CANADA
DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA
Economic Geology Series No. 7
(Third Edition)

PROSPECTING IN CANADA

BY

A. H. Lang

EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1956

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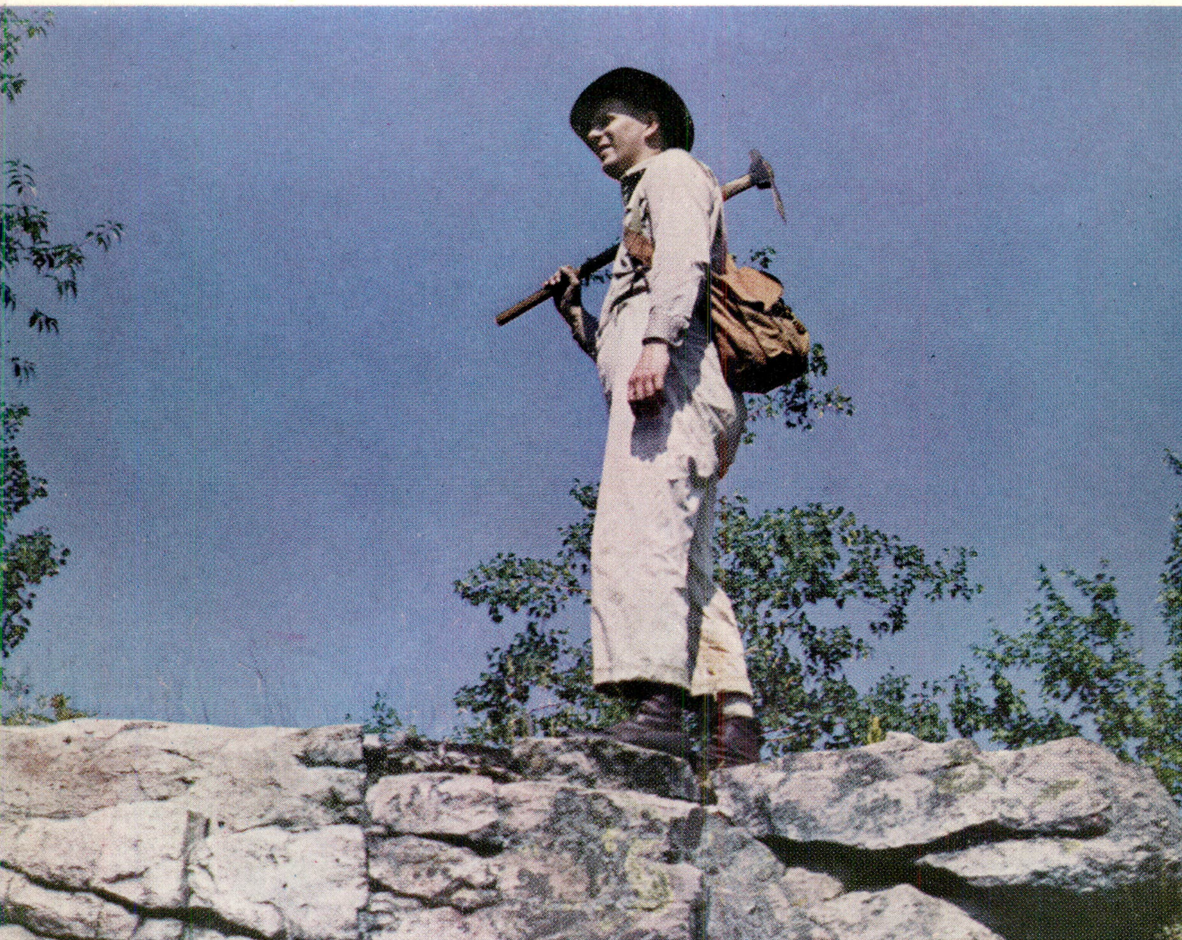

PREFACE

The first and second editions of this book, published in 1930 and 1935, were quickly exhausted. Continuing demand has shown the need for a work of this kind and has encouraged the Geological Survey of Canada to issue a third edition. It does so fully realizing that it is not a prospecting organization and that geology and mineralogy, although the foundations of prospecting, are only part of this large and complex subject. The Survey has, however, been closely associated with prospectors and prospecting for more than 100 years.

Because of the numerous changes in the various subjects treated in the earlier editions, and the newly developed techniques that were not covered, the present one has been almost completely rewritten. The first and second editions consisted of articles written by different officers of the Geological Survey. This had the advantage of drawing on the special knowledge of several men, but as a result, some important topics were omitted, while others were given a disproportionate amount of space. It was therefore decided to have the present edition prepared by one author. Although he would be the first to point out that he is not a prospector, he has had wide related experience in many parts of Canada during his 28 years with the Geological Survey.

This publication is presented with the earnest hope that it may contribute to the continued expansion of the Canadian mineral industry and to the success of at least a few prospectors and companies.

GEORGE HANSON,
Director, Geological Survey of Canada

OTTAWA, February 1956.

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CHAPTER I

PROSPECTING: PAST, PRESENT AND FUTURE

Prospecting, the search for valuable mineral occurrences, is an important occupation in Canada because this country is one of the world's important sources of metals and minerals. Although agriculture is Canada's leading primary industry, forestry and mining vie with one another for second place, and the annual value of production of metals and minerals, including petroleum, is approaching one and a half billion dollars. Mining differs fundamentally from agriculture or forestry because any mineral deposit, however large, will ultimately be exhausted, and new deposits have therefore to be found to replace those nearing exhaustion, as well as to supply new needs. Thus prospecting is the basis of the mining industry, and there is considerable inducement for people to engage in it, particularly in a country like Canada, with its well-established mining industry, its large areas of promising territory, and its strong pioneer tradition.

Prospecting and prospectors are of many kinds, and both depend partly on luck. Some persons engage in prospecting as a hobby or spare-time occupation; some engage in it seasonally and do other work in the winter; some make prospecting their sole occupation and spend the winter studying various phases of the subject in preparation for the next season; some are graduates in geology, geophysics, or mining engineering. Many prospectors work for themselves or as members of partnerships or syndicates, and several companies devoted entirely or partly to prospecting and to the exploitation of promising discoveries employ scientists and engineers, self-trained prospectors, students, and ordinary labourers in organized campaigns. The subject of prospecting is, therefore, a very broad one, including amateurs at one extreme and highly trained scientific specialists at the other. Between these extremes are many competent prospectors who have become proficient by home study and experience, commonly supplemented by attending special classes.

The purpose of this book is to supply basic information for those who wish to become prospectors and for experienced prospectors who desire to review the subject. It is hoped that it may also be useful to persons who contemplate financing prospecting, and to companies that are considering a prospecting campaign in Canada for the first time. Two points must be emphasized at the outset. The first is that no one can become a prospector by study alone; there is much important knowledge to be gained from books, but this must be augmented by actually studying and handling specimens of minerals and rocks, and by experience in the field, preferably under the guidance of an experienced prospector.

The second point is that this volume cannot cover more than the fundamentals of the subject. It is designed primarily to give a would-be prospector with average schooling sufficient information to permit him to begin with a sound grounding, and to indicate where and how additional knowledge can be obtained.

The remainder of this introductory chapter is devoted to outlines of the important part that mining plays in Canadian affairs, the history of prospecting, its present characteristics and probable future trends, and a short explanation of the scope and style of the chapters that follow.

The Stature of Canada's Mineral Industry

In recent years Canada has experienced a great and far-reaching economic development that has placed it among the principal industrial and exporting countries and given it a place in world affairs that is remarkable in relation to its relatively small population. This development is due to many factors, among which the expansion of the mineral industry stands high.

In 1954 the value of Canada's mineral production, including oil and structural materials, was about $1,350,000,000. Although it is true that increased prices per unit of most mineral products make this figure higher than an equivalent production would have been worth several years ago, nevertheless there has been a remarkable increase in the quantities produced; also, the addition of several metals and minerals to the list has made the industry more diversified than ever before. From about $64 million at the beginning of the century, the annual value of production showed a slow general rise to $500 million in 1939. This decreased slightly during the war, then began to increase much more rapidly than formerly owing both to larger quantities and higher prices per unit. In 1950 the total value reached $1 billion* and it continues to rise yearly mainly because of expanding output of nickel, copper, iron, and oil. Canada in 1954 was the leading producer of nickel, platinum, and asbestos; second largest producer of gold (and also of aluminum, but this is processed from imported ores brought here to take advantage of relatively cheap hydro-electric power); third largest producer of zinc; fourth in copper and lead, and a leading producer of uranium. Production from the newly opened iron ore deposits in Labrador tipped the balance so that this country now exports more iron ore than is imported. Discoveries of oil and natural gas during the last few years, mainly in Alberta, have increased greatly the production of these commodities so that Canada now supplies about half her oil requirements, on balance, and has large reserves of gas. The importance of these developments is far from being only in the value of production and in the contribution to the rising standard of living. The efforts of prospectors and mining companies to find and develop new orebodies and the large sums provided by investors constitute a great stimulus to business, employment, and secondary industries, and to the opening of remote regions. In 1954 one large mining company spent $60 million in prospecting and exploration of discoveries, and the total spent by hundreds of companies in this way and in related construction was many times that figure. Civilization and commerce have always followed in the footsteps of the prospector, and, just as Western Canada was developed after the mineral discoveries of the Cariboo, Klondike, and other fields, so today a northern frontier stretching from the Yukon to Labrador is being developed to a degree that would have been thought impossible a few years ago. Few areas, except in the far north, are untouched, but many

* References to billions in this book are used in the North American sense, i.e. 1 billion = 1 thousand million.

parts of the country hold possibilities for further prospecting, especially by highly skilled men using modern methods.

Prospectors of the Past

Prospecting is probably among the oldest of human activities. According to recent authorities, man probably commenced using weapons and tools of wood and stone about 400,000 years ago and shaping them about 200,000 years later, roughly at the same time as he began using fire. Clay for making pottery was used by primitive people in many parts of the world. Gold nuggets and certain precious stones such as turquoise, found in the beds of streams, early attracted the attention of man and were used as ornaments in very early times. Copper found in the metallic state was more valuable to the ancients than gold, because it could not only be shaped by hammering, as could gold, but it was harder and could be made even harder by hammering. The advent of copper and bronze may be said to have given man mastery over his environment for the first time, and the transformation brought about was so marked that the period is known as the Bronze (or Copper) Age, in contrast to the very primitive Stone Age that preceded it. It must be understood that these terms denote a particular type of culture that existed for different periods in different parts of the world, rather than any fixed period of time; for example, the Eskimo have only recently emerged from the Stone Age, while certain New Guinea tribes discovered within the last few years are still in it.

In the lands surrounding the Mediterranean man learned early to shape copper found in its native state, and to smelt the more common metals from their ores. Long before the Christian era, gold, silver, copper, iron, lead, tin, quicksilver, and many varieties of precious and semi-precious stones were well known and widely used. Miners had learned not only the art of washing gravels to recover minerals and ornamental stones, but also of mining solid rock in small shafts and tunnels by driving copper or iron wedges into crevices, and by lighting fires to heat rock faces, thus causing them to crack when cooled.

No doubt in the early part of the Stone Age every man was his own prospector. Men with a special talent for finding, rather than mining and processing, probably began to specialize in prospecting to some extent long before the time of Christ. After the Middle Ages the great mining centre of Europe was in Bohemia and Saxony, where the art of mining was developed to a remarkable degree considering the facilities of the times, and where prospecting and the study of geology and mineral deposits received great impetus. For example Agricola, author of the earliest comprehensive work on mining, based on practices in this region, wrote in 1556: "Many persons hold the opinion that the metal industries are fortuitous and that the occupation is one of sordid toil, and altogether a kind of business requiring not so much skill as labour. But as for myself, when I reflect carefully upon its special points one by one, it appears to be far otherwise. For a miner must have the greatest skill in his work, that he may know first of all what mountain or hill, what valley or plain, can be prospected most profitably, or what he should leave alone; moreover, he must understand the veins, stringers and seams in the rocks. Then he must be thoroughly familiar with the many and varied species of earths, juices, gems, stones, marbles, rocks, metals, and compounds". Mining and prospecting also owe much to the peculiar aptitudes of the men who searched for and worked the tin-copper mines of Cornwall from the time of the Phoenicians to the present, and who carried their knowledge to the far corners of the earth as the British Empire expanded.

Plate II | Early placer miners.

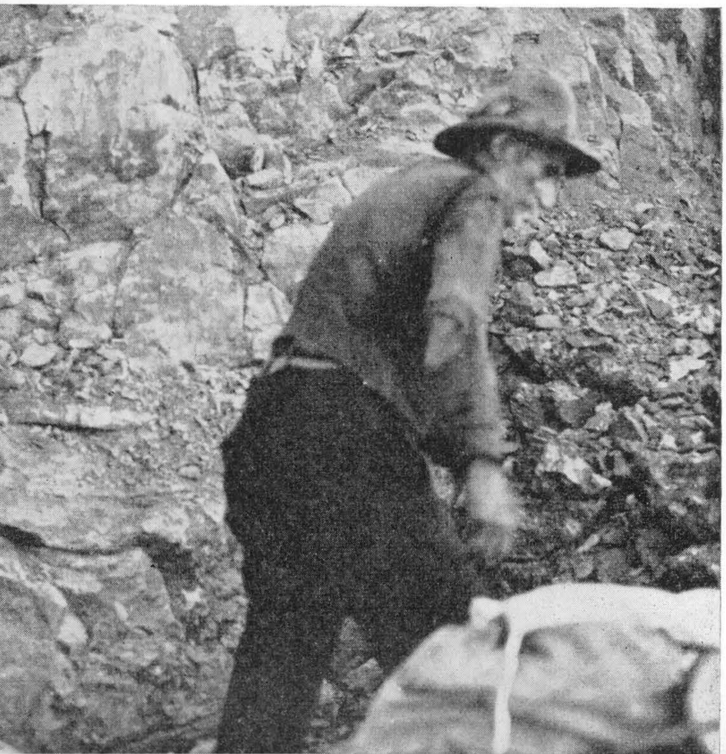


Plate III | An old-timer.

The first Europeans to reach this continent and to leave written records found the natives using stone and a few copper tools and weapons. Many signs of quarrying by natives, and a few of mining, have been found. All the early explorers had the finding of gold and other metals as one of their objectives. Cabot in 1497 noted that the natives of Newfoundland had copper. Jacques Cartier in 1535 obtained a copper knife said to be from the Saguenay country, and shipped to France some worthless stones he thought might be diamonds. Sir Martin Frobisher on his voyage from England to Baffin Island and return in 1576 brought back some rock rumoured to be gold ore, and succeeded in obtaining support for a larger expedition in the following year, when he shipped a great quantity of rock that proved to be worthless, thereby not only marking the first recorded attempt at mining in Canada, but also exhibiting the tendency to over-optimism that has too often accompanied the praiseworthy phases of mining in this and all other countries. A few years later Champlain came to Canada and in his retinue brought a specialist in mining named "Master Simon" to investigate mineral occurrences and try to develop them. He reported discoveries of iron and silver in 1604. After these beginnings, prospecting and a few small mining operations were advanced to some extent by the early French and English settlers in Eastern Canada, but mining did not become an important factor, nor were prospectors numerous, until after the western gold rushes, when great stampedes of fortune seekers followed the discovery of gold in California in 1849, in the Cariboo in 1860, and in the Klondike in 1897. News of these finds went around the world, bringing adventurers as well as many men with experience in mining. The impact of these events on the development of the western United States and Western Canada was partly direct, in the successful mining of large amounts of placer gold, but much more in the pursuits to which many turned after a few years in the placer camps — some seeing the possibilities of prospecting for veins and other 'hard rock' deposits, and others adapting themselves to agricultural and business pursuits. From these beginnings British Columbia and the Yukon became the great mining regions of Canada and remained so until the possibilities of the Canadian Shield were realized and developed after the discoveries at Sudbury in 1883 and at Cobalt in 1903 during the construction of railways through these areas. As a result of these early developments in the Cordilleran region and the Canadian Shield there emerged a group frequently referred to as the 'old-time prospectors'. The best of them had a good working knowledge of geology and mining, but this qualification was not then as important as it is today because these early prospectors were to a large extent travelling untrodden paths where the more obvious occurrences could be found. Their outstanding characteristics were ability to travel and live under pioneer conditions, buoyant optimism, dogged perseverance, and open-handed hospitality. They were adventurers willing and often eager to undergo hardship for the opportunity to lead an independent and roving life and for the chance of 'striking it rich'. With back-packs, horses, and canoes they searched the streams, roamed the hills, and travelled the waterways of the Canadian Shield until few large areas south of the Arctic had not been prospected, at least in a preliminary way. Their basic methods of prospecting were handed down from antiquity. These methods, which are still the basis of all ordinary prospecting, consist of developing a sharp eye for metallic minerals and the 'signs' that often accompany them; tracing fragments of valuable minerals to their source; using the prospector's pan to isolate grains of heavy metallic minerals in sand, gravel, or powdered rock; and scraping, pitting, and trenching to try to expose bedrock in promising places. The main interest of these men was in gold, but many learned also to pay attention to other metals. Almost invariably they financed themselves or formed a partnership with a 'grubstaker', who was commonly a local merchant or other business man. Large and small mines that have since been exhausted, as well as several of the largest present producers, were found by some of these men, but, inevitably, most of them made only minor discoveries or none. For the wealth they uncovered and for their contribution to the general opening up of the country, these pioneers deserve a degree of credit that is only now being fully appreciated.

Prospectors of Today

Although few definite stages in the transition from the pioneers to the prospectors of today can be recognized, important changes in men and methods began about 25 years ago. This is evident in the rise of well-skilled prospectors who are not trained engineers or scientists; in the larger group who have acquired some technical training, generally by attending special short courses in prospecting; in the undertaking of special geological investigations as an important method of prospecting, and the recognition of the place of geologists in planning, supervising, or co-operating in organized prospecting campaigns; and in the development of geophysical and geochemical techniques (*see* Chapters IX and X). The change has accompanied a realization by mining and government officials that the rate of depletion of known mines and the demands for certain materials not being produced required more attention to all factors that might speed important mineral discoveries, including facilities for the instruction of prospectors and means of making prospecting successful and profitable. As a result, courses are now given in several places and problems involved in prospecting continue to be carefully studied. The change has also coincided with a remarkable expansion and improvement in diamond drilling, which is now widely used to test the favourable indications suggested by geological, geophysical, or geochemical investigations, as well as to explore mineral out-croppings found by ordinary prospecting. Modern prospecting has also been greatly influenced by advances in methods of transportation, mainly in the widespread use of outboard motors and float-equipped aircraft, which have been extraordinarily effective in speeding and easing travel and permitting access to remote places, but which may at times have caused too cursory an examination of the routes travelled. Collectively, these factors have made prospecting today more complex, more organized, and more a skilled trade or profession than it was 20 or 30 years ago.

