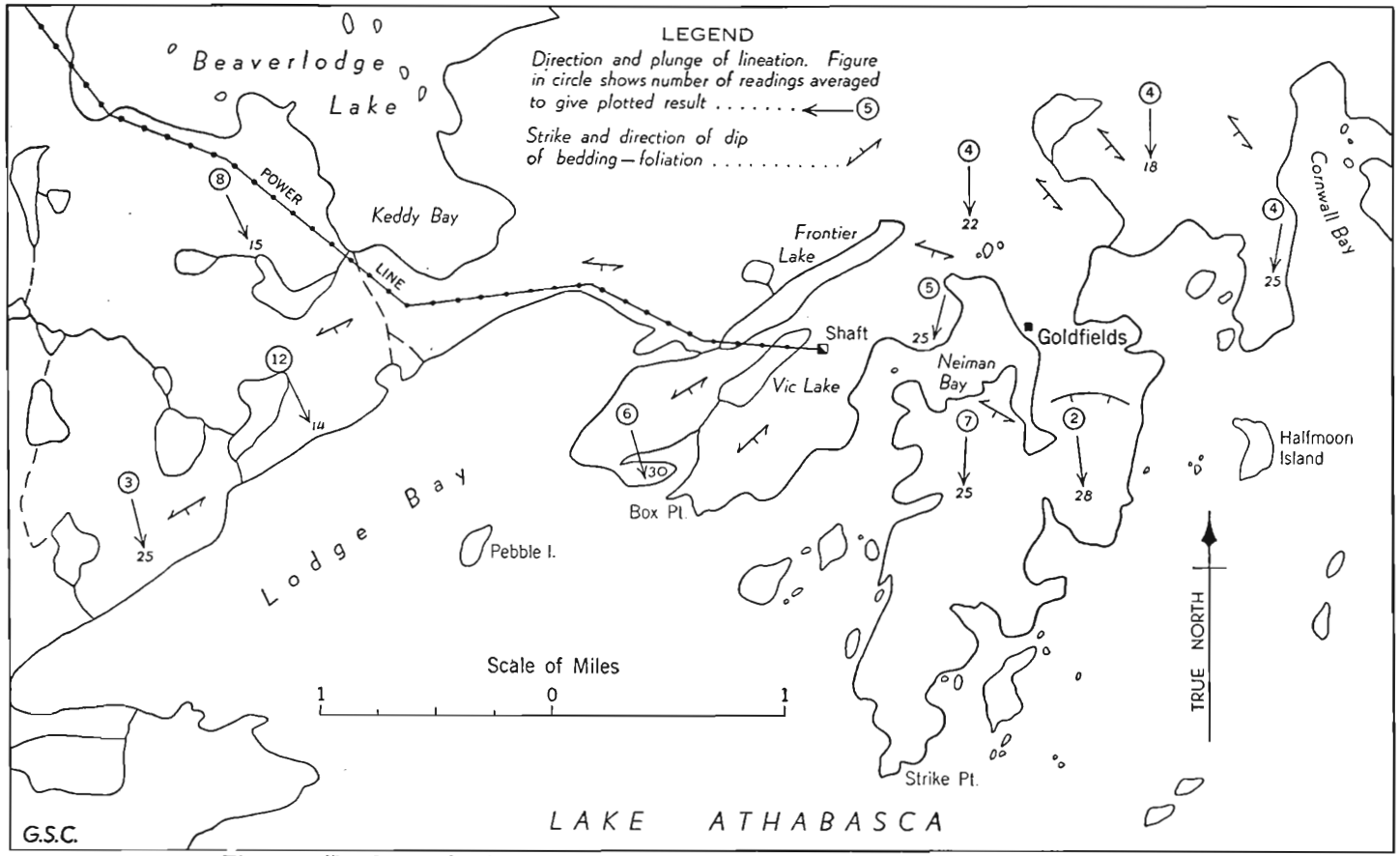


Figure 2. Sketch-map showing attitudes of foliation and lineation near Goldfields, Saskatchewan.

'Rodding' is the result of the isolation of linear masses of rock by means of two or more closely spaced joint planes or combinations of joint planes with bedding foliation planes, all the planes involved being parallel with the lineation direction. The rodding is parallel or sub-parallel with other lineations.

Figure 2 shows the average direction and plunge of the lineation in different parts of the area around Goldfields. The figures in the circles indicate the number of readings averaged to give the plotted result. Near Goldfields Bay, the lineation is strong and trends south about parallel with the axis of the regional synclinorium. Between Frontier and Beaverlodge Lakes the lineation is weak, but is again pronounced west of the portage to Beaverlodge Lake. The horizontal projections of the lineation directions are in the form of a fan, varying from 10 degrees west of south in the Cornwall Bay area to 30 degrees east of south in the vicinity of Lodge Bay. Thus, the lineation is parallel with the axis of the regional synclinorium near that axis, and on the limbs lies between the axis and the direction of dip.

Rock Competency

That the rocks of the Tazin group have undergone movement under great pressure is shown by flow structures developed in the carbonate and other less competent rocks, and by *boudinage* or 'sausage' structures in interbedded rocks of diverse competencies.

The granitic rocks and quartzites appear to have acted during folding as the most competent rocks; amphibolites and other mafic rocks, especially the cordierite-amphibolite and biotite schists, are less competent; and the dolomitic rocks, especially those containing considerable carbonate, are the least competent of all. Evidence of this difference in competencies is found in the *boudinage* structures, with *boudins* of granitic rock enclosed in what was evidently a more plastic mass of amphibolite, or of *boudins* of quartz in amphibolite (*See* Plate V A). It is well known that the carbonate rocks flow more readily under pressure than any of the types mentioned above.

An example of flow in carbonate rocks is to be found at the northeast end of Cornwall Bay. The dolomite there commonly carries reasonably persistent tremolite and diopside bands, but in places the carbonate appears to have flowed, the secondary silicate minerals being broken into very small particles and arranged as trains of small fractured material between bands of almost pure carbonate. In one place the carbonate has, apparently, flowed around, and now partly encloses, an angular mass of quartzite.

It should be noted that most of the rocks mapped as 'dolomite and dolomitic quartzite' are not everywhere as incompetent as pure carbonate rock. Where these rocks are composed of interbanded tremolite, diopside, and quartz bands they are moderately competent, and where composed of quartzite, with isolated crystals or nests of crystals of diopside, are among the most competent of the rocks of the area.

The well-developed foliation along contacts of various units of differing competencies, and the thickening and thinning of these units on the limbs and crests of folds, also indicate rock flowage.

Interpretation of Structures

Bedding Foliation

The bedding foliation of the Tazin group is believed to be due to the deep burial of this inhomogeneous, bedded group, with subsequent flowage, parallel with the bedding, and recrystallization.

It has been shown (page 25) that rock flowage has occurred; the flowage is believed to be related to folding. On *a priori* grounds it will be appreciated that if rock flowage occurs in a bedded series, the beds being of diverse competencies, it will occur principally in the least competent bands, will be bounded by the more competent bands, and must occur principally parallel with the bedding. Slippage or relative movement will be most extreme near the contacts of competent and incompetent beds. It has been noted previously that the foliation of the amphibolites and biotite schists is particularly marked near their contacts with quartzites or granites.

The degree of visible bedding foliation developed in a rock depends on: (1) the amount of differential movement (strain) that the rock has suffered and (2) the mineralogical composition of the rock. The amount of strain that a rock has suffered (and, therefore, the degree of foliation it shows) depends on: (1) its position in the area with respect to major and minor folds; (2) its competency with respect to nearby rocks; and (3) its proximity to rocks of differing competency. If a rock is competent with respect to adjoining bands, movement will be taken up principally in the adjoining less competent bands and the rock will be weakly foliated: for instance, in amphibolite adjoining pure carbonate rock, the amphibolite will be only weakly strained, and only a weak foliation will be developed. If, however, the amphibolite adjoins the more competent quartzite, movement will be taken up principally in the amphibolite, which will develop a marked foliation. In areas of interbedded thin bands of quartzite and amphibolite, the bedding foliation is commonly strong, being developed throughout the amphibolite and particularly near its contacts with the quartzite. In areas where the amphibolite bodies are thick, the bedding foliation, although invariably present, is commonly indistinct except near its contacts with quartzite, where the foliation is strong.

The degree of visible foliation in the Tazin rocks depends greatly on their mineralogical composition. Biotite schists, amphibolite of various types, and granite-gneisses containing biotite, amphibolite, chlorite, or sericite, display the most noticeable foliation, principally because of the shapes of these minerals but also because of their colour. In pure quartzite or carbonate rocks, foliation is not readily visible because of their composition; nevertheless, a petrofabric study by Conybeare (25) has shown a high degree of orientation of quartz grains in some quartzites of the Ace Lake-Raggs Lake area, and undoubtedly carbonate rocks would show a strong pattern if studied by the same methods.

Folding

The structure of the sedimentary rocks in the southern part of the map-area appears to be simple; the folding is not close, most dips being moderate. Perhaps such simple-looking structures in a highly metamorphosed terrain

should be viewed with some suspicion because of the possibility that they might represent recumbent folds or nappe structures, but no evidence of such complications was recognized.

In detail, also, the structure in most places appears to be simple, but here and there, as near the town of Goldfields or near Bearcat Lake, the folding is complex, due to the closer folding and to the occurrence of the structurally incompetent dolomite at those localities. These conditions may, of course, be related. The extreme incompetency of the dolomite, which permits it to flow under the conditions reached in the map-area, is believed capable of producing a variety of intricate structures. Figure 3

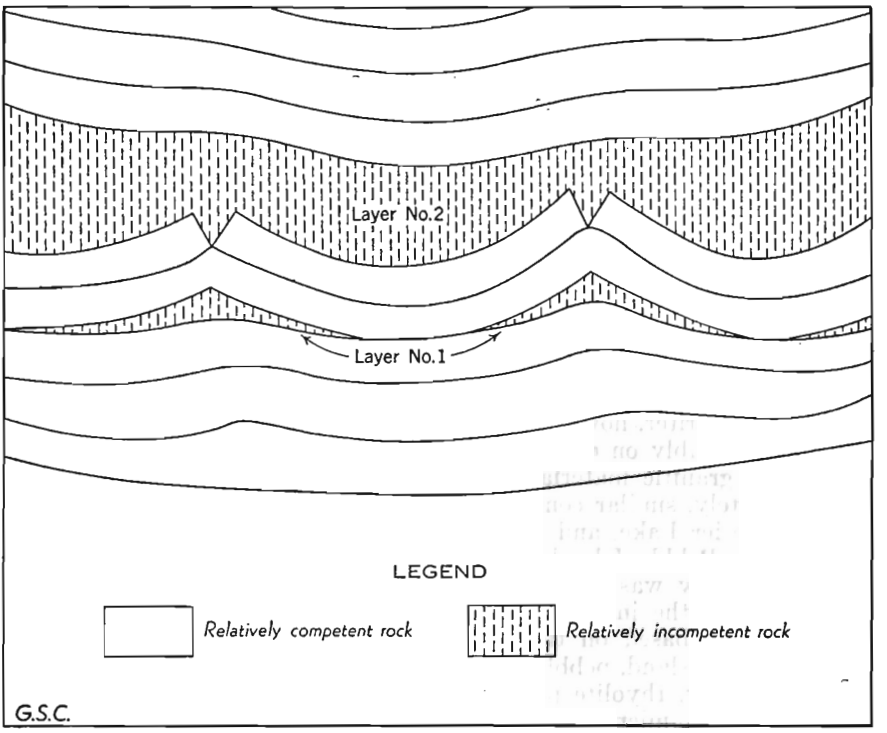


Figure 3. Hypothetical cross-section of folds, illustrating behaviour of incompetent layers (1 and 2) in an otherwise more competent rock.

may be regarded as illustrating the result of hypothetical folding of an interbedded series composed of relatively competent and incompetent rocks. Folds are generally considered to become less pronounced downward, as for example in a syncline, where the upper beds are foreshortened more than the lower beds. As the dolomite flows readily under pressure, it acts almost as a free face; compensation occurs within the dolomite band so that the folds in the band above may have only a limited relation to those in the underlying beds. Structures similar to this are common, but are rarely sufficiently large to show on the map. It is believed, however, that a condition such as this is responsible for the structure illustrated on the map near Bearcat Lake, north of Mackintosh Bay. The apparent lack of conformity

in bands such as these is, therefore, interpreted, not as an unconformity in the sedimentary series, but as a structural discordance due to slippage of the beds along certain incompetent layers during folding.

It is also conceivable, as suggested in Figure 3, that in this type of folding, where the beds are restrained below but relatively free above, at layer 2, due to the presence there of a thick mass of incompetent rock, the thin band of incompetent rock at layer 1 might be squeezed out of the synclines into the anticlines, as indicated in the figure. This is not suggested as a certain result of the folding; it is only desired to point out that diverse and unpredictable types of folds may occur under these conditions.

Problem of the 'Unconformity' Between the 'Beaverlodge Series' and the Tazin Group

In 1936, Alcock (6) described an unconformity within the older formations of the Goldfields area. For the rocks below the unconformity he retained the older name 'Tazin group'; those rocks above the unconformity he named the 'Beaverlodge series'. His principal evidence for this unconformity is the conglomerate shown on the accompanying map three-quarters of a mile northeast of the head of Elliot Bay. There the conglomerate[1], which Alcock considered the base of the Beaverlodge series, rests on ellipsoidal volcanic rocks and granite-gneiss, and grades upward into quartzite. Because of the shearing of the conglomerate parallel with the bedding planes, because of the introduction of vein quartz, tourmaline, and probably pegmatitic material, and because the contact with the underlying ellipsoidal volcanic rocks is drift covered, the relations here are obscure. The writer, however, interprets this occurrence as a conglomerate resting conformably on ellipsoidal volcanic rocks both of which have been intruded by granitic material and related fluids.

Fortunately, similar conglomerates occur on Pebble Island and northwest of Frontier Lake, and there the relations with the underlying rocks, especially on Pebble Island, are better exposed. At these two localities, also, no difficulty was experienced distinguishing the pebbles of the conglomerate from the injected material, a factor that lends doubtful value to observations based on the Elliot Bay conglomerate.

On Pebble Island, pebbles of quartz, quartz and lime-silicate minerals, granite porphyry, rhyolite porphyry, and rhyolite occur in a matrix composed of quartz, microcline, epidote, and chlorite. It is underlain conformably by a recrystallized dolomitic quartzite similar to the matrix of the conglomerate. Pegmatite dykes intersect both these formations. Northwest of Frontier Lake a similar conglomerate rests conformably on white quartzite and is overlain conformably by a quartzite, containing minor amounts of dolomitic material, into which it appears to grade laterally to the south. To the north of the conglomerate outcrop is a mass of granite-gneiss.

There seems little doubt that, at Pebble Island and near Frontier Lake, the conglomerates are intraformational, as they show no discordance in attitude; no break in the sedimentary sequence could be observed; and the conglomerates are underlain in each case by detrital rocks similar to the matrix of the conglomerate. Moreover, granite or pegmatite dykes, where

[1] *See* description of this conglomerate on page 14 and photographs of it (Plate III B).

present, cut both formations. Near the head of Elliot Bay the relations are more obscure due to shearing and injection phenomena, but there is no discordance in the attitude of the beds and no certain evidence of an unconformity.

Alcock (6) states that an unconformity is exposed on the point southwest of the Box mine. The writer examined this locality and interprets the condition there as due to faulting, in that what there appears to be an unconformity is actually a thrust fault of small displacement that intersects the strata at a small angle and has brought into contact two sedimentary rocks of slightly different compositions.

Another locality noted by Alcock (6), where the unconformity is said to be exposed is on "the iron-stained point east of the mouth of Fish Hook Bay. Here associated with the quartzites are red and bluish beds containing hematite in such considerable amounts that the beds may be termed iron formation. The beds form a syncline pitching to the southwest and resting on older grey quartzites of the Tazin group. The two series are not seen in actual contact, but at one place they occur with diverging strikes within 40 feet of each other".

Throughout the sedimentary series, and especially near major flexures, it is common to find beds occurring "with divergent strike within 40 feet of each other". Examples of this could be found at hundreds of places and at many horizons (*See* structures illustrated by Figures 1 and 3). Another criticism that might be made of Alcock's statement, given above, and the hypothesis of the unconformity, is that banded iron formation occurs commonly in the underlying rocks that he mapped as Tazin group, especially near Fish Hook Bay[1]. There is, therefore, no distinctive difference in the lithology of the rocks above and below the alleged unconformity at this point.

Many of the rocks mapped by Alcock as of the Beaverlodge series underlie rocks that he mapped as Tazin group. Thus, Jolliffe (38), who mapped in detail a small area between Fish Hook Bay and Cornwall Bay, found that "quartzite on the east side of Cornwall Bay previously mapped as of Beaverlodge age appears to be overlain by limestone and arkosic gneiss similar to members of the Tazin group".

Elsewhere throughout the map-area, formations previously mapped as of the Beaverlodge series dip under rocks mapped as Tazin group. A study of the structures indicated on Map 339A (6) shows that, if Alcock's hypothesis is correct, most areas mapped as Beaverlodge series must be either long synclinal structures in the Tazin rocks or everywhere bounded on at least one side by faults. The attitudes shown on the map accompanying this memoir indicate that the structures in the belts of 'Beaverlodge series' are not synclinal, that the structure is relatively simple, and that all the beds dip as would be expected of a conformable series of sediments. Moreover, faulting is not an acceptable hypothesis in most instances because the contacts between the sedimentary rock-types are commonly gradational rather than sharp. It is, therefore, considered that rocks previously mapped as of the 'Beaverlodge series' have been shown to be interbedded, and conformable, with the sedimentary rocks of the Tazin group.

[1] In the map-legend accompanying Alcock's report, iron formation was listed as a rock type of the Beaverlodge series, but not as one of the Tazin group.

Conclusions. Conglomerates occur in the Tazin group of sedimentary rocks. These conglomerates contain pebbles of metamorphosed dolomitic rocks, similar to the metamorphosed dolomitic rocks of the Tazin group, and others of granite-porphyry, rhyolite-porphyry, and rhyolite, none of which is similar to exposed rocks in the map-area. In two instances the conglomerates are known to be intraformational. In another occurrence, that near Elliot Bay, the contact is drift covered and the relations are indeterminate; however, the beds above and below the alleged unconformity have the same attitude, and although a disconformity may be represented there is no angular unconformity.

It is possible that an unconformity may occur within the Tazin group, although in the opinion of the writer none has been proved. If and when such an unconformity is located it is recommended that it be considered of local occurrence until it can be traced throughout the map-area. Until such a time, the pre-Athabasca bedded rocks should be regarded as a conformable series.

GRANITE, GRANITE-GNEISSES, AND GRANITOID GNEISSES

GENERAL STATEMENT

More than 50 per cent of the Goldfields-Martin Lake map-area is underlain by a complex of granite, granite-gneiss, and granitoid gneisses. These rocks vary in colour from grey to pink to red, and in texture from well foliated to almost massive. The foliated varieties predominate, and the foliation in these commonly conforms with the attitude of adjacent rocks. The gneiss, although composed mainly of granitic material, that is, feldspar and quartz, contains a variable volume of relics of older rocks of all sizes, from the complexly folded formations southeast of LeBlanc Lake, which outcrop continuously for more than 4 miles, to lenses a few inches long. These relics represent most of the Tazin rock types of the area, with amphibolite particularly widespread and abundant, quartzite abundant, and relics representing altered dolomitic rocks other than amphibolite, less common.

In a typical foliated gneiss, the granitic (feldspar-quartz-rich) fraction contains lenses and bands of amphibolite of all sizes, from units large enough to map to lenses a few inches long. Rarely, the amphibolitic and granitic materials are finely interbanded, forming typical migmatites. The amphibolite commonly contains a little biotite, and at the amphibolite-granite contacts a narrow biotite-bearing zone is commonly developed. Between the lenses of amphibolite the rock may be a biotite gneiss or a chlorite-bearing gneiss, or may contain essentially no ferromagnesian minerals. Biotite granite-gneisses occur elsewhere, but are less common than the gneisses containing amphibolite inclusions. The biotite crystals show a marked parallelism; they may be segregated into bands or distributed throughout the rock. Although the contacts of granitic rocks and amphibolite are sharp, the contacts of the granitic rocks with quartzites are commonly gradational over tens, hundreds, or even thousands of feet. The rocks of these gradational zones or granitized zones have been called granitoid gneisses, and have not been distinguished in the field mapping from granite and granite-gneisses. The granitoid gneisses include the map-unit on Map 363A (6) that Alcock termed a "mixture of orthogneiss and

paragneiss probably mainly or solely altered forms of the Tazin group"; and include what Blake (11) in the adjoining Forget Lake map-area termed "metamorphosed and granitized rocks, dominantly of sedimentary origin". In some areas, however, small distinct quartzite relics occur in the gneiss, the foliation of which parallels the long axes of the inclusions. Two miles west of Cinch Lake, lineations and attitudes on bedding of quartzite relics in the gneiss indicate remnants of an anticlinal sedimentary structure pitching gently northeastward, the alinement of the relics having, apparently, not been greatly disturbed by the introduction of the granitic material.

A granite-gneiss 1½ miles north of Bearcat Lake contains bands rich in light green diopside and darker amphibole. The presence of considerable diopside in the rock is believed to indicate that granitic material has here altered and partly incorporated dolomitic sediments. In many other places the numerous amphibolite relics undoubtedly represent metamorphosed, impure, aluminous, calcareous, or dolomitic sedimentary rocks, although some may also be metamorphosed lavas or tuffs.

At numerous localities the gneiss contains abundant garnet, which is believed to indicate areas of assimilated or altered aluminous sedimentary or igneous rocks. This belief is strengthened by the notable parallelism of belts of garnetiferous gneiss with adjacent sedimentary formations.

Southeast of Charlot Lake, a band of biotite-sillimanite gneiss consists of quartz, strongly pleochroic, red-brown to faint brown biotite, albitic plagioclase feldspar, chlorite, zircon, and iron oxide minerals. Under the microscope, aggregates of fine needles of sillimanite are seen in and near the biotite, and, apparently, have formed from it. The gneiss is cut by numerous small sills and dykes of microcline- and microcline-perthite-rich granite, which contains quartz, muscovite, and albite. The sillimanite-biotite gneiss undoubtedly is a metamorphosed aluminous sedimentary rock, now intimately intruded by granite.

The granitic part of the gneisses of the map-area is composed of potash feldspar, either microcline or orthoclase, with quartz, a plagioclase feldspar that varies from albite (An_5) to basic oligoclase (An_{30}), and minor amounts of biotite, chlorite, sericite, apatite, epidote, carbonate, zircon, sphene, tourmaline, and opaque iron minerals. In a few thin sections andesine feldspar was recognized, and in one slide labradorite, but in these cases the granite-gneiss is believed to be contaminated by material from calcareous inclusions.

Although typical, coarse-grained pegmatite dykes or sills are rare in the area, they are numerous in the meta-sedimentary rocks east of Murmac Bay of Beaverlodge Lake and as far east as Geebee Lake. In this locality, several straight-walled sills in sharp contact with the enclosing rocks are about 80 feet wide and continuous for more than ¼ mile. A thin section from a specimen of one of these dykes, north of Melma Lake, was seen under the microscope to be composed principally of altered albite, in places associated with quartz in graphic intergrowths, quartz, and muscovite. The albite-twin lamellæ are bent and fractured, and the quartz shows strong strain shadows.

Near contacts with sedimentary strata or relics, the foliation of the granitic rocks is invariably parallel with the contacts and the bedding and, therefore, most commonly dips moderately or gently. Away from the sedimentary contacts or relics, the foliation of the granitic rocks tends to be steep or vertical, but is rarely flat-lying.

Several masses of granitic rocks that contain little ferromagnesian material appear in the field to be unfoliated or only slightly foliated, as, for example, the Lodge Bay granite. In thin section, however, these rocks are found to have a strong cataclastic structure. The lack of evident banding is probably due in large part to the lack of the ferromagnesian minerals that serve to emphasize the banded structure elsewhere.

More detailed studies of the granite and gneiss from six localities, described below (pages 33-46), have led to the conclusion that the introduction of granitic material did not occur as a single injection or replacement, but was composite. Although it is certain that the injection or replacement was composite, the order of emplacement of the various materials in all localities is not known; the following is presented, therefore, as an hypothesis that appears to best fit the writer's observations.

(1) What appears to be the oldest granitic material recognized is plagioclase-rich. The plagioclase varies in composition from albite to oligoclase; it may be associated with biotite, now most commonly altered to chlorite, and with only minor amounts of potash feldspar. The rare granitic intrusive tongues and dykes that penetrate, and cut across the foliation of amphibolite, are invariably, so far as the writer is aware, of this plagioclase-rich type, as, for example, those associated with the Lodge Bay granite (*See* Plate V B).

(2) A second phase of injection or replacement led to the crystallization of abundant microcline and quartz, and is believed to have followed closely in time and space the introduction of the plagioclase-rich material. The microcline intimately penetrated the plagioclase-rich rock, being lacking only in the small tongues intrusive into amphibolite or sedimentary rocks and, in certain areas at least, around the borders of the granitic rocks near amphibolite contacts. At the contacts, however, the amphibolite is invariably changed to a biotite schist or gneiss, which implies shearing forces and the introduction of potassium-bearing solutions. In certain areas in the amphibolitic rocks there is evidence of penetration and probably soaking by potassium-rich fluids, with attendant crystallization of microcline, biotite, and tourmaline in the amphibolite (*See* page 62). Certain of the microcline-rich granites occur as conformable, sill-like bodies in the older rocks, as, for example, the Box granite sill. This and probably others of the microcline granite bodies are believed to be akin to pegmatites because they have been observed to grade directly into quartz veins (*See* Figure 5), although in grain size they commonly appear granitic rather than pegmatitic and in general lack the graphic intergrowth of quartz and feldspar.

(3) Later than the microcline-rich phase, are one or more periods of introduction of albite or oligoclase, represented at certain localities, but apparently not at others. Introduction of late soda-feldspar is particularly well established at the Box and Athona gold mines, at the Ace mine, Eagle property, and elsewhere in the Melville Lake-Ace Lake-Raggs Lake area. Although much of the late soda-feldspar has undoubtedly been introduced as a late phase of the granite, some is of post-Athabasca age, as indicated by its occurrence as albite-carbonate veinlets in rocks of the Athabasca series at the Martin Lake mine. It is considered that the late soda-feldspar at the various localities may have originated in any or all of three ways: (a) as a late differentiate of the granitic rocks, as at the Box and Athona gold mines; (b) as a result of deep-seated faulting or shearing and introduction of hydrothermal solutions, as suggested on page 46; and (c) as late differentiate of the soda-rich lavas of the Athabasca series or the late basic dykes. The first two of these processes are favoured by the writer to explain the bulk of the late soda-feldspar, which is considered to be all of hydrothermal origin.

It is, therefore, considered that the late soda-feldspar originated in a variety of ways at different geological times. It is possible that both the gold and pitchblende deposits are related to the introduction of late soda-feldspar; its association with gold is moderately well established, but its relation to the pitchblende deposits is not yet understood.

GRANITIC ROCKS WEST OF LODGE BAY

West of Lodge Bay is a body of granite that appears more massive than in most parts of the map-area, probably because of the lack, or scarcity, of ferromagnesian minerals. This mass is about 3 miles long by 1½ miles wide. In places it shows intrusive relations with the quartzite and amphibolite that border it on the east. In other places the contact with the quartzites is gradational across a few tens or even hundreds of feet. On the west and south, the granite body grades into the banded gneiss. Several bands of amphibolite outcrop in the granite as narrow bands more than a mile long. They dip flatly to the southeast and are, apparently, undisturbed by the intrusion. Several small dyke-like bodies of dark-coloured rocks, 1 foot to 3 feet wide, were observed in the southern part of the granite mass. Due to their unusual composition, they are considered to be older than the granite, the surrounding rocks having been replaced by granitic material whereas they were altered in chemical composition (*See* discussion on page 63). One felsite dyke about 25 feet wide, striking north and dipping nearly vertically, was observed to cut the granite.

Table I gives the estimated[1] mineral composition of eight thin sections of the Lodge Bay granite mass. The more massive looking specimens, such as those from which slides Nos. 1, 2, 3, and 4 were obtained, have similar compositions. Microcline is in excess of albite, but both are abundant. The albite (An_{6-10}) crystals contain long, thin, closely

[1] Obtained by estimating by eye the percentage of various minerals for a minimum of three positions of the slide, averaging the results, and reducing to 100.

TABLE I

Estimated Mineral Composition of Lodge Bay Granite

—	1	2	3	4	5	6	7	8	Average
	%	%	%	%	%	%	%	%	%
Microcline	37	43	46	35	53	32	4	1	32
Albite (An_{6-10})	35	15	25	30	.....	1	44	58	25
Quartz	22	37	25	30	33	55	37	31	34
White mica	6	4	4	4	8	7	14	8	7
Chlorite	Tr.	1	Tr.	1	3	3	1	1	1
Carbonate	Tr.	Tr.	Tr.	Tr.	3	1	Tr.	1	1
Opaque minerals	Tr.	.....	Tr.	.....	Tr.	1	.....	.....	Tr.
	100	100	100	100	100	100	100	100	100

1. Typical granite, weakly foliated.
2. Typical granite, weakly foliated.
3. Granite, close to quartzite contact.
4. Granite, close to quartzite contact.
5. Foliated granite-gneiss, the well-foliated matrix containing chlorite encloses crystals of microcline up to 6 or 8 mm. long.
6. Same as 5.
7. Granite close to amphibolite contact.
8. Granite dykelet 3 inches wide in amphibolite (*See* Plate V B).

spaced, twin-lamellæ, which are most commonly crenulated, bent, or fractured. They invariably contain numerous, minute, scattered flakes of sericite; trains of sericite crystals follow albite cleavage planes and around the crushed edges of the crystals. The microcline is fresh compared with the albite, and contains no sericite except in rare and relatively large crystals in which quartz is enclosed within the microcline crystals. The microcline is fractured, and the fractures are filled with veinlets of quartz, with minor chlorite and carbonate. Some relict structures, which resemble anastomosing solution channels, occur in the microcline. Small, rounded areas of fresh-looking microcline occur in the altered albite of slide No. 4. In contrast with the Box and Athona granites, no perthitic structures, or structures indicating replacement of microcline by albite, were observed. The evidence appears to indicate that albite is the first-crystallized mineral, and has been partly replaced by sericite, microcline, and quartz.

Slides Nos. 5 and 6 are of granite that in the hand specimen is seen to consist of crystals, 6 to 8 mm. in diameter, of feldspar, set in a fine-grained foliated groundmass, which is light green due to tiny flakes of contained chlorite. Under the microscope, the large crystals are seen to be microcline, fractured but otherwise unaltered, set in a groundmass of quartz, sericite, and chlorite. Albite is lacking in these slides, save for a

remnant of one greatly altered crystal in slide No. 6. This albite crystal is almost entirely replaced by quartz and sericite. The fracturing of the microcline crystals is mainly subparallel with the foliation, but other fractures do occur. The fractures are filled with veinlets of quartz together with minor chlorite and carbonate.

The microcline crystals in these slides are interpreted as porphyroblasts that formed in a sheared, albite-bearing rock in which the albite has been almost completely altered to quartz and sericite. The porphyroblasts have suffered later fracturing, and introduction of quartz, chlorite, and carbonate.

Slides Nos. 7 and 8 were obtained from specimens collected from granite near amphibolite contacts, No. 8 being from a dykelet in amphibolite (one of those illustrated in Plate V B). These slides consist principally of albite (much altered to sericite), quartz, and sericite. In slide No. 7 the microcline occurs as minute, well-twinned, unaltered crystals bordering the larger crystals of altered albite; in No. 8 it occurs in a quartz-microcline-carbonate vein that intersects the rock. The veinlet is 0·4 mm. wide and is banded; the walls of the vein are formed of tiny, equigranular crystals of quartz and microcline, with rare sericite and chlorite flakes, and the centre is occupied by a narrow carbonate veinlet. Here the microcline is unquestionably later than the albite.

In all these specimens, the albite is observed to be the earliest formed feldspar and to be replaced by sericite, quartz, and, probably, by microcline. Microcline crystallized late, and is little altered. This implies the addition of potassium-rich fluids to the already crystallized rock, and the removal of sodium as suggested by the equation:

$$3NaAlSi_3O_8 \text{ (albite)} + KOH + 2H_2O \rightarrow H_2KAl_3(SiO)_4)_3 \text{ (sericite)} + 6SiO_2 \text{ (quartz)} + 3NaOH$$

Presumably the sodium moved on to precipitate elsewhere.

GRANITIC ROCKS IN THE VICINITY OF THE BOX MINE

The orebody of the Box mine is contained in a granitic, sill-like body ½ mile long by 150 to 200 feet wide (*See* Figure 4), which strikes northeast and dips southwest at 45 degrees conformably with the surrounding quartzites and gneisses. The gneisses are believed to be mainly of mixed origin, that is, sedimentary rocks to which granitic material has been added. The Box orebody is composed of a pink to red granitic rock, which in the hand specimen appears to be composed of almost equal amounts of quartz and pink or red feldspar. It contains no ferromagnesian minerals, with the exception of chlorite, which occurs mainly as a filling of numerous small fractures. In thin section, the rock is seen to consist of microcline and microcline-perthite, quartz, albite (about An_9), and lesser amounts of chlorite, sericite, sphene, and pyrite. Microcline occurs in large, fractured crystals, commonly partly replaced by albite. Separate crystals of albite have long, thin, twin-lamellæ, which in places are fractured and bent. The quartz forms a mosaic of grains that show strong strain shadows and

intricately sutured contacts with each other. Sericite may occur in veinlets or as isolated crystals in the feldspars. Chlorite is of the penninite variety. The orebody is cut by the stock-work of quartz veins shown in Figure 4.