The outstanding modern prospectors are men who make prospecting a full-time occupation and who have devoted as much attention to learning the theory and practice of their calling as has a first-class mechanic or other skilled tradesman. Their rise coincided with the increase in general education, whereby more persons have in recent years received good schooling, which is a necessary foundation for any technical trade. It coincided with the decline of the earlier phase of prospecting in which only fairly obvious mineral occurrences were found by relatively untrained men, and also with an increase in the amount of risk capital ventured by individuals, syndicates, and companies, which made it easier for a competent and reliable prospector to obtain backing or employment, thereby encouraging more men to qualify themselves. These leaders of the prospecting fraternity have learned their calling by home study, by attending

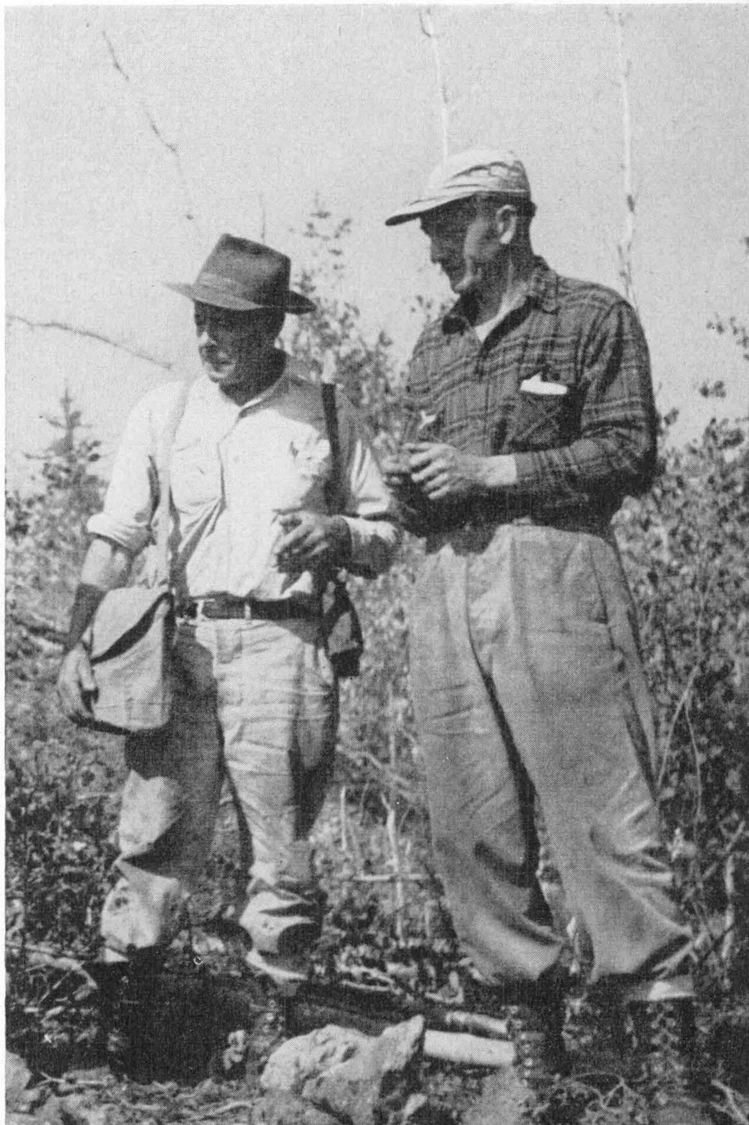


Plate IV | Modern prospectors.

courses, and by working with veteran prospectors, engineers, or geologists. They combine the best attributes of the old-time prospectors with the ability to understand maps and reports and to make simple surveys, sketches, and systematic investigations with a dip needle or Geiger counter. Many of them own prospecting equipment representing a substantial capital investment. They have learned to keep notes, to take proper samples, and to prepare adequate reports on their findings. They use sound common sense, and have acquired good judgment in deciding what to prospect for and what area to select, and whether a mineral occurrence has possibilities. Men of this calibre do not all make important discoveries, and some deposits in recent years were found by prospectors with limited experience, but most leading prospectors have made at least a fair living. They are highly regarded by scientists, engineers, and mining executives, and their services are always in demand.

Other prospectors have made some progress in acquiring skill and knowledge, but for lack of aptitude, education, or incentive are not in the class of those mentioned above. Many of these men work only part time at prospecting. Some have found important deposits and others have profited to some extent by sale of minor discoveries or claims. While the efforts of such men should not be under-valued, it must be obvious that, as readily found deposits steadily become scarcer, and as prospecting comes to depend more and more on indirect and increasingly specialized methods, their continued success must increasingly depend on continued study.

Another type of prospector is the amateur. In the past a relatively small number of enthusiasts of this kind have followed prospecting rushes and mining booms. Today the number has increased enormously, owing largely to over-optimistic publicity and to the present interest in uranium. There will always be a place for amateur prospectors if they will but familiarize themselves with the fundamentals of the subject. Too many start out with little or no idea of what is involved or how to acquire reasonable proficiency. They tend to expect a large measure of assistance from government agencies by requesting individual attention to queries of a general nature, instead of first studying the literature, and they frequently submit samples of valueless rocks and minerals on the off-chance that they may contain something of value. If they do obtain a significant assay or identification, they are unable to form an opinion of the find from a commercial standpoint, nor do they know what steps are necessary for the testing of the find or for its disposal to a mining company if it turns out to have commercial possibilities. All such matters have to be learned by study and experience, and government agencies cannot take the place of these. Such agencies try to be as helpful as possible to the amateur, but their ability to do so is strictly limited, because they are not set up for this purpose.

It has often been supposed that geologists would be ideal prospectors, but although geology has won important recognition in various phases of prospecting, geologists have not usually proved the best prospectors in the ordinary sense of that term. This is probably for two reasons, first, because the attention of geologists is likely to be diverted by matters of general geological interest, and secondly because geologists are usually trained to cover fairly large areas rapidly, and to make necessary observations at one outcrop and then proceed to the next, whereas the prospector must search every part of the outcrop and perhaps scrape or dig to expose more of it. However, it is universally recognized that geologists are invaluable in preparing the maps and reports that guide prospecting, in appraising discoveries, and in supervising organized prospecting programs.

In ordinary surface prospecting, geologists and prospectors form a team, whether it be in the relationship between government maps and reports and independent prospectors or in formally organized ventures.

Geology also has an increasingly important place in the search for extensions of known ore deposits and for additional buried ones in established mining camps and in favourable areas generally. Mining companies employ geologists in increasing numbers to conduct investigations of this kind on their own or on unstaked ground, and government organizations do as much as they can with limited staffs when the work may benefit more than one owner. Such investigations usually comprise detailed geological mapping of surface exposures and mine workings and special studies of pertinent geological problems. In several instances the results have successfully guided programs of diamond drilling that revealed ore.

The application of such phenomena as magnetism and electrical conductivity to the search for buried orebodies has also become recognized as an important branch of prospecting, called geophysical prospecting. Some kinds of geophysical investigations are done from aircraft, but most are done on the ground, as a step between detailed geological investigations and diamond drilling. Another kind of specialized prospecting, called geochemical, has proved useful under certain conditions. Briefly, it consists of chemical tests to trace small amounts of metal in rocks, soil, vegetation or water, which may lead to discovery of a concentration of the metal. Some of the simpler geophysical and geochemical techniques can be used by skilled prospectors and geologists, but most are conducted or supervised by specialized physicists and chemists, the work being combined with geological studies and interpretations.

A significant commentary on the status and trends of modern prospecting in this country is contained in a recently published analysis.[1] This states that seventy-seven important mines have been proved in the last 10 years. Almost all of these have been brought to production, but a few are noted as being likely to commence production in a year or two. It is estimated that thirty-one of the seventy-seven, or 40 per cent, are old mines or partly explored prospects that became productive since 1945 as a result of additional exploration or of changed demands or prices for their contained metals. The remaining forty-six are classed as new finds, most of which were discovered in districts that were previously known to contain mineral deposits, although a few were in new areas. Many of the new discoveries are attributable to a combination of conventional prospecting, geological studies, or geophysical prospecting, but an attempt to assign them to one of these categories revealed that twenty-two of the forty-six discoveries can be attributed to conventional prospecting, as distinguished from more specialized methods usually employed by scientists or engineers, and seventeen to diamond drilling of favourable zones chiefly indicated by geological studies, some being along the possible extensions of previously known orebodies and some in more speculative places. The remaining seven are classed as geophysical indications, most or all of which were followed by diamond drilling. In this analysis, orebodies found by the use of radioactivity detectors, which are relatively simple geophysical instruments, are attributed to ordinary prospecting because these instruments were used by prospectors. These estimates show clearly the approximate number of new mines developed since World War II, the importance of re-investigating known mines and districts, the fact that there is still an important place for competent prospectors who are not engineers or scientists, and the growing emphasis on geology and geophysics.

[1] *The Northern Miner*, Annual Review, Nov. 25, 1954, p. 3.

Prospectors of the Future

No one can predict the future of prospecting with certainty, largely because chance plays such a strong part in this calling. The trends and facts of the past and present nevertheless provide fairly reliable guides for envisioning the prospecting of the next generation or so. The factors on which an opinion of the future of prospecting can be based are:

(1) Most mines now producing were found 20 or more years ago. Almost all of those found more recently, as well as the main ones that will soon be in production, were discovered by well-qualified prospectors, geologists, or geophysicists or by combinations of these.

(2) The number of outcrops that have not been examined carefully by prospectors grows less year by year.

(3) Far more of the bedrock surface in most favourable areas is covered by overburden than is exposed, therefore, it is logical to assume that many buried deposits of ore exist and may be found by special methods now available or which may be developed in future.

(4) Some kinds of deposits that are uneconomic today may become important tomorrow because of new uses for metals and minerals they contain, improved prices, or improved treatment or mining methods. However, these will probably be large low-grade deposits or occurrences of unfamiliar minerals, and prospectors will therefore require special knowledge to benefit from such changed conditions.

(5) For 20 years or more there has been a trend toward the use of more technical and scientific methods of prospecting.

All these considerations indicate that there will be an important place for prospecting in Canada for many years to come; that there will be a place for conventional methods of prospecting as long as any outcrops remain unvisited, and as long as additional exposures are occasionally revealed, but that such prospecting will be based more and more on technical knowledge and less and less on luck; and that there will be increasing attention to special geological, geophysical, and geochemical methods, and probably to methods that are not now apparent. Therefore, it seems there will be opportunities for persons of fair education who are willing to study and to develop keen powers of observation, and who prefer an outdoor life at least in summer, to enter prospecting as a skilled trade, to make it a part-time occupation or hobby, or to go on to become engineers or scientists specializing in the more advanced methods. There seems little doubt that the mining industry will employ reliable, qualified men in the search for ore and that investors will back independent prospecting ventures by similar men. Facilities for training prospectors as skilled tradesmen will probably be increased, both by special courses and by courses given in technical schools. Persons who are unable to obtain such instruction and who intend to make prospecting their calling should be prepared to devote much time to studying as well as to obtaining practical experience. Those who intend to prospect as a minor occupation or hobby should devote as much attention to study and practice as they would if making an intelligent approach to any other hobby. Possibilities for occasional important discoveries by unskilled persons will probably remain for some time, but their chances will diminish with every passing year.

About this Book

No publication on prospecting can contain any certain guides to success, for this depends on a combination of luck, aptitude, perseverance, experience and knowledge. The last is more important than ever before, and this book is intended as an introductory one for those who are thinking of becoming prospectors or of backing prospecting ventures. It will also be a reference for more experienced prospectors. It is so designed that it can be used by those who have to study independently, without attending courses, and also as supplementary reading for those taking courses. Some matters that are beyond the scope of ordinary prospecting are outlined in order to provide an idea of what they involve; these matters are related chiefly to special methods of prospecting and to the appraising of mineral deposits.

The next few chapters deal with fundamental subjects such as geology and mineralogy. Space does not permit covering these subjects as adequately as is desirable for a student of prospecting, but suitable introductory books for further reading can readily be obtained; these subjects are therefore discussed only sufficiently to form a beginning and to make the remainder of the book intelligible. Later chapters deal more thoroughly with various phases of prospecting itself, for which an up-to-date general book dealing with Canadian conditions is lacking.

Numerous references are included so that the serious student can add to his knowledge. It is not necessary for a beginner to purchase all the books listed but he should obtain and diligently study some of the basic ones, such as those on geology and mineralogy written in semi-popular style, and later should gradually become familiar with literature on other phases of prospecting. References on specific regions, metals, and minerals can be consulted as the need arises. Many of the references listed are government reports, or books published commercially that can be ordered through booksellers. All federal government reports including those of the Geological Survey of Canada are available from the Queen's Printer, Ottawa, to whom orders may be sent. Information on other publications, including periodicals, may be obtained from booksellers and orders placed through them. Persons living in outlying areas should write to a bookseller, or to the public library in the nearest large city. Addresses of some of the periodicals are given in Appendix V. Where prices are mentioned, they are intended only to give an idea of the cost, as they are subject to change. Some publications referred to are out of print and some that appeared in magazines will be difficult or impossible for many readers to consult. These references are given because they contain important information and because many readers live in or visit cities where the publications may be found in libraries such as those maintained by Chambers of Mines, provincial Departments of Mines, and branch offices of the Geological Survey of Canada.

After careful consideration it was decided not to issue this publication in pocket size, because the extent of the subject would require several small volumes and because it is not necessary for a prospector to refer to many topics during the day when he is actually prospecting. Instead, this is a book for study at home and possibly on field trips when weight does not have to be kept at the minimum. The prospector who desires to carry in his pocket information on some matters can readily copy the particular data into a notebook; doing so will permit him to make his own handbook to suit his own needs, and the act of writing the information as notes will help him to understand and remember it. Every effort has been made to define technical terms so far as possible, but because many of the topics are technical, the beginner cannot expect to master them effortlessly. He may find it best to read through the various chapters fairly quickly to form an idea of their content, then to reread them more carefully, omitting the chapters on special methods and geophysical prospecting intended mainly for more advanced readers. Several appendixes placed at the end of the volume contain tables and other information that may be useful to some readers and not to others. Consideration was given to including a glossary, but it was decided that the large number of terms that would have to be defined would add unduly to the number of pages; instead, a comprehensive index gives references to the pages on which terms are explained.

The writer hopes sincerely that this book may be useful, despite its imperfections. He begs that he may not be regarded as an oracle on prospecting because the Geological Survey of Canada cannot cope, except through its publications, with requests for general advice on such subjects as the selection of places to prospect, the advisability of prospecting for particular minerals, the worth of discoveries or properties, or the merits of particular methods or equipment.

Acknowledgments

Those familiar with the previous editions of *Prospecting in Canada* and with the textbooklets on mining issued by the Canadian Legion Educational Services, which the Geological Survey of Canada helped to prepare, will realize how much the writer owes to the authors of various parts of those publications. A few sections have been quoted, and information from some others has been included in modified form. He also acknowledges gratefully the splendid co-operation of Canadian Exploration Geophysicists in permitting the use of a series of articles on Elementary Mining Geophysics, which form the chapter on Geophysical Prospecting; this has been edited by L. W. Morley, head of the Geophysics Section of the Geological Survey of Canada, to conform with the needs of the present publication.

The writer is also deeply grateful to the many prospectors, geologists, and executives who have been consulted about various aspects of this far-reaching subject and who have kindly assisted with advice, particularly A. P. Beavan, D. W. Cameron, G. E. Cole, B. T. Denis, C. E. Gamey, A. B. Irwin, J. MacFarlane, P. Price, R. R. Ranson, G. M. Radisics, C. Riley, H. Sargent, and R. S. Woolverton. He is also greatly indebted for assistance to H. P. Kimbell of the Explosives Division, and to M. F. Goudge and G. C. Monture of the Mines Branch, and to members of their staffs, also to many members of the Geological Survey of Canada. Valuable assistance was given by H. R. Steacy and A. E. Hale of the Geological Survey in the preparation of appendixes and diagrams.

CHAPTER II

THE FOUNDATIONS OF GEOLOGY

The different aspects of prospecting cannot be understood properly without an introductory knowledge of the processes that form and change the crust of the earth. A reasonable acquaintance with geology is, therefore, essential for prospectors and is desirable for everyone, for it is a fascinating subject in itself, and one that greatly enhances appreciation of the world in which we live. These processes are not difficult to understand, after a few fundamental facts have been grasped.

The study of the earth is based largely on two important principles whole truth has been demonstrated again and again. The first is that the earth is almost inconceivably old (3 to 4 billion years), and the second that it has undergone many and extensive changes since it was first formed, and that these changes are continuous in character. The crust has been, and is, constantly undergoing changes that result in the destruction of certain parts and the construction of others. The story of the earth's crust is written in the rocks, and although it is not yet completely interpreted, geologists have unravelled it to a fairly satisfactory degree and have proved beyond doubt that processes at work today could account for all the changes that occurred during the long ages of geological time. Therefore, although geology deals largely with events that took place millions of years ago, it is a very live subject because many of the processes believed to have caused these events can be studied in operation at the present time.

The Destruction of the Earth's Crust

We usually think of such natural features as rocks, mountains, rivers, and shorelines as permanent. A little observation, however, will soon show that this is not the case. Rocks are gradually disintegrated by frost and chemical action; mountains suffer landslides; rivers undercut their banks and change their courses; shorelines are eaten away by wave action. These are the more obvious changes taking place, but many others are constantly at work. These changes may seem insignificant in relation to the earth in general, but when it is considered that they have been going on for hundreds of millions of years, it will be realized that their cumulative effect is enormous. Such changes are the foundation of the science of geology.

The earth's crust consists mainly of solid rock, called bedrock, which is exposed at many places. Elsewhere it is covered by a relatively thin covering of soil, sand, gravel, boulders, and angular fragments of rocks, which is collectively called overburden. Both the exposed bedrock and the particles and fragments of rock in the overburden are constantly being attacked by agencies related in one way or another to the atmosphere.

Plate V

Weathering along fractures in lava (basalt).

Plate VI

Erosion in high mountains near Hazelton, B.C., also showing small alpine glaciers and cirques. Talus slopes are shown along the sides of the valley.

The decomposition that takes place at the surface of a rock, or along cracks in it, is generally the result of exposure to moisture in the form of rain or melted snow and is appropriately called 'weathering'. This effect can be seen on the exterior of old stone buildings, where the surface of the blocks is changed in colour and often has a rotten, crumbled appearance; the same changes occur in natural exposures of bedrock or rock fragments. Only a few kinds of rock are soluble in pure water, but most are soluble to some extent when water has accumulated certain substances such as carbon dioxide from the atmosphere and acids from the action of plants on the soil. Weathering is speeded by cracks in rock, which expose additional surfaces and also tend to concentrate solvent action.

The loosening and removal of rock or of the products of weathering is called 'erosion' and takes place in different ways. One of the simplest is direct solution, by which rock is actually dissolved in pure or impure water, but this is not so important as other, mechanical, erosive processes.

A common cause of erosion, particularly in mountains where low temperatures are frequent during summer nights, results from the expansive force of freezing water that fills cracks. This causes pieces of rock to split away from the main mass, and is largely responsible for the piles of angular fragments that accumulate at the base of a cliff and are called 'scree slopes' by mountaineers and 'talus slopes' by geologists.

One of the most powerful agents of erosion is water in motion. Everyone is familiar with the gullies that form in fields after heavy rains have washed away some of the soil, and with the way in which banks are undercut and caused to slump by streams and waves. Less obvious is the way in which powerful streams of water in rapids and falls scour the bed of a creek or river and detach blocks of solid rock. Streams in flood move blocks and boulders, rolling them along and bouncing them against one another so that they gradually are worn and cracked into smaller and smaller pebbles and grains. Besides the action of the water itself, the innumerable sharp particles of sand carried by a swift stream have an abrasive effect that slowly wears down the hardest bedrock or boulders in the path of the current. Similarly, waves pounding the shores of lakes and seas wear the shores back and cause the detached material to be reduced in size, both by the direct action of the water and by the abrasive effect of swiftly moving sand particles in it. Streams gradually widen their valleys by changing their courses from time to time, and slowly deepen the valleys. These changes can at some places be noticed within the lifetime of a man, and when it is realized that the erosive processes may continue for millions of years it is not hard to understand why running water is so effective in wearing down the land and in sculpturing cliffs, hills, and valleys.

Although not so universally effective as running water, winds are important causes of erosion in many regions. The effect of dust storms in blowing away valuable top soil is a serious problem in many agricultural districts. Sandstorms not only cause sand to be moved from place to place, but the abrasive effect of sand particles blown swiftly against larger rock fragments and exposures of bedrock acts like a sand-blast in wearing and polishing them.

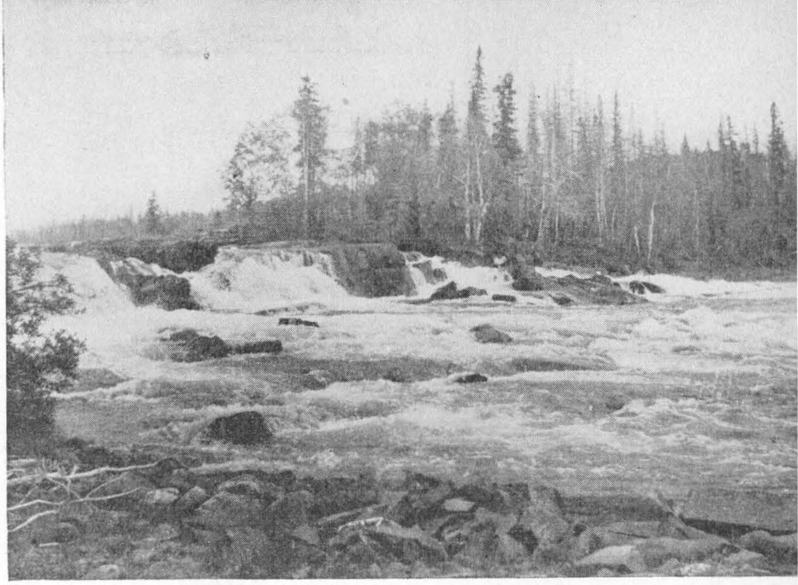
Discussion of glaciers, which are powerful agents of erosion, has been left until the last because they are less familiar and so require more explanation. Perched near the summits of high mountains such as those of Western Canada are many masses of ice, called alpine glaciers, that survive even the hottest summers. Larger glaciers, called ice-fields, exist in a few mountainous places and cover great areas in such arctic regions as Baffin Island and Greenland. Glaciers are formed wherever more snow falls in winter than melts in summer. In such places, the weight of fresh snow causes the underlying snow to be compacted and finally to recrystallize as solid ice. The lower part of a glacier moves slowly by plastic flowage, because of the weight of ice and snow above it. Thus the frozen water that falls as snow gradually moves to the lower end of a glacier where it melts to feed a stream. If the rate of melting is less than the rate of accumulation of fresh snow, a glacier increases in size and is said to be advancing; if the melting predominates the glacier grows smaller and is said to be retreating. Most glaciers are retreating at present, because we are living in a relatively mild period, but at several times in the past the climate was cold enough to cause great sheets of ice, up to thousands of feet thick, to cover large parts of continents. After the ice-sheets had melted, but before the climate had moderated to present conditions, alpine glaciers were much more numerous than they are today and they joined to form long tongues of ice, called valley glaciers, that flowed slowly down the larger valleys of mountainous regions.

Glaciers erode in several ways. The ice in the base flows around fragments of rock and carries them along, to be deposited when and where melting occurs. In addition, these fragments act like bits set in a gigantic slowly moving tool, the larger ones gouging the overburden or bedrock in the path of the glacier,

Plate VII | *Erosion in mountainous terrain, St. Elias Mountains, B.C.*

Plate VIII

Erosion in Precambrian rocks at falls and rapids on Yellowknife River.



and the smaller ones striating and polishing knobs of bedrock into the familiar grooved and rounded outcroppings so common in many parts of Canada. Also, rock fragments fall from the sides of mountain peaks and valleys onto alpine and valley glaciers and are carried along on the surface of the ice until melting takes place. At the heads of alpine glaciers the ice freezes in cracks in rocks, and around rock fragments, and plucks them away to form semicircular basins called cirques.

Plate IX

Erosion along sea-coast, Gulf of St. Lawrence. The rock is sandstone.

Plate X | *Ice-fields and valley glaciers, Coast Mountains, B.C.*

Thus the land areas that exist today are slowly being worn down by natural processes, and the products of erosion are transported and deposited in ways to be explained below. These processes of wearing away and depositing elsewhere have operated in cycles again and again during the long ages whose history is recorded in the strata laid down during successive geological periods. Except for a slow increase in the amount of salts carried in solution in the waters of the oceans, the removal of material from the land areas has always been balanced by the deposition of sediments.

Transportation and Deposition

Eroded material is moved slowly toward the sea, sometimes being trapped permanently at an intermediate point. The movement takes place in several ways. A slow downward creep of rock fragments and soil occurs along the sides of mountains and hills and on slopes below cliffs. This movement is often hastened by slides caused by excessive soaking of the material by water or by the expansive action of frost, or by snow avalanches. When material transported by creep or slides reaches a stream it is added to the normal load of sediment that the stream itself has eroded. Some of the coarser material carried by streams is deposited as bars of boulders, gravel, or sand; the finer material is carried farther, to be deposited as sand, silt, or clay in lakes or in the sea. The debris formed by the erosion by waves is sorted by currents, so that the larger fragments and pebbles remain as beaches, whereas sand is deposited in shallow water, and mud in deeper water. Much of the material that is carried in solution to the sea remains in this state to make the complex brine of sea-water that, contrary to popular belief, is not composed of water and common salt only, but is a mixture containing at least minute amounts of almost every element. Some of these elements, however, are deposited from sea-water by chemical reactions, or by evaporation in tidal ponds, and thereby form deposits of lime, salts, and various other chemical sediments. As already mentioned, wind is also an agent of erosion, and it transports and deposits large amounts of dust and sand in certain regions. Because both water and wind drop sediments intermittently and because there are slight changes in the colour and size of the particles so deposited, many sediments formed by these agencies are clearly stratified, the thickness of individual beds varying from thin layers to strata many feet thick. Glaciers carry clay, sand, and larger angular or rounded fragments of rock and deposit these materials as till in irregular sheets and ridges called moraines; or the finer material may be washed into temporary lakes and rivers formed by water from the melting ice, and deposited as stratified glacial clay, silt, sand, or gravel.

Sediments formed in any of the ways described above may later be eroded while still in an 'unconsolidated' state such as ordinary sand and gravel, and be re-deposited elsewhere, or they may remain and be buried deeper and deeper by overlying sediments until they become compacted and cemented into hard sedimentary rocks of the various kinds described later.

Plate XI

View of White and Yukon Rivers, Yukon Territory, showing streams carrying sediments and depositing them along the valley floor.

Volcanoes and Intrusions

So far, only the strata produced from the wearing away of pre-existing rocks have been discussed. Associated with such strata in many parts of the earth's crust are rocks of another kind, crystallized from a molten or almost molten state. These rocks are grouped under the general name *igneous* (from the Latin word for fire) and are divided into two main classes: *volcanic* rocks formed at the surface; and *intrusive* rocks formed below the surface. Volcanoes and the lavas they emit are among the most spectacular natural phenomena, and as they can be studied in several parts of the world today, the origin of the various kinds of volcanic rocks is well understood. Intrusive rocks cannot be seen in process of formation because they are emplaced below the surface and are exposed long afterwards by erosion. Therefore, our knowledge of the interior and of the origin of intrusive rocks is based on indirect evidence, outlined as follows.

Plate XII

A stock and small masses, dykes, and sills of granite and related rocks (white) intruding metamorphosed sedimentary rocks (dark grey), in the Canadian Shield, Northwest Territories. Three long, young, diabase dykes (dark grey) can also be seen.

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It is known that the temperature within the earth's crust increases downward at an average rate of about 1 degree F. for each 60 feet in deep mines and wells; this rate of increase is probably not maintained at great depths but the interior is certainly at a high temperature, because hot waters of certain springs, and hot lava, come to the surface in many places. The heat is probably in large part generated by the natural disintegration of radioactive elements, such as uranium. It is known, however, that the pressure also increases downward, and although the temperatures at depth are great enough to melt the rocks if they were at the surface, the pressures are so high that much of the material is forced to remain in a solid or plastic state. This is substantiated by the behaviour of earthquake waves, which travel as if the interior was mainly solid; they also provide strong evidence that the interior is divided into zones of different compositions, which probably grade into one another. Another line of evidence is afforded by the fact that the total weight of the earth can be calculated from the effects of gravitation. The weight is much more than it would be if the interior consisted of the same relatively light rocks that predominate in the parts of the crust that can be examined. Therefore, it is clear that the interior must consist of heavy, dense material whose weight at different depths can be predicted mathematically. A third form of evidence is provided by meteorites, which occasionally reach the earth. They are fragments of disintegrated planets, so they provide evidence regarding the interior of planets. Meteorites are of two kinds, some being heavy, dark rock and others a still heavier mixture of nickel and iron, therefore, it is reasonable to suppose that the interior of the earth is composed of similar material.

From the above-mentioned lines of evidence, which corroborate one another, a fairly reliable concept of the interior of the earth has been established. Study of the pattern of earthquake waves shows that the crustal rocks with which we are familiar may extend as much as 50 miles under the continents, below which there is probably a zone of about the same thickness in which the material is less elastic and probably near the melting point. Below this there is probably a thick zone of dense rock that behaves as though it were solid; this zone probably grades into a still denser one containing oxides and sulphides of metals; and this in turn probably grades into a very heavy core composed of nickel and iron, for which there is some evidence of a molten state.

In deeply eroded mountainous regions, or regions that were once mountainous, it is common to find bodies of coarse-grained crystalline rocks such as granite and diorite, which are called *plutonic* rocks to distinguish them from other kinds of igneous rocks. The smaller bodies of plutonic rocks are called *stocks* (*see* Figure 1) and the larger ones, if their areas are more than 40 square miles, are called *batholiths*. The rock must have crystallized slowly and at thousands of feet below the surface to permit growth of the fairly large grains that characterize plutonic rocks. It is generally considered that this material originated in the second zone, immediately below the 50-mile crustal one, and that large liquid or plastic masses called magmas were introduced into the crust. The variations in composition between different kinds of plutonic rocks are generally believed to result partly from a splitting of material within the magma, and partly from reaction of the magma with the adjoining crustal rocks. There are, however, certain granitic rocks that show evidence of having crystallized

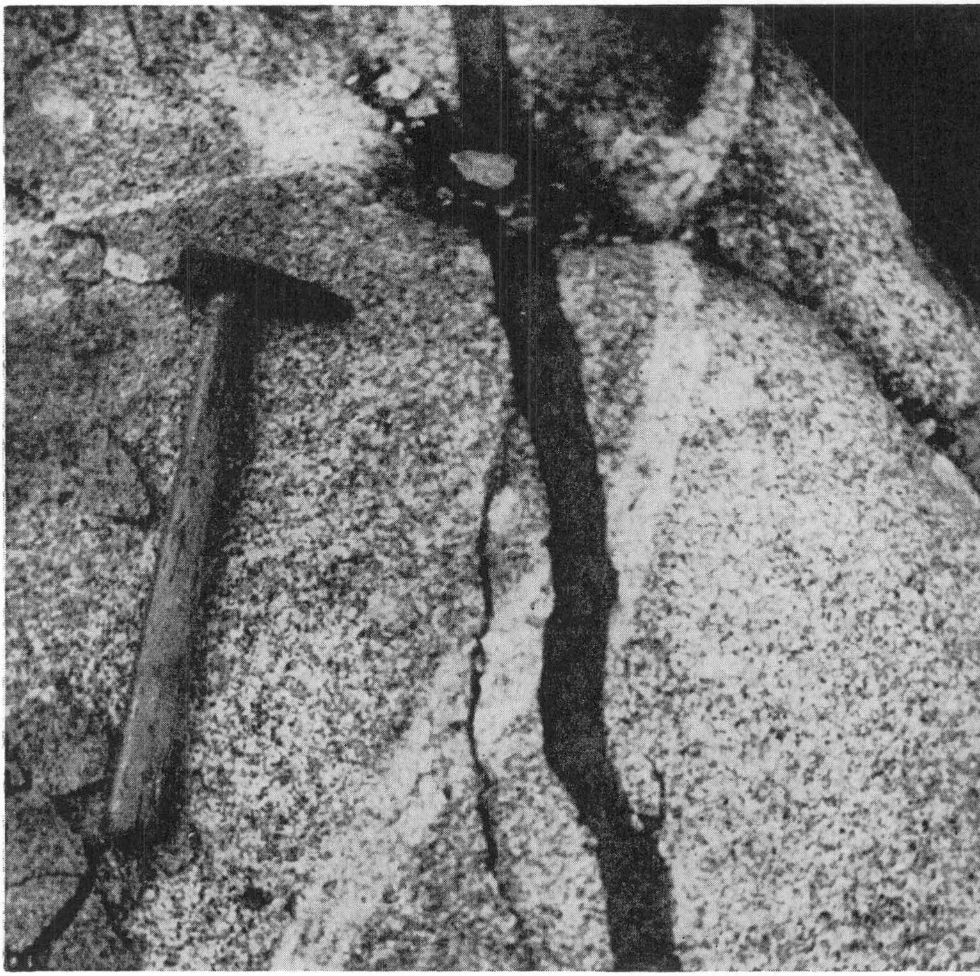


Plate XIII

Granite intruded by a small dyke of aplite, which in turn is cut by a dyke of lamprophyre. The rock names are explained in Chapter III.

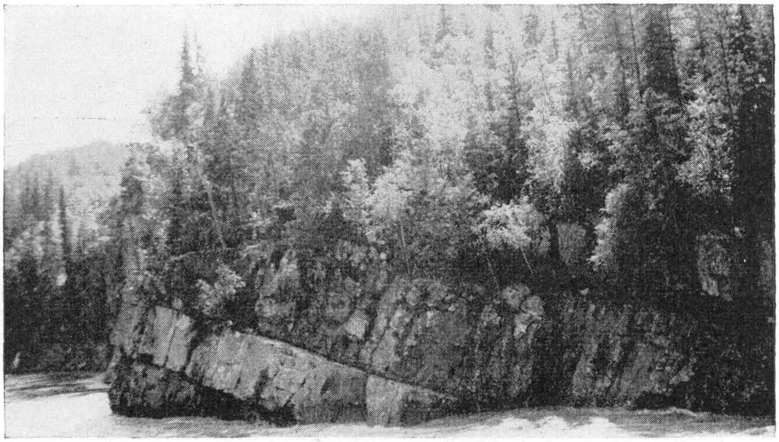


Plate XIV

A sill of granite intruding sedimentary rocks.

from crustal rocks, particularly sedimentary ones, and probably at considerable depths below the surface then existing, and after the crustal rocks had been impregnated with solutions coming from greater depths. Some geologists now believe that all plutonic rocks originate in this way, which is called *granitization*, but most consider that some are formed by granitization and some by crystallization from a liquid magma.

There are also finer grained intrusive rocks, with the same ranges of composition as plutonic rocks. They have three characteristic forms: small irregular-shaped masses whose form has not been given a specific name; long, narrow bodies called *dykes* that fill fractures crossing other rocks; and thin bodies called *sills* that were injected parallel with the beds of sedimentary rocks, the flows of volcanic rocks, or the bands of metamorphic rocks to be described later. The rocks of dykes and sills owe their finer state of crystallization partly to their smaller sizes, which permitted more rapid cooling, and probably also to the fact that some of the molten material penetrated closer to the surface that existed at the time of their emplacement, and thus could cool more quickly.

Lavas, which have about the same compositions as the rocks of dykes and sills, issue from volcanoes and fissures. They flow on the surface or under water, and cool and crystallize fairly quickly because they come in contact with air, cool surface soils and rocks, or water. The various kinds of lavas correspond to the kinds of plutonic rocks, the only essential difference being in the size of the

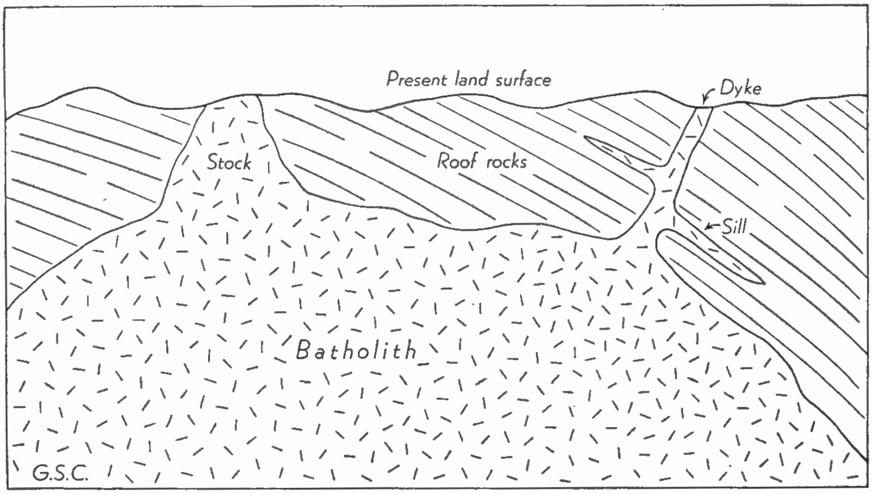


FIGURE 1. Diagrammatic illustration of a batholith not yet exposed by erosion, with related stock, dyke, and sills.

component crystals. Volcanic rocks of another class are formed from the accumulations of volcanic ash and larger fragments that are ejected from many volcanoes. Lavas, ash, and volcanic fragmental rocks are commonly clearly interlayered because of intermittent deposition.

Movements in the Earth's Crust

The crust of the earth is constantly subjected to stresses that cause deformation in the form of cracks, along which movement of one block of the crust relative to another may take place, of great downwarpings and upwarpings, and of contortions on smaller scales. These movements are no doubt caused, to a large degree, by the slow increase in the weight of sediments accumulated in large basins of deposition, the load forcing these basins to sink deeper and probably causing a yielding of the plastic material beneath the crust. There is doubtless also a corresponding lessening of pressure at depth in highland areas as these are slowly reduced in weight by the effects of erosion. Thus the relatively flat surfaces worn down by erosion are slowly uplifted to form plateaux. The uplift causes streams to flow swifter and this increases their erosive power, causing them to dissect a plateau into a second generation of mountains and valleys. Such warpings, however, do not explain the cause of the great lateral stresses required to produce some of the phenomena described below; theories have been developed to explain them but the origin of the forces is not yet well understood.

The various forms of movement that take place in the rocks of the crust, and the 'structures' that result, are of the utmost importance to prospectors because many mineral deposits are related to them.