The gneisses, which, together with the underlying quartzite, enclose the orebody, are variable in composition and texture. Some of them show well-developed *lit-par-lit* injection or replacement, in which the host rock consists principally of quartz, with a moderate amount of chlorite (penninite) and some albite and potash feldspar. The injected material has much the same composition as the Box 'sill' described above. In other places, the gneisses are well-foliated rocks composed of biotite-rich bands about 3 mm. wide alternating with stringers and small lenses of quartz and pink feldspar of about the same width. Under the microscope, the biotite-rich bands are seen to contain albite and orthoclase, with much apatite and accessory sphene and iron ore minerals. Well-formed flakes of sericite are abundant; they penetrate the biotite and occur as numerous flakes in the feldspars. The quartz-feldspar bands and lenses contain microperthite, albite, and quartz, the last showing prominent strain shadows. The rock is cut by numerous quartz veinlets and lenses, which parallel the foliation; several were seen in most of the thin sections examined.

True *lit-par-lit* injection, however, is not common in this area, as the granitic material generally occurs as irregular lenses, pods, small sills, and dykes, which intimately penetrate the host rock.

Southwest of the Box mine, there is less introduced granitic or pegmatitic material and more hydrothermal quartz veins. Here, short, narrow, granitic and pegmatitic dykes and sills grade to quartz veins on the ends (*See* Figure 5). The feldspathic parts are not typical of pegmatite, as the feldspar has an average maximum grain size of only 3 or 4 mm., and graphic intergrowths of quartz and feldspar are not common. Nor do the intrusions show the fine-grained idiomorphic texture typical of aplites. However, because of their composition and association, there is little doubt that they represent a transition between granitic material and quartz veins. Thin sections of the granitic material show almost equal amounts of microcline and quartz and less than 1 per cent each of muscovite, albite, and iron oxide minerals. Quartz veins are numerous, and comprise more than 30 per cent of some outcrops.

Most of the injected stringers of granitic material parallel the bedding foliation of the host rock, but a few are discordant. Some of the quartz veins are concordant, but the most prominent set is crosscutting, striking nearly north and dipping vertically.

Several geologists have worked near the Box mine. Alcock (6), on his 1 inch to 1 mile map, has shown all the granitoid rocks of this area as granite. Cooke (29), who mapped a small area on a scale of 1 inch to 200 feet, concluded that the granitic rocks in the vicinity were mainly granitized quartzites, only the sill-shaped granitic mass enclosing the orebody of the mine and several other small bodies being true granites. Beavan (9) also believed the Box orebody to be in granite. In 1938, Swanson (50) made an excellent detailed map of the orebody on a scale

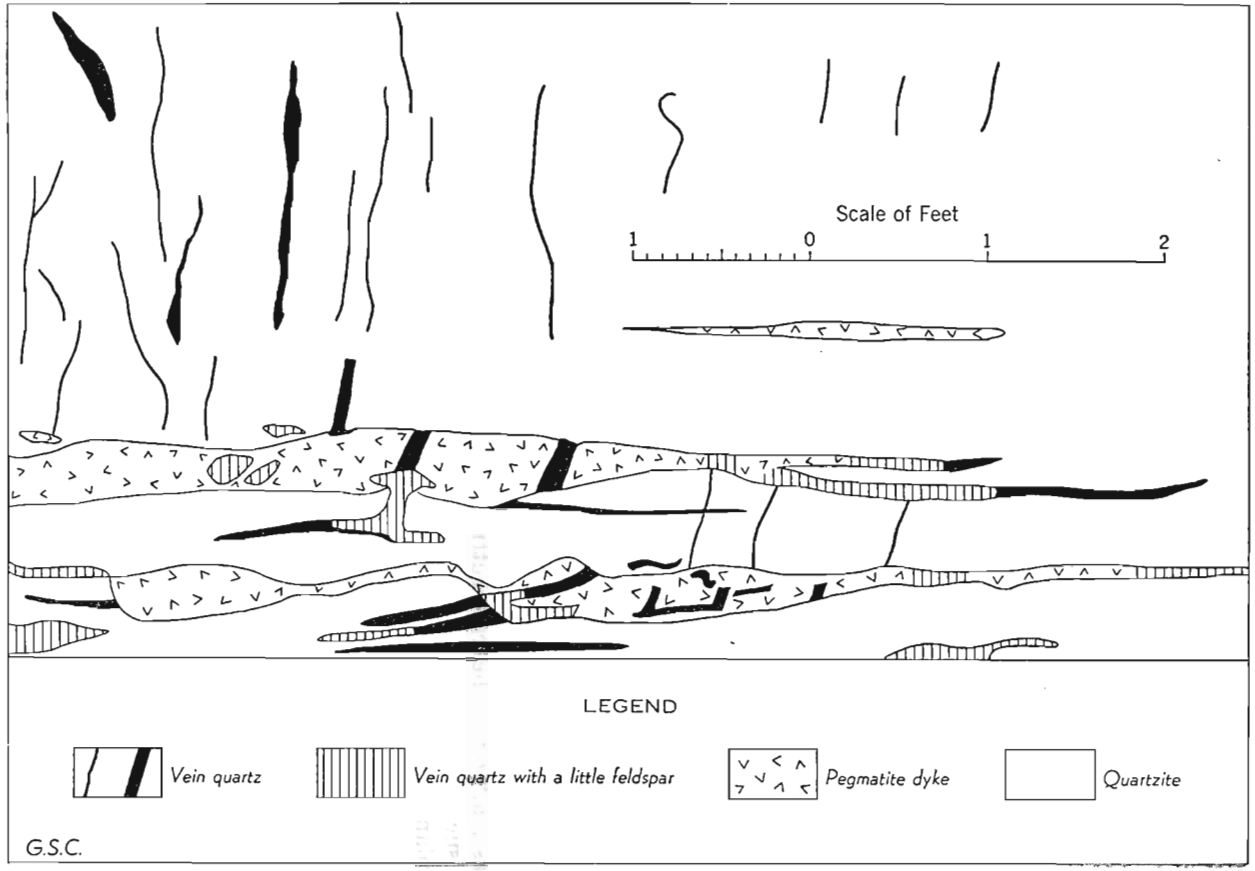


Figure 5. Pegmatite dykes, showing transition to high-temperature quartz veins.

of 1 inch to 100 feet (*See* Figure 4). According to him, the granitic rocks enclosing the orebody represent highly granitized sedimentary beds rather than a true igneous intrusion, for the following reasons:

(1) The body contains many slabs and irregular masses that are clearly sedimentary and seem undisturbed.

(2) Although in some places, mainly along bedding planes, the granitic and sedimentary types are in sharp contact, they commonly grade into one another where the contact crosses the bedding.

(3) Variations in the texture and composition of the granitic body can be more easily related to the stratigraphy than to igneous phenomena.

(4) Microscopic studies by Killin (40), on specimens collected by Swanson, show that the quartz content of the granitic rock is 60 to 70 per cent in many specimens, which is exceptionally high for a normal granite. Killin says that high percentages of quartz were obtained "exclusive of vein quartz which is quite distinct and recognizable as such, the quartz veins having sharp boundaries".

The writer's observations would indicate the composition of the Box orebody as roughly 50 per cent quartz and 50 per cent feldspar. The high percentage of quartz may be due to residual quartzose sedimentary material, but may also be due in part to the high quartz content of the intruded or replacing material as suggested in the discussion of Figure 5, which shows that at least a part of the granitic looking material in the vicinity is of pegmatitic or hydrothermal origin. It may be noted that the quartz-vein material that grades into the granitic material of the dykes shown in Figure 5 cannot everywhere be distinguished from the main rock mass, although the crosscutting quartz veins are readily distinguishable as such. This may also be the case with the Box 'granite', and may be an explanation for at least a part of the high quartz content of that body.

Another feature strongly suggesting a replacement origin for all or parts of this granitic body is the occurrence of what resemble altered amphibolite bodies in the Box 'granite' (*See* Figure 4). In other parts of the map-area where the age relationships are clear, the granite invariably shows intrusive relations with the amphibolite. In Figure 4 it may be seen that the large amphibolite body to the south of the mine 'granite' is continuous with a dyke-like mafic body that cuts through the 'granite'. That part of the 'amphibolite' enclosed in the orebody, however, is seen in thin section to be composed entirely of chlorite, quartz, sericite, sphene, and iron oxides, and is interpreted as an amphibolite that has been subjected to granitization or hydrothermal action. The possibility that the dyke-like, mafic body is a sheared zone in the mine 'granite', into which chlorite and associated minerals have been introduced, is not favoured, because: (1) it is continuous with and apparently grades into the amphibolite; (2) it has sharp walls and an almost uniform composition across the width of the body; and (3) sphene occurs in it in about the

same amount, and distributed in much the same way, as in the adjoining amphibolite. Several other remnants of altered amphibolite or schist occur within the orebody.

The writer, therefore, agrees with Swanson that the granitic sill of the Box mine shows features that can best be explained by considering the granitic material as replacing original sedimentary rocks almost completely, but altering to a lesser extent the more impermeable amphibolite. The replacement is believed to have been of a pegmatitic nature, with a hydrothermal end phase.

A period of albitization followed the formation of the microcline crystals in the Box 'granite', as there is no doubt that the microcline perthites are of the replacement type, as discussed in the case of the Athona granite, page 40.

Beavan (9) describes an interesting quartz albitite pipe-like body near No. 1 shaft in the Box orebody as having the appearance of a zone of intense alteration in the granite, the contacts of the altered zone with the surrounding granite being gradational. The pipe is found on several successive levels of the mine with similar position and diameter (about 6 feet) in each case. The rock consists of albite, in part with chessboard structure, quartz, a very little orthoclase, and chlorite, carbonate, and sericite.

Later, apparently after the pipe had suffered slight crushing, small veinlets and cavity fillings of albite, quartz, sericite, and carbonate were introduced. The albite and quartz are in part euhedral in the filled areas, and some of the albite is deposited on earlier albite. Chlorite and sericite are evidently the latest of these vein minerals, as they replace the late albite and vein the carbonate.

Beavan states that very high gold values are associated with the pipe-like body of albitite. In one place, native gold was observed coated on a chloritic fracture surface in the albite pipe. Some relation between high gold assays and the albitite is suggested.

GRANITIC ROCKS IN THE VICINITY OF THE ATHONA MINE

The Athona granite is intruded, apparently conformably, into formations that strike roughly northwest and dip to the southwest at about 30 degrees (*See* Figure 6). It is in two parts, separated by an amphibolite that is called the 'Upper gabbro' at the Athona mine. The lower part overlies a second amphibolite mass known as the 'Lower gabbro'. The two granite bodies are probably interconnected, as the 'gabbro' masses are not thick. The granites are in sharp contact with the amphibolite, but grade into a granitic porphyry on the north.

On the weathered surface, the Athona granite is grey, flesh coloured, pink, or red, and contains white, pink, or red feldspar crystals that average slightly less that a centimetre across in a groundmass composed mainly of white quartz, with a little chlorite. Locally, the granite contains minor amounts of green biotite. The rock may be massive or foliated, and fractures filled with small quartz stringers cut the rock in several directions.

Under the microscope, four thin sections of this rock were found to be composed of microline crystals showing prominent perthitic intergrowths, 49 per cent; Albite (An_{5-10}) in separate crystals, 24 per cent; quartz, 24 per cent; about 1 per cent each of chlorite and carbonate; and traces of rutile, sphene, and iron oxide minerals.

The microcline-perthite occurs in large crystals; in some cases the albite is in angular patches, but more commonly it forms irregular areas or veinlets, most of which cut diagonally across the microcline crystals. Albite also occurs in large, well-formed crystals, with long, thin, twin-lamellæ. Both the microcline-perthite and the albite crystals in places enclose rounded or elongate quartz grains, and both types of feldspar contain a very fine-grained reddish material, which is either hematite or some alteration product stained by hematite. In the microperthite, the albitic material shows less of this than the potash feldspar.

The quartz grains in the groundmass of the granite show prominent strain lamellæ and intricately sutured contacts with each other. The chlorite is the penninite variety; it is pleochroic (pale green to a very light green) and shows ultra blue interference colours. Commonly, the larger feldspar crystals of the granite are moderately fractured. They are bounded by irregular grains of very fine-grained microcline, albite, quartz, and sericite, and in places these fill fractures in the crystals. The rock is intersected by narrow veinlets of sericite, which also forms small, clear, easily recognizable crystals in the feldspar.

For the following reasons the Athona granite is considered to have been in part replaced and intruded by late fluids that deposited albite and quartz:

(1) The albite in the perthites appears fresh and shows less sericitic alteration and included hematite stain than the other feldspars in the rock; nor is it as crushed or bent as the other feldspars.

(2) The albite in the potash feldspar is believed to have formed as a result of replacement rather than exsolution, because it comprises more than half of some crystals.

(3) Small veinlets of albite and albite and quartz occupy thin fractures in the potash feldspar. Some of the veinlets of albite in perthite are nearly normal to the gneissoid cataclastic structure of the rock, suggesting that they formed after or during deformation.

(4) Beavan (9) describes a small mass of albitized rock in the Athona granite, which may be a pipe similar to that described on the Box property (*See* page 39) although its shape and attitude have not been defined. The one exposed contact is vertical. The rock is an even-grained greenish yellow type that appears highly altered in contrast with the surrounding granite. A zone 3 to 4 inches wide at the contact of the pipe is bleached white. The pipe rock consists mainly of albite, with smaller amounts of quartz and orthoclase. Chlorite, carbonate, and fine-grained cubic pyrite replace the earlier minerals.

Other areas of granite similar to the Athona granite occur on the peninsula between the Athona mine and Strike Point. Bordering the Athona granite on the north and west is a finer grained porphyritic granite containing considerable chlorite. The phenocrysts are crystals of pink feldspar 2 to 8 mm. in length, and slightly smaller quartz grains, both set in a finer grained pink or green groundmass. Streaks of more chloritic material, which vary up to 2 or 3 inches in width, are suggestive of 'ghosts' of replaced or assimilated older rock.

Under the microscope, the pink phenocrysts are seen to be microcline that in places encloses a little albite. The groundmass is mainly quartz, albite, and microcline. Accessory minerals are chlorite, sericite, pyrite, and iron oxides. Small, chlorite-rich, lens-like areas of altered plagioclase mosaic occur in the rock. The plagioclase in these is much altered, and most of it is untwinned; it appears to have a variable composition, some being andesine and some probably as sodic as albite. In many places it contains quartz and potash feldspar, which, apparently, have replaced it. Green chlorite is a particularly abundant associated mineral, and with it is considerable sphene that occurs in aggregates of a size and distribution similar to those in the amphibolites of igneous origin, suggestive of derivation from these rocks. In some thin sections, well-formed crystals of white mica replace the areas of plagioclase mosaic and chlorite.

The microcline of these rocks occasionally shows a perthitic texture, undoubtedly, as in the case of the Athona granite, indicating replacement by late albite. In a few thin sections, minute quartz-albite veinlets were seen under the microscope. The addition of late albite, however, is in minor amounts compared with that in the Athona granite.

Although the rock described above is the most common type, there are many variations. In some places only a few scattered feldspar phenocrysts occur in a fine-grained, reddish, cherty-looking groundmass; elsewhere the rock may have a granitic, holocrystalline texture, and all intermediate types have been seen. Grain variations are very irregular, and may range from one extreme to the other in a few feet.

MACKINTOSH BAY GRANITE

The Mackintosh Bay granite is the large mass exposed south of Mackintosh Bay and on Moose and Cameron Islands. It is a medium-grained, gneissic, grey to pink rock, commonly containing streaks of biotite or chlorite, and more rarely biotite schist, biotite amphibolite, or other inclusions.

The granite has the appearance of having thrust aside the enclosing sedimentary strata during emplacement. Traced from west to east, the sedimentary formations appear to split north of Fish Hook Bay and follow around both sides of the granite to the east side where the strikes converge again. Throughout the granite mass, however, are inclusions that are believed to represent remnants of the altered sedimentary rocks.

On the north, the granite-quartzite contact dips 30 to 50 degrees to the southeast. Around the northeast border the dips are more irregular and steeper, up to 60 degrees to the southeast. On the south the granite dips southeasterly under the sedimentary beds at roughly 45 degrees.

Much of the granite is foliated; the foliation is particularly marked near the contacts, being produced by parallelism of mica and chlorite flakes and by flattened quartz and feldspar aggregates. Near the contacts, the foliation is everywhere parallel with them. On its north side, the granite mass contains less ferromagnesian minerals than elsewhere, the foliation there being less marked. Xenoliths in the granite are orientated with their longer axes parallel with the foliation and the contacts.

Within the granite stock the platy foliation forms a more or less elliptical pattern in plan, but both platy foliation and elongate inclusions show a less regular arrangement than in the border zones. Linear structures are less common than the foliation, but where seen invariably pitch to the southeast at an angle of 25 to 40 degrees. The Mackintosh Bay granite appears to be elliptical in section, the long axis (normal to the elliptical section) plunging approximately 35 degrees to the southeast.

The estimated mineral composition of five thin sections of the Mackintosh Bay granite is presented in Table II.

TABLE II

Estimated Mineral Composition of Mackintosh Bay Granite

—	1	2	3	4	5
	%	%	%	%	%
Quartz	36	28	46	35	45
Potash feldspar	38	42	25	35	5
Plagioclase (An_{8-12})	17	23	25	25	45
Biotite	.....	5	.....	.....	3
Chlorite	9	1	2	2	.....
Sericite	.....	1	.....	2	1
Opaques	Tr.	Tr.	Tr.	1	Tr.
Apatite	Tr.	.....	.....	.....	.....
Carbonate	.....	.....	2	.....	1
	100	100	100	100	100

1. Rosiwal analysis of a specimen of Mackintosh Bay granite made by A. P. Beavan (9).

2-5. Percentages obtained by estimating by eye the percentages of various minerals for a minimum of three positions of the stage, averaging the results, and reducing to 100.

Thin section No. 2 is from a specimen obtained near the southern contact of the granite, and contains biotite, which, under the microscope, is seen to be restricted to certain lenticular areas composed of biotite and a much-altered plagioclase feldspar (albite-oligoclase) in part altered to, or replaced by, chlorite and sericite. The biotite, which is pleochroic light green to a dark greenish grey, is not clear but has a cloudy appearance,

doubtless due to alteration, as it occurs associated with the much altered plagioclase mosaic. The lenticular areas of altered material are set in a mosaic composed essentially of clear quartz and little-altered potash feldspar, some of which exhibits the characteristic grating-structure of microcline.

Thin section No. 3 consists of lenticular areas of altered albite (about An_8) associated with chlorite (which in places has abnormally high interference colours and is pseudomorphous after biotite), and minor carbonate; these areas are surrounded by quartz and microcline, which is slightly altered.

Thin section No. 4 is composed of similar, chlorite-bearing bands associated with altered albite-oligoclase, alternating with bands of fresh-looking potash feldspar and abundant quartz.

Thin section No. 5 consists of clear, unaltered, pleochroic, yellow to dark brown biotite; fresh-looking albite, close to oligoclase in composition; abundant quartz; and a minor amount of orthoclase, carbonate, and sericite.

The Mackintosh Bay granite appears to be composed of two types of material. One is a plagioclase-rich, biotite-bearing type represented by thin section No. 5 (Table II) and the altered plagioclase mosaic of thin sections Nos. 2, 3, and 4, which carries altered biotite or chlorite. The other is the unaltered potash feldspar-rich and quartz-rich material that occurs surrounding the altered plagioclase mosaic referred to above. In slides Nos. 2, 3, and 4, altered remnants of the plagioclase-rich phase occur in the fresher potash feldspar-rich phase, so the latter is considered to represent a later period of crystallization. Thin section No. 5 is considered to be an example of the unaltered plagioclase-rich type because of the relative freshness of the plagioclase feldspar, the unaltered appearance of the biotite, the small amount of potash feldspar, and the lack of evidence of two periods of crystallization. No perthites were noted in any of the thin sections examined by the writer, but Beavan (9) reports that in thin section No. 1 "a little of the plagioclase is in the form of small blades in flame-type perthite", so, presumably, a little albite replaces the potash feldspar.

GRANITIC ROCKS IN THE VICINITY OF ACE, EAGLE, AND MELVILLE LAKES

The rocks in the vicinity of Ace, Eagle, and Melville Lakes have been subjected to intense dynamic metamorphism, some to a much greater degree than others. They have been studied in detail by Smith (48). Some of the rocks have a granitic, almost holocrystalline texture, but in much of this area only a small proportion of the rock is composed of recognizable feldspar, with cleavage faces visible in the hand specimen, the remainder consisting of a fine-grained material that, under the microscope, proves to be granulated quartz and feldspar. In places, chlorite occurs as bands and streaks partly replacing other minerals or occurring as fracture fillings. Carbonate is common. Locally the rocks are banded in strong colours as,

for example, north of Key Lake or on the west shore of Ace Lake, where the colours are due to alternating relatively feldspar-rich, quartz-rich, and chlorite-rich bands. In some places red bands of altered and crushed albite containing much hematite alternate with white quartz bands and greenish bands containing chlorite. In others the red albite bands alternate with lighter pink microcline-quartz bands. Where crushing and granulation are extreme, the hematite-stained feldspar-rich bands may have the appearance of red chert.

Smith (48), after staining tests to distinguish the feldspars, determined the composition of two specimens of igneous-textured granite to be: (a) 26 per cent quartz, 25 per cent albite, and 48 per cent orthoclase; and (b) 42 per cent quartz, 22 per cent albite, and 36 per cent orthoclase. The albite and quartz grains show a normal igneous texture. No ferromagnesian minerals are contemporaneous with the albite and quartz, although chlorite is common as a late mineral filling interstices in the granite. Orthoclase appears to partly replace albite. A myrmekitic intergrowth of albite and quartz traverses several orthoclase grains.

The writer examined a suite of specimens from the Lost Mine vein of the Eagle group, all taken within 3 feet of the vein. The wall-rock is granite, greatly crushed, containing intensely sheared lamellar quartz, crushed and altered albite (about An_6), and minor orthoclase, chlorite, and hematite. The albite contains much red hematite stain. The chlorite occurs in veinlets bounding the feldspar grains; as a filling in fractured areas in the feldspars; and in crushed zones or slippage planes in the quartz. These rocks are intersected by numerous, very small fractures containing quartz veinlets, albite-quartz veinlets, and albite-chlorite-carbonate-hematite veinlets. The quartz and other minerals of these veinlets are fresh and unsheared. It is clear that these relations serve to demonstrate a late period of introduction of albite. Another veinlet from elsewhere on the Eagle property is well banded, and shows the following sequence of minerals from the walls towards the centre: albite, quartz, carbonate, a zeolite, and hematite.

GRANITIC ROCKS OF THE ACE LAKE-RAGGS LAKE AREA

Conybeare (25) mapped the Ace Lake-Raggs Lake area in detail. There the granitic rocks are pink to grey, and have a gneissic texture. The foliation is commonly emphasized by chlorite-bearing bands or lenses. Contacts with adjoining sedimentary rocks are not sharp, and it is difficult, when mapping, to define any boundary between a rock that is considered to be igneous and one that is presumably of sedimentary origin. Conybeare (25) states that "Clean, weathered surfaces show the country rocks extensively attacked and replaced by granitic material that entered the minutest crevices, even down to pore spaces; yielding hybrid types that vary in composition all the way from granite to quartzite". The writer agrees with this statement.

Modal analyses of thin sections of these rocks are given in Table III.

TABLE III

Measured Modes of Granitic Rocks, Ace Lake-Raggs Lake Area
(After C. E. B. Conybeare)

	1								2	3	4	
	%	%	%	%	%	%	%	%	%	%	%	%
Quartz	33	49	41	44	37	27	36	31	51	41	28	33
Albite-oligoclase (An_{10})	47	44	43	31	30	24	23	20	19	.....	60	50
Oligoclase (An_{30})	.....	.....	.....	.....	.....	.....	.....	.....	.....	24	.....	.....
Microcline	15	.....	.....	17	33	35	37	40	17	17	.....	.....
Muscovite	5	.....	.....	.....	.....	.....	.....	.....	13	.....	11	17
Biotite	.....	.....	.....	.....	.....	.....	.....	.....	.....	18	.....	.....
Chlorite	.....	7	13	8	.....	3	4	9	.....	.....	1	.....
Epidote	.....	.....	3	.....	.....	11	.....	.....	.....	.....	.....	.....

1. Granitic rocks, commonly gneissic, with inclusions of hornblende schist.
2. Sheared rock.
3. Granitic rock (quartz-monzonite), intrusive into hornblende schist.
4. Coarse-grained and pegmatitic granite, which cuts rocks of Group 1.

Following are composite descriptions of the rocks by groups compiled from Conybeare's descriptions.

Group 1 (*See* Table III). These are pink to grey, granitic rocks, commonly gneissic, with inclusions of hornblende schist. The plagioclase is about albite-oligoclase (An_{10}) in composition. Commonly the twin-lamellæ of the plagioclase crystals are bent and fractured, and the grains are partly altered to sericite and a dusty reddish material believed to be hematite. In some specimens, fractures in the plagioclase grains are filled with quartz and chlorite. Quartz is abundant, and commonly shows strong strain shadows. Some aggregates of quartz have intricately sutured boundaries adjoining other quartz crystals. It is believed that this is due to fracturing and gliding of the quartz followed by recrystallization. It is noticeable that the microcline crystals in some slides have a fresher appearance than the plagioclase; even the rounded inclusions of plagioclase in the microcline are as much altered as the rest of the plagioclase. It was noted, also, that where microcline and plagioclase are intergrown, the re-entrants of plagioclase into microcline are rounded, whereas those of microcline into plagioclase are pointed and hooked. The writer believes that the above evidence indicates that the microcline is younger than the plagioclase.

The content of chlorite is variable. It is concentrated in zones of crushing that bound grains, and clusters of grains, of quartz and feldspar. Commonly, the flakes of chlorite (penninite) resemble very pale green

biotite. Chlorite also occurs in fractures, commonly associated with epidote. Zircons in the chlorite are surrounded by strong pleochroic haloes. In at least one slide "the rock is cut by veinlets a fraction of a millimeter wide of clear quartz, albite, and calcite".

Specimen 2. This specimen represents a sheared granitic rock. The high quartz and the large amount of white mica are noteworthy. It is probable that the high quartz is due to the reaction of feldspar and water to form white mica and silica, as for example:

$3KAlSi_3O8$ (orthoclase) $+ 2H_2O$ (water) $\rightarrow H_2KAl_3(SiO_4)_3$ (mica) $+ 6SiO_2$ (quartz) $+ 2KOH$

and

$3NaAlSi_3O_8$ (albite) $+ KOH + 2H_2O \rightarrow H_2KAl_3\ (SiO_4)_3$ (mica) $+ 6SiO_2$ (quartz) $+ 3NaOH$

It is apparent, therefore, that if a granitic rock is sheared in the presence of water, with development of potash mica and quartz from the feldspars, KOH, and especially NaOH, will be released.

Specimen 3. This specimen is from a quartz-monzonite intrusive into hornblende schist and quartzite. The texture of the rock indicates partial crushing and recrystallization.

Group 4. These specimens represent discontinuous dykes that cut the rocks of Group 1. Typically, the rock has the texture of a medium- to coarse-grained granite, and in places is pegmatitic. It, also, has been subjected to crushing and recrystallization. The lack of potash feldspar is attributed to the bodies being in part pegmatitic and, therefore, water-rich; in the presence of abundant water it is presumed that muscovite would form rather than potash feldspar.

The evidence presented suggests that the emplacement of the granite-gneiss in the Ace Lake-Raggs Lake area was composite. A plagioclase-rich phase was introduced first, followed by a microcline-rich phase. Conybeare believes that a plagioclase-rich pegmatite was injected after mylonitization, but does not appear to have eliminated the possibility that the so-called mylonite in this locality is a banded sedimentary inclusion in the gneiss, which is cut by a soda-rich pegmatite dyke. Late in the sequence, minute albite-quartz-calcite veinlets were introduced.

LAMPROPHYRE DYKES

Eight lamprophyre dykes were seen in the southeast corner of the map-area. Most are less than 20 feet wide, the largest being 100 feet, and most conform in attitude with the enclosing rocks. These dykes are not shown on the map. They outcrop to the southeast of a line joining Fish Hook Bay to the west shore of Bearcat Lake and thence to the east shore of Viking Lake, and according to Blake (11) this boundary continues in the Forget Lake map-area through Prince and Alces Lakes. Northwest of this boundary no lamprophyre dykes were seen. Blake (11) states that, with a few prominent exceptions, the lamprophyre dykes strike northeasterly in contrast with the late basic dykes of the Goldfields-Martin Lake map-area, which strike most commonly northwesterly. This generalization holds roughly true for the Goldfields-Martin Lake map-area.

On weathered surfaces, the lamprophyre dykes are chocolate-brown to brownish red, and contain numerous phenocrysts of biotite commonly up to a centimetre in diameter set in a fine-grained groundmass. On fresh surfaces the fine-grained groundmass is grey, to green, to brown, and may contain visible crystals of pyroxene or apatite as well as the biotite mentioned above.

The following table shows the estimated mineral composition of the lamprophyre dykes, as determined from two thin sections:

Estimated Composition of Lamprophyre Dykes

—	1	2
	%	%
Biotite	15	10
Pyroxene	.....	7
Orthoclase	52	50
Quartz	10	10
Chlorite	8	18
Apatite	5	2
Magnetite	5	1
Carbonate	5	2

1. From south shore of Bearcat Lake.
2. From south of Geebee Lake.

Under the microscope, the lamprophyre is seen to consist of biotite, augite, apatite, orthoclase, quartz, magnetite, chlorite, and carbonate. Biotite phenocrysts are invariably present, and commonly occur as hexagonal plates up to 10 mm. in diameter. The biotite is pleochroic dark brown to light yellowish brown. Idiomorphic crystals of augite up to 1 mm. in diameter occur in some dykes and are lacking in others; they are green in hand specimens but colourless in thin section. No hornblende was seen by the writer in the two slides examined, but Beavan (9) reports its presence in these dykes. He says it "is less abundant [than the biotite] and lacks euhedral faces. It is a green type, pleochroic purple to green, probably indicating some titanium in its composition". Orthoclase is the most abundant mineral. It occurs as a fine-grained, brownish, altered aggregate, but in one slide has square and lath-shaped forms. Beavan reports a minor amount of fresh sodic plagioclase in one specimen. Chlorite (var. penninite) occurs partly replacing biotite and in the groundmass. Quartz is moderately abundant in small grains.

ATHABASCA SERIES

The name "Athabasca sandstone" was first applied by McConnell (43) to flat-lying siliceous sandstones on the south side of Lake Athabasca. Alcock (6) later applied the same name to rocks of the present area, which unconformably overlie the Tazin group. The Athabasca rocks of the Goldfields-Martin Lake area consist mainly of arkose, sandstone, and conglomerate, with interbedded lava flows in the vicinity of Martin Lake.

SEDIMENTARY ROCKS

Conglomerate

The Athabasca conglomerate was seen to rest unconformably on the older rocks in many places. It contains boulders and angular fragments, some 1 foot to 2 feet in diameter, but commonly 2 to 4 inches, composed of all the older rocks of the map-area. The fragments may be enclosed in a sand or silt matrix, or may be cemented by carbonate, chlorite, or ferruginous material. Two types of conglomerate are differentiated on the map, a type with angular pebbles, which is normally found at the base of the series, and a type with rounded pebbles, which occurs at a higher horizon commonly separated from the basal conglomerate by a band of arkose.

The basal, or angular, conglomerate varies greatly in thickness, and in a few localities is lacking. It is most commonly composed of tightly packed, angular to subangular fragments of all sizes and shapes, which comprise the bulk of the rock (*See* Plate VI A), cemented by minor amounts of sandy, silty, carbonaceous, or chloritic matrix.

The rock is well consolidated and resistant to weathering, forming some of the more prominent hills of the area, such as the hills on Umisk Island or the northeast trending range of hills east of Fredette and Cutler Lakes. In many places it has the appearance of a talus breccia, as all the fragments are derived from adjacent rocks and show no signs of water transportation or sorting. Thus, adjoining a quartzite area, the basal conglomerate may consist entirely of quartzite fragments, whereas, against an area of gneisses, the angular fragments may be entirely of gneiss. Where the conglomerate is composed of fragments of one rock type it may be difficult to distinguish it from a tectonic breccia; thus, the conglomerate at Contact Lake and that southwest of Nero Lake consist of closely packed fragments of gneiss cemented by chlorite, and may be distinguished only with difficulty from adjoining gneissic areas where, in places, the rock is fractured, and veined by chloritic stringers. In other localities, however, the basal conglomerate contains some subangular to rounded fragments in a sandy or silty matrix, the fragments being of different rock types and crudely sorted. The material in these conglomerates has obviously been transported by water at least a short distance.

Stratigraphically above the basal conglomerate and an overlying arkose band is a conglomerate with rounded fragments, which is very different in appearance from the other. Outstanding features of this band are its well-rounded fragments, abundance of sandy matrix, and loose consolidation. The conglomerate is interbedded with arkose, and grades both

upwards and downwards into a coarse, reddish, pebbly arkosic sandstone. The pebbles are well rounded, are of all rock types, and must have been transported a considerable distance. Of particular interest is the occurrence of rounded pebbles of rock identical in appearance and composition with the enclosing conglomerate and arkose.