Fracturing and Faulting

Rocks yield to stress by fracturing, by movement of solid masses, by recrystallization that produces chemical compounds that are stable under the increased pressure, and by plastic flowage under great pressure. The simplest structures produced by stresses in rocks are fractures or joints, which range from small cracks to fractures 100 feet or more in length. They commonly occur in groups

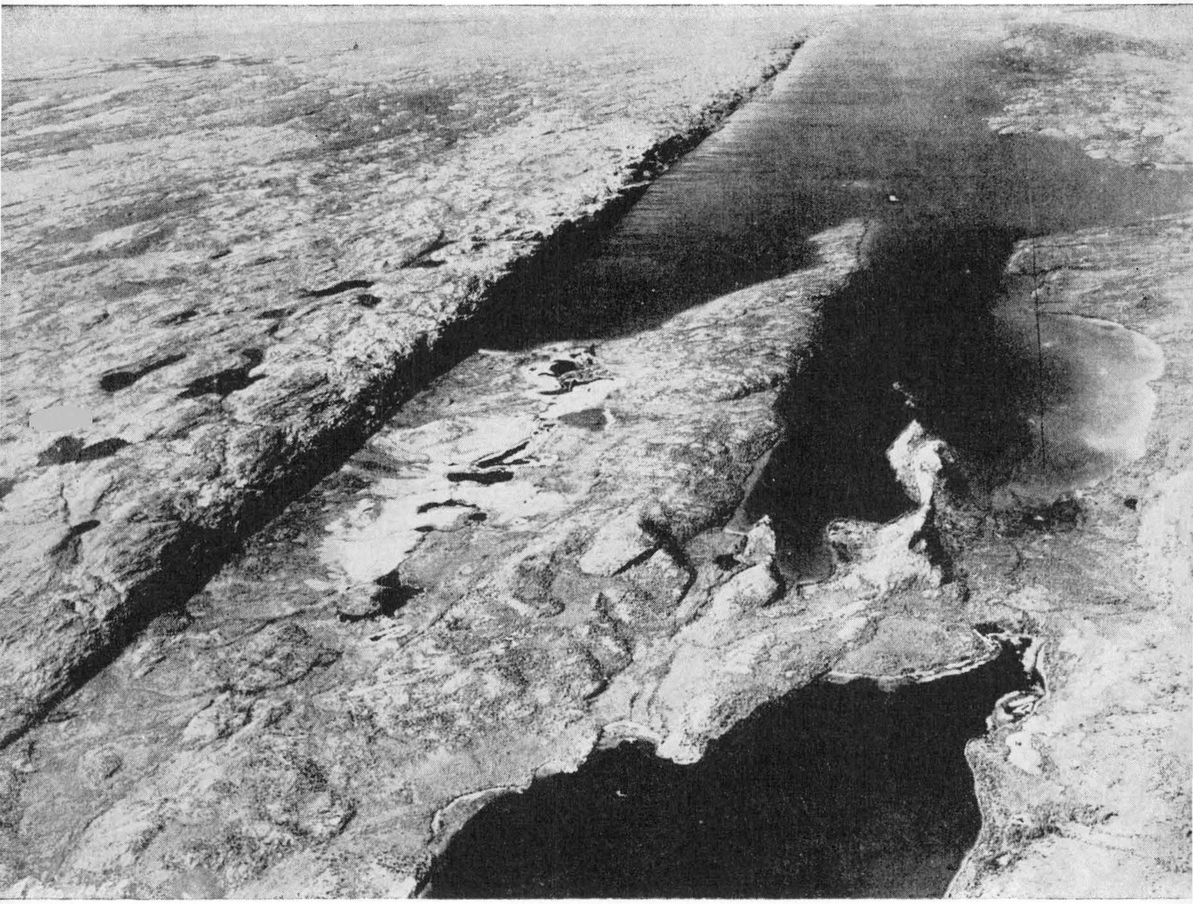


Plate XV | Erosion along a prominent fault in the Canadian Shield, Northwest Territories.

in which several fractures are parallel with one another or intersect one another at angles that are more or less uniform for a particular group. Continued stress may cause the rock at one side of a fracture to move relative to the other, producing what is called a *fault.* The walls of faults are usually polished and grooved, forming characteristic surfaces called *slickensides.* The movement along a fault commonly grinds the rock to form a clay-like deposit of crushed rock

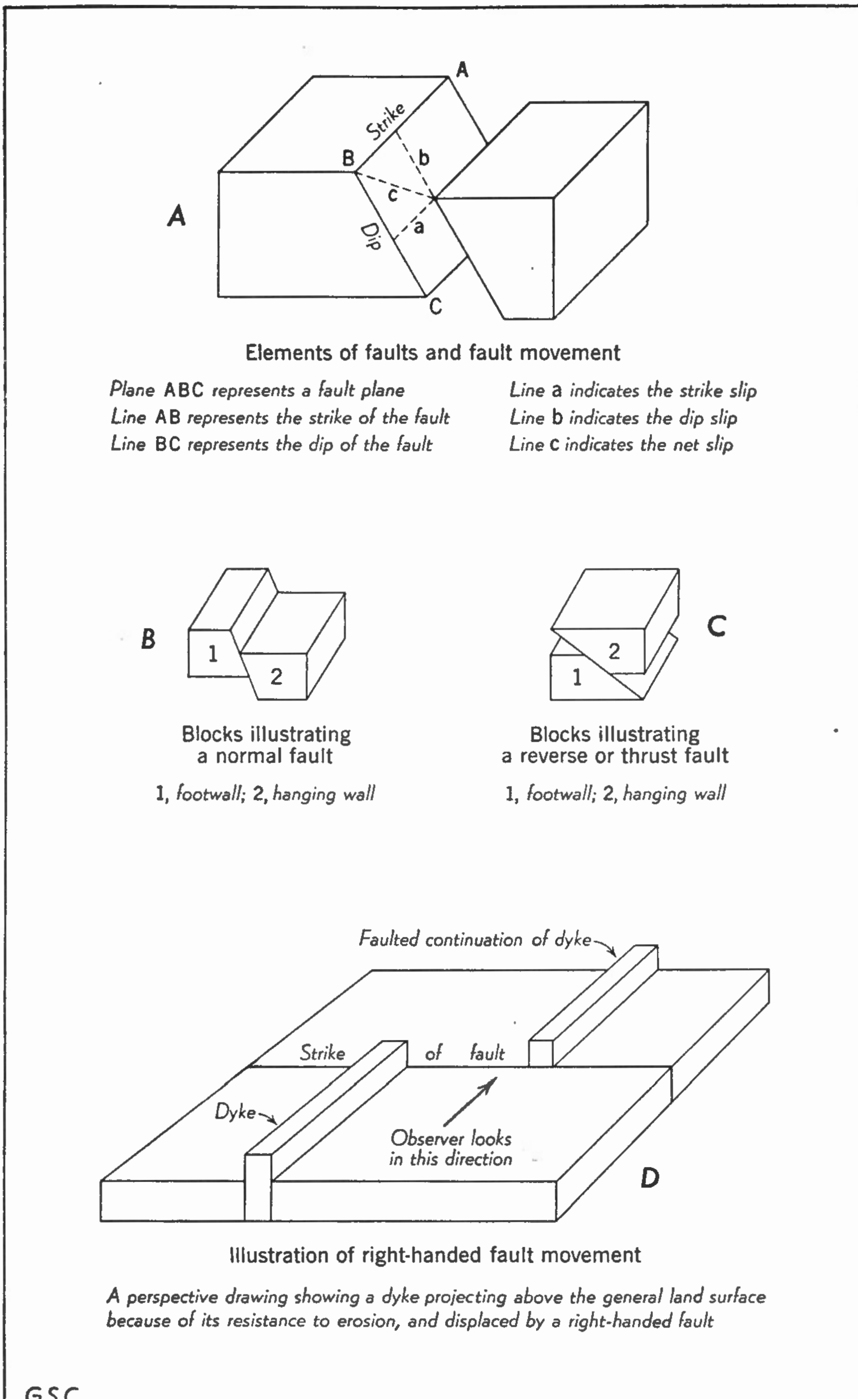


FIGURE 2. Diagrammatic illustrations of faults.

Plate XVI

A series of small normal faults in thinly bedded Precambrian quartzite. (see Chapter III). The darker beds are quartzite containing considerable quantities of the mineral magnetite.

Plate XVII

A fault plane exposed by erosion.

Plate XVIII | *A large dome-shaped anticline in sedimentary strata, Mackenzie Mountains.*

called *gouge*, which may be from a fraction of an inch to several feet thick. Instead of producing gouge, the movement along a fault may cause the formation of a *shear zone*, where the displaced rocks are separated by a band of sliced or sheared rock; or the rock may be crushed into angular fragments, thus forming what is called a *crushed zone* or *brecciated zone* between the walls of the fault. Large faults can be traced for several miles, and the largest extend for hundreds of miles. The displacement of the rocks at one side or other of such faults is very great, being measurable in hundreds of feet, or even in miles. The movement along large faults causes intense vibration in the form of an earthquake.

In order to understand the descriptions of faults contained in geological and mining reports it is necessary to be familiar with a few more definitions, which are explained as follows. Although a fault is represented by a line on a geological map or plan, the movement takes place along a surface that is called the *fault plane* (*see* Figure 2A). The bearing of this plane, expressed as a compass direction, is called the *strike* of the fault plane. Its downward slope is called the *dip* or *inclination*. Some fault planes are vertical, but most are inclined at an angle and, if so, the block of rock lying above the fault plane is called the *hanging-wall* and the block below is called the *foot-wall* (*see* Figures 2B and 2C). If the hanging-wall appears to have moved downward with respect to the foot-wall, the fault is called a *normal fault*, whereas if the hanging-wall appears to have been pushed upwards, the fault is called a *reverse fault* or *thrust fault*. As a rule, the direction of movement is such that it can be measured horizontally as well as in depth. The horizontal displacement is then called the *strike slip* and the vertical displacement is called the *dip slip*, whereas the actual movement is termed the *net slip*, as explained in Figure 2A. A fault whose movement is almost entirely in a vertical direction is sometimes called a *dip slip* fault or simply a *dip fault*, and one that is mainly in a horizontal direction is called a *strike slip* or *strike fault*. Horizontal displacement of a fault is sometimes referred to as *right-handed* or *left-handed*, depending on the direction of the apparent movement. For example, as illustrated in Figure 2D, if the observer stands at the contact of a bed, vein, or dyke that has been faulted, and if he faces the fault, it is called right-handed if the corresponding contact at the other side of the fault is to his right. The word 'contact' is a common one in geological descriptions, referring to the line or surface between two unlike bodies of rock.

Folding

Rocks also yield in the solid state by buckling into folds, which range in size from tiny puckerings to sweeping arches and troughs miles in width. A fold that is arched is called an *anticline*, and its trough-like neighbour is called a *syncline*, (*see* Figure 4). An imaginary line along the crest of an anticline or along the lowest part of a syncline is called the *axis* of the fold, and the sides of the fold are called the *limbs*. Beds of stratified rocks are commonly found in tilted positions, either because they are on the limb of a fold or because uplift has occurred in an unequal manner. Geologists speak of the position of strata as the *attitude*, and they measure and record the attitude of inclined beds by what are called *strike* and *dip*. The strike is the bearing of an imaginary line drawn horizontally along the plane of inclination, and the dip is the angle between the horizontal and the plane of inclination; these terms are illustrated in Figure 3. Similar measurements define the attitudes of fractures, dykes and veins.

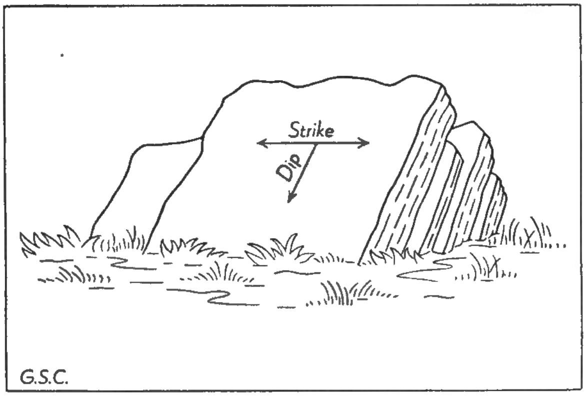


FIGURE 3. Diagram showing an outcrop of beds of sedimentary rocks to illustrate directions in which dip and strike are measured.

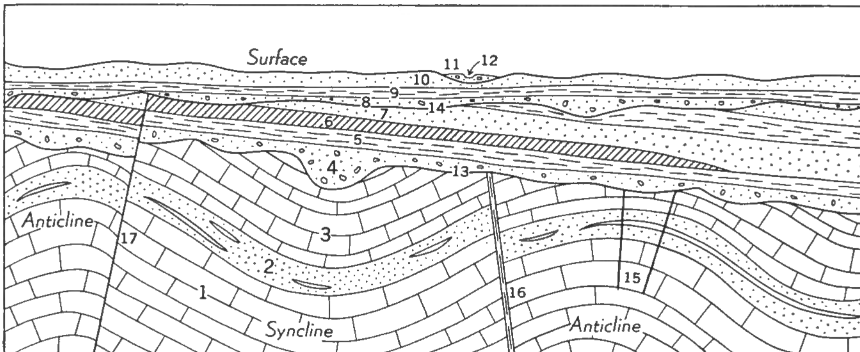
Mountain Building

Fracturing, faulting, and folding are commonly associated in a complex process called *mountain building*, by which large quantities of stratified rocks that accumulated in great sedimentary basins are uplifted and cast into the complicated folds and fault blocks characteristic of mountain chains, and by which older mountainous areas worn down by erosion are uplifted and rejuvenated into secondary mountains. These processes are usually accompanied by igneous activity; in fact, the generally held concept of the origin of magmas is that the local release of pressure caused by upwarping permits the liquifaction of deep-seated rocks that are normally prevented by pressure from existing in a molten state.

Geological Succession

The various sedimentary and igneous rocks that underlie a particular region, described in the order of their ages of deposition or intrusion, constitute what is called the geological succession (*see* Figure 4). This varies from place to place because deposition occurred at one locality while erosion went on at another, because intrusions and volcanic activity occur only at certain times and places, and because many of the rocks once formed may subsequently be destroyed by erosion. Geological conditions generally differ from place to place in another respect, namely, by the manner in which the rocks are tilted, folded, or faulted.

Despite these complications, by comparing the successions in many different areas geologists have established a timetable whose broad features are applicable to all the continents. This has been possible largely because of the presence of fossils in almost all sedimentary rocks laid down during the latter part of geological time, dating from the beginning of the Cambrian period, as explained below. Fossils are imprints or remains of plants or animals buried in sediments and preserved after the sediments became rocks. The time of the beginning of life on our planet is unknown because the simplest living organisms, that no doubt appeared first, lack shells or skeletons that could be preserved as fossils. Life must have begun early, however, because rocks formed about 500,000,000 years ago contain fossilized remains of many different, fairly advanced organisms,



An ancient series (1-3) consists of three conformable formations comprising limestone (1), sandstone with lenses of shale (2), and younger limestone (3). These beds were folded into anticlines and synclines, after which the upper ones were eroded to form the ancient land surface (13). This surface was submerged and on it was deposited another conformable series (4-7), comprising conglomerate and sandstone (4), shale (5), lava flows (6), and sandstone (7). These formations and those of the underlying, folded series were uplifted and tilted. Erosion then produced another land surface (14). This was submerged and a third series (8-10) was deposited, comprising conglomerate and sandstone (8), shale (9), and sandstone (10). The beds of this series remain in their original horizontal position. A modern stream (12) has cut a valley in formation (10) and has deposited sand and gravel (11). The lines (15) represent fractures older than surface (13). A fault, (16), which has formed a wide shear zone, is also older than surface (13). A later fault, (17) is younger than surface (13) but older than surface (14).

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FIGURE 4. Cross-sectional diagram illustrating geological successions.

which undoubtedly were not the first forms of animal life. Most sedimentary rocks less than 500,000,000 years old contain fossils. It has been proved repeatedly that the fossils deposited during any one period were much the same in any part of any continent, whereas the fossils of each period show distinct differences caused by the decline of certain species and the advancement of others. These facts are of the greatest assistance to geologists, who are thus able to use fossils to correlate rocks of the same age in different regions, and to work out the true succession in regions where certain beds are missing or where beds are overturned by intense folding.

Study of the successions in different parts of the world has shown that, for the earth as a whole, geological time can be divided into definite intervals of great duration. When these age intervals were agreed upon, those between times of greatest mountain-building activity were called *eras*, and divisions within eras, separated by much less intense crustal disturbances, were called *periods*. Because of these cycles of mountain-building, uplift, and subsequent erosion and deposition, the rocks representing different eras or periods are commonly separated

Plate XIX | *Small folds in thinly bedded argillite and greywacke.*

by ancient erosion surfaces called *unconformities* (*see* Figure 4). These are of two kinds, called *parallel unconformities* when the strata above and below are horizontal or equally inclined, indicating that erosion and perhaps uplift took place, but that no folding occurred, and *angular unconformities* when the strata below are folded or inclined in quite a different way to those above the unconformity, thus indicating that the older rocks were folded or tilted before the younger ones were deposited.

Because rocks formed during the younger periods and eras are better preserved it is easier to make distinctions between them, therefore, the time units that have been agreed upon are progressively shorter, as illustrated in the accompanying table, which like all geological tables and legends, has the younger units at the top.

Although geologists prior to about 1920 did not have the means of estimating the ages of rocks that are now available, they knew that geological time extended for many millions of years. This conclusion was based on measurements of the average rate of accumulation of sediments being deposited in modern times. When this rate was applied to the enormous thicknesses of sedimentary rocks that were measured for one period after another it was obvious that each period lasted several million years. This was corroborated in another way when it became clear that the forms of life living in one period had evolved from those of the preceding period, and that such changes could only have been accomplished very slowly. Today astronomers are convinced that the earth was formed at least 3 or 4 billion years ago, and this is borne out by applying methods now available for dating rocks that contain small amounts of uranium. That element decomposes slowly, at a known rate, to form other elements. By making delicate analyses of the amounts of uranium and its disintegration products present in a suitable specimen, its age can be calculated. The oldest rock so far tested in this way shows an age of 2,570,000,000 years by one method of analysis and 3,180,000,000 years by another method.

The oldest time, called the Precambrian, lasted more than five-sixths of the entire length of geological time. Because of the lack of fossils in Precambrian rocks, and because these rocks are much deformed and, therefore, difficult to trace from one region to another, it has not been possible to subdivide the Precambrian as definitely as the younger eras. In Canada, Precambrian time is divided into two sub-eras called Early Precambrian, or Archæan, and Late Precambrian, or Proterozoic, but it has not yet proved possible to divide these into periods applicable to all Precambrian rocks found in this country. Late Precambrian time was ended in most regions by a pronounced period of erosion, and this was followed by the Palæozoic era. Although accurate age determinations are not yet available in sufficient numbers to permit precise dating, there is good evidence that the Palæozoic era began about 500,000,000 years ago and lasted about 300,000,000 years. It is divided into several periods, the oldest being the Cambrian; the others are listed in the accompanying table. The Palæozoic was succeeded by the Mesozoic era, divided into the Triassic, Jurassic, and Cretaceous periods. The Mesozoic was followed in turn by the Cenozoic era, which has been divided into several relatively short periods. The older of these form collectively what is called the 'Tertiary', meaning the third large time

GEOLOGICAL TIME SCALE

Era		Period	Characteristic life	Total estimated time in years
Cenozoic		Recent Pleistocene	Man	1,000,000
Cenozoic	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	Mammals and modern plants	60,000,000
Mesozoic		Cretaceous Jurassic Triassic	Reptiles and cycad-like gymnosperms	200,000,000
Palæozoic		Permian Carboniferous	Amphibians and lycopods (giant club-mosses)	
Palæozoic		Devonian Silurian	Fishes	
Palæozoic		Ordovician Cambrian	Higher invertebrates	500,000,000
Precambrian	Late Precambrian (Proterozoic)		Primitive invertebrates and algæ	
Precambrian	Early Precambrian (Archæan)		Nil	3,000,000,000 or more

division after the Late Precambrian. The Tertiary was followed by the Pleistocene period, when the climate of the northern hemisphere became colder than normal, causing great glaciers and ice-sheets to form over much of North America, Asia, and Europe. The climate then became warmer, causing melting of the ice, and these conditions of cold and warmth alternated so that four glacial stages occurred during Pleistocene time.

In the preceding paragraphs, only time terms were explained. Geologists also have a standardized way of distinguishing units of sedimentary and volcanic rocks. The smallest sedimentary unit is called a *bed* or *stratum*, which may be a fraction of an inch or many feet thick. Individual units of lava are called *flows*. The smallest unit that can practicably be shown on a geological map is called a *formation*. In rare instances a formation may consist of a single bed or flow, but most formations consist of a succession of beds or flows, or both, deposited during a short interval of geological time. They may be of only one kind of rock, or alternating beds of different kinds. Formations are customarily given names, such as 'Ottawa formation' or 'Belly River formation'. Some formations have been traced for hundreds of miles, but all end eventually, either by lensing out or by grading into other formations. Prospectors are prone to use the term in other ways, speaking of 'granite formation', 'lime formation', 'favourable formation', etc., but such usages should be avoided except in the case of 'iron-formation', which is a recognized expression. Two or more formations in succession, related in such a way that it is desirable to refer to them collectively, are called a *group* or a *series*, and are given names such as the 'Windsor group' or the 'Cariboo series'. A complete succession of formations for any one period can rarely be found, but where obtained it is called a *system*, such as the 'Cambrian system'.

The ages of intrusive rocks can be estimated from the ages of the rocks they intrude. For example, if a body of granite intrudes the youngest Triassic strata and is overlain unconformably by earliest Cretaceous ones, it must have been intruded and unroofed by erosion during the Jurassic period; and as the erosion would require much time, the intrusion probably took place early in Jurassic time.

Suggestions for Additional Reading

This chapter is only the briefest outline of the main principles of geology, included so that geological matters discussed in the remainder of the volume may be understood by the general reader and by the beginner in prospecting. A competent prospector will require further knowledge of elementary geology. He will find it a most interesting study, and can pursue it either by attending lectures or taking correspondence courses, as explained later, or by reading some of the more popular books available. Some of these are listed below.

Raistrick, A.: Teach Yourself Geology; Hodder and Stoughton, Toronto. Price about $1.50.
This introductory book is No. 57 in the "Teach Yourself" series.

MacLean, A.: Geology for the Layman; Northern Miner Press, Toronto, 2nd Ed., 1947. Price about $3.
A good, short, introductory handbook on geology.

Prospecting in Canada

Fearnsides, W. G., and Bulman, O. M. B.: Geology in the Service of Man; Pelican Book A 123; published by Penguin Books. Price about 40 cents.

An inexpensive book on elementary geology, including sections on geological maps and mineral deposits. Although the treatment and examples are based largely on the geology of Britain, this book would be useful as additional reading for a beginner.

Moore, E. S.: Elementary Geology for Canada; J. M. Dent & Sons (Canada) Ltd., Toronto, 1944. Price about $4.

A useful elementary text on geology, noteworthy for its Canadian illustrations and examples.

Longwell, C. R., Knopf, A., and Flint, R. F.: Physical Geology; Wiley & Sons, New York, 3rd Ed., 1948. Price about $5.

One of the most widely used introductory texts on geology. Although intended mainly for use in university courses, its readability and numerous illustrations make it suitable for anyone.

Carson, Rachel L.: The Sea Around Us; Mentor Books; New America Library. Price about 50 cents.

This book contains very clear and interesting accounts of the parts the oceans play in erosion and in the formation of sedimentary rocks, as well as other subjects of interest to the student of geology.

Walker, J. F.: Elementary Geology Applied to Prospecting; B.C. Dept. Mines, Victoria, B.C., Revised Edition, 1953. Price 75 cents.

A useful elementary book on geology, mineralogy, and prospecting, with particular reference to British Columbia.

Himus, G. W. H.: A Dictionary of Geology; Penguin Reference Books. Price 50 cents.

This inexpensive book provides definitions of numerous geological terms, names of rocks, etc.

CHAPTER III

MINERALS AND ROCKS

Minerals

Minerals are the materials of which the rocks and ore deposits of the crust of the earth are made. A prospector should be able to recognize the main rock-forming minerals and the principal commercial minerals, and some of the less valuable ones that are commonly associated with valuable minerals and that may, therefore, be clues in prospecting. From time to time he may require to learn a few additional minerals for which there is a special demand. He should also be acquainted with the general appearance of ores so that he will be able to recognize occurrences of possible value even if he cannot identify the particular mineral. Mineralogy is a very large and complicated subject; a competent prospector does not need to have an extensive knowledge of it but he should be well grounded in the fundamentals. The following explains the general principles of mineralogy and discusses the additional knowledge that should be acquired and the means of doing so.

The Elements

The matter of which the earth is made is divisible into *elements* that have distinct chemical properties. The ninety-nine elements that have been identified and named are listed in an appendix, together with the symbols that are used to identify them in chemical formulas. Some elements are very abundant, some moderately so, and some are rare. There is strong reason for believing that all the elements in the crust of the earth have now been identified except four unstable ones. Some elements exist by themselves in nature, but most are in combinations of two or more different elements. These combinations are called chemical compounds, and as there are about one hundred elements it is easy to understand why the number of different combinations is very large. The atoms of each element have distinct characteristics, and one or more atoms of one element may combine with one or more of another element. For example, two atoms of hydrogen combine with one of oxygen to form water; to express this the formula of water is written 'H_2O'.

The elements of direct interest to prospectors are of two kinds: metals and non-metals. The metals are opaque to light, have a shiny 'metallic' appearance, and in most cases can be deformed by hammering and are conductors of heat and electricity. The non-metallic elements include the gaseous elements and

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such solid ones as sulphur, carbon, and silicon, which do not have metallic properties. A few elements like arsenic and antimony are called semi-metals or metalloids because they have some of the properties of both metals and non-metals.

What is a Mineral?

A mineral is an element or, more commonly, a chemical compound of two or more elements, that occurs in the earth. More precisely, a mineral is a naturally occurring, homogeneous, inorganic substance having a characteristic chemical composition and fairly definite physical properties. The phrase 'naturally occurring' is included to distinguish between minerals and synthetic compounds produced by man. Minerals are homogeneous, so that any fragment of a particular mineral has the same composition as any other fragment of the same mineral. Minerals are inorganic, because by long-established custom such things as bones, shells, pearls, and other organic materials are excluded, both because of their origin and because they do not have a homogeneous molecular structure. Mercury and water are classed as minerals because mercury is a liquid metal and because water has a definite chemical composition and, particularly when in the form of ice, a definite crystal structure. Petroleum and coal, on the other hand, are not strictly classed as minerals because they are variable mixtures of several chemical compounds; the petroleum and coal industries are, however, classed as parts of the mining industry.

How Minerals are Classified

By long-established custom minerals are classified basically according to their chemical composition and are divided into groups such as native elements (gold, diamond, etc.), sulphides (compounds with sulphur, such as pyrite, which is iron sulphide), oxides (compounds with oxygen, such as uraninite, which is uranium oxide), carbonates (compounds with carbon and oxygen, such as calcite, which consists of calcium, carbon, and oxygen), and several more complicated groupings. Classified by this system, the total number of known minerals is about two thousand.

Certain elements or compounds are intermixed in others and form what are called solid solutions or series in which separate mineral names are applied according to arbitrary limits placed on the amount of a particular element or compound present. For example, silver forms a solid solution with gold, thus accounting for the fact that most gold mines produce silver as a by-product although no distinct silver minerals occur in the ore. Minor amounts of contained silver do not prevent the mineral from being classed as gold, but if gold and silver are present in solid solution in equal quantities, the mineral is called electrum. A common example of compounds occurring in series is found in the group of minerals called plagioclase feldspars, where separate names are applied according to the percentages of sodium or calcium compounds present. Slight variations also may occur in minerals because certain elements or groups of elements having more or less the same properties as one of the essential components of a mineral, may be substituted for it in the crystal structure of the mineral. In this way small amounts of manganese may occur, taking the place of some of the iron in an iron mineral without changing its classification; many other examples could be mentioned.

Many minerals are impure because small masses of another mineral occur as tiny bodies called inclusions or as minute veinlets. Many of these are so small that they cannot be seen except with the aid of a high-power microscope.

Apart from the basic chemical classification of minerals, it is often convenient to classify them in other ways. For instance, minerals may be spoken of as being metallic or non-metallic according to whether or not they display a metallic shine or lustre. It should be noted that this refers to the appearance of the mineral itself, not to the content of the mineral, because many minerals that contain important amounts of a metal do not have metallic lustre. A useful means of distinguishing metallic minerals lies in the fact that, if a metallic mineral is powdered or is scratched across a piece of unglazed porcelain, the powder or 'streak' is invariably darker than the solid mineral. When distinguishing between minerals that yield metals and those that do not, the terms metalliferous and non-metalliferous may be used.

Minerals are also designated as *primary* or *secondary*. Primary minerals are in the state in which they were originally formed. Many minerals when exposed to moisture at or near the land surface are altered to other 'secondary' minerals in much the same way as a piece of iron rusts. Secondary minerals may form large deposits, some of which are mined, but more commonly they form a crust or 'bloom' that occurs in small quantities but which may be an important clue for prospecting because it attracts attention and may lead to the discovery of a deposit of primary minerals (*see* pages 140-142).

Identification of Minerals

Although minerals are classified chemically there are many other ways by which they may be identified, such as by their lustre, colour, weight, hardness, or crystal form. In a few instances, one characteristic is enough to permit definite identification. For a fair number, two or three simple tests will suffice. Thus by sight or simple tests that can be made in the field or at home, a mineralogist can identify a few hundred minerals. Most minerals, however, can be identified positively only by extensive laboratory work that may take the form of microscopic examination, complicated chemical procedures, measurements of crystals, or x-ray photographs that determine the internal crystalline structure. Fortunately, most such minerals are rare and not of great importance in prospecting, and most of the principal ones can usually be identified fairly readily. Therefore, acquaintance with about one hundred principal minerals is more important for prospectors than knowledge of all the remainder. It is not essential for a prospector to be able to identify even that many, for, if he knows what ores look like in general, he can send samples for assay, but it is very desirable to know at least fifty or one hundred of the more important minerals.

Simple chemical tests can be made in the field, often with the aid of a blowpipe to produce a hot flame from a candle or alcohol lamp. Portable kits for testing minerals in the field or at home can be bought from dealers, or the individual items can be bought separately. Certain other chemical tests can be made in camp or at home by means of a few inexpensive acids, etc., that can be bought at a drug store, and by using test tubes or even tumblers or old cups and saucers. Care must be taken to have the vessels clean and to keep the chemicals from spilling and away from children. A magnifying glass or 'hand lens' is useful for examining specimens. A list of useful aids to the identification of common minerals is included in an appendix at the end of this book.

Acquiring Further Knowledge

The foregoing notes give only the barest introduction to mineralogy. The best way to gain further knowledge or to refresh what one has learned before is to attend one of the courses available in several parts of Canada. Information about these is given in another chapter. If it is impossible to attend a course, one can obtain good books intended for self instruction, some of which are listed at the end of this chapter. Study of such books should be supplemented by actually handling and testing specimens. Inexpensive sets of minerals and rocks, and small individual specimens, are obtainable from the Geological Survey of Canada, as explained in an appendix. Other specimens can be bought from dealers, such as Wards Natural Sciences Establishment, Rochester, N.Y. Minerals should also be studied in natural outcroppings, where the weathered appearance is commonly quite different from that of the freshly broken specimens available for study in courses or at home.

If one attends a course, minerals for study and methods of identification will be recommended. For those who wish to learn by themselves, another appendix lists minerals that are recommended for first attention, with notes on their distinguishing characteristics. For carrying in the field, or other purposes, separate copies of this table are available from the Queen's Printer, Ottawa, at small cost. A prospector will benefit by learning more minerals than are listed in this table, and he may also make a hobby of collecting and identifying unusual minerals. He should remember, however, that his main objective is to find useful minerals in paying quantities.

Rocks

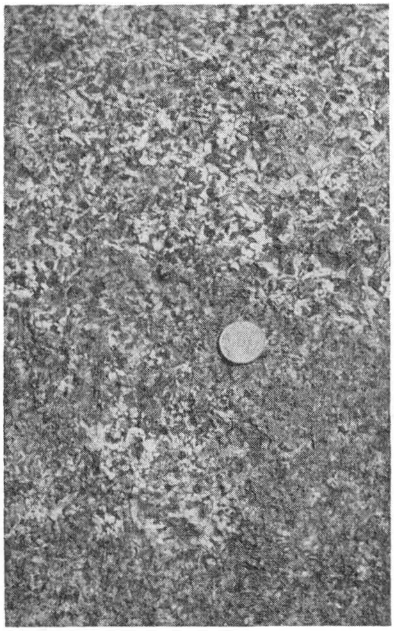
Rocks are substances that form fairly large units of the earth's crust. The distinction between minerals and rocks is that minerals are homogeneous substances that occur as crystals or grains, whereas rocks are aggregates of minerals. They, therefore, occur in relatively large bodies. A few kinds of rock consist of grains of only one mineral; examples are pure sandstone, composed only of quartz, and pure limestone, composed only of calcite. Most rocks, however, consist of fairly evenly distributed grains of two or more minerals. A few rocks, such as coal, consist of organic matter that is not a mineral by strict definition.

In an academic sense, large bodies of liquids, snow, ice, sand, gravel, and clay are rocks, but for practical purposes they may be disregarded in this connection. With this reservation, rocks are divided into three main classes called *igneous*, *sedimentary*, and *metamorphic* rocks. Much has already been said, in the preceding chapter, about the origin of igneous and sedimentary rocks; in the following sections the characteristics and classifications of the principal kinds of igneous and sedimentary rocks will be discussed. No mention was made of metamorphic rocks in the previous chapter because they are a special class formed from igneous or sedimentary rocks that have undergone certain changes.

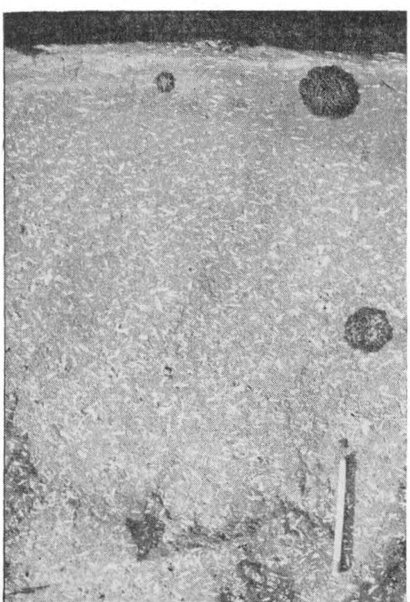
Plate XX

A. Diorite (lower) intruding granite (upper). Note the finer grained texture of the diorite close to the granite, caused by chilling against it.

B. Lamprophyre dyke intruding granite.



C. Diabase, coarser grained than usual.



D. Dyke of feldspar porphyry.

It is customary for geologists to use fairly simple classifications that can be used in the field by ordinary observation or by use of a pocket lens or by a few easy tests, and also to use if necessary more detailed classifications that can be applied only after laboratory studies such as chemical analyses or examinations with a microscope have been performed. Field classifications suffice for most prospecting and for understanding the essentials of most geological reports; therefore, they are the only ones discussed here.

Igneous Rocks

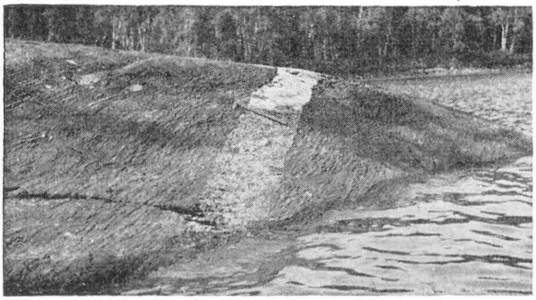
Almost all igneous rocks are crystalline. As explained previously, they result either from the cooling of liquid 'magma' introduced into the crust from below, or from the melting or near melting of other rocks. Most of the mineral grains that crystallize in this way do not get a chance to form crystal outlines because they grow against one another and so form interlocking grains with irregular outlines. In some instances, however, crystal faces develop. In most igneous rocks the common rock-forming mineral is one of the feldspar family of minerals, generally accompanied by smaller amounts of quartz. Other common rock-forming minerals are those containing iron and magnesium, called ferro-magnesian minerals, such as hornblende, pyroxene, and biotite; these minerals are dark coloured. There are also many 'accessory minerals', such as magnetite, which may occur in almost any kind of igneous rock in small amounts that do not affect the classification of the rock. It is customary to class as *acid rocks* the igneous rocks composed mainly of feldspar or quartz, with few or no grains of ferro-magnesian minerals. Conversely, rocks containing much ferro-magnesian material are called *basic*. These are unfortunate terms because they are widely used in another sense in chemistry. More appropriate terms are *siliceous*, for rocks containing much quartz or feldspar, and *femic* or *mafic* for the ferro-magnesian rocks.

Separate classifications are used for the 'plutonic' rocks that form stocks and batholiths, for the 'dyke' rocks that form dykes, sills, and small irregular intrusive masses, and for the 'volcanic' rocks that form at the surface of the earth. However, because these different kinds of igneous rocks all come from the same sources, the compositions are related. For example, the same molten material would produce granite if it crystallized coarsely as a stock, or aplite if it crystallized finely as a dyke, or rhyolite if it crystallized finely as a flow of lava. The mineral composition would be the same in all three cases, but the grain size or *texture* would be different. The *structure* might also be different; this term refers to the arrangement of the mineral grains, which may be scattered, as in an ordinary granite, or banded as a result of flowage in some lavas. The use of the word 'structure' for these internal structures of rocks must not be confused with large-scale structures such as folds and faults.

Plutonic Rocks

These are relatively coarse-textured rocks in which the grains can usually be seen with the unaided eye, as in granite, with which everyone is familiar. Plutonic rocks are classified primarily according to the amount of feldspar and quartz they contain, and the groups are further subdivided into numerous varieties based on distinctions that can be made only by use of a microscope or of chemical analyses. For field purposes it is sufficient to use the following classification.

Granite is a relatively light-coloured rock composed mainly of feldspar, and containing enough grains of quartz to be seen with the unaided eye or with a pocket lens. Many granites also contain relatively small amounts of white mica,

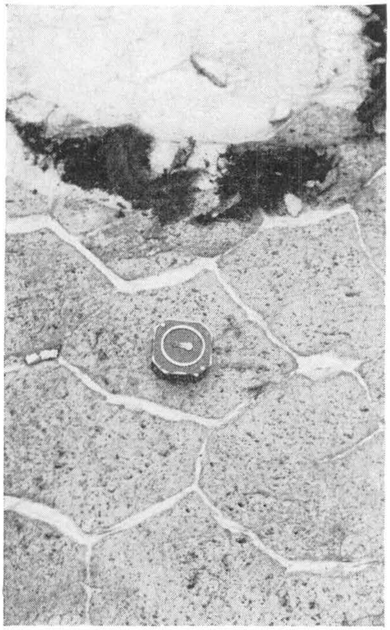


A. Pegmatite dyke intruding schist.

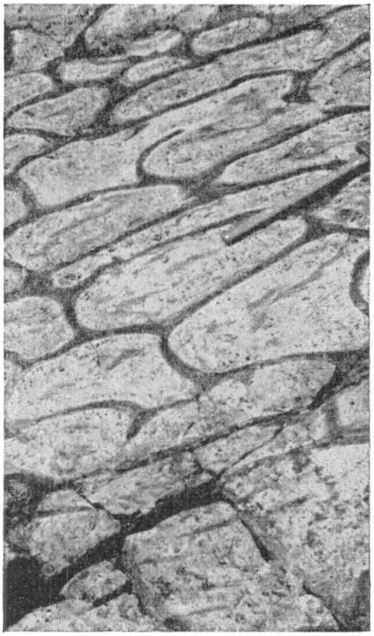
B. Pegmatite dyke intruding sandstone (dark grey). The dyke has been faulted, and an aplite dyke, marked by the hammer-head, was afterwards intruded along the fault.

Plate XXI

C. Rhyolite lava containing polygonal fractures filled by small veins. Such fractures are caused by shrinkage of the lava during cooling.



D. Pillows in greenstone.



biotite, or hornblende. If the rock contains relatively large crystals scattered in a matrix of ordinary granitic material it is called *granite porphyry.*

Syenite is a relatively light-coloured rock composed mainly of feldspar. Little or no quartz can be seen with a lens. If it contains crystals of feldspar in a medium-textured syenitic matrix it is called *syenite porphyry.*

Diorite is a fairly dark-coloured rock composed mainly of plagioclase feldspar with fairly large amounts of one of the amphibole family of minerals—commonly hornblende—or one of the pyroxene family of minerals. If the rock includes relatively large crystals in a dioritic matrix it is called *diorite porphyry.*

Gabbro is a dark-coloured rock composed mainly of one of the amphibole or pyroxene family of minerals, together with considerable plagioclase. Gabbro generally contains from 40 to 70 per cent amphibole or pyroxene. As plagioclase is light coloured and the amphiboles and pyroxenes are dark, diorite and gabbro can be roughly distinguished in the field by estimating the proportion of light and dark minerals, diorite containing about 20 to 40 per cent dark minerals, and gabbro about 40 to 70 per cent. If the rock contains relatively large crystals in a medium-textured gabbroic matrix it is called *gabbro porphyry.*

Ultrabasic plutonic rocks consist entirely or almost entirely of dark ferromagnesian minerals, with little or no plagioclase. There are several varieties, such as peridotite, pyroxenite, and hornblendite, but these may be difficult to distinguish in the field, so it is sufficient to group them as 'ultrabasic rocks'.