Arkose and Sandstone

The Athabasca arkose and sandstone consist largely of reddish beds of sand grain, but the grain size varies from a very coarse pebbly sandstone to a fine-grained siltstone. The rock ranges from a scarcely consolidated sediment to one that is hard and massive looking. It is most commonly red, though in places it is purple, brown, pink, or nearly white. Bedding is well marked, in places by colour-banding, in others by bands of different grain size. Crossbedding (*See* Plate VI B) and ripple-marks are common in the sand-grained rocks, and mud-cracks are well displayed in some siltstone beds. The fine-grained siltstone beds are invariably a deep red colour, and their volume is small, as they occur mainly as narrow bands in the coarser clastic material.

Under the microscope, the arkose and sandstone are seen to consist of angular to rounded fragments of quartz and angular to subangular fragments of clear unaltered microcline, microperthite, and albite, as well as grains of altered feldspar and minor amounts of biotite, sericite, serpentine, apatite, sphene, magnetite, tourmaline, and zircon. The grains are cemented by calcite, chlorite, and hematite, and to a lesser extent by fine-grained detrital material. Small cubes of secondary pyrite were noted in some specimens. In thin section, the siltstone is seen to consist of very small fragments of fresh feldspar and quartz with accessory biotite, tourmaline, and muscovite, all cemented by carbonate and hematite. In the field the siltstone was considered to be a red shale, but as the fragments are predominantly detrital and of silt grain size (0·06 to 0·004 mm.), and as decomposition has been minor, most feldspar grains being fresh and unaltered, the term arkosic siltstone has been applied to these rocks.

The red colour of the beds is in small part due to original red stain in the detrital material. Most of it, however, occurs in the fine-grained matrix of the arkose and sandstone, and the finest grained rocks of this series, the arkosic siltstones, are invariably a deep brick-red colour. The red colour is distributed through a great thickness of Athabasca beds and over a wide area, so cannot be due to hydrothermal action or any local secondary condition: it must, therefore, be due to the oxidizing conditions of deposition, coupled with the abundance of hematite in certain of the older formations from which these sediments were derived.

The sand-grained sediments of the folded areas are more feldspathic than those of the flat-lying sediments on the islands in Lake Athabasca. The writer considers the former to be mainly arkoses or feldspathic sandstones, whereas the Athabasca rocks of the islands in Lake Athabasca are mainly feldspathic sandstones or sandstones. At one locality on Course Island, well-rounded grains of frosted quartz occur in a sandstone, indicating that this deposit consists of wind-blown grains of sand.

VOLCANIC ROCKS

Basalts are intercalated with Athabasca arkose in a much faulted, structural basin near Martin Lake. Mapping has generalized the fault system and many more faults occur than are shown.

At the south end of Martin Lake at least nine lava zones were recognized, separated by arkose. The flows are fewer and thinner to the northward and are lacking north of the latitude of Melville Lake. The lava zones, each composed of one or more flows, vary between 25 and 400 feet in thickness, averaging perhaps 120 feet, and are separated by rather thicker beds of arkose. The whole section containing the flows is about 2,500 feet thick.

The basalts are dense, dark green, black, or reddish brown rocks, which in places are aphanitic but most commonly contain feldspar phenocrysts 1 to 2 mm. long, rarely up to 5 mm., set in a fine-grained groundmass. The groundmass may be dark grey or green, or it may be reddish brown due to staining by hematite. Amygdules $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter, but rarely as much as 1 inch or 2 inches, are common in most of the flows, being distributed in irregular bands and patches. Efforts to distinguish the boundaries of individual flows by a study of the distribution of amygdules, were not successful. Minor flow breccias were noted, but again it was not found possible to correlate them with the tops or bottoms of particular flows.

Consideration was given in the field to the possibility that some or all of the apparent flows might be sills, especially as many diabase dykes in the map-area are amygdaloidal. The amygdules developed in many of the igneous rocks of the Martin Lake syncline, however, are abundant, commonly large, and complexly banded, whereas those noted in the diabase dykes of the area are relatively small and inconspicuous. The igneous bodies, too, appeared to be conformable with the sedimentary strata, and the occurrence of flow breccia, small pebble-like inclusions of granitic rock, and rare, indistinct flow banding all seemed to indicate an extrusive origin. Conybeare[1] reports the occurrence of boulders of basalt in a conglomerate that is again overlain by basalt, which is again suggestive of an extrusive origin. In conclusion, it may be stated that most of these igneous rocks are undoubtedly flows, and probably all are flows, but it is possible that one or two of the coarser and non-amygdaloidal bodies may be sills. In one locality, an amygdaloidal flow toward the base of the section was seen to be cut by a trap dyke 3 inches wide, doubtless related to the flows.

Under the microscope the lavas are seen to consist of a fine-grained felt of plagioclase crystals commonly 0·25 to 1 mm. long, rarely up to 5 mm., set in a finer grained aggregate of other crystals, mainly pyroxene, chlorite, serpentine, epidote, calcite, and quartz, or in a brownish, slightly recrystallized glass. Accessory minerals are apatite, sphene, magnetite, pyrite, hematite, ilmenite, and leucoxene. Of the specimens examined, a few were found to contain relatively fresh, well-twinned crystals of

[1]Personal communication.

labradorite or andesine-labradorite feldspar, in part altered to fine-grained sericitic material. Most of the lavas, however, contain more sodic feldspar, and this is commonly more altered to sericitic material than are the more basic feldspars mentioned above: some of this feldspar is albite and some is of intermediate composition. The rocks that contain crystals of pyroxene, only in part altered to chlorite, have the more calcic and least altered feldspars; the specimens containing the altered more sodic feldspars contain no pyroxene but abundant chlorite, serpentine, and epidote. In many specimens, large crystals of chlorite are undoubtedly pseudomorphous after pyroxene. Dawson (32) reports serpentine pseudomorphs of crystals that must have been olivine originally, but no remnant of this mineral has been observed.

TABLE IV

Chemical Analyses of Volcanic Rocks

Oxides	I	II	III	IV
SiO_2	46·07	48·78	51·22	59·59
TiO_2	0·63	1·39	3·32	0·77
Al_2O_3	16·29	15·85	13·66	17·31
Fe_2O_3	9·14	5·37	2·84	3·33
FeO	4·26	6·34	9·20	3·13
MnO	0·01	0·29	0·25	0·18
MgO	4·53	6·03	4·55	2·75
CaO	4·64	8·91	6·89	5·80
Na_2O	5·48	3·18	4·93	3·58
K_2O	1·56	1·63	0·75	2·04
H_2O+	3·08	1·76	1·88	1·26
H_2O-	0·40			
P_2O_5	1·08	0·47	0·29	0·26
CO_2	3·30	.....	0·94	.....
S	0·04	.....	.....	.....
BaO	.....	.....	.....	.....
Totals	100·51	100·00	100·72	100·00

I. Fresh meta-basalt taken from No. 2 flow at the Martin Lake mine, Goldfields, Saskatchewan; analyst, R. J. C. Fabry, Geological Survey of Canada.
II. An average for 161 basalts. Daly (30).
III. Average spilite, 19 analyses. Sundius (49).
IV. Average andesite, 87 analyses. Daly (30).

The amygdules consist mainly of calcite and chlorite, with minor quartz and dolomite. One rock specimen contains amygdules from 1 to 4 mm. in diameter, with the following sequence of depositional rings from the outside inward:

1. Quartz crystals
2. Calcite
3. Chlorite: a, fine-grained, almost isotropic
   b, well-formed rosettes of fibrous chlorite (in other amygdules the sequences of these chlorites is reversed)
4. Calcite

In most amygdules, one or more of these stages is missing, especially the first calcite stage, which is rare, but the sequence appears to be invariable at this locality. Other specimens from the underground workings at Martin Lake show the following sequence of minerals from the outside inward: (1) chlorite; (2) calcite; and (3) pink dolomite crystals.

Dawson (32) has published a chemical analysis of a specimen of basalt, apparently fresh and free of amygdules, taken from the No. 2 flow at the Martin Lake mine, 18 inches from a pitchblende-bearing vein (*See* Table IV, No. 1). He considers the rock to be an altered basalt. An examination of the table shows that the rock is most closely akin to the spilites in the high soda content.

One further chemical determination of soda and potash was made for the writer by R. J. C. Fabry of the Geological Survey, in order to determine the alkali content of these volcanic rocks. The specimen, from the shore of Beaverlodge Lake just over ½ mile southeast of the Martin Lake adit entrance, contains 3·44 per cent Na_2O and 1·40 per cent K_2O. The feldspar, which is much altered to sericite, is a calcic oligoclase. The remainder of the specimen consists of chlorite, calcite, pyrite, magnetite, and hematite.

In conclusion, it is considered that the volcanic rocks of the Martin Lake syncline include some true basalts, with labradorite feldspar and pyroxene, but most of the ferromagnesian minerals are entirely altered to chlorite and serpentine and many of these rocks contain an abnormally high percentage of soda, and show spilitic tendencies.

STRUCTURE

The Athabasca series outcrops in three areas: (1) in the belt 18 miles long that trends northeasterly from Beaverlodge Lake to Anne Lake; (2) on islands in Lake Athabasca, where it is essentially flat-lying; and (3) in the small area adjoining Tazin Lake. Near Beaverlodge Lake, these rocks can be seen to overlie the Tazin group with pronounced structural unconformity. The unconformity is exposed at several places on the east side of the lake, but is especially well shown at the southwest side. There, as can be seen on the map, the northeast-striking sedimentary and volcanic rocks of the Tazin group are truncated, in plan, by the Athabasca beds, which trend east-southeast. Two prominent parallel ridges, one composed of quartzite, the other of amphibolite, trend northeast from near Peebles Lake, the contact between them lying in a valley. As is shown on the map, where the Athabasca contact is reached, the ridges and valleys

appear to plunge about 35 degrees to the northeast, the valley being submerged in deposits of Athabasca sediments and the crests persisting northward to where they, too, are submerged. All along this contact the older rocks show signs of deep weathering. On the southeast side of the Athabasca belt north of Beaverlodge Lake, the basal conglomerate rests directly on granite and granite-gneiss. On its northeast side the Athabasca belt is bounded by the Black Bay fault.

The main belt of Athabasca sedimentary rocks occupies two structures—a southern basin, and a northern, asymmetrical basin. The southern basin is the much faulted structure in the vicinity of Martin Lake. It is estimated that the total thickness of the Athabasca series in the basin is about 8,000 feet of which roughly 1,000 feet are volcanic and the remainder sedimentary rocks. Near the Martin Lake property of Eldorado Mining and Refining (1944) Limited is a shattered zone on, or near, the extension of the St. Louis fault, and numerous faults noted in other parts of the basin have a crude radial relation to the basin. A narrow band of Athabasca conglomerate strikes southwestward from Nero Lake. The few attitudes obtained from it indicate that the conglomerate dips to the east near the eastern contact of the basin, and that this contact must, therefore, be along a fault.

The northern, asymmetrical basin comprises the belt that extends northeasterly from Fredette to Anne Lakes. Within it most of the beds dip steeply northwest. It is estimated that the Athabasca series has a thickness here of 5,000 feet. At the base of the series is the conglomerate containing angular to subangular pebbles. The conglomerate is overlain by arkose, which in turn is overlain by a conglomerate, with rounded pebbles and containing grit and sand bands, that forms the northwestern margin of the basin. In this upper, conglomeratic member, the northwestward dip flattens, and in some places is horizontal or reverses its direction of dip. The lower members of the series are not repeated on the northwest side of the structure, doubtless due to faulting. One feature of interest is the occurrence of well-rounded pebbles of Athabasca sandstone associated with pebbles of granitoid rocks, quartz, etc., in the upper conglomerate. The excellent rounding of these pebbles suggests that they were derived from a distant basin formed prior to the present one, as the sandstone must have been well consolidated to yield these pebbles on erosion.

The Athabasca arkose and sandstone on the islands in Lake Athabasca are flat-lying, but otherwise resemble those rocks of the first-described belt. They are probably not more than a few tens to 100 or 200 feet thick. Many or all of the dips shown, which vary from 0 degree to 12 degrees, may be depositional. The arkose and sandstone rest unconformably on the folded Tazin quartzites. Here, the old, uneven land surface on which the Athabasca sediments were laid down is being exposed by erosion, the harder Tazin quartzite forming the hills and the softer, less consolidated Athabasca arkose and sandstone occurring only in the valleys or low-lying ground, especially in positions where it was protected from the southwestward-moving ice-sheet. Little of the quartzite has been eroded since the deposition of the Athabasca arkose, as 'sandstone dykes', that is, Athabasca arkose or sandstone preserved in cracks and fissures in the Tazin quartzite, are numerous, as mentioned by Alcock, and occur on

the highest hills in the islands of the southwest group. Dykes of Athabasca sandstone were also noted in Tazin rocks on Bigfowl Island, indicating that the Tazin-Athabasca contact was not far above the present surface at this point.

The Athabasca series exposed on the shore of Tazin Lake rests unconformably on the older gneisses. As mapped, it is seen to strike northerly and to dip moderately steeply to the west. To the west, however, just beyond the map-area, Athabasca strata dip gently toward the north. About 3 miles north of the map-area is the pronounced lineament of Tazin River, which, as it does not follow the regional strike, undoubtedly indicates a fault. It is presumed that the Athabasca sedimentary rocks of that area (6, Map 363A) are a remnant preserved by downfaulting along a fault occupied by Tazin River.

ORIGIN AND CORRELATION

The Athabasca series is of continental and shallow water origin, as attested by the red colour of the beds, which indicates oxidizing conditions of deposition, and by the abundant crossbedding, ripple-marks, and mud-cracks. Disintegration rather than decomposition of the parent rock and short transportation of the sedimentary material are indicated by the abundance of fresh feldspar and the angular shape of many of the grains in the arkose and of many of the pebbles in the conglomerate. The great thickness of these shallow water deposits near Martin and Fredette Lakes indicates that they must have been deposited on a sinking floor on which deposition kept pace with subsidence, so that shallow water conditions were maintained.

It has been noted that many, if not all, of the areas of disturbed Athabasca strata are bounded by faults or by conglomerates bearing angular detritus and resembling talus breccias. This suggests that the deposition may have been controlled in part by faulting. It is possible that part of the subsidence of the interior of the Martin Lake basin may have been due to extrusion of lava from beneath its centre and, therefore, contemporaneous with the deposition of the upper beds. It is necessary, however, also to postulate folding to explain the steep attitude of these beds.

The character of the conglomeratic, arkosic, and crossbedded sediments in the folded areas indicates that they were deposited near shore in shallow water. Mud flats occurred locally. This type of deposition is common in basins of interior drainage or in deltaic or shallow water littoral deposits. Because of the talus type conglomerates, with angular pebbles at the base of the series, and the location of known faults, it is believed that the Athabasca sediments were deposited in separate basins formed by earth movements resulting, mainly, in faults.

The flat-lying Athabasca sedimentary strata of the islands in Lake Athabasca differ from the beds of the folded areas in that, except for a few minor pebble bands, they contain no conglomerates, and are more siliceous and less arkosic, being dominantly feldspathic sandstones or sandstones. They may be grey, to pink, to red, commonly exhibit crossbedding, and more rarely exhibit mud-cracks in the finer grained bands. Alcock's description of the Athabasca sandstone in the type area south of Lake Athabasca is as follows: "the dominant rock type is a sandstone

consisting almost entirely of quartz. It varies in colour from white to buff and reddish. The grains are well rounded and in places the rock is hard and well cemented; in others it is weak and friable. The texture locally is uniform; in other places larger rounded grains and pebbles of quartz up to several inches in diameter are scattered irregularly throughout the sandstone".

A note on the Tectonic Map of Canada[1] states that the Athabasca sandstones south of Lake Athabasca are intruded by basic sills, and are intersected by northeast and east-northeast striking regional faults in the Black Lake area. Hriskevich (35) reports that the Athabasca series in the Black Lake area, which adjoins the Athabasca series south of Lake Athabasca, is composed of buff and white sandstones with thin interbeds of pebble-conglomerate. The sandstone is composed almost exclusively of subangular to subrounded grains of quartz, with rare grains of feldspar. The beds are horizontal or nearly horizontal, and are commonly crossbedded. These sandstones are intersected, and displaced, by the northeasterly trending Black Lake fault. Pitchblende deposits are related to this fault in the same way as the pitchblende deposits are related to faults in the Goldfields-Martin Lake area.

The writer has followed Alcock (6) in correlating the Athabasca arkose and feldspathic sandstones in the areas of folded rocks to the north of Lake Athabasca with the Athabasca sandstones of the type area south of the lake. The evidence in favour of this correlation is as follows: (1) the change in composition and structure is gradational from the arkosic rocks of the folded basins to the north of the lake, to the less feldspathic and flat-lying sandstones of the islands in the southern part of the map-area, to the siliceous sandstone with well-rounded quartz grains described by Alcock from the type-area of this series south of Lake Athabasca; (2) their unconformable relations with the older rocks and their similar degree of consolidation; and (3) the strata of both areas contain basic igneous rocks and are intersected by northeast and east-northeast striking regional faults.

In conclusion, although the correlation may not be absolutely certain, the name Athabasca series is established by long usage in the area north of Lake Athabasca, and in the opinion of the writer these rocks should be called Athabasca and correlated with the Athabasca sandstones south of the lake until such time as they are proved to be of a different age.

LATE BASIC DYKES

Small, black, dark green, or brown basic dykes occur throughout the area, but are most numerous in the northern part. They vary in composition from gabbro to syenodiorite. They are most commonly of very fine grain, but lath-like crystals of feldspar up to 1 mm. long may be seen in some of them. Many contain numerous small amygdules composed of calcite or chlorite. The amygdules vary in diameter from those 2 or 3 mm. in diameter to others that can only be recognized with the hand lens or under the microscope. Most of these dykes are from 1 foot to 20 feet wide, are usually straight, dip nearly vertically, and can rarely

[1]Geological Association of Canada, 1950.

be traced more than 100 feet. As traverses in the area were spaced at ½- to ⅓-mile intervals, relatively few of these dykes have been mapped. They are shown by a conventional symbol on the map, which indicates their strike, but it is not possible to indicate their true size and shape. They are considered to be the youngest rocks in the area because they have been observed to intersect rocks of the Athabasca series, and Beavan (9) reports that one of them intersects a lamprophyre dyke on the south shore of Mackintosh Bay.

One large, coarse-grained gabbro dyke north of Neely Lake averages 150 feet in width and has been traced for 1½ miles. Another coarse-grained mass of more than normal thickness outcrops on the large island in Fredette Lake, but due to poor exposures its attitude and relation to the Athabasca sedimentary beds (whether sill or dyke) were not determined. Certain of the dykes branch or fork in an irregular manner and may enclose large and small fragments of the intruded rock; this is especially true of the two lines of dykes striking westward from LeBlanc Lake, where swarms of small, interconnected branching dykes strike in general east-west and form zones of intrusion in the gneiss.

TABLE V

Estimated Mineral Composition of Coarse-grained Late Basic Dykes

—	1	2	3	4
	%	%	%	%
Total feldspar	56	54	50	60
Plagioclase	53 (An_{67})	52 (An_{60})	? (An_{10})	45 (An_{45-30})
Orthoclase	3	2	?	15
Quartz	6	5	17	12
Amphibole	4	26	15	2
Biotite	7	7	.....	1
Epidote	.....	.....	3	.....
Chlorite	10	3	10	12
Iron oxide minerals	6	3	3	5
Apatite	4	2	2	2
Sphene	.....	.....	.....	1
Sericite	1	.....	.....	.....
Rutile	.....	.....	.....	Tr.
Carbonate minerals	1	.....	.....	.....
	100	100	100	100

Thin sections Nos. 1, 2, and 3 were obtained from specimens of the large quartz gabbro dyke north of Neely Lake; No. 4 was obtained from a specimen from the large basic dyke or sill on the island in Fredette Lake.

Most of the late basic diabase dykes have the mineral composition of a quartz gabbro, but five of those examined contain sodic plagioclase (An_7 to An_{30}) and others contain minor potash feldspar and biotite. The estimated mineralogical composition of thirteen thin sections of specimens from these dykes is given in Tables V and VI.

Under the microscope the Neely Lake dyke is seen to have the composition of a quartz gabbro, in places much altered, apparently, by later fluids related to the intrusion. Thin sections Nos. 1 and 2, Table V, represent the quartz gabbro, and slide No. 3 represents an altered phase of the same dyke. Slides Nos. 1 and 2 consist of well-twinned crystals of relatively fresh labradorite feldspar, with augite, amphibole, biotite, chlorite, and minor amounts of interstitial granophyric intergrowths of quartz and orthoclase. The labradorite is in part altered to sericitic-looking material, and to a lesser extent is replaced by chlorite. The augite crystals are colourless in thin section. The hornblende commonly rims, partly or completely, the augite crystals and is pleochroic green to light brownish green to light yellowish green. Lamellar twinning is common. The biotite, which is strongly pleochroic, deep reddish brown to very light brown, is especially common near quartz and granophyric material in the slides. In places it is apparently pseudomorphous after the hornblende, and crystals of the latter may contain several areas of biotite, the basal cleavages of which parallel a prismatic cleavage of the hornblende. Quartz and granophyric intergrowths of quartz and orthoclase occur interstitially. Chlorite is partly pseudomorphous after augite and hornblende crystals, and more rarely occurs as a fine-grained aggregate associated with quartz.

Slide No. 3 represents a quartz-rich specimen of the same Neely Lake dyke. In this slide, only the outlines of many large crystals of plagioclase are visible; the plagioclase itself is almost completely altered to a fine-grained aggregate of sericite and clinozoisite and to an unidentified, fine-grained, brownish material. The remnants of plagioclase are certainly much more sodic than labradorite, and are believed to be albite-oligoclase, about An_{10}. No augite occurs in the slide, but hornblende is common and in various places shows all stages of alteration to penninite. Epidote is common in small grains, but biotite is lacking. Quartz is abundant, but intergrowths of quartz and potash feldspar are rare as compared with Nos. 1 and 2 slides. The extreme alteration of the feldspar makes any estimate of the percentage of plagioclase to orthoclase of doubtful value.

The Neely Lake dyke is concluded to have the composition of a quartz gabbro, which shows abundant reaction of late fluids with the earlier crystallized minerals to form the following reaction series: (1) augite to hornblende to biotite; (2) augite, hornblende, and biotite to chlorite; and (3) labradorite to sericite(?), clinozoisite, and albite-oligoclase.

Radioactive zircon and another unidentified radioactive accessory mineral occur in this dyke.

The coarse-grained basic dyke or sill on the island in Fredette Lake (*See* thin section No. 4, Table V) is similar to some phases of the Neely Lake dyke. The reaction series of augite to hornblende to biotite and augite hornblende to chlorite are evident. Granophyric intergrowths of

TABLE VI

Estimated Mineral Composition of Fine-grained Late Basic Dykes

—	1	2	3	4	5	6	7	8	9
	%	%	%	%	%	%	%	%	%
Plagioclase	55	55	52	55	60	50	47	55	55
Composition	(An_{55})	(An_{57})	(An_{52})	(An_{50})	(An_{50})	(An_{30})	(An_{7})	(An_{7})	(An_{7})
Condition		Feldspars relatively fresh				Feldspar much altered to sericite and replaced by chlorite			
Augite	15	12	4	...	...	16	...	...	12
Amphibole	...	...	Tr.	6	Tr.	2	...	3	...
Biotite	...	...	...	4	7	...	6	...	...
Chlorite	6	3	8	5	10	18	30	25	28
Groundmass	10	22	25	14	10	...	...	...	...
Black iron ores	8	4	7	7	7	4	7	6	1
Pyrite	Tr.	Tr.	...	...	Tr.	...	...	Tr.	...
Apatite	...	...	...	...	...	...	Tr.	1	Tr.
Epidote	...	...	...	...	...	2	2	Tr.	1
Quartz	3	2	2	2	1	5	5	8	1
Carbonate	3	2	2	4	2	3	2	2	1
Number of amygdules in slide	15	45	25	15	20	20	15	2	10
Average size (mm.)	0·25	0·05	0·3	0·6	0·3	0·2	0·4	1	0·3
Sequence from outside in 1	Quartz	Chlorite	Quartz	{Quartz	Quartz	{Chlorite	{Chlorite	Quartz	Quartz
2	Calcite	Quartz	Calcite	{Chlotite	Calcite	{Quartz	{Epidote	Chlorite	Chlorite
3	...	Calcite	...	Unknown	...	Hematite	Quartz	Hematite	Calcite
4	...	...	...	Calcite	...	Calcite	Calcite	Calcite	...
			(c)	(c)	(c)	(bc)	(c)	(b)	(a)

(a) These are segregations rather than amygdules, being irregular in form and having no distinct banding.
(b) A veinlet of quartz and calcite cuts this slide. (c) The amygdules contain needles of actinolite.

{ These minerals apparently crystallized together.

1. 25-foot dyke northwest of Charlot Lake.
2. Small dyke, Elder Lake.
3. Small dyke north of Fredette Lake.
4. Small dyke north of Fredette Lake.
5. Small dyke southwest of Fredette Lake.
6. Small dyke north of Fredette Lake.
7. Small dyke south of Donaldson Lake.
8. Small dyke on south side of Mickey Lake.
9. Small dyke cutting Athabasca conglomerate north of Cutler Lake.

quartz and potash feldspar are more abundant than in the observed specimens of the Neely Lake dyke. The plagioclase ranges in composition from a calcic to sodic andesine (An_{54-30}), the cores of the crystals being more calcic than the rims.

The estimated mineral composition of several of the smaller basic dykes is shown in Table VI, thin sections Nos. 1 to 9.

Sections 1 to 5 are of gabbroic rocks containing abundant, relatively fresh labradorite feldspar, and show ophitic texture. In two of the slides a little well-crystallized sericitic material occurs in the feldspar grains, in another, a little chlorite, and in other slides the feldspar is unaltered. The augite is colourless in thin section, is commonly elongated parallel with the c-axis, and shows lamellar twinning parallel with the orthopinacoid (100). In general, the augite, amphibole, and biotite are similar to those described from the Neely Lake dyke, but in these slides the crystals are small, and although all minerals of the reaction series described above occur in the various dykes, no crystal was seen to be rimmed by another mineral lower in the reaction series. The amphibole and biotite crystals occur in the fine-grained matrix between laths of feldspar, and are rarely more than 0·05 mm. in length. All these dykes contain a considerable groundmass of isotropic, or very fine-grained, indeterminate material. The opaque minerals are believed to be mainly magnetite, though they include some ilmenite and a little pyrite. An interesting feature of these dykes is that they all contain numerous small amygdules composed of quartz, calcite, and chlorite. These are well rounded, and most of them are well banded, indicating cyclic deposition, from the outside in, of quartz, chlorite, and calcite. Rarely, chlorite may be deposited with, or before, the quartz. Very small acicular crystals of almost colourless actinolite may occur in any of the minerals of the amygdules; more rarely, epidote occurs near the edge.

Thin sections Nos. 6 to 9, Table VI, also show ophitic texture, although in places it is marred by alteration. As in the other slides, almost 50 per cent of the rocks is feldspar, which is much altered to a sericitic-looking material, and replaced by chlorite. In one slide, the feldspar is oligoclase-andesine, in the three others it is apparently albite (An_7), but as the feldspar is much altered the identification is less certain than in previously described slides. The ferromagnesian minerals may be augite, amphibole, or biotite, mainly similar to those of other slides, but in slide No. 10 the amphibole is a faintly coloured actinolite that shows a colourless to very faint green to faint bluish green pleochroism, and is associated with segregations of chlorite and calcite. It will be noted that no groundmass is recorded for these slides: abundant fine-grained chlorite (var. penninite) occurs in three of them and may represent a recrystallized groundmass, and it is perhaps significant that chlorite plus groundmass in Nos. 1 to 5 slides, Table VI, roughly equals the percentage of chlorite in slides 6 to 9. Quartz is more abundant in the altered rocks represented by thin sections 6 to 9 than in slides Nos. 1 to 5 from the fresher rocks. Amygdules occur in all four slides of the more altered rocks, with the possible exception of slide No. 13, but here at least are segregations of chlorite, calcite, and quartz. In this respect it is suggested that a dyke cutting the relatively porous Athabasca series, as does that represented by slide No. 13, would

not be expected to retain the associated volatile constituents as well as one in the basement complex, and is, therefore, less apt to be amygdaloidal. The amygdules of the altered dykes are similar to those of the unaltered ones except that in two of the slides incomplete bands of hematite surround the calcite core.

The coarse-grained late basic dykes of the Goldfields-Martin Lake area are of the quartz gabbro type, and show a wide range of differentiation and of alteration by later fluids that are believed to be related to the intrusions. The most outstanding features of the dykes are: (1) the earliest formed minerals, augite and labradorite, indicate a gabbroic composition; (2) studies of thin sections indicate a sequence of prominent reactions, augite, hornblende biotite and labradorite, sodic feldspar; and (3) the last-crystallized material is a granophyric intergrowth of quartz and potash feldspar.

The fine-grained dykes are, in the opinion of the writer, all related to each other and to the larger dykes; the freshest looking are of gabbroic composition, but contain amygdules in which a late crystallization of quartz and calcite occurred, thus suggesting their consanguinity with the larger quartz gabbro dykes. The variation in the character of the ferromagnesian minerals is explained as due to the varying progress locally of the reaction series, augite to hornblende to biotite, up to the time of injection and consolidation. The occurrence of amygdules in these dykes indicates abundant volatile constituents and a shallow depth of consolidation.

The fine-grained dykes represented by thin sections Nos. 6 to 9, Table VI, are believed to be related to the others because of the similar variation of the ferromagnesian minerals, and the presence of amygdules. The variation in the feldspars is not considered to present a serious objection to the hypothesis of consanguinity because of the extensive alteration that accompanies the sodic feldspars, and because the results of a somewhat similar alteration of labradorite to form albite-oligoclase and clinozoisite was observed in the large Neely Lake dyke.

It is further suggested that the late basic dykes are genetically related to the flows of the Athabasca series because: (1) what appear to be the freshest phases of both are of gabbroic composition, that is, composed essentially of augite and labradorite feldspar; (2) both the dykes and the flows have a more soda-rich later phase or period of alteration during which intermediate or soda-rich feldspar was developed; and (3) both dykes and flows are commonly amygdaloidal, the minerals deposited in the amygdules being commonly the same, namely quartz, chlorite, and calcite, and are commonly deposited in the same order. Further, there may be some spatial relation of the dykes and the area of folded Athabasca sedimentary rocks on the north shore of Lake Athabasca as, according to Blake (11), the late basic dykes are rare southeast of a line drawn northeastward from Moose Island, which is in the southeast corner of the map-area, but common to the northwest of this line. It may be noted that Turner and Verhoogen (51) consider soda-rich diabases (gabbro dykes) to be commonly associated with areas of spilitic volcanic rocks.

CHAPTER III

REGIONAL ALTERATION AND STRUCTURAL RELATIONSHIPS

CONTACT METAMORPHIC EFFECTS OF GRANITE ON AMPHIBOLITE

The contact metamorphic effects of granite on amphibolite have been studied mainly in the southern part of the map-area, especially in relation to the problem of the relative ages of these rocks. Most commonly the contacts between these rocks appear sharp in the field; occasionally they are irregular, with penetration of granitic tongues or lenses into foliated amphibolite; rarely pneumatolytic effects appear to be localized along the contacts, or zones of amphibolite are in part replaced by granitic materials.

An example of a sharp contact on the Athona property has been described by Beavan (9) in the following table:

Distance from contact	*Mineralogical changes*
Inches	
15	Unaltered amphibolite
9	Beginning of alteration of hornblende to biotite plus leucoxene; feldspar sericitized; hornblende developing poikiloblastic quartz and albite
6	Hornblende altering to talc(?) and, in part, to fresh, more bluish hornblende
4	All fine hornblende altered to biotite; hornblende remnants altered to carbonate; andesine in process of alteration to carbonate; quartz metacrysts introduced
1	Greenish brown biotite partly altered to chlorite; veins of abnormal adularia, quartz, calcite, and chlorite; replacement of the groundmass by potash feldspar; estimated composition:

	Per cent
Biotite	15
Orthoclase	42
Chlorite	35
Apatite	3
Calcite	5
	100

The unaltered amphibolite is of relatively coarse grain whereas the biotitic phase adjacent to the granite is fine grained.

Many variations of the above sequence were observed. Thus, on the Athona property, the writer observed that the amphibole in amphibolite near a granite contact was altered to clusters of small biotite crystals, but that still nearer the contact the biotite occurs in bands associated with chlorite alined parallel with the contact, giving the rock a fine-grained appearance.

A series of specimens was taken across the amphibolite contact on the foot-wall of the Box orebody and examined in thin section. Near the contact the amphibolite is a banded rock composed of large (commonly 2 mm.), pleochroic (blue-green, green, to yellow-green) crystals of amphibole, showing a strong, preferred orientation and poikiloblastic structure, and containing inclusions of quartz and calcite. The amphibole crystals are altered around their edges to a finer grained felt of greenish biotite flakes, which are alined nearly parallel with the amphibole crystals and the foliation. Rarely the biotite is altered to chlorite (var. penninite). Between the amphibole grains is a fine-grained felt of altered feldspar, epidote, biotite, quartz, and potash feldspar. Lenses and bands of fresh-looking microcline and quartz comprise a considerable volume of the rock; they parallel the foliation indicated by the other minerals. Two inches on the amphibolite side of the granite-amphibolite contact the rock is fine-grained, banded, and green in colour. It contains no amphibole, but under the microscope is seen to consist of tiny flakes of green biotite and chlorite set in a banded groundmass of altered plagioclase feldspar, quartz, potash feldspar, a zeolite, and various accessory minerals.