Dyke Rocks

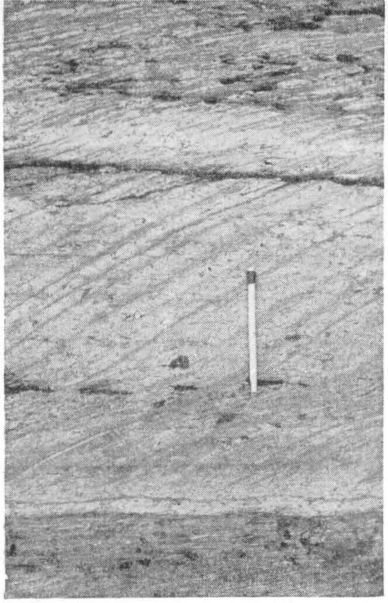
Ordinary dyke rocks are similar to granites or other plutonic rocks except that they are finer grained, because, occurring in smaller bodies, they cooled and crystallized more rapidly. The dyke rock equivalent in composition to granite is called *aplite,* which is usually a pink or red rock with a sugary appearance, in which grains of quartz can be distinguished by eye or with a lens. The equivalent of syenite is called *felsite,* a dense pink or grey rock in which no quartz can be seen. The equivalents of diorite, gabbro, and ultrabasic plutonic rocks are fine-grained dark-coloured rocks, generally called *lamprophyre,* but sometimes called *trap,* or *gabbro* if equivalent to gabbro in composition. Many examples of dyke rocks about equivalent to gabbro have a peculiar arrangement of small lath-shaped crystals, called *diabasic texture*; such rocks are commonly called *diabase.*

Besides occurring as even-textured rocks, many of the above-mentioned classes of dyke rocks may contain distinct crystals in a fine-grained matrix. These are *porphyries,* differing from granite porphyry, etc., in the finer texture of their matrices. Such porphyries are generally named according to the composition of the large crystals or *phenocrysts*; common examples are *quartz porphyry, feldspar porphyry,* and *hornblende porphyry.*

Another common kind of dyke rock is *pegmatite,* a coarse-grained rock formed under special conditions that permitted the growth of large mineral masses or crystals. The commonest examples are *granite pegmatites,* composed essentially of large masses of feldspar and quartz, from about ½ inch to 1 foot or more in diameter; they may also contain crystals of mica, apatite, and many other minerals. More rarely, pegmatites are encountered whose compositions correspond to syenite, diorite, or gabbro.

Volcanic Rocks

Flows of lava correspond in composition to one or other type of plutonic rock. Those equivalent to granite or syenite are light in colour and are called respectively *rhyolite* and *trachyte.* Dark-coloured lavas equivalent to diorite or gabbro are called *andesite* and *basalt* respectively. A flow of andesite or basalt



A. Fracture cleavage in a bed of tuff. Note that the bedding is horizontal, and the cleavage developed by pressure is at about 45 degrees to the bedding.

B. Volcanic breccia or agglomerate, overlain by tuff.

Plate XXII

C. Conglomerate. This is a fairly young formation of Triassic age, therefore the matrix tends to weather away and to free the pebbles and cobbles. In older conglomerates, such as those of Precambrian age, the matrix is usually recrystallized so that it and the pebbles form a hard rock that weathers or fractures across the pebbles instead of around them.

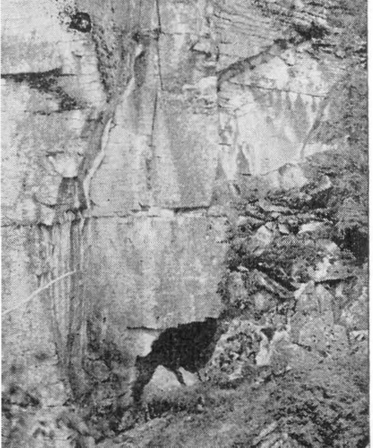
D. Fractures in sandstone. Note the three directions of fracturing.

A. *Shale, of a variety a little harder and more slabby than usual.*

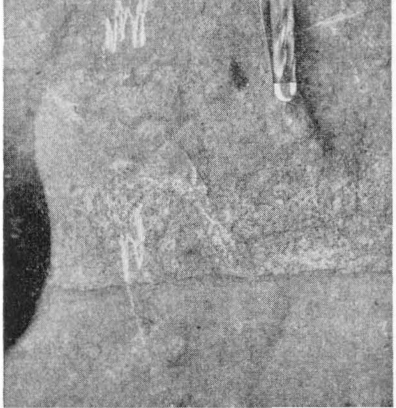
B. *Limestone, showing irregular weathered surface caused by variations in composition of the rock.*

Plate XXIII

C. *A cliff of dolomite. Outcrops of limestone may have a similar appearance.*



D. *Coarse and fine greywacke, interbedded.*



may consist of rounded masses called *pillows* that result from the manner in which semi-consolidated lava may become segregated to form these characteristically shaped masses (*see* Plate XXI D). Lavas may be even grained or porphyritic; the latter are generally called *rhyolite porphyry*, *andesite porphyry*, etc., but may also be designated by the composition of the phenocrysts, as *quartz porphyry* or *hornblende porphyry*.

Volcanic explosions may shatter lava that has crystallized in the throat of a volcano, causing the ejection of large angular fragments, or small ones called volcanic ash. Such material is deposited in beds either on dry land or after it has fallen on bodies of water. Rocks formed in this way are called *clastic* rocks, meaning 'broken'. Those formed from volcanic ash are called *tuff*, and those containing larger fragments are named *volcanic breccia* or *volcanic agglomerate*; they are distinguished according to their compositions, as *rhyolite tuff*, *andesite breccia*, etc. In a sense, these rocks are sedimentary but they are distinguished from ordinary sedimentary rocks because of their volcanic origin.

Sedimentary Rocks

The processes by which sediments are produced by erosion and deposited on dry land or under water have already been discussed. Such sediments become gradually compacted by the weight of overlying material, and the grains may be cemented together by silica, calcium carbonate, or other compounds crystallized from impurities dissolved in water that percolates between the grains. In these ways sediments become solid sedimentary rocks, which are classified according to the size and composition of their grains.

The coarsest sedimentary rocks, formed from gravels containing pebbles or boulders, are called *conglomerate*. Somewhat similar rocks, containing large angular fragments such as are formed by rock slides, are called *agglomerate*. Rocks composed of small rounded particles no larger than peas, but not as small as ordinary grains of sand, are called *grit*.

Rocks formed by the consolidation of sand are among the commonest of sedimentary rocks. Fairly pure sand composed almost entirely of quartz grains forms *sandstone*. If the grains are very small the rock is called *siltstone*. If grains of feldspar are fairly abundant the rock is called *feldspathic sandstone*, but if feldspar predominates, it is called *arkose*. Sands containing large amounts of ferro-magnesian minerals as well as feldspar, such as result from erosion of diorite or gabbro, produce *greywacke*. Sands deposited at the same time as volcanic activity took place nearby are commonly mixed with volcanic ash, and when consolidated they form such rocks as *tuffaceous sandstone* or *tuffaceous greywacke*.

Finer grained sediments, chiefly muds and clays, produce *shales*. These are generally thinly bedded grey or black rocks that are fairly soft and brittle; small slabs that are easily detached from outcrops can usually be broken between the fingers.

Most water, whether fresh or in the sea, contains considerable calcium carbonate in solution, along with other chemical compounds. Under favourable chemical conditions these compounds are expelled from solution to form soft sediments that may become hardened into rock. *Limestone*, formed from calcium carbonate, is the commonest of such sedimentary rocks. It is fairly soft, generally white or grey in colour, although it may be black, and its weathered surfaces commonly have a characteristically rough and pitted appearance owing to the fact that calcium carbonate is slowly soluble in rain or other water. Some limestones, particularly if impure, are difficult to identify by eye but the fact that they effervesce readily if a drop of weak acid is applied aids in their identification. Almost as common as limestone is *dolomite*, composed mainly of magnesium carbonate. Dolomite resembles limestone, but can usually be distinguished from it by the fact that it does not effervesce readily when weak acid is applied; if a little of the rock is powdered or scratched with a knife, it will effervesce.

Metamorphic Rocks

When pressure or heat, not sufficient to cause melting, is applied to a deeply buried rock its constituent minerals recrystallize. They may crystallize as the same mineral but in grains of different size or orientation, or new chemical compounds that are more stable under the new conditions of pressure or heat may form. Rocks transformed in this way are called *metamorphic*. In true metamorphism, no appreciable material is introduced or taken away during the process. Other kinds of rock alteration, by which material is added or taken away, are mentioned later in connection with ore deposits.

Rocks that consist mainly of quartz, feldspar, or calcite recrystallize to form uniform, massive rocks. In this way sandstone becomes *quartzite*, and limestone becomes *crystalline limestone* or *marble*. Shale becomes *argillite*, or *slate* if the rock splits along planes independent of the bedding. Ferro-magnesian minerals tend to form platy minerals such as biotite and chlorite, and grains of these become oriented parallel with one another to form banded or foliated rocks. If the rock is still quite hard and firm, but composed of thin alternating bands of siliceous and ferro-magnesian minerals, it is called *gneiss*. It is common to distinguish between *paragneiss*, produced by metamorphism of impure sandstone, arkose, or greywacke, and *orthogneiss* produced from plutonic rocks. Metamorphic rocks in which soft platy minerals like mica and chlorite predominate are called *schist*, which usually results from extreme metamorphism of shales or igneous rocks. Flows of andesite and basalt, and tuffs of like composition, are commonly metamorphosed to form greenish rocks composed largely of chlorite, to which the general term *greenstone* is applied.

Further Considerations Regarding Rocks

Rocks can be subdivided into almost innumerable varieties because, unlike most minerals, the types grade into one another. The types mentioned above are about all that can be recognized without special tests, and the ability to distinguish these is all that the most competent prospector would require except

A. *Slate. Note that the cleavage, or direction in which the rock tends to split, is approximately parallel with the plane of the photograph, whereas the bedding is parallel with the left side of the quarry.*

Plate XXIV

B. *Granite-gneiss, common in many parts of the Canadian Shield.*

in special cases such as might arise if he were searching for additional bodies of a particular ore known to occur in a very narrowly defined type of rock. In such a case he could take special steps to familiarize himself with the rock concerned.

One cannot learn to recognize the common rocks merely by reading about them. The best way is to attend a course, when instruction and specimens will be provided. If this is not possible, specimens can be bought at small cost, as explained in Chapter XIV and Appendix V. Tables to assist in the recognition of the common rocks are included as an appendix, but the serious student of prospecting who cannot attend a course will be well advised to use one or more of the following popular books as additional aids to his study of specimens. He should also familiarize himself with the appearance of rocks as they occur in the field, because specimens almost always exhibit only fresh surfaces, but outcrops are weathered and are commonly quite unlike the fresh rock that is sometimes difficult to expose even after considerable picking or hammering. Also, some kinds of rocks are easier to recognize from a weathered outcrop than from a fresh surface.

Suggestions for Additional Reading

Pough, F. H.: A Field Guide to Rocks and Minerals; Houghton Mifflin. Price about $4.

Dana, E. S., revised by C. S. Hurlbut, Jr.: Minerals and How to Study Them; Wiley and Sons, New York, 3rd Ed., 1949. Price about $4.

Miller, W. G., revised by Parsons, A. L.: Minerals and How They Occur; Copp Clark Co. Ltd., Toronto, 2nd Ed., 1928. Price about $1.25.

Pirsson, L. V.: Rocks and Rock Minerals; 3rd Ed., 1947, revised by A. Knopf; Wiley and Sons, New York. Price about $4.

CHAPTER IV

MINERAL DEPOSITS

Minerals occur in two principal ways: (1) as normal components of rocks, either as the essential rock-forming minerals or as the 'accessory' minerals that may be present in small amounts evenly distributed through the rock, and (2) as concentrations in rocks. Such concentrations are of many different kinds, shapes, sizes, and origins. Their one common characteristic is that they are all local concentrations distinct from the rock in which they are found. Small concentrations of minerals are usually called *mineral occurrences*, and larger ones are usuallly called *mineral deposits*, but the terms may also be used interchangeably when the question of size is not involved, as in the heading of this chapter. The prospector must learn to distinguish between small mineral occurrences, which are fairly plentiful, and *prospects*, which are mineral deposits having some prospect of being of commercial size and mineral content.

Mineral deposits are of many classes and modes of origin. It is customary to regard them as comprising the metalliferous and non-metalliferous deposits and also the mineral fuels. The latter are concentrations of coal, oil, and natural gas, and are treated separately. Metalliferous deposits are those containing minerals of interest for the extraction of one or more metals. Such minerals are sometimes called 'metallic', but it is preferable to restrict that term to minerals having metallic lustre, whereas some important metal-bearing minerals such as scheelite do not have such lustre; therefore, the term 'metalliferous' is used as a more inclusive word for describing deposits of possible interest for metals. The name 'industrial minerals' is now customarily used to describe the large group of deposits that includes concentrations of non-metalliferous minerals such as asbestos and mica, as well as unconsolidated sediments, sedimentary rocks, and igneous rocks that are useful in industry, and such rocks may be regarded as special classes of mineral deposits. Unlike metalliferous deposits, industrial deposits are generally valuable because of the properties of the mineral or rock itself.

Most prospectors are concerned mainly with searching for metalliferous deposits, therefore the following discussion of the principal geological types of deposits and their origins deals principally with these deposits. Several of the types described also yield industrial minerals. It should be borne in mind that although it is very useful to classify deposits, as an aid in understanding and describing them, some deposits are 'border-line cases' that do not fit definitely into the scheme of classification. Also, the manner in which some deposits were formed is not yet known definitely. Therefore, prospectors should not be too concerned about the exact classification of every discovery, unless this is fairly obvious, because the size of the deposit and the quality of assays or minerals obtained from it are the most vital considerations.

Types and Origin of Deposits

Few deposits consist of a single mineral. They usually contain one or more minerals that may be of value, in a worthless matrix of rock or of concentrations of valueless minerals. The valuable or possibly valuable minerals may be dispersed so finely that they can be seen only under a microscope, or they may be in grains visible to the unaided eye, or they may be in pure masses several inches or even feet in size. These are sometimes called *ore minerals* even if they do not occur in commercial quantities in the particular deposit being discussed. The worthless non-metalliferous rock or minerals accompanying the ore minerals is called *gangue* and the minerals comprising it are called *gangue minerals*. The most common gangue minerals are quartz and calcite, but many others such as dolomite, feldspar, and chlorite may be present. Valueless metalliferous minerals in a deposit are also sometimes referred to as gangue minerals.

Metalliferous deposits are of many kinds and they can be classified in several different ways. It is sometimes desirable to group them according to the metal contained, but this is often unsatisfactory because many deposits contain two or more useful metals. In connection with prospecting it is best to classify deposits according to their manner of origin because this influences the selection of suitable localities for prospecting.

It is convenient to divide deposits first into what are called *primary* and *secondary* deposits, and then to divide the primary deposits into several categories. Primary deposits are regarded as those still in the original form, and secondary deposits are those that have been derived from the alteration of primary ones and that have not been transported far from the primary source. This is a very useful distinction, but it may not be entirely accurate; to explain this reservation it is necessary to discuss briefly the principal theories regarding the origin of metalliferous deposits.

Few kinds of metalliferous deposits can be observed in process of being formed. Almost all were formed during some long-past geological period, at great depth beneath the surface, and are now found at or near the present land surface because erosion has bared them or brought the present surface relatively close to them (*see* Figure 5). Laboratory experiments help to provide information on the origin of certain kinds of deposits but they fall far short of reproducing the actual conditions under which the deposits were formed. Therefore, reliance has to be placed largely on indirect information.

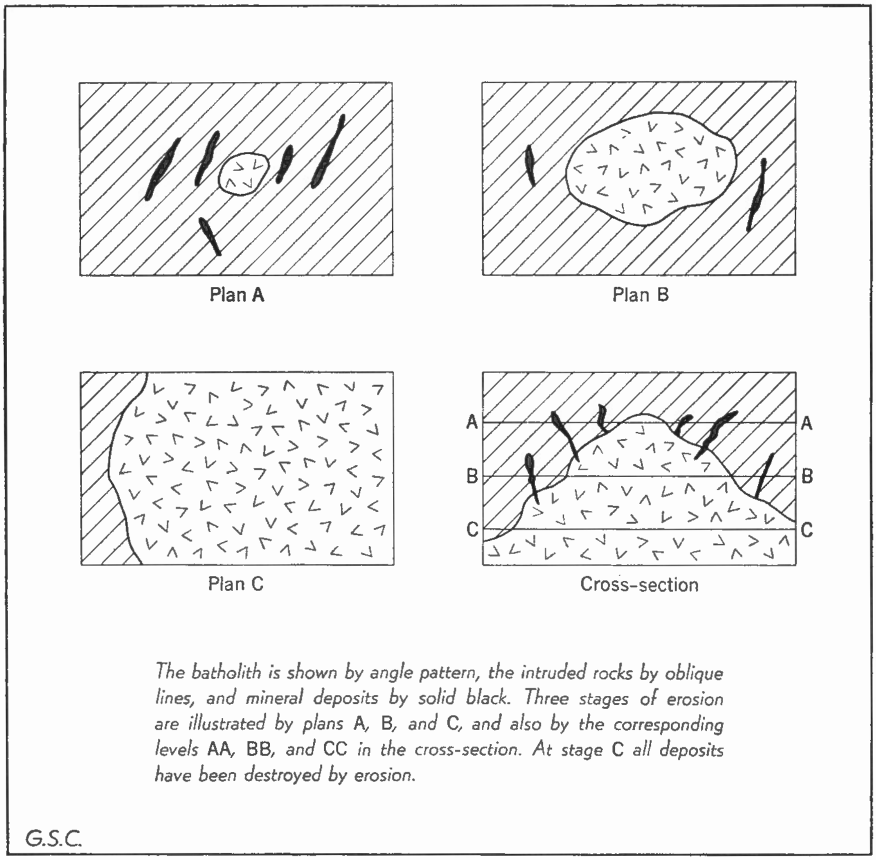


FIGURE 5. Diagram to illustrate stages in the erosion of a batholith and its related mineral deposits.

There is no doubt that many metalliferous deposits owe their origin to igneous intrusions. Some deposits occur in the upper parts of stocks and batholiths, and many others are in the invaded rocks at the igneous contacts or fairly close to them (*see* Figures 5 and 6). This relationship has been observed in so many places that almost all geologists today agree that the origin of these deposits is related in some way to the intrusive rocks. Furthermore, innumerable analyses of igneous rocks from different countries prove these rocks to contain minute amounts of metals, even such comparatively rare ones as gold, silver, etc. Many kinds of deposits are therefore regarded as concentrations of metallic minerals derived from such intrusives, some by crystallization of late phases of the intrusion itself, and some by hot solutions or gases that were expelled from the intrusion and that carried the metal or metals along with them in a liquid or gaseous state. It was formerly believed that all igneous rocks resulted from crystallization of a molten magma introduced into the earth's crust from below. This gave rise to the concept of primary deposits, that is, those in their original

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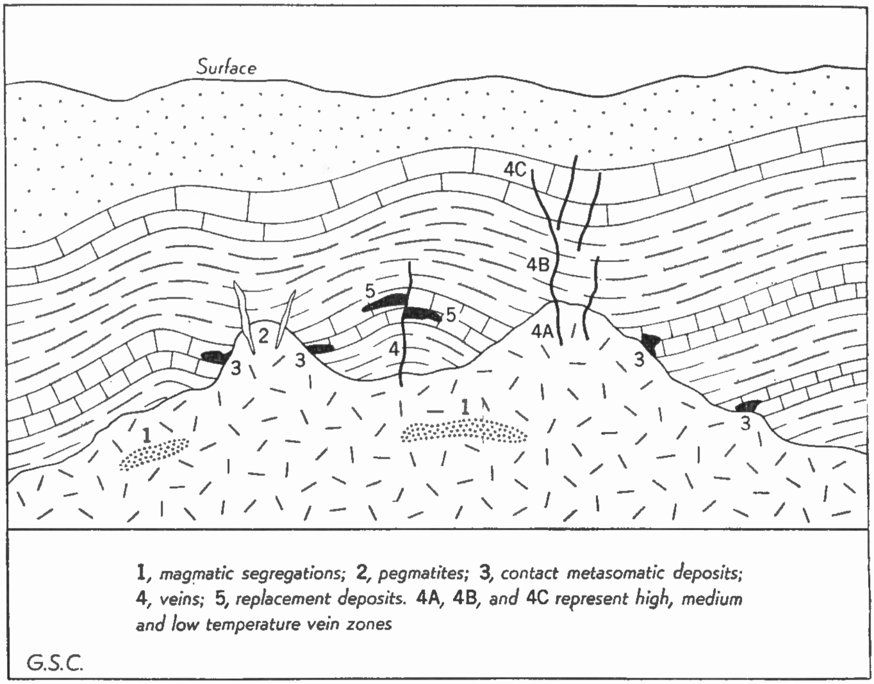

FIGURE 6. Diagram illustrating mineral deposits related to igneous intrusion.

state of deposition. Now, however, there is strong evidence that at least some igneous rocks are formed either from a magma that originated from the melting of sedimentary or other rocks in the crust, or from recrystallization of such rocks without actual melting. If so, any metals contained in intrusive rocks so formed or emanating from them would probably have been previously in the crustal rocks that were transformed into igneous rocks. Furthermore, solutions emanating from a magma may dissolve and redeposit metalliferous minerals originally contained in the crustal rocks lying above the intrusive body even though these were not converted into igneous rocks. Mineral deposits formed in these ways are not, strictly speaking, primary, but it is convenient to regard them as primary because they are so different from those classed as secondary.

Other important deposits are formed as sediments derived from the weathering or erosion of rocks containing small amounts of metalliferous minerals or containing mineral deposits. Such sedimentary deposits are not strictly primary, but it is convenient to include them in the broad primary category. Primary deposits may, therefore, be divided into two main groups called: (1) deposits related to intrusions, and (2) sedimentary deposits; certain others do not seem to belong to either of these groups.

Deposits Related to Intrusions

The principal kinds of deposits directly related to igneous intrusions are magmatic segregation deposits, contact metasomatic deposits, pegmatites, and some veins, and replacement deposits. Many metalliferous deposits belong to one or other of these categories, of which veins and replacement deposits are the most important. They are, however, not discussed in order of importance, but instead, those that are most directly related to igneous rocks are described first.

Magmatic Segregation Deposits

Certain deposits found in batholiths, stocks, and sills (*see* Figure 6) are concentrations of accessory minerals such as magnetite and ilmenite or of uncommon minerals like chromite. Some such concentrations may form at the time of crystallization of the main body of rock, but most appear to have developed later than the main rock. In these cases the ore minerals probably remained in a molten part of the body until after some of the igneous rocks had crystallized, and later formed injection or replacement bodies in the earlier-formed rock. Certain of the deposits, therefore, possess some characteristics of replacement deposits, but it is convenient to regard them as magmatic because the important consideration is that deposits of these kinds will be found within intrusive bodies and they will have, more or less, the characteristics of the intrusive rocks themselves.

Examples of magmatic segregation deposits are certain concentrations of magnetite, titaniferous magnetite, and ilmenite occurring in granites and related rocks. These deposits are relatively rare compared with the innumerable occurrences of igneous rocks in which magnetite or ilmenite are merely accessory minerals in very small amounts. Deposits of chromite, platinum, diamond, and some kinds of copper and nickel deposits, in gabbro and ultrabasic rocks, are also regarded as members of this class.

Contact Metasomatic Deposits

It was mentioned in Chapter III that some rocks are altered or 'metamorphosed' by the pressure or by the heat of nearby intrusive rocks. Strictly speaking, the term 'metamorphism' refers only to the formation of new, stable minerals by recrystallization of minerals already in the invaded rock, without introduction of additional material. If, during the process, material is added from solutions or gases emanating from the intrusive body, the term *metasomatism* is applied. Metals from the intrusive body may be introduced into rocks altered in this way, in quantities sufficient to form mineral deposits of a type called *contact metasomatic*. These are commonly called 'contact metamorphic' instead, but that expression is not so suitable because it suggests no introduction of minerals to the rock already present.

Water, silica, sulphur, iron, magnesia, or other compounds or elements from the intrusive body are considered to enter pores or fractures in the invaded rock and to react with it to form minerals like garnet, diopside, and epidote. The compositions of the intrusive and of the invaded rocks are important factors in determining the character and extent of the alteration. Limestone and dolomite, for instance, are very susceptible to alteration of this kind, and granitic intrusives commonly cause the alteration.

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The deposits usually lie at the contact and more or less parallel with it. Such deposits are generally very irregular in outline because the alteration proceeds farthest along favourable bands of rock or along zones of fracturing, whereas resistant patches of rock are only slightly altered. Deposits may also be formed in favourable rocks some distance from the contact.

Minerals containing iron, copper, zinc, lead, gold, tin, tungsten, molybdenum, or manganese are sufficiently abundant in some deposits of this kind to form orebodies. Some are large and important, but as a rule they are small and difficult to mine because of their irregular shape and the erratic distribution of the ore minerals.

Pegmatitic Deposits

Pegmatites have been mentioned briefly in Chapter III. They must be discussed more fully here because they form some of the commonest mineral deposits. During the crystallization of magma to form a stock or batholith certain elements and compounds such as water, fluorine, and carbon dioxide become concentrated in the still uncrystallized part of the magma, along with some of the ordinary rock-forming material. Metals and rare elements present may also be included. After the main intrusive body has crystallized and fractures have formed in it, some of this remaining material is injected along the fractures to form pegmatites, both in the stock or batholith itself and in the invaded rocks not far from the contact. Some pegmatites appear to replace earlier rocks, instead of filling simple fractures. The water, fluorine, or other constituents seem to have the power of causing the coarse-grained crystallization so characteristic of pegmatites, which are usually coarser grained than the ordinary intrusive rocks with which they are associated. Some pegmatites contain crystals several feet in size. Differences between porphyry and pegmatite are that the former contains scattered large crystals in a relatively fine-grained matrix, whereas most pegmatite consists of coarse material, with only minor patches of fine-grained material, if any, and that the larger mineral units in porphyry always have distinct crystal outlines whereas those in pegmatites do not necessarily have them.

Pegmatites are most commonly associated with granite, and such pegmatites are composed mainly of feldspar and quartz, together with lesser amounts of accessory minerals like mica, apatite, zircon, etc., characteristic of the related granite. These pegmatites are properly called 'granite pegmatite'. Other, less common, kinds such as 'syenite pegmatite', 'diorite pegmatite', etc., have the characteristics of the rocks with which they are associated; for example, syenite pegmatites do not have appreciable amounts of quartz, and diorite pegmatites contain the feldspars and the ferro-magnesian minerals typical of diorite.

Bodies of pegmatite take many sizes and shapes, ranging from short bodies an inch or more in width to great masses more than a mile long and hundreds of feet wide, but most are fairly small. Many are properly called dykes, although few of these are as regular in form as the dykes composed of other kinds of rocks.

Plate XXV

A mass of pegmatite (white) containing crystals of phlogopite mica (black).

Others occur as sills and as irregularly outlined masses. Still others form narrow, more or less parallel sheets interspersed between layers of schist or gneiss, forming a special kind of gneiss called *migmatite*. Many pegmatites are composed of zones differing in size of crystals or in mineral content, or both. Many pegmatites have clearly defined walls, but others grade into the wall-rock as though the pegmatitic material had reacted with or replaced the wall-rock. Bodies of pegmatite commonly occur in groups, so that if one is found others probably will occur in the same general locality. Because they are associated with deep-seated intrusive rocks and occur in or near them, they are exposed only in regions that have been eroded deeply.

Pegmatites are widespread but relatively few contain deposits of commercial value. Some are of value because their coarse crystals permit them to be a source of common non-metalliferous minerals like feldspar, quartz, and mica, and some because they contain payable amounts of rarer minerals containing lithium, beryllium, niobium, tantalum, molybdenum, tin, and other elements. These minerals are usually only minor constituents of pegmatites, if they occur at all, and only exceptional occurrences contain enough of them to make mining profitable. Minerals containing uranium or thorium are found in many pegmatites, but rarely in commercial quantities. Gold, and sulphide minerals like pyrite and pyrrhotite, are found sparingly in some pegmatites, but pegmatites are not important sources of these minerals.

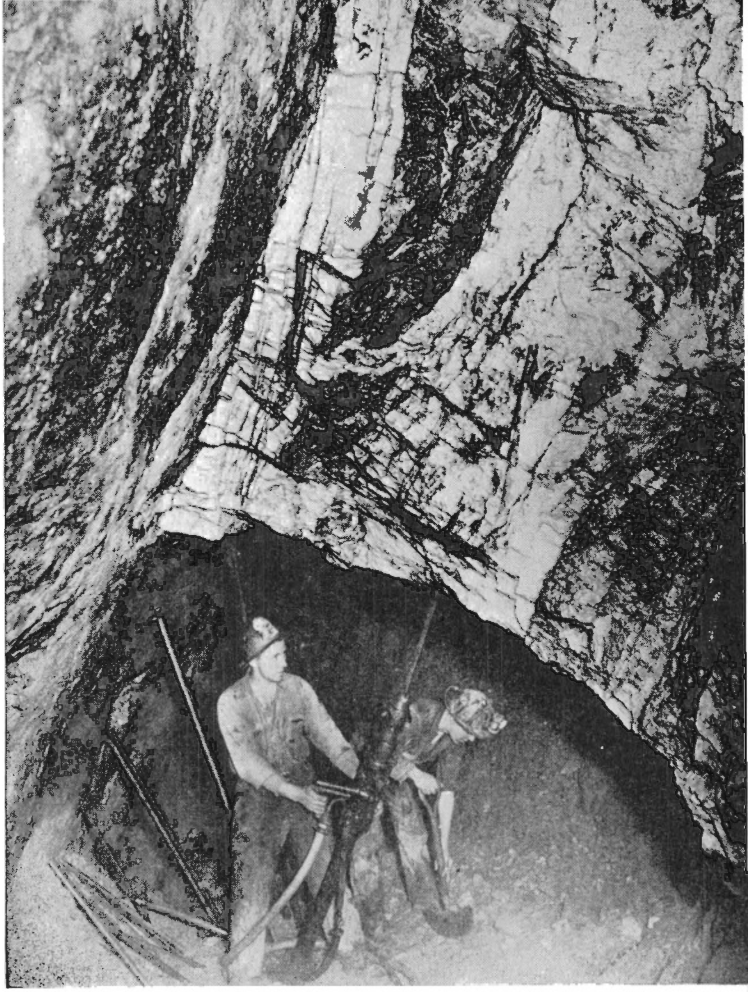
Most pegmatite deposits are relatively small, and even if they are mined for one or more valuable constituents this is usually on a small scale. They are generally mined from the surface, with portable equipment that can be moved to another occurrence when one body has been exhausted. Their main importance as sources of metals is for ones like beryllium and lithium that are not likely to be found in larger and more uniform deposits of other types. When searching for pegmatites containing such metals prospectors should remember that it is relatively easy to find a pegmatite containing an occasional mass or crystal of a mineral containing the metal sought, but that deposits containing commercial quantities are much harder to find. Nevertheless, if only a little of a metal is found in one pegmatite, others in the same region may be investigated carefully in the hope that a worthwhile deposit can be found. In some countries, pegmatites are important sources of gems such as emerald, sapphire, and topaz. Although pegmatites are very common in Canada, important deposits of gems have not yet been found in them, but prospectors should keep in mind the possibility of discovering such deposits.

Veins

Among the most common and most important types of mineral deposits are veins and related deposits. A typical vein is a fairly regular body composed of one or more minerals occupying a fracture or fault and, therefore, narrow in one dimension but fairly extensive in the other two dimensions (*see* Plate XXVI). However, deposits of this general class are formed in openings of many other sizes and shapes. Many are roughly lens-shaped, being fairly short and tapering at the ends. Others, although fairly regular in shape, are too small to be classed as true veins and are called stringers; there is no definite distinction between the sizes of stringers and veins, but it is usual to call them stringers if they are less than an inch or two in width. Many veins or stringers occur individually, but many others are in groups, and are often called *compound veins* or *vein systems*. A series of closely spaced parallel stringers forms a *sheeted vein* and a network of stringers joining one another at various angles forms a *stock-work* (*see* Plate XXVIII). A fault that is marked by a zone of sheared rock may contain veins or lenses, and minerals may also impregnate some of the sheared rock as well; deposits of this kind and those in sheared rocks caused in other ways are called *shear zone* deposits. Some fault zones contain a breccia composed of angular fragments of rock; the open spaces in such zones, and, less commonly in breccias of other kinds such as volcanic breccias, may have minerals deposited in them and form a *breccia filling*. Cavities formed in limestone or other soluble rocks, by the action of percolating surface water, may later have minerals deposited in them to form *cavity fillings*.

Plate XXVI

A large, banded quartz vein.



Some veins and other deposits of this general class contain only one or a few ore minerals; but most contain gangue minerals as well, and gangue minerals are commonly more abundant than the ore minerals. Quartz is the most common gangue mineral. Many veins consist only of quartz, or contain only a few insignificant grains of metalliferous mineral. Others may contain sections called *ore shoots* that will pay to mine, interspersed with material that is too low grade to be profitably mined.

Deposits of the kinds mentioned in the preceding two paragraphs are found where fractures, faults, or other openings provided conditions favourable for mineral deposition, and where metal-bearing solutions or vapours were active. Some deposits seem to have filled an open crack or other space, and some seem to have forced apart the walls of a fissure by pressure. Others show evidence of having partly dissolved and replaced rock in a shear or breccia zone or along the sides of a fissure; thus some deposits of the general 'vein' class have characteristics of the replacement class to be discussed in the next section.

The material filling many deposits of the vein class fairly obviously was derived in some way from igneous magmas, because these veins occur in the border zones of stocks or batholiths, either in the intrusive rock itself or in the invaded rocks not far from the contact (*see* Figures 5 and 6). Furthermore, some veins have been traced into dykes of pegmatite through a gradational change in mineral content. This fact has led some geologists to conclude that veins are really dykes injected in a molten state and then cooled. There is much evidence, however, to show that veins of almost all classes were more probably deposited by solutions composed largely of hot water in which the metals were dissolved, hence such deposits are called *hydrothermal*, which means 'hot water'. These hot solutions and their contained elements are generally believed to originate as the last phases of a cooling magma. Some ore minerals crystallize from solutions at high temperatures, others at moderate temperatures, and some at fairly low temperatures (*see* Figure 6). Some large veins are zoned, with the higher temperature part occurring at greatest depth or closest to an intrusive body. Also, a particular district may contain deposits of one temperature class in one part, and of another class in another part, depending on the distance from the intrusive source. Minerals crystallize from solutions when and where a sufficient degree of cooling or release of pressure takes place, and also where the chemical balance is destroyed by the presence of wall-rocks of certain chemical compositions. The nature of the wall-rocks, therefore, has an effect on the location of ore shoots in certain deposits.

Some veins may be deposited by waters from the surface, instead of by water actually derived from an igneous magma at depth. Water from the surface may percolate through pores or cracks in the upper part of the crust, dissolving small amounts of metals contained in the rocks; if such waters reached sufficient depth they would become warm and might act in the same way as 'hydrothermal' solutions to deposit minerals in open spaces in the rocks. This may account for some veins but it does not seem a plausible explanation for most of them, which were formed at depths where surface waters would not likely penetrate, and which were later uncovered by deep erosion. As illustrated in Figure 5, the present surface may be thousands of feet below the surface that existed at the time a mineral deposit was formed.

Replacement Deposits

Replacement is a process of more or less simultaneous removal by solution of certain parts of a body of rock, and deposition of ore or gangue minerals in their place (*see* Plate XXX). It is not the same as the filling of cavities mentioned above, but a slow piecemeal process by which mineral-bearing solutions work their way through cracks or pores, many of microscopic size, dissolving the nearby rock and substituting other minerals. As has been mentioned, this process is partly responsible for some pegmatite, contact metasomatic, and vein deposits, but it also forms special kinds of deposits, some of which are large and important.

Typical replacement deposits are found in regions where igneous intrusions occur, and these deposits contain minerals similar to hydrothermal vein deposits so they are considered 'hydrothermal replacements'. Almost any kind of rock may be replaced by suitable solutions if openings are available for their passage,

Plate XXVII

More or less parallel stringers of quartz in syenite.

but limestone and dolomite are most favourable. The ore minerals substituted are usually sulphides such as chalcopyrite and galena, and gold or other precious metals may accompany them. The gangue may be unreplaced rock, or minerals such as quartz, carbonates, or chlorite. Rocks containing bands or masses of different compositions are commonly replaced selectively, leaving relatively unaltered the bands that are less favourable for replacement (*see* Plate XXXI). Some deposits contain large masses of ore minerals, and others, called 'disseminated deposits', contain finely dispersed grains of ore minerals in schist or other 'host rock'. The location of the deposits, or of ore shoots in them, is determined in part by the character of the rocks and in part by structural conditions such as contacts, folds, fracture zones, shear zones, and brecciated zones that made parts of the rock favourable for the introduction and circulation of solutions. Replacement deposits are usually irregular in shape and without as clearly defined walls as vein deposits. In many deposits a core containing ore minerals is surrounded by a zone of replaced rock containing certain non-metalliferous minerals characteristic of what is called 'wall-rock alteration'. Recognition of such altered rock sometimes leads to discovery of the ore-bearing core either by further prospecting on the surface or by diamond drilling. Replacement deposits are of

Plate XXVIII

A stock-work of gold-bearing quartz stringers.

Plate XXIX

Gash quartz veins in brittle quartzite, and absent in alternating beds of more plastic argillaceous rock. This illustrates the occurrence of quartz veins in 'competent' hard beds, which may be on a much larger scale.

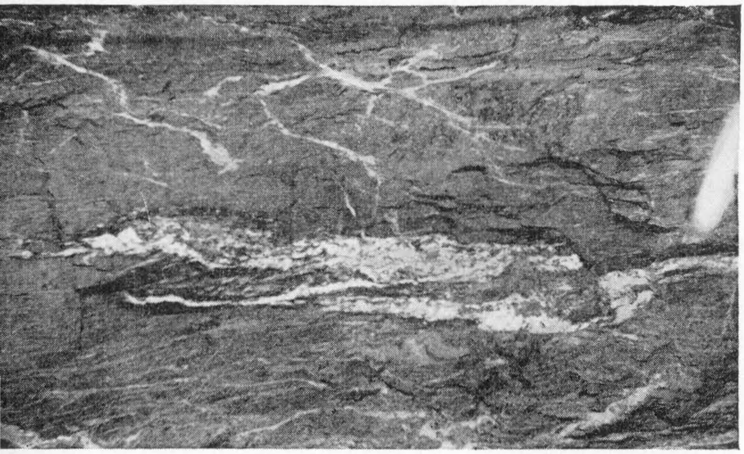


Plate XXX

Vein quartz (white) replacing chlorite schist.