All amphibolite contacts with granite, however, do not show the fine-grained, biotitic, border phase. Southwest of Gatzke Lake, one of these contacts is marked by a coarse-grained biotite gneiss that contains idiomorphic crystals of feldspar up to 1 inch in diameter. It is suggested that some pneumatolytic action was concentrated along this contact.

The alteration effects on amphibolite by granitic material are not only to be observed at the contacts. Jolliffe (35) lists in the map-legend of his Cornwall Bay-Fish Hook Bay sheet, "Replacement Bodies of Granite Porphyry in Amphibolite", and describes them in his report as follows: "Many irregularly shaped granitic bodies occur in hornblende-biotite gneiss. Their contacts are invariably gradational from hornblende-biotite gneiss through biotite gneiss containing irregularly distributed feldspar metacrysts. The latter gradually increase in size and number until they form a light weathering rock composed of feldspar, biotite, and quartz. The bodies thus do not represent a normal intrusive rock".

On the Athona property a considerable body of amphibolite has been partly replaced by granitic material, which is represented by angular to lenticular, light-coloured areas, commonly ½ inch in diameter and resembling porphyroblasts, in a dark-coloured groundmass. This occurrence grades on all sides into normal amphibolite. Under the microscope the light-coloured areas are seen to be composed of an aggregate of very fine-grained sericitic material containing fairly fresh, small crystals of microcline, some chlorite, and a few patches of biotite. The dark groundmass of the rock consists of augite; hornblende, which is pleochroic blue to green to yellow; brown biotite, which is associated with abundant greyish blue tourmaline; zeolites; and accessory sphene, epidote, and carbonate. The occurrence of microcline and especially tourmaline in this rock is strong evidence in favour of a replacement origin, the amphibolite undoubtedly being replaced by fluids emanating from the nearby granite. At several other localities similar effects were observed.

In the areas of granitic rocks there occur rare, narrow and continuous bodies of basic rock that appear to be sill-like or dyke-like in form. It has been argued (29) that these are late basic dykes that cut the granite,

and indeed, in the field, they appear to be such. The mineral composition of these bodies is, however, unlike any known intrusive rock and the writer has concluded that they represent remnants of basic rocks that survived the granitization of the enclosing rocks and remain as greatly altered inclusions, retaining their original dyke-like or sill-like form, in the younger granitic material in which they are enclosed. Several of these bodies occur near the southeast border of the Lodge Bay granite. Examination of a thin section of one of these bodies, 18 inches wide and at least 30 feet long, shows 60 per cent biotite, 25 per cent epidote, 8 per cent quartz, 4 per cent carbonate, and 3 per cent pyrite. The biotite is a green variety occurring in stumpy crystals. The epidote occurs in idiomorphic crystals.

As is shown in Figure 4, the Box orebody contains several masses of basic rock, one of which is continuous with an amphibolite dyke south of the orebody. Cooke mapped this dyke as amphibolite and claimed that it shows that the amphibolite is younger than the granite. A specimen of the dyke, however, taken from the "mine granite", is seen under the microscope to consist of 37 per cent chlorite, 22 per cent sericite, 34 per cent quartz, 4 per cent opaque minerals (hematite and ilmenite), and 3 per cent sphene. The rock is strongly foliated. It is believed that this rock is the product of extreme hydrothermal alteration of the amphibolite, during the emplacement, by replacement processes, of the "mine granite".

DISCUSSION OF THE RELATIVE AGE OF THE AMPHIBOLITE AND THE GRANITE

Different opinions have been expressed as to the relative age of the amphibolite and granite in the map-area (6, 29, 9), and as the field relations are confusing, a discussion of the problem seems desirable.

Rarely, narrow dykes of granite intersect the amphibolite. A good example is to be found on the eastern contact of the Lodge Bay granite where the amphibolite is intersected by several narrow dykes of granite, which isolate angular fragments of the amphibolite (*See* Plate V B). Here the granite is undoubtedly younger than the amphibolite. Further, the contact metamorphic effects in the amphibolite near the granite contacts described on pages 61 and 62 have been interpreted to indicate introduction of granitic material into amphibolite rather than, as some have supposed, of amphibolitic material into granite. The texture and composition (especially the tourmaline content) of the replacement areas of granite in amphibolite (*See* page 62), is best explained as due to the introduction of younger granitic material into older rocks, now amphibolite.

Arguments that have been presented (29) to show that the amphibolite is younger than the granite are given below, together with the writer's interpretations of the features discussed.

(1) Amphibolite dykes are stated to cut the granite of the Box orebody (29). Swanson (50), however, decided that the "granite" is not a true igneous body, but is composed of highly granitized sediments. The principal amphibolite "dyke" was examined in thin section by the writer, and was found to be, not amphibolite, but a strongly foliated aggregate of chlorite, sericite, and quartz, with minor sphene and opaque minerals. This "dyke" is apparently continuous with a larger amphibolite body southeast of the orebody (*See* Figure 4), and is probably a tongue of amphibolite

that has been intensively altered (by granitization or hydrothermal processes) by the introduction of the "mine granite". An alternative, though not the favoured hypothesis, is that this so-called dyke represents a shear zone in the gneiss that has been impregnated by chlorite.

(2) Amphibolite in some instances, but not in others, appears to show chilled contacts against the granite. Examination of thin sections, however, has shown that this finer grain is a result, not of chilling, but of contact metamorphism, the coarse-grained amphibole being altered to fine-grained biotite and chlorite near the granite contacts (*See* pages 61 and 62).

(3) It has been stated that the amphibolite "dykes" display an original gneissic structure developed by flow movement during the injection of a viscous magma, the gneissic structure tending to parallel the contacts rather than the general structure, and that where a narrow amphibolite dyke follows a curved course, the foliation tends to parallel the contacts throughout. The writer believes, however, that this structure is due to flowage under pressure of a less competent rock (the amphibolite) in contact with a more competent rock (the adjoining granite). Indeed, there seems no other way of explaining the boudinage structures described on page 25, in which exactly these relations hold true. Furthermore, all the minerals whose crystals lend the rock its gneissic structure—the amphiboles, the biotite, and the chlorite—are of secondary origin. Their alinement, therefore, is unlikely to be a primary feature of the rock. It is conceivable that the gneissic structure may reflect an alinement of the original minerals present, but the degree of perfection of the alinement and the parallelism of the lineation direction of the amphibole crystals with the fold axes suggest a secondary origin for these features.

It is concluded that the evidence presented above indicates that the granite is younger than the amphibolite.

METAMORPHISM OF THE TAZIN GROUP

It has not been found possible in the present work to outline distinct zones of regional metamorphism in the map-area. It is believed that this failure is due to three principal causes: (1) the lack of widespread bands of aluminous sediments in the area; (2) the fact that the metamorphic processes associated with the emplacement of the granitic material were accompanied and followed by replacement phenomena that in many places resulted in an alteration of the chemical composition of many of the original rocks, with metasomatic or replacement effects commonly predominating over the strictly regional metamorphic effects; and (3) the rocks over considerable areas have suffered strong retrograde, dynamic metamorphism following regional metamorphism.

On the accompanying map the overprint letters indicate where many of the standard metamorphic index minerals, such minerals as sillimanite, cordierite, garnet, andalusite, amphibole, epidote, and chlorite, are found. Most of the noted occurrences of these index minerals are in the "mafic rocks", to which the following discussion chiefly applies. In general, the overprint letter A, by itself, indicates a coarse-grained amphibolite, commonly associated with andesine feldspar, which is at least a moderately high-grade metamorphic rock; the symbols AE or AEC commonly indicate

a finer grained and lower grade metamorphic rock than the amphibolite, except where the development of epidote or chlorite is due to later hydrothermal or dynamic action. The chloritic rocks, overprinted C, indicate a low grade of regional metamorphism. Many of these rocks contain sheared and altered relics of such minerals as garnet, cordierite, and andalusite, that are much altered to chlorite and sericite. In these cases, rocks of the garnet, cordierite, and andalusite grades have undoubtedly suffered retrograde (dynamic) metamorphism along major or minor fault of shear zones. The chlorite-bearing mafic rocks (*See* Map 1015A) occur principally near Beaverlodge Lake and in the mafic belts trending northeastward from Melville and Tam Lakes. It will be noted that the chloritic rocks are surrounded by rocks typical of a higher grade of metamorphism. For these reasons the writer suggested in his 1947 preliminary report that the entire map-area had probably attained a degree of metamorphism higher than the chlorite grade, and that zones of chlorite rocks mark zones along which later retrograde (dynamic) metamorphism has occurred, or zones of hydrothermal alteration. However, Smith (48), although agreeing that many of the chloritic zones are zones of retrograde metamorphism, believes that some chloritic sedimentary rocks in the Tam and Eagle Lakes area preserve some original sedimentary structures, and show no relict structures under the microscope that would be preserved if they had been subjected to a grade of regional metamorphism considerably higher than the chlorite grade. Moreover, more detailed mapping in the Tam and Eagle Lakes area has indicated areas of little-sheared folded sediments in which the folding is moderately open. These rocks, therefore, are not mylonites, and there is little evidence of strong retrograde metamorphism in them. It is concluded that this part of the area did not attain a grade of metamorphism much higher than the chlorite grade.

Blake[1] states that to the east of the map-area the grade of metamorphism is commonly higher, the mafic rocks being commonly amphibolites or pyroxene bearing amphibolites. To the west of the map-area, as far as Camsell Portage, the grade of metamorphism of the mafic rocks is commonly lower, most of these rocks being of the chlorite grade of metamorphism, and rocks containing garnet are rare. There is, thus, a general decrease in grade of metamorphism from east to west.

The less metamorphosed chlorite grade rocks near Beaverlodge Lake might be considered to have been in a zone that was higher in the earth's crust during the period of maximum metamorphism prior to Athabasca time. This less metamorphosed zone was then down-folded with the Athabasca series and preserved as an area of less metamorphosed rocks in rocks of higher grade. Retrograde dynamic metamorphism affected certain belts of these rocks before, during, and after the deposition of the Athabasca series. These chlorite-grade rocks, then, might be considered as a sort of outlier of the chlorite-grade rocks to the west.

MAJOR FAULTS AND SHEAR ZONES

Two major faults are recognized in the area, the St. Louis fault and the Black Bay fault. Both are marked on the ground by prominent lineaments, which are visible on air photographs and shown on topographic maps.

[1] Blake, Donald A. W.: Geol. Surv., Canada, personal communication.

The St. Louis fault strikes north of east from the north shore of Beaverlodge Lake to Raggs Lake and Prince Lake, and has been traced by Blake (11) northeastward beyond the map-area through Alces Lake. At Ace and Flack Lakes, diamond drilling has shown that the fault dips southward at about 50 degrees. The apparent horizontal displacement of an intrusive contact between mafic rocks and gneisses northeast of Verna Lake indicates that the northwest side was apparently displaced northeastward about 1,100 feet with respect to the southeast side. The preservation of Athabasca sedimentary beds along the south side of the fault between Beaverlodge and Ace Lakes indicates that since Athabasca time the south side has moved downward with respect to the north side. Underground workings of Eldorado Mining and Refining (1944) Limited at the Ace mine have intersected the St. Louis fault at a depth of 250 feet, where the dip is 47 degrees to the south. According to Robinson[1], the position of the fault at this depth is marked by a zone of intensely sheared rock 2 to 2½ feet wide, intercalated with thin seams of gouge. The widest (5-inch) band of gouge adjoins Athabasca conglomerate, which forms the hanging-wall of the fault. The foot-wall consists of Tazin mafic rocks, indicating that the Athabasca series has here been down-faulted at least 250 feet with respect to the older rocks. However, the total displacement is probably much greater than this. A zone of mylonitization and brecciation, commonly up to 100 feet wide, accompanies the fault. Other mylonitized or brecciated zones occur parallel with or subparallel with the fault zone. These crushed rocks are discussed more fully on page 67. Smith (48) and Conybeare (25) report finding pebbles of mylonitized gneisses in the Athabasca conglomerate at Contact Lake and Ace Lake, indicating that mylonitization along the fault and elsewhere occurred in pre-Athabasca time. Further, it will be noted that the Athabasca beds are downthrown on the south side of the fault, indicating post-Athabascan normal faulting, which implies tension. Tensional movements, however, are not capable of producing extensive mylonitization, which requires strong compressive forces or shearing. It seems probable, therefore, that the St. Louis fault is an old feature formed by compressive or shearing forces prior to the deposition of the Athabasca series, and that subsequent, post-Athabascan movements along this zone of weakness consisted of normal faulting.

The Black Bay fault bounds Black Bay of Lake Athabasca on the southeast, and strikes northeastward to a point near Anne Lake. From Cinch Lake to Anne Lake it forms the northwest boundary of a belt of Athabasca sedimentary strata. Although the fault could not be traced in the field northeast of Anne Lake, a prominent, northeasterly striking lineament followed by Tazin River beyond the map-area appears to mark an extension of the Black Bay fault.

As the Black Bay fault parallels the strike of the gneisses and sedimentary rocks, the amount of horizontal displacement along it could not be detected, but the occurrence of Athabasca sedimentary rocks on the southeast side indicates that this side is downthrown with respect to the northwest side. According to Robinson[1], stripping operations along the fault zone northwest of Fredette Lake revealed 18 inches of gouge and a

[1] Robinson, S. C.: Geol. Surv., Canada, personal communication.

dip of 50 to 70 degrees southeast. It is probable, therefore, that the post-Athabasca movements along the Black Bay fault were due to tensional forces, as in the case of the St. Louis fault and by analogy it is considered that the mylonitized or crushed zone along the Black Bay fault was caused by compressional or shearing forces in pre-Athabasca time. Strike faults parallel with the Black Bay fault are common on the northwest side of the fault. Among these are the Crackingstone fault in the valley of the river that drains Fredette Lake, the break between Jean and Don Lakes, and the break trending southwest from near Jean Lake past the mouth of the Rix-Athabasca adit.

North of the St. Louis fault, in the vicinity of Melville, Eagle, and Mic Lakes, are numerous faults, breccia zones, and shear zones that strike between north 40 and 70 degrees east. These occur in the area where the St. Louis and Black Bay faults converge.

A major east-west fault, mapped by Blake (11) in the adjoining Forget Lake map-area, enters the Goldfields-Martin Lake area along the north shore of Max Lake, and doubtless is indicated by the lineament that extends from there to the west tip of Yahyah Lake. On the west shore of Max Lake the fault is characterized by abundant introduction of vein quartz.

MYLONITES, FLASER-GNEISSES, AND CRUSH BRECCIAS

Dynamic metamorphism has been very prominent locally as well as in some rather extensive parts of the map-area. Completely and partly crushed rocks, mylonites[1], flaser-gneisses[2], and crush breccias, are particularly well developed in the vicinity of the St. Louis and Black Bay faults, and in the area between Ace and Melville Lakes. Here almost massive-looking granite-gneisses may grade to flaser-gneisses, crush breccias, or mylonites in a few feet, and these changes may be repeated many times in a few hundreds of feet across the strike of the bands. Where not forming a definite fault or crushed zone, the zones of crushing commonly outline lens-shaped areas of less-crushed gneiss of all dimensions from the augen structures seen under the microscope or in the hand specimen, to lens-shaped areas of gneiss 1 foot, 50 feet, or 1,000 feet long. Less extensively mylonitized or crushed areas occur elsewhere throughout the map-area, and everywhere the pre-Athabasca rocks show at least some microscopic evidence of crushing, such as undulating extinction in quartz grains, and fractured crystals.

Where there are no dark minerals, the mylonites most commonly have the appearance of a pink or red chert, although in all but the most intensely crushed zones a few grains of fractured feldspar may be recognized in the hand specimen. Under the microscope, however, the rock is seen to consist of very small, angular fragments of quartz and feldspar in roughly the same proportion in which they occur in granite. The pink to red colour is

[1] *Mylonite* (Lapworth, 1885). "A coherent, aphanitic, cataclastic, metamorphic rock, with banded structure, which has been formed by the milling down of rock material to a microscopic breccia as a result of movements along a fault. Cataclastic structure predominates over structures due to recrystallization. Commonly a few porphyroclasts of incompletely crushed material are enclosed in the aphanitic paste." In this report, all finely crushed rocks are called mylonites whether they show a banded structure or not, as it is considered to be more a matter of composition of the original rock than a difference in the degree of crushing that determines whether the rock shall be banded or unbanded. Mylonitization is the process of extreme crushing by which mylonites are formed.

[2] *Flaser-gneiss*. A general term for dynamically metamorphosed rocks, usually igneous, that contain coarse-grained lenticular masses or phacoids of parts of the original rock in a finely crystalline foliated groundmass (Holmes)

due to hematite stain, principally in the feldspar. Where the crushed rock contains a little chlorite, it is commonly finely banded, the darker bands rich in chlorite alternating with the pink or red bands. In the more intensely crushed zones, amphibole and biotite are lacking although chlorite is common. Undoubtedly any original amphibole or biotite has been altered to chlorite in the more intensely affected zones.

A few feet from the most intensely crushed zones, the fine-grained, crushed rocks commonly contain augen and lenses of less crushed granite in which white to colourless quartz, and pink to red, hematite-stained feldspar can be recognized in the hand specimen—a typical flaser-structure. Under the microscope, the less crushed bands and lenses are seen to be composed of feldspar and quartz grains, which are shattered and granulated around the edges of the crystals and in bands traversing the crystals. Narrow, dark bands in these rocks, which together with the crushed pink bands form the matrix of the rock, contain chlorite; or biotite or amphibole partly altered to chlorite. In many of these rocks the augen and lens-like forms of the less crushed materials are less well developed, and the rock is composed of rounded, elliptical, and irregularly shaped rock fragments set in a fine-grained crushed groundmass. These rocks have been termed crush breccias. The crush breccias are in places difficult to distinguish from the Athabasca conglomerate, particularly where both are composed entirely of fragments of granite-gneiss and in areas where the Athabasca series itself has suffered some crushing.

Up to the present only the effects of the crushing have been discussed. Commonly, however, there has been recrystallization and introduction of various substances into the crushed zones. Thus the fine-grained mylonites may contain small rounded grains of apparently recrystallized albite (26) and, more rarely, similar grains of microcline. In other cases, albite has been deposited as clear unaltered rims around cores of altered and hematite-stained plagioclase crystals (26). Albite also occurs in tiny veinlets cutting the rock. Other minerals that have been introduced into the crushed zones in varying amounts are chlorite, silica, carbonate, and hematite. Chlorite is particularly conspicuous in veinlets and as an intergranular filling material. Quartz veinlets are abundant. Carbonate is common as small veinlets and, rarely, forms up to 25 per cent of the rock (26).

In the field mapping, it commonly proved difficult to distinguish between mylonitized granite-gneiss and fine-grained (crushed?) sedimentary or volcanic rocks. Because of this difficulty, and because the mylonites were not recognized as such until petrographic work was done at the end of the first field season, a separation has not been attempted in all cases and a map-unit has been set up (*See* Map 1015A) to include undifferentiated mylonites and fine-grained sedimentary or volcanic rocks.

The wide band of fine-grained rock adjoining the Black Bay fault from Cinch Lake to Fredette Lake, and the three smaller areas adjoining the fault to the southwest, are believed to consist mainly of mylonite and flaser-gneiss, as the rocks seen in the outcrop agree with the description of mylonites given above, and thin sections of certain rocks in this band are seen to be micro-breccias. Further, the mafic rocks in the band are all composed of chlorite schist. These features, together with the close

relations of the band to the fault, indicate with near certainty that most of this band is composed of mylonites and flaser-gneisses. It is probable, however, that some sedimentary inclusions occur in this band. The great width of the crushed band (commonly ½ mile wide) may be due in part to the occurrence of several parallel or subparallel planes of movement.

Certain bodies of fine-grained cherty rocks along the St. Louis fault are believed to be mylonites, probably with some introduced material. Near the northwest corner of Max Lake are two bands of white, siliceous rocks that at first sight were considered to be quartzite. On the south side of the more northerly band, however, white veins of quartz cut the adjacent rocks, and are similar to, and apparently continuous with, the 'quartzite'. As the entire siliceous belt crosscuts the regional structure, it is considered to be composed of vein quartz introduced along a wide fault or fracture zone. Blake (11) states that a regional east-west fault has been traced westward in the Forget Lake map-area as far as the northeast corner of Max Lake. It is assumed, therefore, that the pronounced lineament extending from Max Lake to Yahyah Lake in the Goldfields-Martin Lake area is a continuation of this fault.

Between this lineament and Donaldson Lake are several bands of fine-grained rock of doubtful origin in the granitic gneisses. These bands generally follow lineaments visible on air photographs and are considered to be composed of crushed or mylonitized rocks. Most of these rocks have a cherty appearance; some are pink due to contained hematite, some whitish, and some are green due to contained chlorite. These rocks are of doubtful origin, because there remains the possibility that some of them may be relics of sedimentary or volcanic origin in the gneiss.

GRANITIZATION

All who have worked in this map-area agree that most of the exposed granites have gradational contacts with the older rocks with the exception of the amphibolites, and that these older rocks have been "granitized" in varying degrees. There has been, however, divergence of opinion as to which rocks are intrusive granites and which are granitized sediments.

In 1936, Alcock (6) described the "older" granite and granite-gneiss as follows: "They vary....from massive granitic rocks to well-banded gneisses, and in composition from granites to granodiorites. ....there are wide areas underlain by gneisses of sedimentary origin. These are in places so injected and altered into granitoid rocks that they have been mapped as hybrids. The differentiation of the gneisses into paragneisses, hybrid gneisses, and orthogneisses, however, requires very detailed work, and the results would in many cases have to be expressed on a percentage basis". Alcock, however, believed some of the granite to belong to a later period, and describes it as in places showing chilled contacts against the basic igneous rocks.

In 1937, Cooke (29) mapped in detail the Box and Athona mines. He concluded that much of the rock that Alcock mapped as younger granite on the Box property is granitized quartzite, and considered only the "mine granite" and a few other small bodies of rock to be true granites. Later, Swanson (50) mapped the Box "mine granite" in detail, and concluded that it "is composed of sediments more granitized than usual, rather than

being a true igneous intrusive" (*See* discussion, p. 38). It will be seen that there is little agreement among these geologists as to what are intrusive granites and what are granitized sediments in this area.

Beavan (9) studied in detail the Mackintosh Bay and Athona granites. He believes that the former granite was emplaced by "upward movement of magma from the southeast with concomitant distension of the magma walls. This movement persisted after the expulsion of small amounts of pegmatite and solidification of the stock, as shown by the folding of small dykes, and bending of joints in the granite. It was completed before the intrusion of several lamprophyre dykes into the zone of maximum shearing in the north wall of the stock". Regarding the Athona granite, Beavan states: "it is necessary to infer movement of magma up the pitch, about 15 degrees from the southwest". The references to 'magma' implies that Beavan believes these rocks to have been emplaced as a liquid melt.

Smith (48) studied in detail the area around Contact Lake. He remarked that "it (is) difficult to come to any definite conclusions about the nature of the granitization. It would appear, however, that a large proportion of the granite is pure intrusive matter, and that....some parts, especially at the contacts with the mafic sediments, contain appreciable amounts of dissolved pre-existing rocks. Lens-shaped bodies of dark chloritic sedimentary material with very gradational contacts are caught up in the main granitic mass. Thus it is thought likely that the rather fluid granitic solutions soaked the sedimentary bodies while the main magma, in the form of sill-like masses generally parallel to the regional structure, stoped out and partially migmatized large blocks of Tazin sediments".

Conybeare (25) states: "There are within the Ace Lake (Raggs Lake) area no discrete bodies of granitic rock, unless the dykes be considered as such. . . . In few places can the boundaries of granitic rock be mapped; for they are gradational into feldspathic and quartzose schists through medium to fine-grained feldspathic and quartzose rock, and into hornblende-schist through banded and streaked gneiss. Within the areas of granitic rock are bands and streaks (schlieren) of altered hornblende schist. The evidence suggests that the granitic rock has been formed in situ by the permeation of tenuous fluids and gases, or of ions, into the country rock".

The features that bear on the problem of the emplacement of the granitic material in the map-area, whether it was injected as a molten magma, or whether emplaced by a granitization process (deposited from tenuous fluids), are listed below, together with remarks on the significance of each.

(1) Most contacts of granite with intruded siliceous rocks such as quartzites or impure quartzites are gradational over tens or hundreds of feet. This indicates that at least moderately widespread replacement (granitization) has occurred.

(2) The occurrence of sharply defined dykes or sills of altered amphibolite in the granites of the Box mine and of Lodge Bay, the dykes being older than the enclosing granite, provides certain evidence of widespread replacement if the interpretations given for these features are accepted, and it is difficult to explain them in any other way. The minerals found in these altered dykes, especially the large euhedral crystals of epidote

and biotite in the dyke in the Lodge Bay granite, are indicative of relatively low temperature replacement conditions rather than those attendant upon the higher temperature injection of a molten magma.

(3) Most of the relict structures in the Tazin rocks do not appear to have been displaced by the emplacement of the granitic rocks. Thus, small separate relics of quartzite in the granitic rocks may retain their position and attitude sufficiently to outline large structures that appear to have antedated the emplacement of the granitic material, as for example those shown on the accompanying geological map 1¼ miles west of Cinch Lake. Again, near Fold Lake, granitic rocks and quartzite occur between amphibolite bands that are considered to outline and bound a specific layer of quartzite. The granitic rocks appear, in places, to have replaced this quartzite without distending the amphibolite walls, and therefore, without change in volume. This indicates a replacement process rather than the addition of a molten magma. In most parts of the map-area replacement rather than displacement is the rule; however, the Mackintosh Bay granite is a notable exception. As may be seen on the accompanying map, the sedimentary formations bounding the granite appear to split north of Fish Hook Bay, and to follow around both sides of the granite body to the east side where the strikes of the sedimentary beds converge. The emplacement of the granite must have forced the strata aside. This indicates addition of material without subtraction of a similar amount, and is suggestive of, but does not prove, intrusion of a magma, as it is possible that such dilation could be due to deposition of granitic material from tenuous fluids without subtraction of a like amount

(4) Most contacts of granite and amphibolite are sharp. This could be construed as favouring the hypothesis of intrusion of a molten magma, but could also be explained as due to the great imperviousness of the amphibolites to granitizing fluids, and is, therefore, an inconclusive feature. Another noteworthy feature of the smaller amphibolite lens-like inclusions in the granitic gneisses is the constancy of the composition of these inclusions. As they undoubtedly reflect some relict structure of the older rocks, this constancy of composition is surprising as it seems unlikely that the older rocks from which they are derived would all have had the same composition. It is, therefore, suggested that some form of the process termed metamorphic differentiation has operated here, and that the more basic materials have been deposited in the more basic relics that are now amphibolite, at about the same time that more acidic material was deposited in the more siliceous rocks. This is one of the so-called granitization processes advocated by Reynolds (44) and is commonly considered to require tenuous fluids as the transfer agency. A convincing example of magnesia transfer is to be found in the peculiar composition of the cordierite-bearing amphibolite (*See* page 16), in which the alumina (Al_2O_3) and magnesia (MgO) percentages are uncommonly high. If it be assumed that the alumina content has changed little (the alkali content being low), then the rock was probably originally a shale in composition and much MgO has been added. Indeed, whatever the original composition, excepting only the possibility that it was a dolomite, which seems highly improbable because of the high alumina content, MgO must have been added in abundance. This evidence of introduction of abundant magnesia, together

with the proven precipitation of at least some soda- and potash-rich feldspars from tenuous fluids, suggest a parallel with the processes described by Reynolds (44).

(5) In the descriptions of the granites and granitoid gneisses of the map-area, evidence has been presented to indicate that the granitoid rocks were formed during two or three phases of crystallization. Apparently the oldest crystallized material is that now represented by the more altered plagioclase-rich mosaic of crystals as seen in thin section. In places the plagioclase-rich material can be shown to be intrusive into the Tazin rocks. A second period of crystallization is a potash feldspar-rich phase, which, in the discussion of the Lodge Bay granite, proved to have crystallized later than the plagioclase-rich phase. Further, microcline-rich pegmatites were observed to grade to hydrothermal quartz veins near the Box mine, indicating a potash-rich hydrothermal phase at this locality. At the Box and Athona mines, and associated with certain mylonite zones near Eagle, Ace, and Donaldson Lakes, considerable late-crystallized albite has been noted, in part occurring as replacements in fine-grained crushed rocks, mantling altered plagioclase crystals, and as tiny banded hydrothermal veinlets associated with any or all of quartz, chlorite, carbonate, and hematite. Because of the banded vein structure and its associated minerals, it is certain that most of the late albite is hydrothermal in origin. It is, therefore, claimed that the introduction of at least a part of the microcline and probably all of the late albite is a result of metasomatic or hydrothermal processes, and that these minerals were deposited from potash-rich and soda-rich tenuous fluids.

In conclusion, the granites are believed to have been emplaced mainly by a granitization or replacement process, but various small bodies such as the Mackintosh Bay granite may have been emplaced as a molten magma. Even in these cases, however, introduction of later fluids, some of which are undoubtedly related to the intrusion, have considerably altered the composition of the original rock. It is suggested, though certainly not everywhere proved, that the earliest phase was most commonly soda-rich and was followed by a potash-rich phase. Locally the potash-rich phase is followed by the introduction of hydrothermal albite.

The last-mentioned stage, the introduction of hydrothermal albite and quartz, may in part be related to the major period of granitization, as suggested in the cases of the Box and Athona mines, but undoubtedly much of it is related to other and later periods of earth movements, intrusion, and metamorphism. Thus, the mylonites contain late-crystallized sodic plagioclase that is believed to have been generated by the earth movements (*See* page 46). Again, the Athabasca basalts, in part, show spilitic tendencies and contain sodic feldspar, and the differentiates of the late basic dykes also contain sodic plagioclase. The period of metamorphism that produced the chlorite-epidote rocks undoubtedly was responsible for the formation of some albite and oligoclase.

CHAPTER IV

ECONOMIC GEOLOGY

The Goldfields-Martin Lake map-area has been prospected in turn for iron, gold, and uranium. In addition to these metals, copper, nickel, platinum, cobalt, tungsten, vanadium, silver, lead, zinc, mercury, selenium, antimony, and arsenic occur in small amounts.

IRON DEPOSITS

The earliest report suggesting that mineral deposits of possible economic importance occur in the area, was that by J. B. Tyrrell (52) of the Geological Survey, who in 1895 reported the iron-rich rocks near Fish Hook Bay. These rocks comprise the banded iron formations of the Tazin group, and contain hematite, magnetite, jasperoid, and ferruginous quartzite. In 1914 and 1916 Alcock (1, 2) examined these deposits and stated that they were not of ore grade. In 1921, some of the iron deposits near Fish Hook Bay were staked, and in the following year these were re-examined by Allan and Cameron (7), who concluded that no considerable volume of material of ore grade is represented. Average samples and selected specimens were taken from the more promising looking iron-bearing zones. The iron content of the average samples ranged from 4·22 to 34·02 per cent, and of the picked specimens from 6·86 to 38·22 per cent. A description of one of these deposits is given on page 11.

Apart from the vicinity of Fish Hook Bay, the only outcrop seen by the writer that contains material rich enough in iron to be termed 'iron formation', is that described on page 11 near Elliot Bay.

GOLD DEPOSITS

Characteristics of Gold Deposits

At the Box and Athona mines, the gold occurs in albitized granite cut by numerous narrow quartz veins. Apart from quartz and albite, the principal gangue minerals are microperthite feldspar, chlorite, and rare tourmaline. The metallic sulphides occurring at these properties are, in order of abundance: pyrite, sphalerite, galena, chalcopyrite, arsenopyrite, pyrrhotite, and molybdenite.

Beavan (9) made a detailed study of the textures and structures of the gold and associated minerals, and the reader is referred to his thesis for further details. He lists the ore and gangue minerals in the following paragenetic sequence from high to low temperature: albite, tourmaline, quartz (continuing precipitation from high to low temperature), pyrite (continuing precipitation), arsenopyrite, pyrrhotite, chlorite (continuing precipitation), sphalerite, chalcopyrite, galena, calcite, and hematite. Minor amounts of arsenopyrite also occur with the albite-tourmaline-

pyrite asociation. Molybdenite is reported by Alcock (6) to occur in the granite at the Athona property. Presumably it was deposited from high-temperature hydrothermal solutions.

Beavan believes that a little gold was precipitated at a relatively high temperature, associated with albite, quartz, tourmaline, and pyrite, under hypothermal conditions; but that most of the gold was precipitated at lower temperatures at the same time as the galena and chalcopyrite, under mesothermal conditions. Quartz, chlorite, and pyrite were precipitated through a wide temperature range, and, although mainly earlier than the gold, overlap its temperature range of precipitation. As much of the gold occurs in fractures in coarse, blocky pyrite, the common association of gold and coarse pyrite is not due to simultaneous crystallization of these two minerals, but to the precipitation of later gold in earlier pyrite.

It is believed that the gold-bearing and associated mineral deposits are genetically related to the granitic material in which they occur, because: (1) the gold deposits occur in the granitic rocks at the Box, Athona, and Frontier Trust properties; and (2) a succession of granitic and pegmatitic bodies and quartz veins provide a traceable 'line of descent', and indicate that the granitic rocks are genetically related to the auriferous veins, namely, from the microcline granite to the albitized microperthite granite, albite granite, albite-quartz veinlets, quartz-albite-tourmaline veins, quartz-tourmaline-chlorite-pyrite veins, and quartz with the gold-pyrite and gold-galena associations.

At the Box mine (*See* page 93), small amounts of chlorite, hematite, and pitchblende occur as fracture fillings; the fractures in places intersect the gold-bearing quartz veins and are, therefore, younger than the gold deposits. If it be accepted that the gold of the Box and Athona mines is genetically related to the granites in which it occurs, then there must be at least two periods of gold mineralization in the area, as free gold occurs in the Martin Lake pitchblende deposit in the Athabasca series, which is of post-granite age.

ATHONA MINES LIMITED

References: Alcock (5, 6,); Beavan (9); Byrne (12); Cooke (29).

History. The claims comprising the Athona property, southeast of Goldfields, were staked between September 1934 and the spring of 1935. Work consisted first of extensive trenching and diamond drilling. In the first company report, issued in 1936, it is stated that the 'Main zone' was considered to have a large tonnage of ore of an average grade of $5.01 in gold, at $35 an ounce. Further values of a similar nature but not of such promise were found in an 'East Vein system' and also in a 'Central zone'. It was decided to explore the zones underground, and to erect a pilot mill with a capacity of 15 tons a day to do bulk sampling of the various zones.

The annual report of the company for 1936, issued in 1937, indicates that preliminary estimates of grade were too high. The Main zone was estimated to contain 510,000 tons of ore with an average grade of $3.85 a ton.

Further underground development was carried out in 1937 and 1938, but at a slower pace because of difficulties in financing the property. The annual report for 1938 indicated the following ore reserves in the Main

zone: probable ore, 1,340,000 tons at $3 a ton, and total 'indicated ore' including the above, 3,485,000 tons, with an average estimated grade of $2.80 a ton.

It was estimated that 70 per cent of the ore could be mined by open-cut methods at a cost of 50 cents a ton on a 1,500-ton per day basis. The total cost of mining, milling, and handling the ore was estimated at $1.50 a ton, if arrangements could be made to have the ore milled at the Box property 1 mile away.

Operations were discontinued early in 1939. The annual report for 1939 showed ore reserves as follows: main zone, 1,185,000 tons probable ore averaging $3 a ton; East zone, 30,000 tons probable ore averaging $9 a ton, and 50,000 tons possible ore at $6 a ton. Underground work had consisted of the sinking of two shafts and extensive developments on the 125- and 250-foot levels. Approximately $600,000 had been spent in developing the property up to this time. The claims are still in good standing. The reasons given for cessation of operations were that, although development work was completed, ore estimates made, and the property ready to bring into production, no arrangements had been made with the Box property for treatment of ores on a custom basis, and no satisfactory source of power was available for operation of a mill on the property.

Geology. The geology in the vicinity of the Athona mine is shown on Figure 6. Two roughly tabular bodies of amphibolite, one called the 'Upper gabbro', the other the 'Lower gabbro', at the mine dip southwest at 20 to 60 degrees. Between them, and overlying the 'Upper gabbro', is a granite here called the Athona granite; it is described on pages 39 to 41. Underlying the 'Lower gabbro' is a porphyritic (feldspar) fine-grained granite. Three trap dykes cut the granite and amphibolite. A fault near the shore on the east side of the peninsula strikes north 10 degrees east and dips easterly at 55 to 60 degrees. Beavan (9) reports that "it contains greenish, sticky gouge up to 6 inches thick, and slickensided surfaces on which the striations dip 45 degrees northeast (average). The movement on this fault as determined by drilling, is a thrust with 60 feet dip slip, the east side moving up and south with respect to the west side. The fault contains several thin lenses of mauvish, translucent quartz. The vein filling is absolutely barren".

The position of the Main zone is shown on Figure 6. It is about 80 feet wide, contains a series of narrow, parallel quartz veins striking north 13 degrees east and dipping westerly at 80 degrees. In this zone there are five main veins that vary in width up to 7 inches, the individual veins persisting for as much as 400 feet along strike. Small quartz stringers branching from the main veins are commonly less than 1 inch in width and strike in various directions.

Near the Main zone, the granite-amphibolite contact dips gently to the southwest, the amphibolite capping the granite. The veins comprising the ore zone occur almost exclusively in the granite, being exposed on the surface only to the north of the shaft. Where the mineralized quartz veins intersect the granite-amphibolite contact they pass into the overlying amphibolite, but pinch out within a few inches of the contact. Thus the zone is exposed on the surface to the north of the granite-amphibolite contact, but passes under the amphibolite capping to the south.

The veins contain small amounts of sphalerite, galena, pyrite, chalcopyrite, pyrrhotite, and native gold. Sphalerite and galena, the most abundant of the sulphides, may occur in massive form or as streaks

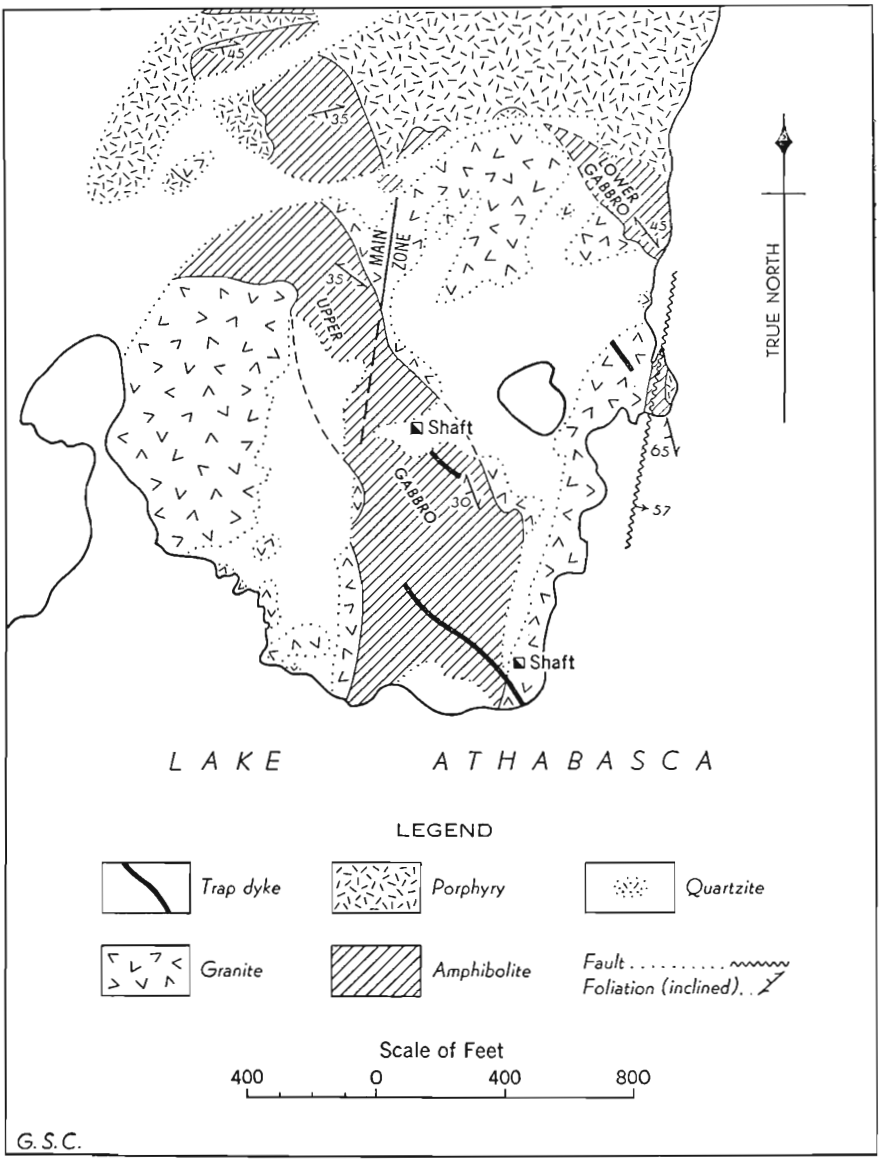


Figure 6. Geological sketch of the Athona mine, near Goldfields, Saskatchewan.

or fine-grained masses in the quartz. Rare small vugs in the veins are lined with some of the sulphides. Beavan (9) states that "sphalerite and galena generally indicate high grade of local extent. Most of the

native gold is in the quartz veinlets, either alone or with the sulphides. The gold is fairly coarse and easily seen. Quartz with neither visible sulphides nor gold is almost invariably barren". Beavan also reports a concentration of the gold in the veins in the granite close to the overlying amphibolite contact.

Pyrite also occurs as finely disseminated cubes in the granite. Gold occurs principally in the vein quartz, but is associated to a minor degree with chlorite in the granite, and more rarely fills fractures in feldspar.

The East zone is a less extensive vein system similar in attitude and mineralogy to the Main zone. It is reported (9) to occur near the fault shown on Figure 6, but the exact location of the zone is not known to the writer. Beavan reports that the vein zone occurs in granite underlain by amphibolite; but that the quartz veins and associated minerals do not extend into the amphibolite.

THE CONSOLIDATED MINING AND SMELTING COMPANY OF CANADA LIMITED

Box Mine

References: Alcock (5, 6); Beavan (9); Christie (18); Cooke (29); Jewitt (37); Killin (40); Swanson (50).

History. The Box property, near the town of Goldfields, was staked by Tom Box in August 1934. After preliminary sampling and diamond drilling, No. 1 shaft was begun in July 1935. No. 2 shaft was started in September of the same year, 1,280 feet northeast of No. 1 along the strike of the formations. Three levels have been driven between the two shafts at depths of 100, 300, and 500 feet respectively; some stoping has been done; and enough further development work (much of it underground diamond drilling) to outline several large blocks of low-grade gold ore.

Concurrently with the progress of the development work at the mine, construction work was started on a 1,000-ton mill. The site of a hydro-electric power plant, designed to be capable of developing 6,000 horsepower, was formed by diverting the waters of Tazin Lake through a chain of lesser lakes to the chosen site on Wellington River, 22 miles from Goldfields. The first power unit of 3,300 horsepower was installed and a transmission line to the Box property was constructed. The hydro-electric construction project is described by Stiles[1].

The mill commenced operation about the end of June 1939. Up to that time it was estimated that some $4,000,000 had been expended to bring the mine into production. This included $1,500,000 spent on the power plant.

On the occasion of the pouring of the first gold brick at the mine on August 15, 1939, the president of The Consolidated Mining and Smelting Company of Canada Limited issued the following statement, which summarizes the development of the property during the preliminary stages:

"The first development work indicated fairly large tonnage of ore carrying about $4.80 per ton. Plans were made to install initial plants to treat 1,000 tons per day, and a power plant at Tazin Lake to develop the power required.

[1] Stiles, E. M.: The Wellington Lake Power Project; Trans. Can. Inst. Min. Met., vol. 43, pp. 468-480 (1940).

"Work on the mine, mill, and power plants was being carried on simultaneously and was about three quarters completed when the stope development showed definite signs that the ore could not be mined at anything like the grade estimated. Construction work was curtailed and an extensive drilling campaign started to establish whether the company should shut down entirely and take its loss, or whether enough ore of sufficient grade could be developed to justify the completion of the plants.

"The result of this campaign was that the company's engineers expressed the opinion that sufficient ore of something less than one half the original estimated value was indicated, and that this should more than repay the further expenditure required to complete the plants and put the mine into operation, provided the mining and milling costs which they estimated they could make were realized."

At the end of 1939, the annual report of the company indicated the following ore reserves at the Box property:

Probable ore, 2,328,000 tons—0·061 oz. or $2.13 per ton
Possible ore, 264,000 tons—0·091 oz. or $3.18 per ton
Possible ore, 10 to 15 million tons—0·03 to 0·04 oz. or $1.05 to $1.40 per ton

Average total costs for the 1939 period of operation were $1.81 a ton. A small profit was made in October, November, and December. Recovery by the mill was excellent. The production in 1939 was 8,000 ounces of gold valued at $288,000.

The mine operated through 1940 at an operating profit of $59,000. Costs were cut from $1.81 to $1.558 a ton. The grade of the ore during this period averaged only 0·0479 ounce a ton or $1.676 a ton at $35 an ounce. Production in 1940 amounted to $762,794. The milling rate was 1,400 tons a day.

Operations were suspended in May 1942 because of shortage of man-power, and the property has been in the hands of a caretaker since that date. Since 1949, the company has supplied power developed at the Wellington Lake plant to Eldorado Mining and Refining (1944) Limited. A short transmission line was built to connect the old power-line with the Eldorado properties north of Beaverlodge Lake.

Geology. The orebody of the Box mine is in a granitic, sill-like body ½ mile long and averaging 120 feet wide (*See* Figure 4, after C. O. Swanson). It was known as the "mine granite" at the mine. This body and the enclosing rocks strike northeast and dip 42 degrees to the southeast. The granitic body is bounded on its northwest side by quartzite and granitized quartzite; to the southeast it passes into the adjoining rocks, the boundary being gradational and best marked by the decrease in the volume of quartz veins. The origin of this body has already been discussed (*See* page 35).

The "mine granite" is cut by a stock-work of quartz veins (*See* Figure 4). An older set of quartz veins composing one element of the stock-work strikes parallel with the granitic sill, but dips more flatly to the southeast. Rudely banded quartz veins striking in this direction (dip undetermined) contain albite, tourmaline, pyrite, and a little gold. A younger and more prominent set of quartz veins strikes north 10 degrees west and dips westerly between 60 and 80 degrees. Associated with these veins are lesser, quartz-filled fractures striking north 20 degrees east and dipping 55 to 60 degrees

northwest. The veins striking north 10 degrees west carry most of the important ore minerals, including coarse, blocky, auriferous pyrite or aggregates of pyrite crystals, lesser amounts of galena, sphalerite, and chalcopyrite, and rare scattered specks of gold. Most of the veins are less than 3 inches wide but they may attain a width of 10 inches. As shown on Figure 4, they occur throughout the granitic body, but are particularly well developed and numerous adjoining schistose inclusions in the "mine granite", as though movement localized in these more incompetent bands had resulted in the opening of fractures in the more competent granitic rocks adjoining them. Apart from these two principal sets of veins, other minor sets of veinlets occur.

About 300 feet southwest of No. 2 shaft, two breccia veins cross the granitic body, striking from 10 to 25 degrees south of east. These are vuggy veins with a quartz-calcite filling. The quartz is commonly euhedral, the crystals in places stained red with red hematite and containing a little pyrite. Apart from the above-described veins, numerous partly filled fractures intersect the granitic body, and the quartz veins. Some of these contain chlorite, quartz, carbonate, hematite, and pitchblende, as described on page 92.

Most of the gold at the Box mine occurs in the pyrite in the north-striking quartz veins. Cooke (29) states that one lump of pyrite was found on analysis to contain 9 per cent gold. Examination in polished section shows that the pyrite is intersected by numerous fractures of microscopic size and that the gold occurs in the fractures, commonly associated with chlorite and quartz. Apart from the gold in the pyrite of the veins, gold occurs rarely as scattered specks in vein quartz, and is reported to occur in the 'granite', probably in a manner similar to the occurrences at the Athona property.

Frontier Trust Property

Reference: Beavan (9).

This now inactive property was controlled by The Consolidated Mining and Smelting Company of Canada Limited. The deposit was explored from an adit driven northwestward from the northeast end of the small lake northwest of Frontier Lake (*See* Map 1015A). It occurs in a 'sill' of fine-grained pink granite about 40 feet thick, which is intruded into quartzite lying below an amphibolite mass. The dip of the granite, quartzite, and amphibolite is 30 degrees to the southeast. The granite is composed almost entirely of quartz and potash feldspar in contrast with the granite of the Box and Athona mines, which contains abundant albite.

Very little vein quartz occurs in the granite 'sill' except in the hanging-wall close to the amphibolite capping, where there are small, irregular veinlets of glassy, tourmaline-bearing quartz. The 'sill' contains scattered crystals of pyrite of various sizes, which are partly to completely altered to hematite to a vertical depth of 600 feet below the outcrop. Minute stringers of quartz cut the pyrite cubes. Gold occurs either associated with the pyrite or as flakes coating fracture surfaces in the granite. Pyrite, hematite, and gold were the only metallic minerals recognized.

OTHER PROPERTIES

References: Alcock (5, 6); Beavan (9); Robinson (45).

Apart from the three properties already described, numerous gold prospects were staked in the map-area. Alcock (6) describes properties belonging to or controlled by the following additional companies or syndicates: Murmac Lake, Athabaska Mines, Limited; North West Minerals, Limited; Athabaska Portal Gold Mines, Limited; Greenlee Gold Mines, Limited; Ventures, Limited; and the Borealis Syndicate, who did some underground work on their property near Neely Lake. Beavan (9) gives further short descriptions of the properties of the Goldfields Mining Company, and Greenlee Gold Mines, Limited. In addition, gold has been reported by Robinson from the following uranium prospects: the Nicholson Mines Limited property, the Fish Hook Bay group, the Martin Lake mine, and the Bolger group.

URANIUM DEPOSITS

General Statement

The presence of uranium in the Goldfields area was first recognized in 1935 on the present Nicholson property 2 miles east of Goldfields, and reported on by Alcock (6). The uranium-bearing hydrocarbon, thucholite, was recognized by H. V. Ellsworth, of the Geological Survey of Canada, in material sent for identification from the Box mine in 1942.

During World War II, when intensive exploration for uranium minerals was undertaken, the Nicholson again received attention. In September 1944, the showings were examined by R. F. Murphy and A. W. Jolliffe, the former acting for the Crown company, Eldorado Mining and Refining (1944) Limited, and the latter for the Geological Survey of Canada. As a result of this examination and of information from W. G. Jewitt of The Consolidated Mining and Smelting Company of Canada Limited that yellow uranium stain had been observed on the shore of Fish Hook Bay, Eldorado staked the Fish Hook Bay property adjoining the Nicholson on the north and east.

In the period 1945 to 1948, prospectors employed by the Crown company staked what are now the Gil, R.A. (Martin Lake), Ace, Eagle, Ura (Fay), Bolger, Mic, Emar (Donaldson), Hab, and Don groups, as well as other less important showings. In 1948, the Dominion Government repealed the war-time ban on prospecting for uranium by the general public. Subsequently, in March 1949, the Saskatchewan Government established several areas of 25 square miles each, covering all unstaked ground within 20 miles of the north shore of Beaverlodge Lake. Concessions to prospect these areas were then sold to companies and individuals. Such of these areas as reverted to the Crown were thrown open to public prospecting in June 1950.

Since 1948, many uranium occurrences have been found by the various companies and individuals prospecting in the map-area. Several thousand radioactive occurrences have been located; diamond drilling has been done at many properties; and underground exploration has been undertaken at the Martin Lake, Ace, Eagle, and Ura properties of the Crown company, at

the Nicholson property near Lake Athabasca, at the Rix-Athabasca deposit southwest of Jean Lake, and at the Nesbitt Labine property south of Eagle Lake. The area is still being actively prospected.

Characteristics of Uranium Occurrences

Uranium-bearing deposits of two types are known in the Goldfields-Martin Lake map-area, namely, vein-type deposits containing pitchblende, and the so-called pegmatite-type deposits containing uraninite.

URANINITE OCCURRANCES

Robinson (45) has identified uraninite from several localities, and has supplied most of the available data on its occurrence. It has been identified from the Hacker zone on the Fish Hook Bay property, from the Nesbitt fault area south of Gatzke Lake, from the Rix Athabasca concession, and from the KK concession. Company geologists suspect its presence in very fine grains on the Amax Athabasca concession, and on the EE and SS concessions, as well as other concessions in the northern part of the map-area.

One type of occurrence is in relatively massive, moderately fine-grained, red granite or gneiss. From such a radioactive rock, underlying an area reported to be at least 1,200 feet square on the Rix Athabasca concession, Robinson has isolated and identified uraninite and monazite. A similar radioactive area of red granite 1,000 feet by 50 feet on the Amax Athabasca property is considered, by the company geologists, to contain scattered crystals of uraninite, and the radioactivity of numerous spots in the granite-gneisses in the northern part of the map-area is attributed to the presence of the same mineral.

Near the Nesbitt fault, south of Gatzke Lake, radioactive occurrences are due to the presence of tiny crystals of uraninite (45) in a gneiss composed of orthoclase, plagioclase, and quartz, which is traversed by thin seams of mixed chlorite and clinozoisite. The uraninite occurs both in the chloritic matrix and in the feldspar. Small flakes of molybdenite also occur in the gneiss. According to Robinson (45), one specimen from this locality contained crystals of uraninite in hydrothermal quartz, or hydrothermal quartz-vein material gradational to pegmatitic material.

In the Hacker zone, minute uraninite crystals occur in ragged biotite bands in a quartz-rich rock. This rock also contains similar ragged bands of chlorite associated with arsenopyrite and chalcopyrite.

Robinson has informed the writer that uraninite was identified from a pegmatite-type specimen stated to have come from a locality near the north side of Viking Lake. Associated with the uraninite was fergusonite, a niobate and tantalate of uranium, and other rare-earth elements.

With the possible exception of an occurrence in the KK concession, for which no description is available, the uraninite of the map-area does not occur in the typical, sharp-walled, straight, coarse-grained pegmatite dykes like those of the Grenville district of Ontario. Such pegmatite dykes occur in the map-area only to the east of Beaverlodge Lake and south of the St. Louis fault. On the contrary, the uraninite of the map-area is commonly

fine grained, and has been recognized only under the microscope. It occurs in moderately coarse-grained granite bodies of considerable dimensions, in small, chlorite-filled seams in granitic or pegmatitic material, and in pegmatitic material that is considered to be transitional to hydrothermal quartz veins. The geological evidence appears to favour the hypothesis that the uraninite crystallized at or about the same time as the enclosing granite, pegmatite, or vein material, and that the uraninite is genetically related to the granitic rocks.

PITCHBLENDE OCCURRENCES

The pitchblende deposits of the map-area occur as vein-type deposits in faults, shears, fractures, or fracture zones, or in their immediate vicinity. The various features and properties of the veins, and interpretations regarding the origin and age of the deposits, are given below.

Structure

Reference to the accompanying geological map will show that most of the vein deposits of pitchblende are related to faulting. Thus, the R.A. (Martin Lake), Ura (Fay zone), Ace, Bolger, and Emar (Donaldson and Love zones) are related to the St. Louis fault; the deposits near Fredette Lake and Cinch Lake are probably related to the Black Bay fault; and most other deposits are related to lesser faults or shear zones shown on the map. Actually, the most important vein deposits are not in the main fault zones but occur in related fractures and under the following conditions:

(1) Pitchblende commonly occurs in subsidiary fractures parallel or subparallel with the main fault zones, as at the Martin Lake, Fay zone, Ace, Bolger, and Donaldson and Love zones. The best deposits of this type appear to be associated with faults striking roughly in the direction of the St. Louis fault (north 60 to 85 degrees east), but pitchblende also occurs in fractures subparallel with the Black Bay fault near Fredette Lake on the FF1 concession. Whether or not significant deposits may occur in other shear or fracture zones striking parallel with the Black Bay fault is one of the major problems at the Amax Athabasca, Rix Athabasca, Cinch Lake Uranium, and other companies' properties.

(2) Pitchblende commonly occurs in *en échelon* zones of minor fractures striking roughly east and associated with northeast to north-northeast trending fault zones, as at the Mic, Don, Martin Lake, and Rix Athabasca properties, and as probably indicated by the relation of the Pinky, Emir, and Tom cross faults to the Black Bay fault and other faults trending in the same direction that have not been recognized in the field mapping because they are parallel with the strike of the formations. Pitchblende is particularly abundant in the cross faults or fractures close to the northeast striking faults or shear zones. Allen (8) considers that the shear zones and fractures that strike slightly north of east are older than those trending north 35 degrees east; that is, the St. Louis fault is older than the Black Bay fault. He considers that the later movements along faults striking in the north 35 degrees east direction opened the

older east striking shear zones, leading thereby to their mineralization near the later faults. In some instances, however, as at the Mic property, there is little or no evidence of shearing along the easterly striking subsidiary fractures, which are probably tension fractures formed by the movement along a nearly northeasterly trending fault zone.

(3) Intersecting fault zones form favourable localities for the passage of hydrothermal solutions and, therefore, a likely place for mineralization. Examples are the Nesbitt Labine ABC group, Martin Lake, Mic, and numerous others.

(4) Contacts of dissimilar rock types are favourable localities for mineralization because differential movement is particularly common at contacts, and where differential movement occurs the more competent rock is commonly fractured, forming channelways that may allow passage of mineralizing solutions, as, for example, at the Mic deposit.

(5) The intersections of fault zones with certain bands or horizons of rocks whose chemical composition makes them an effective precipitant of pitchblende and associated minerals, are naturally favourable places for important mineral deposits. This is discussed more fully in the following section on 'host rocks'.

Host Rocks

Pitchblende deposits appear to favour certain types of host rocks. Thus, on the Martin Lake property (R.A. group), the pitchblende occurs in fractures in the basalt, but not to any appreciable extent in the same fractures where they intersect the adjacent Athabasca arkose. On the Gil group, the pitchblende occurs in fractures in amphibolite, but not in the same fractures where they intersect the adjacent Tazin quartzite. On the Nicholson and Fish Hook Bay properties, the mineralization appears to favour dolomitic bands or breccia zones with carbonate cement, rather than quartzite; on the Pitche group, it favours a graphitic band in the quartzite rather than the purer quartzite; and at the Bolger, Eagle, Tam South, and others, it occurs in the fine-grained chloritic rocks or in chlorite-epidote rocks.

Although many pitchblende deposits occur in rocks classified as granite or granitoid gneisses, these host rocks are commonly much altered and not typical of the rocks of this division: one example is the wide belt of sheared gneiss, containing abundant carbonate, of the Donaldson zone of the Emar group; another is the granitized, mylonitized, and hydrothermally altered Fay zone of the Ura group; and yet another is the sheared gneiss, containing considerable chlorite, of the Heron shear. However, more rarely, as at the Rix Athabasca Uranium Mines Limited, Leonard Series deposit and at the Mic zone of the Eagle group, pitchblende occurs in a fractured zone in typical granite-gneiss.

In conclusion, on a statistical basis, the preferred host rocks for pitchblende are the more basic rocks (basalts, amphibolites, chlorite-epidote rocks, and chloritic rocks), dolomitic bands in sediments, or carbonate-bearing zones. Granitoid rocks are favourable, particularly where much

crushed or fractured, and where they contain considerable carbonate or chlorite; Athabasca arkose and conglomerate are only moderately favourable; and pure quartzite is definitely unfavourable ground.

Red Alteration

Hematite, specular hematite, or red hematite stain are invariably associated with the pitchblende occurrences, and the carbonate of the mineralized veins is commonly, at least in part, stained red or brown by hematite. Where granitoid gneisses occur in the vicinity of the radioactive deposits, the feldspars are stained red. A good example of this was seen at the southwest corner of Neely Lake, where a radioactive fissure in white granite-gneiss is flanked for a width of a few feet by granite-gneiss that is red due to the staining of the feldspars. Over most of the map-area this feature is not so obvious, because the feldspars of the granitoid gneisses are pink or red, probably due to the large amount of iron derived from the intruded or replaced sedimentary formations. This earlier stain may mask the later introduction of hematite or iron stain associated with the pitchblende deposits. However, in several places, as in the case of the Box orebody, a deeper-than-normal brick-red stain is associated spatially with the pitchblende deposits.

Another important type of rock alteration that is commonly associated with the pitchblende deposits is what has been called "red, cherty-looking alteration". It has been noted in the section on mylonites that the crushing or microbrecciation of granitic rocks commonly yields a red cherty-looking product in which crushed fragments, or partly recrystallized crystals, of feldspar can be recognized only on close examination; and some of the reported red, cherty-looking material in granitic areas may be of this type. Such crushed zones, moreover, may be favourable localities for pitchblende mineralization. Such zones of red, cherty-looking alteration, however, are not restricted to granitic areas, and are probably most conspicuous and most important in the fine-grained chloritic rocks, as at the Ace mine and Tam South prospect. Because the pitchblende-bearing veins at these properties are most commonly enclosed in zones of this red alteration, which, therefore, are considered an important factor in exploration, a study of the wall-rock alteration at the Ace, Tam South, and other properties was undertaken by Dawson (32). He has termed the red, cherty-looking alteration product at the Ace mine 'red aplite', and has found it to consist mainly of untwinned red oligoclase (An_{15}), with quartz, chlorite, and calcite as minor constituents. He considers the 'red aplite' to be a feldspathic, probably hydrothermal, replacement of a considerable variety of rock types including argillites, chlorite schists, granites, paragneisses, and mylonites. Megascopically the 'red aplite' is commonly very fine grained, so that it is not possible to detect individual crystals in it; however, rare small feldspar phenocrysts can be recognized in hand specimens. The 'red aplite' occurs principally in lenticular bodies immediately beneath the St. Louis fault zone, and in places has resulted in *lit-par-lit* replacement of the schists. Elsewhere, Dawson has noted that the 'red aplite' crosses the foliation of the host rocks as dense red veinlets, and that in places it has been subjected to cataclastic deformation.

Albite-oligoclase (An_{10}) is stated by Dawson (32) to occur as vein fillings; the grains show good twinning and but little alteration. Albite of this generation is veined by the later minerals of the pitchblende deposits, including albite of a slightly later generation, and calcite, chlorite, and quartz.

Vein Structure

Pitchblende occurs most commonly in narrow veins and stringers filling tension fractures; in shear zones, breccia zones, or fault zones; and less commonly as local disseminations in the host rock. The veins contain any or all of carbonate, comb quartz, specular hematite, chlorite, and albite. Many show structures that are generally considered to indicate deposition in open (tensional) fractures, such as banding, brecciated fragments of wall-rock, comb quartz, rims of colloform pitchblende around the terminations of crystals, and, rarely, vugs. Robinson (45) reports that the vein minerals themselves have, in some deposits, been brecciated and subsequently recemented. Where pitchblende occurs in the wall-rocks away from veins, it commonly adjoins small masses of chlorite or carbonate.

Mineralogy

The mineralogy of the pitchblende deposits of the map-area has been described in two papers by Robinson (45, 46), to which the reader is referred, and from which the following summary is compiled.

The gangue minerals accompanying the pitchblende are most commonly hematite, specular hematite, carbonate (including calcite, dolomite, and ankerite), quartz, chlorite, and albite. Numerous metallic minerals, in very minor amounts, are associated with the pitchblende in the various deposits. In approximate order of abundance these are: pyrite, chalcopyrite, galena, and bornite, the copper selenides (including umangite, klockmannite, and berzelianite), niccolite, the cobalt-nickel arsenides (rammelsbergite, skutterudite, and cobaltite), arsenopyrite, sphalerite, pyrrhotite, native copper, native silver, and native gold.

Although fresh pitchblende is a dull black mineral with the hardness of steel, the pitchblende encountered to date in the map-area is commonly altered by weathering or hydrothermal processes to a softer material, and may be black, to greenish black, to brownish black. At the surface it alters to the conspicuous bright yellow, orange, or green stain, due to various alteration products, including gummite, zippeite, and tyuyamunite.

Most commonly the pitchblende shows a botryoidal to colloform habit, and commonly forms curved rims or coatings on earlier formed vein minerals or fragments of wall-rock; and is in turn coated with the later deposited minerals. In many deposits these botryoidal and colloform masses of pitchblende have been brecciated, and fragments cemented by later vein materials, including calcite and pitchblende. Apart from its occurrence in botryoidal and colloform forms, pitchblende occurs as 'wisps' in a chlorite gangue, as a replacement of carbonate, and as small bodies of apparently massive pitchblende. What appears to be massive pitchblende, however, is never pure, but consists of a hematite-pitchblende association or of pitchblende with numerous inclusions of calcite, chlorite, galena, chalcopyrite, or other minerals.

The uranium-bearing hydrocarbon, thucholite, is reported from the Nicholson and Box properties. Evidence quoted by Robinson (45), and other evidence presented by Davidson and Bowie (31) indicate that this mineral is formed by the hydrothermal alteration of pitchblende associated with the processes of polymerization.

Paragenesis

Robinson (45, 46) states that the paragenesis of the pitchblende deposits is complicated, and that no precise, tabulated sequence of mineral deposition is warranted by the study completed so far, but suggests the following several stages, one or more of which may be represented at any one locality: (1) fracturing and brecciation, accompanied and followed by introduction of hematite, feldspar (albite or oligoclase), and/or silica into the wall-rock; (2) more movement, followed by deposition of the older calcite, with some hematite and chlorite, on the walls of the fractures; (3) deposition of colloform pitchblende, largely as coatings on earlier minerals, accompanied by hematite, which was deposited as specularite in the late stages, and followed, in many deposits, by brecciation of the pitchblende; (4) locally, introduction of arsenides—rammelsbergite first, followed by niccolite, skutterudite, cobaltite, and arsenopyrite, in that order; (5) introduction of the sulphides—pyrite, chalcopyrite, and galena—with further pitchblende and gold, accompanied by calcite and/or quartz or chlorite; (6) locally, introduction of the selenides—berzelianite first, followed by umangite, clausthalite, and klockmannite, with a little quartz and calcite; (7) late veining by calcite and, rarely, by chlorite; and (8) supergene alteration of the deposits, locally to depths of 300 feet.

It will be noted that several periods of deposition of pitchblende, hematite, calcite, and chlorite are indicated. At the Martin Lake mine alone, well-defined rims and veins indicate that three generations of hematite, three of calcite, and two of pitchblende are represented.

Age Determinations

Five determinations of the lead-uranium ratios of pitchblende from this area were made up to the end of 1950, one from the R.A. group (Martin Lake mine), one from the Gil group, and three from the Nicholson or Fish Hook Bay properties. These determinations are tabulated below.

Property	Pb/U ratio	Age[1] in hundreds of millions of years	Analyst
R.A. group (Martin Lake mine)	0·129	8·64	Rodden (39)
Gil group	0·114	7·64	Ellsworth
Nicholson Mines Limited property	0·088	5·90	Kroupa
Nicholson property or Fish Hook Bay group	0·087	5·83	Ellsworth
Nicholson property	0·211	14·14	Kroupa

[1] Calculated from the formula: Age in years $= \frac{Pb\ (6700) \times 10^6}{U + 0{\cdot}33\ Th}$

It will be noted that four of these determinations agree moderately well, but the fifth is very different. No separation of ordinary and radiogenic lead was made in these determinations. Robinson (45) following microscopic studies of these ores, has reported that appreciable quantities of galena occur as minute inclusions in the pitchblende at both the Gil group and at the No. 4 zone of Nicholson Mines Limited, and that clausthalite (PbSe) occurs in the pitchblende at the Martin Lake mine. Further, with the exception of the Martin Lake specimens, the specimens analysed were obtained from surface workings, or workings close to the surface, and according to Ellsworth showed considerable alteration by surface waters and possibly by hydrothermal solutions. Presence of non-radiogenic lead and leaching would tend to increase the Pb/U ratio (uranium being commonly more soluble than lead), and make the calculated age too high. On the other hand, loss of radon gas during the disintegration of the uranium would have the opposite effect. Evaluation of these factors leads to the belief that, purely from the evidence presented above, the lower values for age are more likely to be correct. Ellsworth (33), however, comments on the surface specimens as follows: "in view of the nature of these materials it would be unwise, in the writer's opinion, to attach too much importance to any of the age results from this area until isotope determinations have been made". The sample from the Martin Lake mine, on the other hand, was undoubtedly obtained from underground, and must have been fresh as compared with the others. The U_3O_8 percentage in this sample is given as 67·5, and the PbO percentage as 7·96.

Recently Collins, Lang, and Robinson (22) have reported and discussed the age of several pitchblende deposits in the map-area as determined by the lead isotope ratios of Pb^{206} to Pb^{207}. Their results are shown in the table below.

Name of deposit	Age in 10^8 years	Remarks
ABC group	9·0— 9·7	
Ace group	18·4—18·6	
Ace Creek	13·7—15·0	
Beth (Gully) zone	9·8—10·6	
Donaldson zone	8·5— 9·5	
Eagle Group Main zone	14·5—14·9 16·0—16·9	3 determinations
Fish Hook Bay group (Hacker zone)	18·5—19·4	
Martin Lake	16·5	Average of 10 determinations 14·1—17·2
Mic zone	12·5	
Nicholson group (No. 2 zone)	12·0—12·2	
Nicholson group (No. 4 zone)	18·1—18·5 10·3—13·3	
Rix Athabasca	16·1	
YY concession	9·6—10·0	

The great variety of ages for the various deposits appears to indicate several periods of mineralization. The Hacker zone of the Fish Hook Bay group, in which the radioactive mineral was provisionally determined as uraninite (45) is, as might be expected, indicated as the oldest of these

deposits. Pitchblende from the Ace group was determined as about $18 \cdot 5 \times 10^8$ years old and one determination from the No. 4 zone of the Nicholson property gave a similar age. Particularly noteworthy are the determinations made on specimens from the Martin Lake property that gave consistent values in the vicinity of $16 \cdot 5 \times 10^8$ years. As this pitchblende occurs in a vein deposit in rocks classed as of the Athabasca series, this series is indicated as older than $16 \cdot 5 \times 10^8$ years. If this is correct, it means that these moderately folded to flat-lying, fresh-looking sediments, which rest with strong angular unconformity on the Tazin rocks and gneisses, must be of great antiquity, and should be classified as of Archæan rather than of Proterozoic age. This is a surprising conclusion, and one that will not be readily accepted until much further work is done. It may be pointed out that if the pitchblende at the Martin Lake mine is as old as $16 \cdot 5 \times 10^8$ years, it should contain double the amount of lead indicated by the Pb/U ratio (0·129) (*See* p. 86), and the lead content of this specimen should have been of the order of 16 per cent instead of the reported 7·96 per cent. A loss of lead of this magnitude is difficult to explain.

Numerous lesser ages given in Table VII probably indicate several periods of mineralization of post-Athabasca age. It may be noted, too, that deposits related to the St. Louis fault system—the Ace, Ace Creek, and Donaldson—are, apparently, of very different ages. Collins, Lang, and Robinson (22) state that "the discrepancies between age determinations for a single deposit, and for different deposits in a single region must be explained before broad conclusions (based on age determinations made by the lead isotope method), are justified".

Origin

The source of the pitchblende deposits of the map-area is unknown. Work done to date on the age determinations suggests that the pitchblende was deposited during several geological periods. The deposits cannot be related to any recognized igneous rocks because much of the pitchblende occurs as vein-type deposits in rocks of the Athabasca series and in the late basic dykes that have been observed to cut the Athabasca series. Because the volume of the dykes is small, and because their distribution bears no apparent relation to the distribution of the pitchblende occurrences, it is not believed that the pitchblende is genetically related to the late basic dykes. As the Athabasca rocks and the late basic dykes are the youngest recognized rocks in the map-area, much of the pitchblende is younger than any of the rocks of the area. Further, although two phases of deposition of pitchblende, the colloform phase and the massive phase, are indicated by the paragenesis as described on page 86, both these phases have been recognized at the Martin Lake mine and both are, consequently, of post-Athabasca age.

The pitchblende deposits are definitely related to faulting, some of which, at least, is of post-Athabasca age. It may, therefore, be stated that much of the pitchblende was deposited in post-Athabasca time from hydrothermal solutions whose source is unknown, the deposition, and possibly the generation of these solutions being controlled by faulting and fracturing.

In several important deposits on the Ace and Eagle properties, pitchblende is spatially related to hydrothermal alteration and introduction of soda feldspars. It has been suggested (*See* pages 46 and 72) that the solutions responsible for this alteration originated by deep-seated earth movements.

It will be noted that there are at least four periods of earth movements indicated in the map-area, as follows: (1) the folding of the Tazin group, probably of about the same period as the emplacement of the granitic rocks; (2) earth movements along the St. Louis, Black Bay, and related faults, followed by the deposition of the Athabasca series on a sinking floor in the Martin Lake basin; (3) the folding of the Athabasca series; and (4) movements along the St. Louis, Black Bay, and other faults; the movements on the two major faults included a normal faulting component, as shown by the preservation of down-faulted blocks of Athabasca series rocks adjoining them. The age determinations also suggest that there may have been several periods of mineralization, and, therefore, probably several of, at least minor, earth movements of post-Athabasca age.

It has been suggested that the pegmatite deposits of uraninite are related to the granitic rocks of the first of these periods of earth movements, although even this cannot be accepted with certainty. The pitchblende deposits are related to the fourth and later periods, but it is possible that some of them are related to the second and third.

Description of Properties

Lack of sufficient information will not permit a description of all the radioactive occurrences in the area. At this early stage in the development there is no guarantee that the most important zones have been located, or that those described can be properly evaluated. Descriptions of the properties, indicated on the accompanying index map (*See* Figure 7), follow, in alphabetical order, with name of companies first and those of properties second.

AMAX ATHABASCA URANIUM MINES LIMITED

Concession CC1

Concession CC1 lies along the Black Bay fault from Black Bay of Lake Athabasca northeastward to Cinch and Martin Lakes. Three hundred and twenty radioactive occurrences were found on this concession in 1949 and 1950, of which at least seventy are considered by the company to justify further work. The radioactivity is confined almost entirely to the rocks lying northwest of the Black Bay fault. The locations of six of the more promising or interesting of these occurrences are shown on the accompanying geological map.

It is believed that several major faults or shears, parallel with the Black Bay fault, intersect the rocks of the concession beneath drift-filled valleys. The radioactivity discovered to date is mainly in short cross-fractures branching off from these assumed faults, and is commonly strongest where the cross-fractures disappear in muskeg close to the

assumed northeastward striking faults. Strongly radioactive deposits occur both in amphibolite and in granitoid gneisses, many of which here contain a considerable amount of mafic material. Half a mile north of the western bay of Cinch Lake is a low-grade radioactive zone in the gneiss, at least 1,000 feet long and 50 feet wide. The rock of this zone is reported to be fine grained, of flinty appearance, brecciated in places, intensely red, and containing considerable mafic material. It is suggested that this is a crushed zone in the gneiss into which hematite stain and some radioactive materials have been introduced. The company engineer states that in this and several other places where radioactivity can be detected over appreciable areas "there is a strong suggestion that the radioactivity may be in the form of finely disseminated uraninite".

Work on the concession during 1951 included the drilling of ten deep diamond drill-holes through the Black Bay fault. Several of these holes intersected radioactive deposits; the most promising deposit discovered is in the hanging-wall side of the fault approximately 1 mile southwest of Cinch Lake (*See* Map 1015A).

AMERICAN CANADIAN URANIUM COMPANY LIMITED

Tom and Paul Groups

The Tom group of claims includes the radioactive occurrences associated with the Tom fault, with subsidiary subparallel faults, and with a north striking fault near its intersection with the Tom fault. The Tom fault is shown on the accompanying geological map striking easterly between Mickey and Donaldson Lakes. It dips south at about 75 degrees, and near the indicated radioactive occurrences is a sheared zone about 6 feet wide containing gouge and breccia. The sheared and brecciated zone contains quartz and carbonate vein material, and chlorite, specularite, pyrite, chalcopyrite, and pitchblende.

The principal Paul group deposit is on a peninsula on the south side of Mickey Lake (*See* Map 1015A). Pitchblende occurs in irregular fracture zones that strike northwesterly. Company reports state that the radioactive fractures occur in sedimentary rocks close to the axial trace of a synclinal structure that plunges flatly to the southwest. Pitchblende appears to be confined to, or concentrated in, places where the fractures cross particular bands of mafic sedimentary rocks, and to be lacking in the interbedded quartzite.

AMERICAN YELLOWKNIFE GOLD MINES LIMITED

Concession YY

The principal radioactive occurrence found to date on this concession is near a granite-quartzite contact one-quarter mile south of Beaverlodge Lake (*See* Map 1015A). The radioactive occurrences are in a series of subparallel, east striking and steeply dipping fractures or fracture zones. The fractures contain carbonate, hematite, chlorite, and pitchblende.

AURORA YELLOWKNIFE MINES LIMITED

Concessions CC2 and CC3

The property of Aurora Yellowknife Mines Limited comprises parts of the CC2 and CC3 concessions; it lies along the Black Bay fault from Martin Lake to Fredette Lake. During 1950, one hundred and twenty-six radioactive occurrences were found on the property, many of which are considered by the company to justify further work.

The northeasterly striking Black Bay fault, the most important structural feature of these concessions, dips about 65 degrees to the southeast. It is nowhere exposed on the property as it is drift covered or lies beneath Fredette Lake. Parallel with the Black Bay fault are lesser faults, one of which, the Crackingstone fault, lies ¼ mile to the northwest and is shown on the accompanying geological map. Between the Black Bay and Crackingstone faults is a subparallel structure called the Townend fault. One trench across this fault exposed a strong chlorite-bearing shear zone. Associated with the strike faults are numerous cross faults and cross fractures, the most important of which is the Pinky fault.

Two radioactive occurrences associated with the Black Bay fault are shown on the accompanying geological map. One of these is in ground close to the intersection of the Pinky and Black Bay faults, the other is a mile to the southwest. The host rock in both these cases is a fine-grained, reddish, granitic rock considered to be a mylonite or flaser-gneiss. The fracture fillings consist of carbonate, hematite, and disseminated pitchblende.

Another group of radioactive occurrences, one of which is indicated on the map, lies near the Crackingstone fault in crushed gneiss impregnated with chlorite; others lie near the Townend fault.

Numerous other radioactive deposits occur in mafic bands or in gneiss elsewhere in the concession. One of them, about 1,000 feet south of the southeast bay of Jean Lake, lies in a short shear zone, striking north 30 degrees west, which intersects a diabase dyke. This shear zone contains a stringer of carbonate, hematite, and pitchblende, which would appear to be later than the diabase dyke.

Some old trenches along the Crackingstone fault exposed veinlets of quartz and calcite containing chalcopyrite and traces of sphalerite and galena. It is believed that this work was done about 1935 on the Midas group of the Borealis Syndicate, in search for copper. A little pitchblende was noted in one of the trenches.

BEAVERLODGE URANIUM MINES LIMITED

Bar Group

The principal radioactive occurrence on this group lies in mafic rocks close to the west shore of the south arm of Mickey Lake. The wall-rocks are amphibolite, chlorite-epidote rock, and argillite, with subordinate quartzite and pegmatite. The radioactive deposits are in one or more fault zones that vary in strike from north 40 to 65 degrees west and dip from 40 to 65 degrees to the southwest. The fault zones are composed of anastomosing fault fissures in brecciated, red, altered rocks. The fissures contain fillings of quartz, calcite, hematite, and pitchblende.

CINCH LAKE URANIUM MINES LIMITED

Jam group

The Black Bay fault crosses this property. To date a total of one hundred and ninety-seven radioactive occurrences, all lying northwest of the fault, have been discovered. A group of radioactive deposits, collectively designated as the "River showing", lies about 2,000 feet west of Cinch Lake, as indicated on the accompanying geological map. Pitchblende there occurs in shear zones, some of which strike west to northwest and dip south, and others strike northeast and dip nearly vertically. The host rocks are crushed gneisses and chloritic rocks. Red alteration of the wall-rocks of the veins is a prominent feature of several of these deposits.

CLIX ATHABASCA URANIUM MINES LIMITED

Concession AA

Eighty-four radioactive occurrences were found on the AA concession in 1950, and at least eleven of these are considered by the owners to justify further work. Three of the more promising of these occurrences are shown on the accompanying map in the amphibolite band just east of Peebles Lake. The most northerly of these occurs in a narrow drift-filled valley, along a faulted or sheared contact between quartzite on the northwest and amphibolite on the southeast. Radioactivity was detected in small cross fractures in the quartzite wall of the contact zone, in quartzite float in the centre of the valley, and in chloritic material near the contact. The quartzite near the radioactive occurrences is stained red by hematite.

The intermediate occurrence 1½ miles to the southeast is in amphibolite, and is believed to be related to a fault or fracture striking north-northeast. Radioactive material occurs principally in cross fractures near, and roughly normal to, the assumed major fault, and to a lesser extent in minor fractures parallel with it. Carbonate and pitchblende occur in some of the fractures.

The most southerly of the three more promising occurrences lies about 2,000 feet to the south-southwest of the one last described, where two, steeply dipping, vein-filled cross fractures or faults in the amphibolite band strike roughly east. These veins average 3 inches in width and are composed of quartz, carbonate, hematite, and pitchblende. Jasper-red and red-brown iron stains are associated with the more highly radioactive parts of the veins.

Many of the other occurrences are in granitoid rocks, commonly associated with small inclusions. One was found in the Athabasca conglomerate south of Beaverlodge Lake.

THE CONSOLIDATED MINING AND SMELTING COMPANY OF CANADA LIMITED

Box Mine[1]

Many minor radioactive 'anomalies' were found in testing the outcrop of the orebody of the now inactive Box gold mine. They are associated with narrow fractures, a few feet long, in the "mine granite" in which the orebody occurs. This granite is stained a deep red by hematite, principally

[1] For a more complete description of this gold mine *See* pages 77 to 79 of this report.

in the feldspars. The fractures contain chlorite, and in one place a small veinlet of pitchblende was noted. Fragments of pitchblende have also been found in the overburden 2,000 feet southeast of the No. 2 shaft. The fractures associated with the radioactive anomalies cut the gold-bearing quartz veins and are, therefore, of later age. The anomalies are more numerous at the northeast end of the orebody, near the No. 2 shaft, than toward the southwest end, and there the orebody has a striking brick-red colour in contrast with the pink to reddish colour at the southwest end. It is suggested that the brick-red colour is due to introduction of iron oxide into the feldspars of the mine granite by the solutions that deposited the pitchblende.

CONTINENTAL EXPLORATION LIMITED

Axe Group

The Axe group includes the area at the junction of Martin and Cinch Lakes. Several radioactive occurrences, some of which contain pitchblende, lie in basalt of the Athabasca series.

ELDORADO MINING AND REFINING (1944) LIMITED

Ace Group

References: Dawson (32); Lang (42); Robinson (45, 46).

The Ace group of claims lies across the St. Louis fault near Ace Lake. It was staked by Philip St. Louis while prospecting for the Crown company in 1946. The mineralization is closely related to the St. Louis fault, which here strikes north 60 degrees east and dips about 48 degrees to the southeast. The fault, which is marked on the surface by a deep draw, separates mafic rocks of the chlorite-epidote type to the north, including a rock that company geologists term a quartzitic argillite, from granite-gneiss to the south. Preserved against the down-thrown southern or hanging-wall side of the fault is a basin of Athabasca sedimentary beds (*See* Figure 8).

Radioactive anomalies were found both in the rocks on the foot-wall side of the fault and in the Athabasca conglomerate, the latter being considerably weaker and more scattered. The principal radioactive occurrences are in narrow fractures filled with carbonate, chlorite, and pitchblende, in the foot-wall rocks within 100 feet of the fault. The veins or stringers strike subparallel with the fault and dip at various angles toward it. Apart from these visible stringers, pitchblende occurs in veinlets or disseminations of microscopic size. The pitchblende is commonly associated with a fine-grained red alteration of the wall-rock.

The foot-wall zone was explored to a depth of 300 feet by closely spaced drill-holes. This drilling suggested the presence of two fairly large bodies of moderate grade close to the fault, one near Ace Lake and the other about 700 feet farther southwest. Systematic underground work done from a prospect shaft near Ace Lake confirmed the presence of these ore zones. The west orebody rakes toward the west, apparently because of the angle at which favourable beds intersect the St. Louis fault.

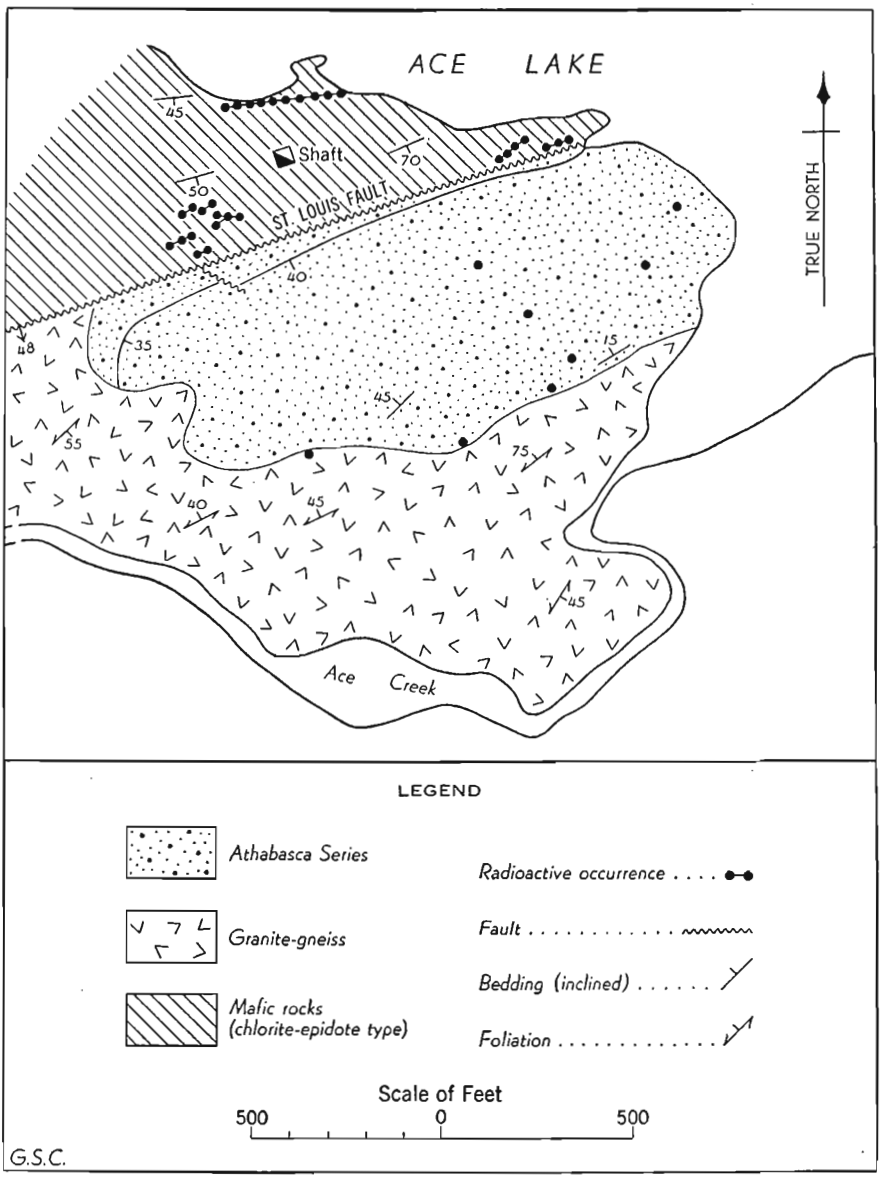


Figure 8. Geological sketch of Ace mine area, north of Beaverlodge Lake, Saskatchewan. (After H. C. Norman, Eldorado Mining and Refining (1944) Limited.)

Robinson (46) states that opaque minerals occur in the Ace mine in roughly this order of abundance: hematite, pyrite, pitchblende, chalcopyrite, galena, clausthalite, bornite, and sphalerite. He also notes that apparently massive pitchblende is seen under the microscope to contain other minerals as impurities, which usually comprise at least 50 per cent

of the whole by volume. This material is most commonly a mixture of pitchblende with calcite, chlorite, hematite, pyrite, chalcopyrite, and galena. Where much disseminated pyrite or chalcopyrite is present with pitchblende, the mixture has a bronze colour in the hand specimen.

Concerning the red alteration at the Ace mine Robinson (46) states: "Pitchblende appears to be virtually restricted to zones of red aplitic rock consisting primarily of plagioclase feldspar densely impregnated with red, dusty hematite. This rock shows wide variation in texture but commonly consists of relatively coarse-grained clear feldspar. In part, this rock shows evidence of having been mylonitized (crushed), probably prior to the introduction of hematite. The local, clear, and more coarse-grained areas may be due to recrystallization of feldspar under the effect of permeating hydrothermal solutions.

"The occurrence of this red aplitic rock is not restricted to any one type of host rock and appears to be gradational into other types of rock—greenstone, chlorite-sericite schist, and even Athabasca conglomerate. The 'aplite' shows evidence of having been severely fractured locally, and it is in the larger fractures that the veins of pitchblende, calcite, chlorite, and quartz have developed. In this crushed material stringers and interstitial patches of hematite-stained calcite occur. This calcite is usually coarse grained; single crystals may span a vein ½ inch wide or comprise the whole of an interstitial patch of equivalent size. Quite commonly, fragments of 'aplite' containing stringers or disseminated calcite are cemented by chlorite. Chlorite is also common as films and stringers in the 'aplite' and along margins of calcite and quartz veins. Chlorite stringers and veins are commonly cut by narrow stringers of white calcite, which may contain sulphides and specular hematite. Pitchblende occurs most commonly in contact with calcite, particularly in and near calcite veins. However, pitchblende disseminated in aplite is most commonly in contact with, or surrounded by, chlorite and to a lesser extent by calcite."

Beaver Group

The Beaver group was staked by Einer Larum and Muldal while prospecting for the Crown company in 1945. The company has since relinquished these claims. The showings are in narrow 'breaks' or breccia zones in Athabasca conglomerate; they strike about north 70 degrees east and have a steep to vertical dip. A few minor mineralized fractures strike north 20 degrees west. Mineralization is represented by carbonate and quartz veinlets carrying hematite, disseminated sulphides and pitchblende.

Bolger Group

References: Lang (42); Robinson (45).

The Bolger group lies north and east of Ace Lake. The main showing, 1,000 feet east of Verna Lake and 800 feet south of the St. Louis fault, was found by means of the Geiger counter through a snow cover 2 to 4 feet deep.

The property is underlain by banded mafic rocks of the fine-grained amphibole-epidote-chlorite type. Over an area of 6,500 square feet the overburden, which is several feet deep in most places, is rich in yellow and orange uranium stain. This overburden lies in a slight depression on the hillside, and its uranium content may have been derived from surface waters that had leached nearby uranium-bearing veins.

Trenching through the overburden has revealed a zone of fractures striking north 70 degrees east, almost parallel with the St. Louis fault. The fractures are filled mainly with carbonate and chlorite, and the wall-rocks and rock fragments in the zone show much red alteration. Pitchblende occurs irregularly in the fractures, and small amounts of pyrite, galena, chalcopyrite, and niccolite have been reported (45). Conybeare[1] reports that native silver occurs as tiny blebs and stringers in carbonate veinlets that cut across, and are, therefore, later than, the pitchblende.

Don Group

The main occurrences of the Don group are south of Don Lake. The claims are underlain by amphibolite, quartzite, and granite-gneiss. A strong lineament, visible in air photographs, strikes northeast through the property, and lesser parallel features occur to the southeast. It is believed that these lineaments indicate faults or fractures. Quartz veins, small diabase dykes, and weak shear zones carrying pitchblende, all steeply dipping, strike normal to the assumed faults. The most important occurrences found to date consist of a group of fissures filled with quartz, brecciated wall-rock fragments, carbonate, hematite, pitchblende, and minor amounts of disseminated pyrite. One radioactive occurrence in this group lies along the contact of a late basic dyke with the older rocks, and appears to be younger than the dyke.

Eagle Group

References: Dawson (32); Lang (42); Robinson (45).

The Eagle group of claims lies north of Beaverlodge Lake and extends eastward from Melville Lake to Eagle Lake. It is underlain by a complex assemblage of rocks consisting mainly of chlorite-epidote rocks, quartzite, and reddish granite-gneiss. The rocks are crossed by several fracture zones or shear zones most of which strike northeast. There are several separate groups of mineral showings. The most westerly group, called the Eagle Shaft showings, is about 7,000 feet north of the north corner of Beaverlodge Lake. The Mic showings are just northwest of Mic Lake; the Gully zone lies about 1,200 feet west of Eagle Lake; and the Tam South showings are about 1,700 feet northeast of the north corner of Beaverlodge Lake. Radioactivity has also been detected at several other widely scattered localities.

The *Eagle Shaft showings* (Figure 9) are associated with four, northeasterly striking zones that converge to the southwest. From northwest to southeast these are the Edie, Spur, Conglomerate, and Lost Mine zones. The zones are inferred to be faults, shear zones, or fracture zones, from topo-

[1] Conybeare, C. E. B.: personal communication.

graphic breaks, crush breccias, abrupt truncation of beds (in the case of the Conglomerate fault only), and in some places by exposed shearing and slickensides. Drilling and underground work have not, however, indicated the presence of strong faults. In places, the rocks near the faults contain pitchblende, which is most abundant in mafic rocks near contacts with granite-gneiss. The Spur and Lost Mine zones are being explored from the Eagle shaft, which is about 4 miles by road from the Beaverlodge camp. The Spur zone strikes north 70 degrees east, dips

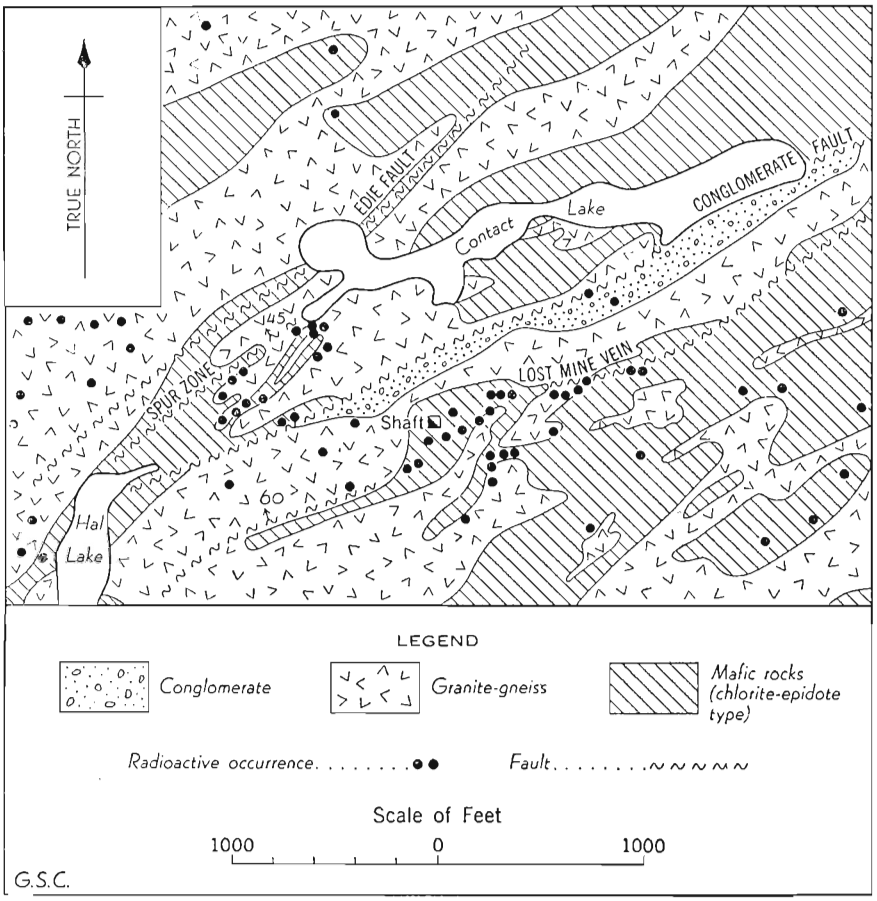


Figure 9. Geological sketch of the Eagle Shaft showings of the Eagle group, north of Beaverlodge Lake, Saskatchewan. (After R. Edie and E. E. N. Smith, Eldorado Mining and Refining (1944) Limited.)

steeply southeast, and is up to 18 inches wide, consisting of a series of small fractures containing carbonate, quartz, chlorite, stringers of pitchblende, and minor amounts of sulphide minerals. There is considerable hematitic alteration. Some fractures are well mineralized, but they have slight continuity, either laterally or vertically. This lack of continuity is caused partly by the intercalation of unfavourable quartzite beds and granite sills. The Lost Mine vein is about 1,000 feet southeast of the

Spur zone. It has an average strike of about north 80 degrees east, and dips vertically to steeply southeast. It consists of a zone up to 8 feet wide, containing fractures mineralized in much the same way as described for the Spur zone. The Spur zone was traced intermittently on surface for about 700 feet, and the main part of the Lost Mine zone was exposed by a trench 200 feet long, with intermittent exposures extending for several hundred feet to the west and east. The zones were explored by 22,000 feet of diamond drilling from the surface, which confirmed the presence of two series of narrow veins. The results were sufficiently encouraging to suggest the advisability of underground exploration. A vertical shaft, placed between the two zones, was begun in January 1950, and sunk to a depth of 300 feet. Crosscuts were driven on the 150- and 275-foot levels northwesterly toward the Spur zone and southerly toward the Lost Mine zone. From the latter crosscut, line drives were run to the west and east to permit diamond drilling, at 100-foot intervals, to explore the main Lost Mine zone and a parallel zone lying about 200 feet farther south. By autumn of 1950, about 3,800 feet of lateral work and 8,000 feet of diamond drilling had been done, mainly on the 150-foot level. Unfortunately, the shaft timbering and headframe were destroyed by fire in the early summer of 1951, and no development work has been done since at this locality.

The *Mic showings* are about 800 feet northwest of Mic Lake and 7,000 feet northeast of the Eagle Shaft showings. Pitchblende occurs in a series of irregular, narrow fractures, mainly within 25 feet of a strong topographic break or lineament, which trends northeasterly through these claims, and which is assumed to mark a fault or shear zone. The strike of the pitchblende-bearing fractures is about normal to that of the assumed fault. The showings lie near the contact between mafic rocks and red gneiss, and most of the mineralized fractures are in the gneiss. The pitchblende is associated with chlorite, quartz, carbonate, and minor pyrite and galena (45).

The *Gully or Beth Lake zone* is about 1,200 feet west of Eagle Lake and 5,000 feet east of the Eagle shaft. A sharp depression probably marks a fault or shear zone striking north 35 degrees east. Narrow, radioactive fractures occur on both sides of the depression, and contain quartz and minor amounts of carbonate and chlorite, together with hematite, pitchblende, and traces of pyrite, chalcopyrite, and galena (45).

The *Tam South* showings (Figure 10) are about 1,700 feet northeast of the north corner of Beaverlodge Lake. They occur in well-banded mafic rocks of the chlorite-epidote type, probably mainly of sedimentary origin, which apparently overlie quartzites, the latter being exposed at the core of an anticlinal structure that plunges gently east-northeast. These formations have been intruded by granites now represented by banded gneisses. A wide sheared zone extends northeasterly from the northwest tip of Tam Lake. Carbonate-pitchblende veins occur near this zone at various places, some striking parallel with the zone but more commonly normal to it. Dips are steep to vertical. The strongest veins so far noted are in the mafic rocks just north of the quartzite contact 800 feet north of Tam Lake. A more recently discovered zone, known as the Tam North, lies about 3,000 feet to the northeast of the Tam South showings, possibly on the same sheared zone.

Emar Group

Reference: Lang (42).

The Emar block of claims extends easterly for about 3½ miles from the southeast end of Mickey Lake to the west end of Raggs Lake. The claims are underlain mainly by reddish granite-gneiss, with inclusions of amphibolite and chlorite schist. The St. Louis fault crosses the group diagonally for a distance of 2 miles. North of the fault are several mineralized zones of which two are described below. The more westerly of these is the Donaldson showing, shown on the accompanying geological map as about 5,000 feet in length; the other is the Love showing, just northeast of the north tip of Flack Lake.

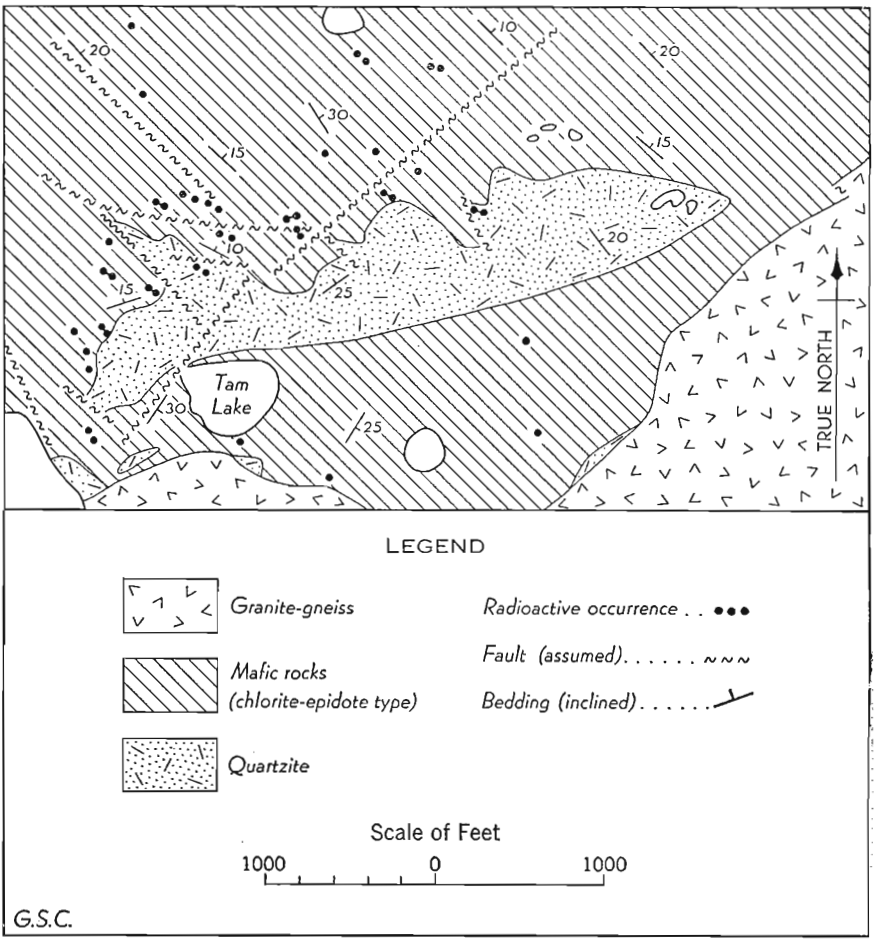


Figure 10. Geological sketch of the Tam South showings of the Eagle group. (After Iain Bain, Eldorado Mining and Refining (1944) Limited.)

The *Donaldson fracture zone* is as much as 400 feet wide and has been traced for more than 5,000 feet. It lies subparallel with the St. Louis fault and about 1,000 feet north of it. Mineralization has been

detected at intervals for a length of about 3,500 feet along the fractured zone. The rock of the fractured zone contains brick-red, hematite-stained feldspar, with shreds of green chlorite, the interstices between the feldspar grains being filled by white carbonate. Quartz is typically lacking, or occurs in only minor amounts. Pitchblende, associated with hematite, occurs most commonly with carbonate gangue as stringers and lenses along shears, minor faults, and tension fractures, which are in general subparallel with the St. Louis fault. Quartz stringers and veins occur in this area, but are not abundant. They strike about north 80 degrees west, dip vertically, and contain euhedral crystals of quartz. Three of these quartz veins are known to be radioactive. Many calcite-filled fractures cut across the pitchblende-mineralized fractures and are not themselves radioactive. Probably much of the calcite was introduced after the formation of the pitchblende-bearing veins.

The main showing on the *Love zone* is about 300 feet north of the St. Louis fault near the northwest end of Flack Lake. A shear zone parallel with the St. Louis fault crosses reddish granite-gneiss and contains carbonate and small amounts of pitchblende.

Fish Hook Bay Group

References: Lang (42); Robinson (45, 46).

On the Fish Hook Bay property, two hundred and seventy-eight separate radioactive anomalies have been located on the surface, and visible pitchblende has been found at about 15 per cent of these. One occurrence, the Hacker zone, contains uraninite. The most important occurrences are localized in the region of the prominent Fish Hook Valley, in what have been designated, from south to north, as the A, B, and C zones.

As indicated on Figure 11, the area is underlain by quartzite, ferruginous quartzite, dolomitic quartzite, dolomite, and either siliceous or dolomitic iron formation. These rocks have a general north-northwest strike and dip 30 to 50 degrees to the southwest. The formations grade into one another both across and along strike. The A zone is a weak, almost vertical shear. Appreciable pitchblende appears to be confined to irregular fractures in a bed of dolomitic rocks lying between beds of ferruginous quartzite. The B and C zones are in a drift-covered valley underlain by ferruginous quartzite that, along the two zones, has been crushed to a breccia and later recemented by calcite and hematite. The crush zones strike roughly north and dip west nearly parallel with the bedding planes of the enclosing formations. In the B zone, the mineral showing is confined mainly to the hanging-wall of the crushed zone; in the C zone, it lies mainly in the foot-wall.

In the A, B, and C zones, the chief gangue mineral in the pitchblende-bearing veins is calcite. Hematite is almost invariably present in the vein and in the wall-rock; chlorite is common; and quartz occurs sparingly. A little disseminated pyrite, chalcopyrite, and galena occur in the veins (45) and an unidentified, black, vanadium-bearing mineral has been reported.

Some 700 feet west of the south end of the B zone is a vein in which masses of botryoidal pitchblende are accompanied by niccolite, arsenopyrite, and cobalt-nickel arsenides.

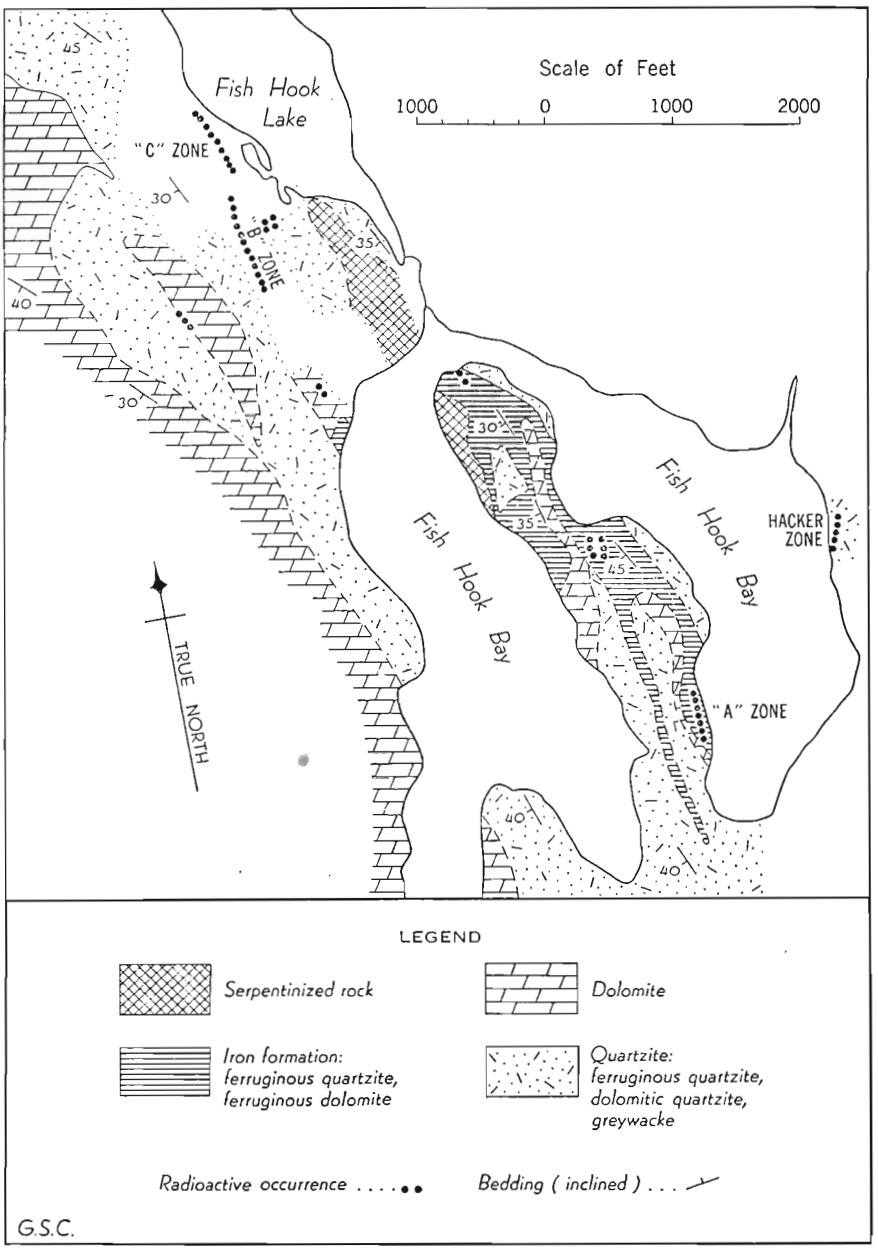


Figure 11. Geological sketch of the Fish Hook Bay group, Lake Athabaska, Saskatchewan. (After Eldorado Mining and Refining (1944) Limited.)

The *Hacker zone* occurs in quartzite, and has been traced for a length of about 300 feet. The principal or only radioactive mineral has been identified provisionally as uraninite by Robinson (45), who has described the occurrence as follows: "In the Hacker vein the mineral (uraninite) occurs as a swarm of minute grains, some of which show cubic outlines, in ragged bands of biotite, which are found in a rock composed mainly of quartz but also containing similar ragged bands of chlorite that are devoid of uraninite. The rock may well be a product of hydrothermal alteration. In the same deposit, chalcopyrite and arsenopyrite are found in chlorite, with which traces of carbonate are also associated; however, no association of these minerals with uraninite was observed".

Gil Group

References: Christie (18); Lang (42); Robinson (45).

The Gil group lies near the shore of Lake Athabasca, just west of the portage to Beaverlodge Lake. As shown on Figure 12, the area is underlain by quartzites of the Tazin group, which are intruded by relatively thin sills of basic igneous rock, now amphibolite. Although generally conformable, the sills in places cut across the bedding-foliation of the quartzites, which strike northeast and dip gently southeast. The quartzites are well jointed and disintegrate readily; they are exposed mainly on northwesterly facing scarps, which are capped by the more resistant amphibolite sills. The gently south-facing dip-slopes are underlain principally by amphibolite.

Several veins containing pitchblende have been found in the amphibolite. All occur in minor fractures or weak shear zones a few inches wide, striking about north 70 degrees east. Although these fractures are very minor features, some of them can be traced for remarkable distances along their strike, as for example that south of Henry Lake, which is 1,200 feet long.

The veins show rough banding and in places are vuggy. Brecciation is common, with carbonate and a minor amount of euhedral quartz filling the spaces between the wall-rock fragments. Carbonate occurs in these veins, and is stained deep red-brown, probably due to hematite, wherever pitchblende occurs. The pitchblende may occur as small veinlets cutting the carbonate; in small (up to 5 mm.), rounded or angular masses within the carbonate; or as nodular masses adjoining the carbonate veinlets. It is invariably associated with hematite, and commonly with minor amounts of disseminated chalcopyrite and bornite. Galena, copper selenides, and native copper were recently identified by Robinson (45) from these deposits.

All the pitchblende so far found on the Gil group occurs within the amphibolite masses. None has been observed in the quartzite. Thus, for example, in the long mineralized fracture south of Henry Lake—which crosses from amphibolite to quartzite, and to amphibolite again—hematite and pitchblende occur where amphibolite is the wall-rock but are lacking where the wall-rock is quartzite. This is true also of a small pitchblende-bearing vein west of Seaberg Lake, which is barren where it intersects an inclusion of quartzite.

As the evidence seems to show that, in this area, the radioactive minerals occur only in the amphibolite, the thickness of the sills in which the veins occur is important. Unfortunately, diamond drilling has shown that in the vicinity of the showings they are less than 50 feet thick, and are separated from other thin sills by great thicknesses of quartzite.

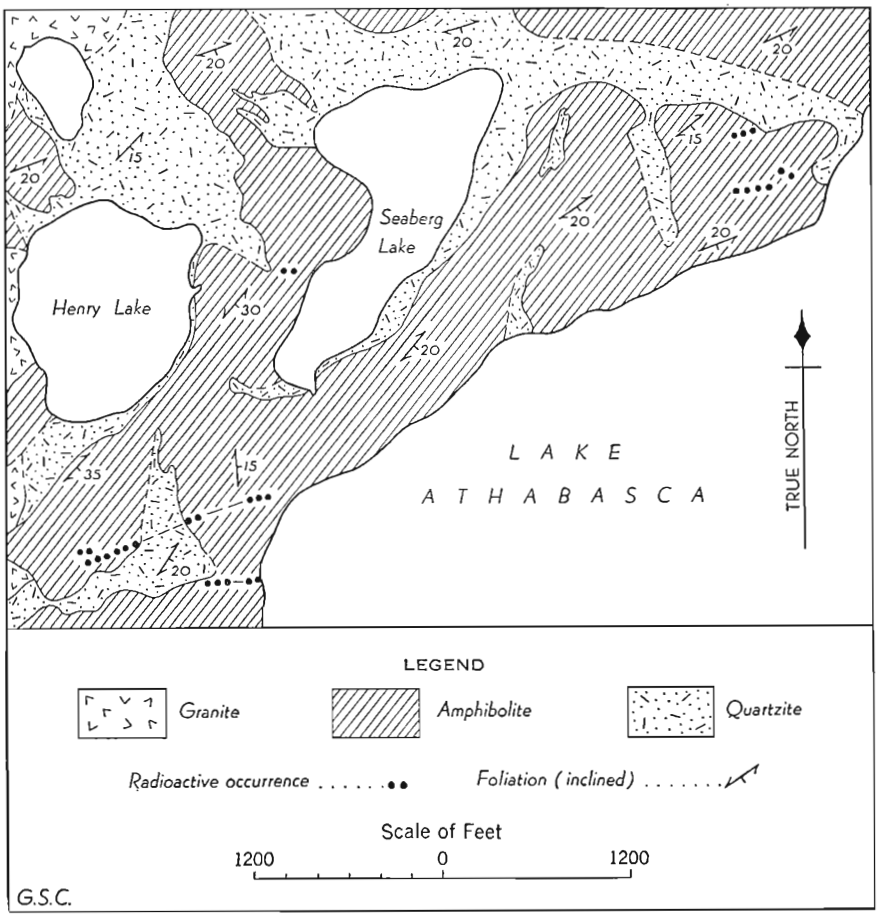


Figure 12. Geological sketch of the Gil group, Lake Athabasca, Saskatchewan.

Hab Group

The claims of the Hab group lie about a mile northwest of Donaldson Lake. They are underlain by quartzite, mafic rocks (chlorite-epidote type), and granite-gneiss. The radioactive minerals occur in quartz-filled shear zones that roughly parallel the strike of the host rocks. Gangue minerals associated with the quartz are chlorite and minor carbonate. Near the radioactive minerals, the quartz may be a dark-coloured, smoky

variety. Both pitchblende and thucholite(?) (not confirmed) are reported, accompanied by hematite and minor amounts of disseminated pyrite. The pitchblende content is highest where mafic rocks form the vein walls.

R.A. Group

(Martin Lake mine)

References: Allen (8); Dawson (32); Lang (42); Robinson (45, 46).

The R.A. group, which includes the Martin Lake property, was discovered by Philip St. Louis and Einer Larum while prospecting for the Crown company in 1946. The claims lie across the southwestward extension of the St. Louis fault. The northeasterly trending faults at the Martin

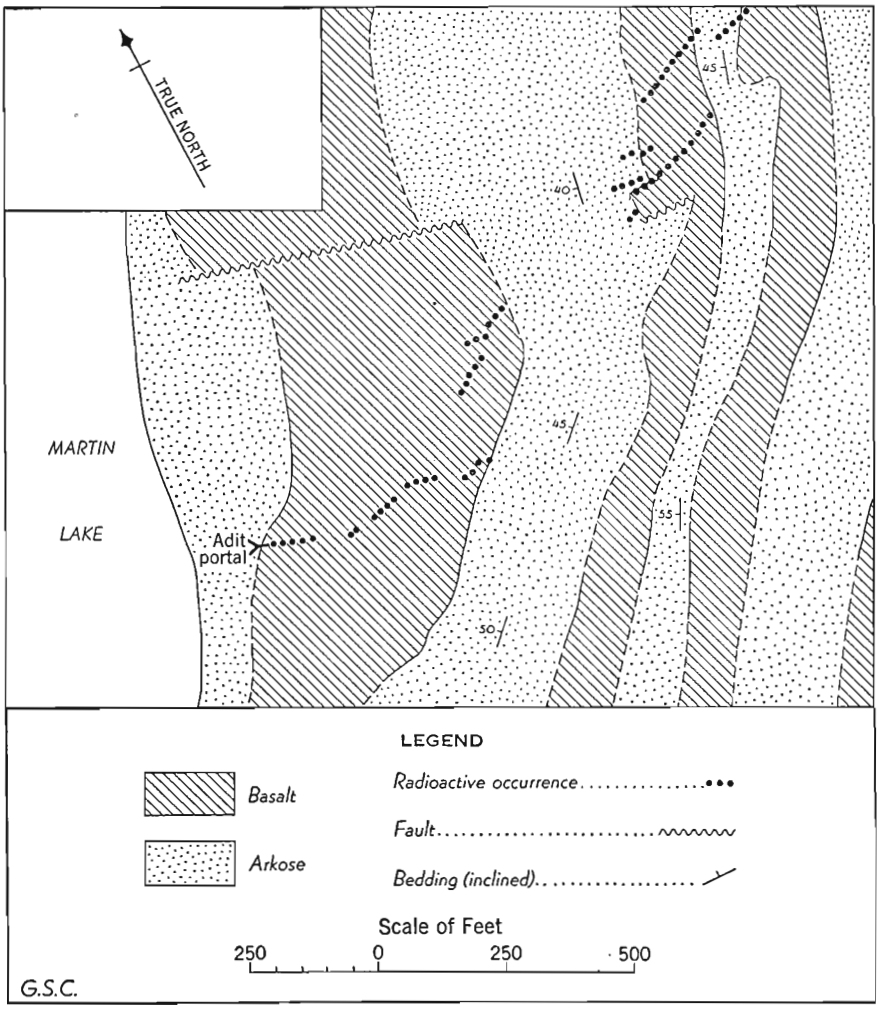


Figure 13. Geological sketch of the Martin Lake property, Martin Lake, Saskatchewan. (After H. C. Norman, Eldorado Mining and Refining (1944) Limited.)

Lake property are almost certainly related to the St. Louis fault, but whether the fault is represented by these fractures, or whether the main fault swings in a more northerly direction to pass through the drift-covered depression in the northern part of the R.A. group is not known (*See* Figure 13).

The group is underlain by interbedded arkose, sandstone, and basaltic lavas of the Athabasca series, that strike northerly through the property and dip 45 to 80 degrees to the west. Tops of beds are to the west, as indicated by ripple-marks, mud-cracks, and crossbedding in the sedimentary rocks. Many of the lava flows are amygdaloidal, the vesicles being filled with quartz, chlorite, calcite, and dolomite.

Allen (8) made a detailed study of the fracture system at the Martin Lake property, and states that several steeply dipping shear zones cut across the strike of the formations and contain the radioactive veins. He states, further, that the principal mineralized faults and shear zones have an average strike of north 68 degrees east and that shorter ones strike about north 85 degrees east. The latter ones commonly occur as branching spurs along non-radioactive shear zones striking north 35 degrees east, thus forming *en échelon* zones.

The veins and ore minerals are more abundant in the basaltic flows than in the arkose or sandstone, probably mainly because of the chemical composition of the basalt, but the greater structural competency of the basalt may have been a factor.

The pitchblende-bearing faults or shear zones contain carbonate and chlorite gangue, and hematite occurs both with the vein material and staining the wall-rock. Robinson (45) reports the occurrence of minor amounts of copper selenides, clausthalite, chalcopyrite, native copper, and native gold in this deposit.

To explore this property, an adit was begun in 1948 from a point near Martin Lake, and about 3,200 feet of underground development work was done as well as considerable underground diamond drilling. Lang (42) states that: "One main mineralized block and several minor ones were partly outlined, but it is difficult to estimate sizes and average grades because of the irregularity of the stringers and the differences in grade that would be effected by mining selectively or by taking larger amounts of lower grade material. An unfavourable feature of the mineralization (from the treatment point of view) is the large amount of carbonate gangue".

Ura Group

(Fay zone)

References: Dawson (32); Lang (42); Robinson (46).

The Ura group is at the north end of Beaverlodge Lake between the R.A. and the Ace groups, and is traversed by the St. Louis fault for more than a mile. The first discoveries on this group were the Ura showings; later the Ace Creek showing and the Fay zone were discovered.

The *Ura showings* consist of a zone of fractures in Athabasca conglomerate and arkose, about 100 feet south of the St. Louis fault. The zone parallels the fault, is from 50 to 200 feet wide, and has been traced

for about 2,000 feet. It contains irregular carbonate-pitchblende veins up to 8 inches wide and up to 300 feet long that dip 65 degrees southeast, as well as networks of small radioactive quartz stringers.

The *Ace Creek showing* is at the southeast side of the creek about 2,000 feet southwest of the St. Louis fault. There, a carbonate-bearing shear zone striking north 70 degrees west and dipping steeply northeast commonly shows red alteration for a width of 4 to 5 feet. Pods of pitchblende up to an inch wide have been found in places across a width of 2 feet and for a length of 25 feet. According to Robinson (42), pitchblende, hematite, galena, and chalcopyrite occur in the carbonate veins.

The *Fay zone* lies in the Tazin rocks on the foot-wall side of the St. Louis fault. It is a fracture zone that strikes and dips parallel or subparallel with the fault. The zone does not outcrop because of overburden, but was discovered during systematic diamond drilling of the rocks near the fault. The mineralization and structure are believed to be similar to those of the Ace orebodies.

The following description is based on an account by Robinson[1]. The zone is in brecciated rocks that may be granitic, quartzitic, or mafic (chloritic). The breccia is cemented by chlorite, and contains patches of calcite. Red 'aplitic' alteration similar to that on the Ace property is common; this 'aplite', which is composed primarily of plagioclase feldspar densely impregnated with red dusty hematite, has been shattered and recemented by chlorite and calcite. Narrow calcite veins traverse all the rocks of the fractured zone. They contain hematite, pyrite, pitchblende, and minor amounts of chalcopyrite, bornite, galena, and marcasite. Vanadium is known to occur in minor amounts, but no vanadium mineral has been recognized. Barren veinlets of younger calcite cut the mineralized calcite veins.

GOLDFIELDS URANIUM MINES LIMITED

Concession DD1

The principal radioactive occurrence found to date on this concession is at the southwest boundary about 1 mile southwest of the most easterly corner of the concession. This radioactive deposit is in granitic gneiss that strikes northeast and dips 65 degrees to the southeast. Pitchblende is reported to occur as a vein-type deposit in a fault zone up to 4 feet wide that strikes northwest and dips 40 degrees to the southwest.

Concession EE1

The EE1 concession includes the northeast end of Elder Lake and a part of Neely Lake. Thirty-four radioactive occurrences were found on this property during 1950, most of them in granitoid gneiss. A few are related to fractures. One radioactive occurrence is associated with narrow joints in granite, which are reported to contain mica, graphite, and pyrite. Small, discontinuous radioactive spots in massive, coarse, red granite, a few of them marked by yellow stain, are probably related to uraninite or to some other original constituent of the granitic rock.

[1] Robinson, S. C.: Geol. Surv., Canada, personal communication.

Near the shore of Neely Lake is a shaft that was sunk in granite and granitoid gneisses by the Borealis Syndicate about 1936, while prospecting the area for gold. The granite is much fractured, and is cut by numerous quartz veins and stringers that contain pyrite and, presumably, some gold. Graphite occurs in fractures nearby. Although the dump and the nearby trenches were examined, no radioactive anomalies were detected.

Concession FF1

The FF1 concession lies northeast of Fredette Lake. Numerous radioactive occurrences were found on this property during 1949 and 1950; two of them are associated with major structural features, and are described below.

The Black Bay fault has been exposed on this property by trenching the radioactive occurrence shown on the accompanying geological map ¼ mile north of Fredette Lake. The fault is there a well-defined break about 2 feet wide and dips 50 to 70 degrees to the southeast. It is filled with gouge, clay, and highly sheared rock. The most radioactive material occurs in a fracture zone, 25 feet wide, in the foot-wall of the fault, the host rock being a fine-grained dark-coloured rock rich in chlorite. The fractures are roughly parallel with the fault, and are filled with quartz, calcite, specular hematite, pyrite, chalcopyrite, and pitchblende. Some of the quartz shows comb structure and is coated with red hematite stain. The pitchblende occurs as pods in the wall-rock or as small stringers, ½ inch wide or less, bordering the quartz veinlets. Red, cherty-looking alteration is limited to the vicinity of the radioactive veinlets.

A second occurrence lies along the Emir fault, which strikes roughly east and dips north at about 75 degrees. The fault-valley floor is covered by overburden; its position is well marked in the west but to the east the extension of this fault lies under a wide swamp, and it is uncertain whether it intersects the Black Bay fault. Radioactivity has been detected for considerable lengths along and near the fault, being commonly strongest where the fault is intersected by northeasterly striking fractures. Values occur in the granitoid gneisses and in small diabase dykes. The radioactive occurrences are commonly associated with quartz, carbonate, pyrite, graphite, and chalcopyrite. Red alteration is common. K. R. Dawson[1] noted pitchblende in a fracture in a basic 'diabase' dyke. The dyke has a reddish colour for 2½ feet on either side of the pitchblende-bearing fracture.

Concession NN

The NN concession includes most of Fold Lake, and extends from there southwesterly beyond the map-area. Seventy-six radioactive occurrences were found on this concession in 1950, of which fourteen are considered by the company to justify further work. Two of these occurrences are shown on the accompanying map. One of these is in a radioactive shear zone in mafic rocks at the nose of the northward-plunging syncline southwest of Fold Lake. The radioactive zone parallels the structure

[1] Dawson, K. R.: Geol. Surv., Canada, personal communication.

around the nose of the fold. Pitchblende has been obtained from it, and is associated with comb quartz and small amounts of pyrite, chalcopyrite, and molybdenite.

A second radioactive zone is shown on the accompanying geological map 2,000 feet west of the south end of Fold Lake. Pitchblende occurs in mafic rocks in a fracture or weak shear zone that is believed to be related to a strike fault.

Concession SS

The SS concession extends from LeBlanc Lake northeastward beyond the map-area. One hundred and thirty-five radioactive occurrences were discovered on the concession during 1950, but pitchblende was nowhere found. J. R. Macdonald, the company engineer, states that the radioactivity occurs in pegmatitic or granitic rocks, in biotite-rich zones associated with shears, in pod-like occurrences of chlorite and biotite, and elsewhere.

One of these radioactive occurrences lies about ½ mile west of the west end of Gatzke Lake. It is in a biotite- and chlorite-rich shear zone an inch or so in width on the contact of a mafic band and granitoid gneisses. It contains considerable pyrite, less chalcopyrite and molybdenite, and a little carbonate. The radioactive mineral is very finely disseminated, mainly in the chlorite, and could not be identified.

Concession TT

The TT concession includes Desjardins Lake on the south and extends northeastward beyond the map-area. Seventy-five radioactive occurrences were found on the concession during 1950.

One occurrence, which was discovered by the Geological Survey in 1948, lies a short distance southeast of Gatzke Lake northwest of and parallel with the Nesbitt fault. As outlined by the company, radioactive deposits occur in a discontinuous zone about 3,000 feet long, of which about 1,000 feet is radioactive. In part, the radioactive occurrences are controlled by faults and shear zones. Elsewhere they cannot be related to detectable structures and occur in almost massive gneiss. Secondary uranium 'stain' occurs in fractures. The following account is after Robinson (45). The more massive rocks are composed of coarsely crystalline orthoclase, plagioclase, and quartz, intersected by thin seams composed of a mixture of chlorite and clinozoisite. Much hematite occurs with the chlorite, and has stained the whole of, or the periphery of, individual feldspar grains. Crystals of uraninite occur both in the chloritic matrix and in the feldspar. In all cases the uraninite occurs as individual, equant to euhedral grains; there is no massive or botryoidal vein-type pitchblende. Some very small grains with a vitreous lustre are surrounded by radiating fractures in the rock and are doubtless radioactive, but have not been identified. Microscopic grains of iron sulphide and flakes of molybdenite also occur. One specimen submitted from this area contained crystals of uraninite in hydrothermal quartz, or hydrothermal quartz vein material gradational to pegmatitic material—as a few scattered crystals of feldspar occur in the quartz. In thin section, the quartz is seen to be an aggregate

of ragged interlocking grains cut by thin stringers of chlorite. In the section examined, three grains of uraninite, one showing cubic euhedral form, the other two subhedral, occur widely separated in the quartz. One of the grains has been broken and subsequently cemented by quartz. Some hematite is disseminated in the chlorite, but there is none in the quartz.

In the southern part of the concession, radioactive deposits are associated with the Medusa fault that trends west to northwest through what has been called Medusa Lake, about a mile north of Coe Lake. Parallel with this fault are subsidiary fault zones that contain most of the pitchblende, together with calcite, amethystine comb quartz, and, in several places, native gold. Pitchblende is most common where the faults intersect amphibolite or lime-silicate rocks rather than in the granitic gneisses.

MCIVER A. CHUM GROUP

The Chum group, staked by R. C. Heron in 1948, lies in what is now the DD concession. The claims cover part of a fault or shear zone along which radioactivity has been detected at intervals for a length of about 1,200 feet. The 'break', which is called locally the 'Heron shear', is marked on the ground by a prominent drift-floored valley. Trenching has exposed sheared granite-gneiss, which contains stringers of chlorite and a little pyrite and pitchblende.

MILLAR W. N. CONCESSIONS DD2 AND DD3

This property extends from Jean Lake on the southwest to Elder Lake on the northeast. To date, one hundred and forty-eight radioactive occurrences have been found, many of which are considered to justify further work.

One of these radioactive occurrences, shown on the accompanying geological map, is near the southeast side of Jean Lake in a shear or fault zone in mafic rocks; the structure strikes northeast and dips 40 degrees to the southeast. Subsidiary, radioactive, easterly striking and vertically dipping cross fractures occur in the hanging-wall of the shear or fault zone.

The other principal discovery is in granitoid gneiss roughly a mile northeast of Jean Lake. It is near a northeasterly striking shear or fault zone that is one of a series of such structures extending northwestward from Jean Lake to the Don showings of the Crown company. Radioactivity has been detected in a group of easterly striking, vertically dipping cross fractures. Nearby is a radioactive zone striking southeast and dipping 70 degrees to the southwest.

NESBITT LABINE URANIUM MINES LIMITED

Maj and Jam Groups

Figure 14 shows the principal radioactive occurrences on the Maj and Jam groups. This area is underlain by a bedded series composed of Tazin meta-argillites, quartzites, cherty quartzites, and slates. The Tazin rocks contain small masses of amphibolite and are intruded by granite.

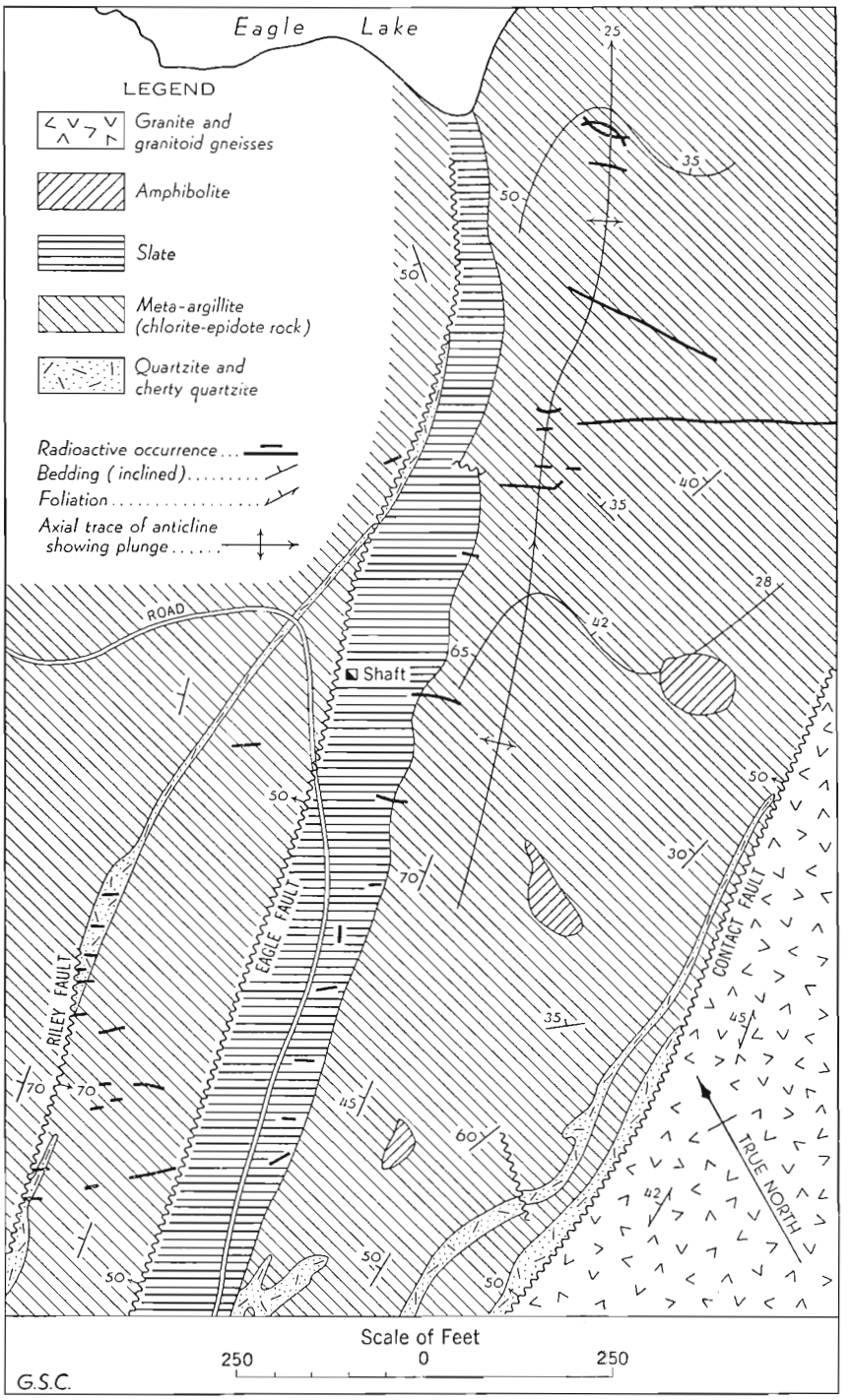


Figure 14. Geological sketch of the Jam and Maj groups, north of Beaverlodge Lake, Saskatchewan. (After J. Silman, Nesbitt Labine Uranium Mines Limited.)

Three faults strike northeasterly in the vicinity of these radioactive occurrences. The Contact and Eagle Lake faults dip to the northwest at 50 degrees, and the Riley fault dips southeast at 70 degrees. Northwesterly striking fractures between these faults contain fillings of calcite, hematite, pitchblende, and pyrite.

One zone of pitchblende-bearing veins lies to the southeast of the shaft between the Riley and Eagle faults. It is estimated that these faults will converge about 200 feet below the surface. It is probable that the abundance of the pitchblende-bearing fractures in this vicinity is due to the proximity of these faults.

A second zone of abundant radioactive fractures is northeast of the shaft. There the northwest-striking radioactive fractures are most abundant near the axial trace of a minor anticlinal flexure that plunges north 40 degrees east at about 25 degrees.

A third radioactive zone lies southwest of the shaft near the contact between meta-argillite and slate.

ABC Group

The ABC group lies between the north corner of Beaverlodge Lake and Melville Lake. The principal radioactive occurrence is near the junction of two faults. One of these faults strikes northeasterly parallel with the regional strike of the older rocks, dips about 50 degrees to the northwest, and separates mafic from granitic rocks. The other fault strikes north-northwest along the contact of the older rocks with the Athabasca series, and dips 40 degrees to the west-southwest. Streaks and masses of hematite and pitchblende are reported to occur in the fault zones in a gangue of chlorite, quartz, carbonate, and altered rocks. Robinson (45) also reports minor amounts of pyrite and chalcopyrite from this zone. The company plans to explore this zone by underground workings.

NICHOLSON MINES LIMITED

References: Jolliffe (38); Lang (42); Robinson (45, 46).

The Nicholson property, 2 miles east of the town of Goldfields, was first explored as a copper prospect in 1930. An investigation of its gold possibilities was begun in 1935. The No. 4 zone was then explored by two adits, a total of about 350 feet of underground workings. In the course of this work uranium stain and pitchblende were discovered.

The formations in the vicinity of the deposits are a generally conformable but intricately folded series of bedded rocks—dolomite, dolomitic quartzite, amphibolite, ferruginous quartzite-breccia, and quartz-mica phyllite—cut by a basic sill and associated dykes, now altered to amphibolite. For the most part at least, the ferruginous quartzite-breccia was once a pure, massive, and, therefore, friable quartzite, which was brecciated during later folding or faulting movements. However, some of the rock mapped as breccia in the vicinity of the Nicholson veins may have resulted from shattering of the dolomitic quartzite, with introduction of hematite. Although, on Figure 15 the structure appears to be simple, in reality it is not. The interbedded quartzite and dolomite (competent

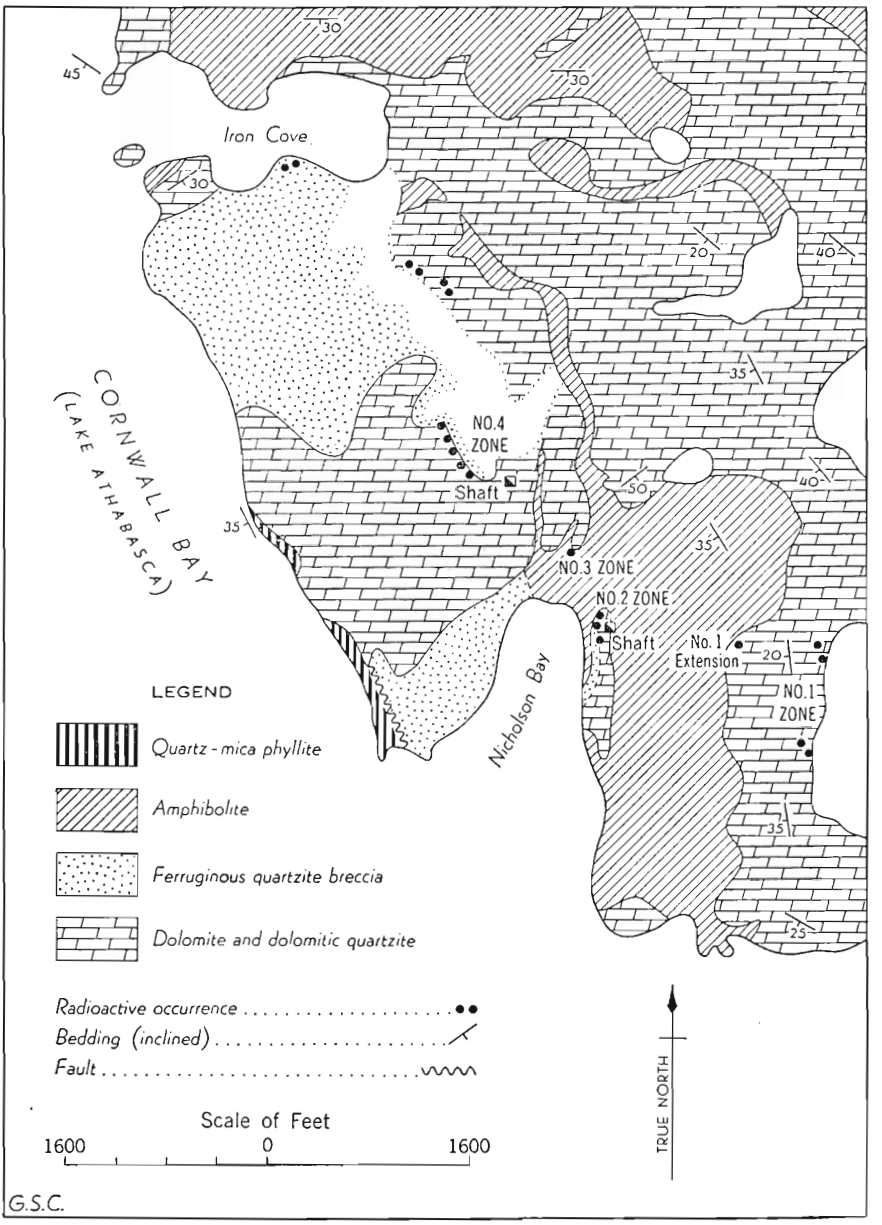


Figure 15. Geological sketch of the Nicholson Mines Limited property, Lake Athabasca, Saskatchewan. (After A. W. Jolliffe, 1946.)

and incompetent respectively) are complexly folded. Near the No. 4 showing, it is not possible to determine the attitude of the ferruginous quartzite-breccia, and only rarely that of the dolomitic quartzite. Moreover, the rapid changes in attitude of the latter render the few determinations that are possible of little value in unravelling the local structure.

The *No. 1 zone* is on the east side of the property. It strikes north 64 degrees west and dips 45 degrees northeast. The showing is a discontinuous vein-type deposit close to a contact between dolomitic quartzite and ferruginous quartzite-breccia. Ellsworth[1] reports that the vein material consists of carbonate, pitchblende, chalcopyrite, niccolite, greyish nickel-cobalt arsenides, nickel and cobalt arsenates, annabergite, and small grains of thucholite, and that the pitchblende has been altered by hydration and silication.

The *No. 2 zone* is about 200 feet east of the head of Nicholson Bay. It consists of a series of *en échelon* shears and fractures with general northerly strike and almost vertical dip. It occurs in quartzite close to its contact with ferruginous quartzite-breccia. The zone is up to 18 inches wide and has been traced for 180 feet. It contains soft, mud-like gouge and coarse carbonate, with pitchblende, some specularite, and minor disseminated chalcopyrite. Robinson (45) also reports pyrite, galena, niccolite, cobalt-nickel arsenides, native silver, and native gold from this deposit. Kaiman[2] identified tiemannite (HgSe) and dyscrasite (Ag_3Sb) from other specimens. High assay returns in platinum are also reported.

The *No. 3 zone* is a copper showing, 600 feet north of the head of Nicholson Bay, at a contact between amphibolite and dolomitic quartzite. Robinson (45) reports the occurrence of bornite, pyrite, chalcopyrite, hematite, and pitchblende, in a gangue of carbonate, quartz, and chlorite.

The *No. 4 zone* lies about 1,600 feet northwest of the north end of Nicholson Bay. It strikes north 30 degrees west, dips almost vertically, and has been traced at intervals for almost 1,100 feet. The mineralized break lies close to the contact of ferruginous quartzite-breccia with dolomitic quartzite. In the latter, bands of pure quartzite alternate with bands of altered dolomite, and the pitchblende appears to favour that part of the breccia adjacent to the dolomite.

The mineralized zone on the surface consists of a 'break' occupied by an irregular vein containing quartz, soft platy hematite, and carbonate. The vein pinches and swells, and has a maximum width of about 3 feet. The vein material is commonly roughly banded, and in places contains angular fragments of the wall-rocks. Vugs are common, including a cavern about 8 feet by 20 feet and 12 feet deep, encountered by the underground workings. On the 200-foot level, however, the vein is massive, showing evidence of having been formed at least partly by replacement.

According to Robinson (45), the vein contains niccolite, cobalt-nickel arsenides, and chalcopyrite, and lesser amounts of pyrite, arsenopyrite, galena, and sphalerite. The uranium-bearing minerals are pitchblende, thucholite, and an amorphous black material composed of a mixture of pitchblende and hisingerite (a hydrous iron silicate).

[1] Ellsworth, H. V., Geol. Surv., Canada, personal communication.
[2] Kaiman, S., Mineralogist, Mines Branch, Dept. of Mines and Technical Surveys, personal communication.

In 1949, a shaft was sunk to a depth of 232 feet near the No. 4 vein, and lateral work was done on the 100- and 200-foot levels. To the end of 1950 about 3,000 feet of lateral work had been done. Lang (42) comments as follows: "The shoots encountered on the 100 and 200 foot levels are of good width and grade, and they are fairly long, but where evidence of mineralization is lacking, there is little evidence of an unmineralized 'break'. The discovery of a second shoot in an unexpected place on the lower level suggests that other branching or '*en échelon*' bodies may exist. Work to date has shown a substantial amount of material of good grade, but the tonnage suggested above the 200-foot level is insufficient to justify the building of a treatment plant. The company has announced plans for deepening the No. 4 shaft and exploring on two additional levels, with the hope of establishing enough ore for that purpose".

PITCHE GROUP

The Pitche group of claims was staked by R. Tamblyn and P. Bloomstrand in 1950. The principal radioactive occurrences lie between Beaverlodge and Milliken Lakes about a mile southeast of the most westerly bay of Beaverlodge Lake. The radioactive occurrences are in northwesterly striking shear zones that intersect quartzite, quartz-sericite schist, and graphitic quartzite. Pitchblende occurs principally where the shear zones intersect bands of graphitic quartzite, and to a lesser extent in the other quartzose rocks. With the pitchblende is abundant dull yellow tyuyamunite (a hydrous calcium-uranium-vanadate), pyrite, chalcopyrite, and one or more unidentified, black, opaque, vanadium minerals.

PITCH-ORE URANIUM MINES LIMITED

The property of Pitch-Ore Uranium Mines Limited is immediately south of the Martin Lake property of the Crown company, and is underlain by arkoses and intercalated basic flows of the Athabasca series.

The most promising discovery to date, which is shown on the accompanying geological map, is in or near a north striking fault that passes northward to a point near the mouth of the adit on the adjoining Martin Lake property. The fault dips about 75 degrees to the west. Pitchblende occurs mainly in the andesite or basalt flows rather than in the arkose, both along the fault and in related northwesterly striking fractures in the lavas. The pitchblende is commonly associated with red-stained calcite. The mineralogy of these deposits resembles that of the adjoining Martin Lake property, which is described in more detail on earlier pages.

RADIORE URANIUM MINES LIMITED

The property of this company lies south of the St. Louis fault and adjoins the Bolger group of the Crown company. Many radioactive occurrences have been located, two of which are shown on the accompanying geological map.

The radioactive deposits ⅓ mile south of the east end of Verna Lake occur in fine-grained chloritic rocks in shear zones that strike east and dip about 40 degrees to the south. The zone consists of irregular slips

along which graphite has formed, and is cut by fractures striking northwest and dipping steeply. Stringers of comb quartz and carbonate are found along both the slips and the fractures.

The radioactive occurrences $\frac{3}{4}$ mile south of the west end of Collier Lake are along an east striking fault zone in gneisses of uncertain origin. Red alteration is abundant. Pitchblende occurs near the intersection of cross fractures with the fault zone or, less commonly, in subparallel fractures near the fault zone. S. Kaiman[1], who examined specimens from this locality, states that the pitchblende occurs as disseminated blebs and stringers. Galena, and to a lesser extent pyrite, occur as very fine inclusions in the pitchblende. Pyrite also occurs in veins and in disseminated masses. Carbonate veins cut both the rock and the pitchblende veins. Kaiman reports a considerable amount of scheelite in the material examined.

RIX ATHABASCA URANIUM MINES LIMITED

Concession DD1

Concession DD1 lies between Black Bay of Lake Athabasca and the southwest end of Jean Lake. One hundred and sixty-seven radioactive occurrences were discovered on this concession in 1950, of which at least fifty are considered by the company to justify further work.

The company staff consider that the Leonard deposits, which lie 1 mile southwest of the southwest end of Jean Lake, are at present the most promising radioactive occurrences. The known radioactive zones in this deposit occur mainly in or near the eastern contact of the mafic band southwest of Jean Lake. A lineament, marked by a stream-filled valley and a scarp, runs southwestward from Jean Lake to the east end of the Leonard deposits and beyond. This lineament is believed to indicate a major fault structure subparallel with the Black Bay fault. The Leonard deposits occur in a group of at least ten easterly striking faults or cross fractures that form a series of *en échelon* zones branching off from the assumed fault. The most southerly of these zones dips vertically, whereas the others, to the north, dip southward, apparently converging at depth. These zones contain vein-type deposits of calcite, quartz, hematite, and pitchblende. S. M. Roscoe[2] states that the best of the mineralization in these zones occurs where they intersect narrow bands of pegmatite that intrude the amphibolite. The pegmatite was evidently more extensively fractured than the amphibolite during the faulting movements. It was planned to explore the most southerly known zone of the Leonard deposits, which is at least 370 feet long, by means of an adit, during the summer of 1951.

Another radioactive deposit of interest is about $2\frac{1}{3}$ miles due west of the west end of Cinch Lake. It occurs in mafic rocks near a granite-mafic contact. The radioactive material occurs in a northeast-striking zone of subparallel and branching fractures from 1 foot to 2 feet wide and dipping 45 to 65 degrees to the southeast. The fractures are

[1] Kaiman, S., Mineralogist, Mines Branch, Dept. of Mines and Technical Surveys, personal communication.
[2] Roscoe, S. M., Geol. Surv., Canada, personal communication.

filled with carbonate and quartz-vein material and contain pitchblende, pyrite, and chalcopyrite. Some vein quartz is of the smoky variety, and hematite stain is common. To the west of the zone is a northeasterly trending drift-covered valley, which may mark the position of a fault.

Roughly $\frac{3}{4}$ mile farther south is an east-striking basic dyke 5 to 10 feet wide that dips to the south at 55 degrees. It is intrusive into granite. Uranium-bearing minerals occur in fractures in the granite, and quartz-carbonate veinlets lie along both contacts of the dyke. A little pyrite was noted.

About $\frac{1}{3}$ mile farther south is an area in the gneiss at least 1,200 feet square that shows appreciable radioactivity. Robinson[1] has isolated and identified uraninite and monazite from samples of this material.

A fifth radioactive occurrence is in gneiss close to, and immediately southwest of, the transmission line. The radioactivity occurs in quartz and calcite vein material associated with red hematite stain in a shear zone that strikes northeasterly and dips about 70 degrees to the southeast. The shear zone is marked by a fault-line scarp.

A sixth radioactive occurrence is in gneiss roughly $\frac{1}{2}$ mile south of the southwest end of Jean Lake. Three groups of branching fissures, which strike roughly east and dip 40 degrees south to vertically, contain radioactive material.

STRIKE GROUP

The Strike group of claims includes several radioactive occurrences near the end of the southeast arm of Mickey Lake. That shown on the geological map is in fractures in gneiss, the fractures containing quartz, hematite, and pitchblende. At a nearby occurrence, radioactivity is associated with a diabase dyke, and can be detected along fractures in the dyke and along its contacts.

[1] Robinson, S. C., Geol. Surv., Canada, personal communication.

PLATE II

A. Beaverlodge Mountain looking westward across Frontier Lake. The gentle southward-facing dip-slope is underlain by amphibolite; the northward-facing scarp is of quartzite capped by a thin sill of amphibolite (101495A). (Page 5.)

B. Dolomite, showing the typical appearance of the weathered surface (101486A). (Page 12.)

PLATE III

A. Pebble Island conglomerate (104943). (Page 13.)

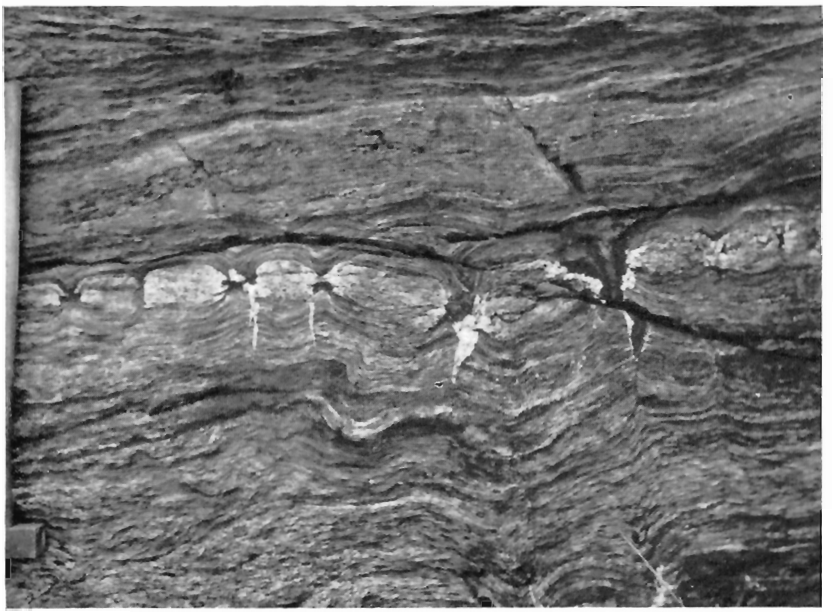
B. Elliott Bay conglomerate (104940). (Page 14.)

PLATE IV

A. Ellipsoidal volcanic rocks near Elliot Bay associated with a white band of cherty material (104949). (Pages 10, 18, 19.)

B. Crenulated or mullion structure in altered, quartzitic, sedimentary rocks near Goldfields (101493A). (Page 23.)

PLATE V



A. *Boudinage* or sausage structure developed in a narrow quart-epidote rich band in amphibolite. Short stringers of later quartz have formed alined with the gaps between the *boudins* (101500A). (Page 25.)

B. Granite intrusive into amphibolite, west of Lodge Bay of Lake Athabasca (1946-7-11). (Pages 32, 34, 35, 63.)

PLATE VI

A. Basal Athabasca conglomerate on the south shore of Beaverlodge Lake (104944). (Page 48.)

B. Colour banding and crossbedding in red arkosic Athabasca sandstone, Beaverlodge Lake (104950). (Page 49.)

INDEX

Page

ABC group, age determination .. 87
Description 111
Ace group, age determination ... 87
Description 93
Ace Creek showing, age determination 87
Description 106
Alcock, F. J. ..3, 8, 10, 14, 18, 20, 28-30, 36, 48, 53-55, 69, 73, 74, 77, 80
Allan, J. A. 3, 10, 13, 73
Allen, R. B. 2, 82, 104
Amax Athabasca Uranium Mines Ltd., description 89, 90
American Canadian Uranium Company Ltd., Tom and Paul groups 90
American Yellowknife Gold Mines Ltd., Concession YY 90
Amphibole-epidote rocks of volcanic origin 18, 19
Amphibole-epidote-chlorite rocks. 17, 18
Amphibolite of intrusive origin .. 19, 20
Amphibolite of sedimentary origin 15
Amygdules, in Athabasca volcanic rocks 50, 52
In late basic dykes 55, 58
Andalusite-sericite-biotite schist. 17
Annabergite 113
Archæan rocks 9
Archer, W. W. 2
Arkose, Athabasca 49
Athabasca series, albite-carbonate veinlets in 33
Arkose and sandstone 49
Conglomerate 48
Origin and correlation 54
Origin of term 48
Structure 52
Table of formations 9
Volcanic rocks of 50
Athabasca Portal Gold Mines, Ltd. 80
Athona granite 39-41
Athona Mines Ltd. 33
Contact metamorphism at 61
Geology 75
History 74
Aurora Yellowknife Mines Ltd. .. 91
Axe group 93

Bain, Iain 2
Banded iron formation 10, 13, 73
Beavan, A. P. ..4, 14, 20, 36, 39, 40, 42, 43, 47, 56, 61, 70, 73-75, 77, 79, 80
Beaver group 95
Beaverlodge series 8, 28
Beaverlodge Uranium Mines Ltd. 91
Bedding foliation 26
Berzelianite 85
Beth Lake (Gully) zone, age determination 87
Description 98

Page

Bichan, W. J. 2
Black Bay fault 5, 65, 66, 89, 91, 107
Blake, Donald A. W. 2, 31, 46, 60, 65-67, 69
Bloomstrand, P. 114
Bolger group 80, 95
Borealis Syndicate 80, 107
Bornite 85, 94, 106, 113
Boudinage structure 25
Boudins 25
Bowie, S. H. U. 86
Box, Tom 3, 77
Box mine, geology 78
Granitic rocks in the vicinity of 35
History 77
Uranium occurrences 92
Breccia, crush 67
Buffam, B. S. W. 2
Byrne, N. W. 2, 74

Cameron, A. E. 3, 10, 13, 73
Camsell, Charles 3, 8
Canadian Pacific Airlines 3
Chalcopyrite ...73, 76, 79, 81, 85, 90, 91, 94, 96, 100, 102, 105-108, 111, 113, 114, 116
Chert 19
Chlorite-epidote rocks 18
Chlorite-sericite schists 18
Chloritic rocks 18
Chum group 109
Cinch Lake Uranium Mines Ltd. 92
Clausthalite 87, 94, 105
Clix Athabasca Uranium Mines Ltd. 92
Cobaltite 85
Collins, C. B. 87
Competency 25
Concessions, general 1, 80
AA 92
CC1 89
CC2 and CC3 91
DD1 ..... 106, 115
DD2 109
DD3 109
EE1 106
FF1 107
NN 107
SS 108
TT 108
YY 90
Conglomerate, Athabasca 48
Tazin 13
of Elliot Bay 14
of Frontier Lake 14
Of Pebble Island 13
Conglomerate fault zone 96
Consolidated Mining and Smelting Company of Canada, Ltd., The, Box mine 77
Frontier Trust property 79
Contact fault 111
Contact metamorphism 61
Continental Exploration Ltd. ... 93
Conybeare, C. E. B. 2, 26, 44-46, 50, 66, 70, 96

Page
Cooke, H. C. 4, 36, 63, 69, 74, 77, 79
Copper, native 85, 102, 105
Cordierite-amphibolite rocks 16
Cordierite-cummingtonite rocks .. 17
Corrugations 23
Crackingstone fault 67, 91
Crenulated structure 23
Crush breccia 67
Cummingtonite 16

Daly, R. A. 51
Davidson, C. F. 86
Dawson, K. R. 2, 51, 52, 84, 85, 93, 96, 104, 105, 107
Dolomite and dolomitic quartzite. 12, 13
Don group 96
Donaldson zone, age determination 87
Description 99, 100
Dowling, D. B. 3
Dynamic metamorphism 67
Dyscrasite 113

Eagle group, age determination .. 87
Description 96
Eagle Lake fault 111
Eagle Shaft showings 96-98
Edie, R. 2
Edie zone 96
Eldorado Mining and Refining (1944) Ltd., Ace group 93
Beaver group 95
Bolger group 95, 96
Don group 96
Eagle group 96-98
Eagle Shaft showings 96-98
Gully or Beth Lake zone 98
Mic showings 98
Tam South showings 98
Emar group 99
Donaldson zone 99, 100
Love zone 100
Fish Hook Bay group 100-102
Hacker zone 102
Gil group 102
Hab group 103
R.A. group (Martin Lake mine) 104
Ura group (Fay zone) 105
Elliot Bay conglomerate 14
Ellipsoidal volcanic rocks 28
Ellsworth, H. V. 80, 86, 87, 113
Emar group 99
Emir fault 107

Fabry, R. J. C. 16, 51, 52
Faults, Black Bay 5, 66
Contact 111
Crackingstone 67, 91
Eagle Lake 111
Emir 107
Medusa 109
Nesbitt 81
Pinky 91
Riley 111
St. Louis 65, 66
Tom 90
Townend 91

Page
Fay zone 105, 106
Fergusonite 81
Ferruginous quartzite 10
Fish Hook Bay group, age determination 87
Description 100
Flaser-gneiss 67
Folding, of Tazin group 26
Frontier Lake conglomerate 14
Frontier Trust property 79

Galena 73, 76, 85, 91, 96, 98, 100, 102, 106, 113
Garnetiferous biotite schist 17
Geological Association of Canada 55
Gil group 102
Gillanders, E. B. 2
Gold deposits, characteristics of .. 73
Properties 74-76, 80
Goldfields Mining Company 80
Goldfields Uranium Mines Ltd. .. 106-109
Granite 30
Granite-gneiss 30
Granitic rocks, in the vicinity of Ace, Eagle, and Melville Lakes 43
In the vicinity of the Athona mine 39
In the vicinity of the Box mine 35
Of the Ace Lake-Raggs Lake area 44
West of Lodge Bay 33
Granitization 69
Granitoid gneiss 30
Greenlee Gold Mines, Ltd. 80
Griffith, J. W. 2
Gross, W. H. 2
Gully zone 98
Gummite 85

Hab group 103
Hacker zone 81
Age determination 87
Description 102
Hanes, E. 2
Hematite 10, 11, 73
Heron, Lawrence 2
Heron, R. C. 2, 109
Heron, Roy 2
Heron, Stirling 2
Heron shear 109
Hisingerite 113
Hriskevich, M. E. 55
Huckle, J. H. H. 2
Hudson's Bay Company 3

Iron deposits 73
Iron formation 11, 73

Jam group 92, 109
James, W. F. 2
Jasper 10, 13
Jasperoid 73
Jewitt, W. G. 4, 77, 80
Johnston, C. S. 2
Jolliffe, A. W. ..1, 10, 11, 13, 29, 62, 80, 111
Joubin, F. R. 2

Page

Kaiman, S. 115
Kesten, S. N. 2
Kidd, S. J. 2
Killin, A. F. 4, 38, 77
Klockmannite 85
Kroupa, E. 86

Laatsch, K. 2
Lamprophyre dykes, composition 47
Description 46
Lang, A. H. ..2, 93, 95, 96, 99, 100, 102, 104, 105, 111, 114
Larum, Einer 95, 104
Late basic dykes 55, 56, 58
Leonard deposits 115
Lineation 23
Lodge Bay granite 33, 63
Lost Mine zone 96
Love zone 100

McCartney, G. C. 2
McConnell, R. G. 3, 48
McIver, A. 109
Mackintosh Bay granite 41, 42
Macleod, J. W. 2
McMurray Air Service Limited .. 3
Mafic rocks, definition 15
Description 15
Magnetite 11, 73
Maj group 109
Martin Lake mine 33, 80
Age determination 87
Description 104, 105
Medusa fault 109
Metamorphism, contact 61
Dynamic 67
General 64
Mic showings, age determination 87
Description 98
Millar, W. N. 109
Mineral Belt Locators Syndicate 4
Molybdenite 74, 81, 108
Monazite 116
Montgomery, L. M. 2
Moore, G. W. 2
Muldal 95
Mullion structure 23
Murmac Lake, Athabasca Mines, Ltd. 80
Murphy, R. F. 2, 80
Mylonite 67

Nesbitt fault 81
Nesbitt Labine Uranium Mines Ltd. 1
ABC group 111
Maj and Jam groups 109
Niccolite 85, 96, 113
Nicholson Mines Ltd. 1, 80
Age determination 87
Description 111
Norman, H. C. 2
Northern Transportation Company 3
North West Minerals, Ltd. 80
Nyman, Gus 3

Page

Parker, J. E. M. 2
Pebble Island conglomerate 13
Pegmatite 31, 36
Pillow lavas 18
Pinky fault 91
Pitchblende occurrences 82-116
Pitche group 114
Pitch-Ore Uranium Mines Ltd. .. 114
Platinum 113
Proterozoic rocks 9

Quartzite, Tazin 10

R.A. group, age determination .. 86, 88
Description 104, 105
Radiore Uranium Mines Ltd. 114
Rammelsbergite 85
Reynolds, D. L. 71, 72
Riley fault 111
River showing 92
Rix Athabasca Uranium Mines Ltd. 1
Age determination 87
Description 115
Robinson, S. C. ..2, 66, 80, 81, 85-87, 93-96, 100, 102, 104-106, 108, 111, 113, 116
Rodden, F. J. 86
Rodding 25
Roscoe, S. M. 2, 115
Ross, J. S. 2

St. Louis fault 5, 65, 66, 93
St. Louis, Philip 93, 104
Sand plains 5
Sandstone, Athabasca 49
Saskatchewan Government, concessions 1, 80
Saskatchewan Government Airways 3
Sausage structure 25
Scheelite 115
Serpentine 13
Sillimanite 14, 17, 31
Sillimanite-cordierite-biotite gneiss 17
Siltstone, Athabasca 49
Silver, native 85, 113
Skutterudite 85
Slickensides 23
Smith, E. E. N. 2, 17, 44, 65, 66, 70
Smith, J. R. 2
Sphalerite 73, 76, 79, 85, 91, 94
Spur zone 96
Strike group 116
Structure, Athabasca series 52
Tazin group 20-23
Stubbins, J. B. 2
Sundius, N. 51
Swanson, C. O. 4, 36, 63, 69, 77

Tamblyn, R. 114
Tam South showings 98
Tazin group, description 8, 10
Relation to 'Beaverlodge series' 28, 29
Structure 20
Table of formations 9
Tectonic Map of Canada 55

	Page
Territories Air Service Limited ..	3
Thucholite	86, 113
Tiemannite	113
Tom fault	90
Tom and Paul groups	90
Tourmaline	14, 17, 73
Townend fault	91
Turner, F. J.	60
Tyrrell, J. B.	3, 73
Tyuyamunite	85, 114
Umangite	85
Ura group	105, 106
Uraninite occurrences	81
Uranium deposits, characteristics	80-89
History	80
Properties	89-116
Ventures, Limited	80
Verhoogen, J.	60
Volcanic rocks, Athabasca	50
Tazin	20
Walli, E.	2
Walter, J. R.	2
Wellington Lake power project ..	77
Winchell, A. N.	16
YY concession, age determination	87
Description	90
Zippeite	85