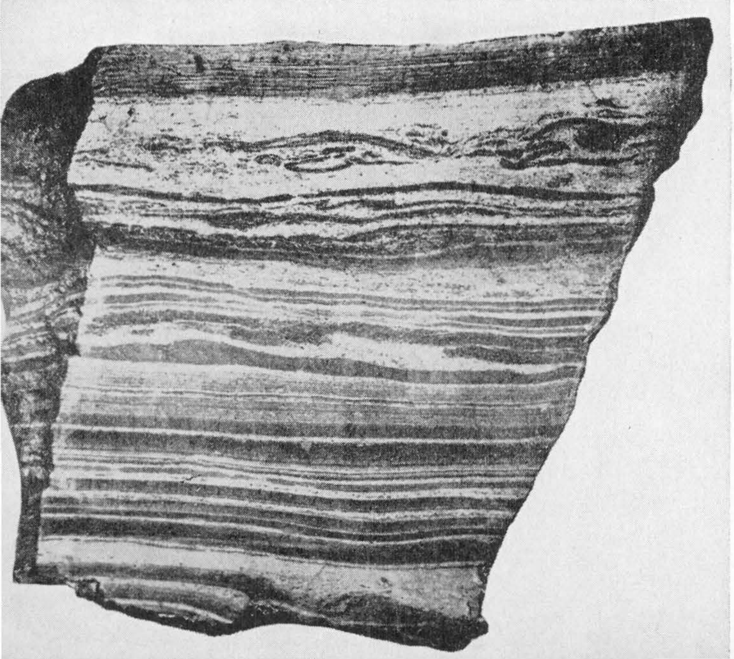


Plate XXXI

Bands of lead-zinc and other sulphide minerals (white to grey) replacing beds of sedimentary rock (unreplaced rock shown in dark grey and black).
Photo about $\frac{2}{3}$ size of specimen.

all sizes, and many are too small or too low in metal content to be minable. On the other hand, some of the largest ones are among the most important copper, lead, zinc, and precious-metal deposits.

Some replacement deposits, including certain very important ones, have been found in regions where there are no exposed intrusive rocks and no other signs of intrusive activity. Some geologists believe that these deposits were formed by solutions derived from underlying intrusive masses that have not been exposed by erosion, because some such deposits are so similar to deposits in other districts where the intrusive relationship seems obvious, that this is the most plausible explanation for them. It is possible, however, that some replacement deposits are formed by cold or warmed water from the surface that travelled through pores or fractures in large amounts of near-surface rocks, dissolving metals present in minute quantities in these rocks and then concentrating them as replacements in favourable places, or that molecules or compounds containing such metals were diffused and concentrated in ways that are not yet well understood. Such a process may also account for the formation of some veins.

Sedimentary Deposits

In ways explained in Chapter II, sediments precipitated from sea water or formed from the erosion of rocks exposed at the earth's surface lead to the formation of unconsolidated sediments that in turn become hard sedimentary rocks. Such sediments and sedimentary rocks may in their entirety be useful commercially, particularly as deposits of industrial minerals; or they may contain concentrations of heavy minerals and thus form 'detrital' deposits.

Detrital mineral deposits are of two main kinds: (1) those that are still unconsolidated and are called 'placer deposits' or 'placers'; and (2) consolidated detrital deposits, which are placers that have been changed into metal-bearing conglomerate, sandstone, or other sedimentary rock, and which, therefore, form one of the classes of consolidated sedimentary deposits.

Placer Deposits

Placers are parts of bodies of sand or gravel containing concentrations of ore minerals derived from the destruction of rocks or mineral deposits. The word 'placer' is believed to have been derived from an old Spanish word meaning 'sand bank'. The lighter and more brittle minerals are seldom concentrated in placers. The minerals that form placers are usually heavy, resistant to chemical decomposition or solution, and so hard and tough that they do not wear easily or split into smaller and smaller fragments. The most important placer minerals are, therefore, gold, platinum, cassiterite, ilmenite, diamonds, and rubies. Magnetite that existed originally as an accessory mineral in igneous rocks is concentrated in considerable quantities to form 'black sand', but such placers are rarely workable as sources of iron. Garnets are commonly found in placers and are often mistaken for rubies.

Several requirements are necessary for the formation and preservation of placers. First, there must have been a supply of valuable minerals in the bedrock or its contained deposits, although these minerals may have been dispersed in small quantities. Secondly, weathering must have gone on for a long time. Thirdly, conditions must have been favourable for concentration. This last condition usually demands a region of hills or mountains to provide streams with sufficient velocity to carry off the lighter products of erosion. The most favourable conditions are in areas where erosion continued for a long time, reducing the land surface to a fairly level state, after which the surface was uplifted and dissected by streams that concentrated the residual minerals lying on the ancient surface. Lastly, the placers must have been preserved. Many placers were doubtless destroyed by later erosion, including glaciation. The effects of glaciation probably account for the fact that workable placers have not been found in the Canadian Shield, although the rocks of the Shield contain many primary gold deposits, the weathering of which doubtless produced placers that were destroyed by glaciation. The prevalence of placers in glaciated parts of the Cordilleran region is explained by the rugged topography that apparently protected many placers from destruction by preventing glaciers from scouring evenly all parts of the surface.

Some placers are formed on the slopes below outcrops of mineral deposits. These are the first stage of placer formation and are not commonly large concentrations because the placer minerals soon are washed into streams. Others are formed along beaches where waves erode rocks or re-work and concentrate glacial gravels or sands containing small amounts of valuable minerals. Most placers, however, occur in stream gravels, generally those deposited in ancient channels rather than in the beds of present streams. The valuable minerals are usually concentrated on or near bedrock at the bottom of the channel, and may be lodged in crevices in bedrock; in some placers, however, 'paystreaks' may occur within the gravel some distance above bedrock. Most valuable placer minerals are in fairly small grains, but in the case of gold, nuggets may be present. Many placers are covered by glacial drift, which makes their discovery and mining difficult. Most placers in the Cordilleran region of Canada are of interglacial or post-glacial ages but some are known or believed to be of Tertiary age. In rare instances placers have been found in Tertiary gravels overlain by Tertiary lava flows.

Consolidated Sedimentary Deposits

Placers formed during early geological periods, if they are not destroyed, become consolidated into beds of conglomerate or sandstone containing detrital deposits of magnetite, gold or other minerals. Certain deposits have undoubtedly been formed in this way. Several other important deposits may have originated in this way, but the evidence regarding them is not conclusive. For example, the gold ores in Precambrian conglomerates in South Africa, which are the world's principal source of gold, were at first believed unquestionably to be consolidated placers. It has been shown more recently, however, that at least some of the gold and other metalliferous minerals that accompany it were probably deposited after the rock was consolidated. As can well be imagined, the importance of these deposits has caused endless investigation of this problem, but despite the efforts of many eminent authorities, it is not yet certain whether the ore minerals were introduced hydrothermally to form deposits that have only an accidental resemblance to placers, or whether the gold passed through a placer stage and was later dissolved and slightly rearranged. Much the same problem arises in attempting to explain certain other deposits of gold, uranium, and other metals. It is not difficult to distinguish those that are definitely of detrital origin if the ore minerals are not too finely dispersed to be seen with a microscope, because detrital grains are either rounded from the wear of transportation by water or are split into angular fragments, whereas minerals introduced by solutions show interlocking crystal structure or other characteristic microscopic textures and relationships. On the other hand, a deposit that existed once as a placer and then was recrystallized, and whose ore minerals in this process may also have been moved a short distance from their resting place in the placer stage, would be difficult or impossible to distinguish from one whose ore minerals were introduced by hydrothermal solutions from an igneous source. It is important for geologists to try to solve these problems because ore shoots or additional deposits might be found under quite different sedimentary or structural conditions depending on whether the ore minerals were concentrated as placers or by solutions.

Other deposits found in sedimentary rocks are formed as chemical precipitates in basins of water at the earth's surface. Certain iron deposits form the most common metalliferous examples. What are called 'bog iron' deposits can be seen in process of formation today in some districts. They are formed where water percolating through rocks dissolves iron and issues as springs in or near bogs containing carbonaceous material that reacts chemically with the iron-bearing solutions to cause the formation of limonite, which settles to the bottom of the bog. Deposits of this kind are found in Canada, particularly in the St. Lawrence valley of Quebec where many years ago they supplied the ore for Canada's first iron industry.

Extensive sedimentary beds composed of iron minerals and silica are found principally in Precambrian and Palæozoic strata, and these are called 'sedimentary iron-formation'. The iron and silica were evidently deposited chemically from sea water at the time the sediments that produced the rocks with which they are interbedded were laid down. In one type, iron compounds combine with silica to form small rounded pellets called 'oolites'. Another type consists of thin layers of hematite and magnetite interbedded with layers of silica. Most deposits of the latter type are too low in iron content to be workable except where they have been enriched by the action of circulating solutions that extracted iron from certain parts of the deposits and concentrated it in others, or which carried away much of the silica, thus indirectly increasing the iron content. Prospecting for deposits of this kind is done by first looking for iron-formation and then searching it for parts that are low in silica and high in iron; this is judged by the appearance and proved by analyses.

Secondary Deposits

Almost all metalliferous minerals lying at or near the surface are altered by the effects of surface water that attacks them and causes the formation of new ones, generally oxides or hydroxides (compounds composed of a metal plus hydrogen and oxygen). These new minerals are called *supergene* or *secondary* minerals, and deposits composed of them are called *supergene* or *secondary* deposits. Some minerals containing metals, such as copper, iron, and uranium, are readily attacked by surface waters, others are less susceptible, and a few like gold and platinum are so resistant that they do not form compounds in this way. Deposits containing secondary iron minerals have a characteristic rusty appearance and are called *gossans*.

Most supergene deposits found in Canada contain only small amounts of secondary minerals such as limonite, malachite, cobalt bloom, and secondary uranium minerals, extending for a few inches or a few feet below the surface, but in exceptional cases secondary minerals have been found in mines at 500 feet or more below the surface. As a rule, the altered parts of the deposits contain both secondary minerals and some of the original minerals, and although the total metal content is not exactly the same as in unaltered parts of the deposit it is usually not greatly different. Therefore, at most Canadian deposits the secondary effects have only a minor influence on the value of the deposit. The main significance of secondary minerals formed in this way in Canada is that they are often important clues in prospecting for primary deposits. Small amounts of secondary minerals may stain a fairly large area and thus make detection of a deposit easier, and some secondary minerals are brightly coloured. In this connection there are three points to remember. One is that the secondary minerals may occur a short distance from the unaltered deposit, not necessarily immediately above it. Another is that many secondary minerals are soluble in water and may be removed from the actual surface of an outcrop by rain or other moisture, so that it is often necessary to pick into an outcrop to find them; they may be preserved as fillings in narrow fractures or cavities. Lastly, it must be remembered that a very small deposit or a larger one having an unimportant metal content may produce a spectacular display of secondary minerals, hence a conspicuous gossan or other secondary deposit does not necessarily indicate that an important primary deposit exists.

Alteration may also cause the removal of valuable metals from the upper part of a deposit, so that sampling of this part yields misleadingly low assays or fails to detect a particular metal at all. The metal so removed may be dispersed, or it may be concentrated in a lower part of the deposit to form what are called 'zones of secondary enrichment' or *bonanzas*, which rarely extend to great depths. Bonanzas are not common in Canada, apparently mainly because of glacial erosion that must have removed the altered parts of many deposits. Also, the fairly cool climate of this country may have retarded the chemical action between surface water and minerals, and thus caused conditions more unfavourable for the formation of bonanzas than those that prevailed in warmer countries. The possibility of impoverishment or enrichment cannot be ignored, however, particularly by engineers or geologists engaged in the examination of prospects.

Suggestions for Additional Reading

Bateman, A. M.: The Formation of Mineral Deposits; Wiley, 1951.
Price about $5.50.

An authoritative and up-to-date book written for laymen and beginning students.

Lindgren, W.: Mineral Deposits; 4th Ed., McGraw-Hill, 1933. Price about $8.

This and the following book are among the many standard advanced textbooks on the geology of mineral deposits that may be used as references by experienced prospectors.

Bateman, A. M.: Economic Mineral Deposits; 2nd Ed., Wiley, 1950.
Price about $7.50.

Fuels

The principal fuels are wood, coal, petroleum, and natural gas. All but wood are classed as *mineral fuels* because they are produced from rock formations, but they are not minerals as defined in Chapter III.

Coal, petroleum, and natural gas accounted for about 25 per cent of the total value of Canada's mineral production in 1953. This amounted to about $102 million for coal, $197 million for petroleum, and $11 million for natural gas. In spite of the great importance of these products only a little space is devoted to them in this publication because there is not much demand for additional coal discoveries at present, and because prospecting for petroleum and natural gas is so specialized that it is beyond the scope of ordinary prospecting. Therefore, the following passages are only brief outlines of these topics to provide general information for those who are interested.

Coal

Coal is formed from an accumulation of vegetable matter in previous geological periods. Every gradation between hard coal, soft coal, woody coal, and peat has been recognized, and many coals contain the imprints of leaves, ferns, and other vegetable forms. The vegetation grew in swamps of fresh or brackish water, accumulated at the bottoms of these basins or floated into concentrations, and turned into a peaty substance. Subsequent burial by sand or mud protected it until, layered between sedimentary rocks, it became gradually converted into coal through the agencies of pressure and heat.

Because of this origin, coal is found as seams or beds in sedimentary rocks, such as shales and sandstones, which were laid down in fresh or brackish water. Sedimentary rocks of the Carboniferous and Cretaceous ages contain the most important of the world's deposits of hard coal, and beds of Tertiary age yield most of the world's lignite.

The three main types of coal, with their distinguishing features, are as follows.

Lignite: brownish black colour; plant and woody structure commonly apparent; high moisture content causes disintegration upon drying.

Bituminous: black, brittle, with alternation of dull and lustrous layers; well-jointed, breaking into cubes or rectangular blocks; burns with smoky yellow flame.

Anthracite: black, hard, brittle, with shiny, conchoidal fracture; ignites slowly and burns with a smokeless blue flame.

Several intermediate ranks such as subbituminous and semianthracite are recognized. The principal chemical differences in the progression from lignite to anthracite consist of a relative increase in the carbon content and a relative decrease in volatile constituents and moisture. A geologically ancient coal will probably, over a long period, have been subjected to sufficient pressure and heat to transform it to coal of high rank or perhaps to graphite. The higher pressures and temperatures that accompany intense folding of beds is very important in producing changes from lignite towards anthracite.

Folding of coal seams increases their chances of outcropping. The mining of intensely folded or faulted seams, however, is usually more costly than the working of unbroken, only slightly tilted beds.

The character of the rocks enclosing a coal seam may greatly affect the cost of mining. A roof of weak shale may require much support, yet one of strong sandstone may not be suitable for some underground methods of mining. The character of the roof is also very important in strip mining.

Most of the coal mined in Canada is bituminous. It is used mainly for heating and for the production of steam. Lesser amounts are used for the manufacture of coke and artificial gas. Special grades of coke are used extensively in the production of iron and steel from iron ore. The principal Canadian coal deposits are in the eastern and western parts of the country, very large mines being worked in Carboniferous formations in Nova Scotia and in Mesozoic formations in British Columbia and Alberta. Tertiary coals are also mined in Western Canada.

Canada has many producing coal mines and large known reserves of coal, but the coal mining industry is faced with difficulties. One reason for this is that coal must compete with fuel oil and natural gas, which are preferred for some uses; in fact, some authorities believe that the long-term outlook for coal is as a chemical raw material rather than as a fuel. Another reason is that many of the industrial plants that require coal or coke are situated in the interior of Canada, far from the principal coal mines which are in the eastern and western parts of the country; this interior market is served largely by coal from the United States. Because of the conditions outlined above it is not likely that general prospecting for coal would be worth while in Canada in the near future. There are no doubt special cases where a coal-mining company, knowing of a demand for a certain type of deposit in a certain region, would send a qualified man to search. The average prospector, however, if working in areas where coal may be found, should note any new occurrence of coal he sees while prospecting for other minerals, in case he could interest someone in it; or if he knew that a local demand existed in a place near outcrops of formations suitable for the occurrence of coal, he might search for a deposit.

Suggestion for Additional Reading

Coal in Canada; Coke in Canada; Reviews issued annually by the Dept. of Mines and Tech. Surveys, Ottawa.

Petroleum and Natural Gas

Petroleum is more familiarly known as 'crude oil' or simply 'oil'. It is customary to distinguish 'natural gas' from other gases, but for the purposes of this discussion it can be assumed that the word 'gas' refers to naturally occurring combustible gas. Oil and gas are vital to our present way of life, particularly because of the great demand for gasoline, and Canada is fortunate in having large supplies, mainly in the Great Plains region. Canada is now producing about half of the oil used in this country, and there is ample gas if it could be transported to all parts of the country. Extensive pipelines have been built and others are planned, for both oil and gas, but because of the great distances involved it may be more economic to import oil for certain parts of the country even if the production is much increased, and it would not be practical to extend gas lines to all communities.

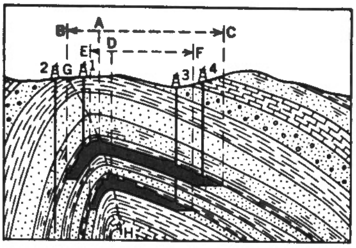
Origin of Oil and Gas

Petroleum and natural gas are allied substances of organic origin accumulated under special conditions in porous beds in the earth's crust. The organic materials were deposited in past geological ages in bodies of water, together with the sand, silt, and mud of normal sediments such as are brought down the rivers of today to be deposited in the sea. No oil or gas has been found in rocks of Precambrian age, presumably because of lack of suitable living organisms during Precambrian time.

Organic materials long exposed to air or water decompose, but salt water retards the decomposition and, if sedimentation is sufficiently rapid, organic matter is trapped in the sediments. Bacteria present in the sediments are believed to aid in the freeing of waxy and fatty matter from organic material, and this action takes place best in salt water. This probably explains in part why oil and gas are associated with marine rather than freshwater sedimentary formations. Sands and gravels may contain little organic matter, but the finer particles of clay have about the same weight as particles of organic matter, therefore, dark shales, particularly those of marine origin, are considered the most favourable source beds for oil and gas. Some limestones may also have a high content of organic substances, especially those formed in fairly warm seas. The organic substances trapped in shales and limestones are slowly subjected to heat and pressure and changed into gas and small globules of oil, which are at first widely scattered and must migrate into suitable concentrations and be trapped to form commercial deposits.

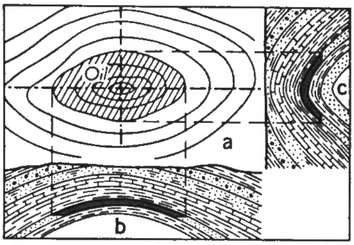
Porosity and Permeability

Nearly all rocks contain some open spaces between the constituent grains. If these 'pore' spaces are sufficiently close together and connected the rock is permeable and allows the slow passage of liquids or gases through it. The most



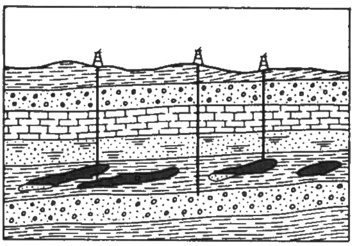
A

Simple asymmetric anticline with two oil-bearing strata; *G H shows change in dip of axis of the fold; B C width of productive area for the upper sand; E F for the lower sand. Axes of folds at A and D lie near the left edge of the productive area. Well No. 1 is productive; No. 2 is barren; No. 3 produces from upper and lower sand; No. 4 produces from upper sand.*



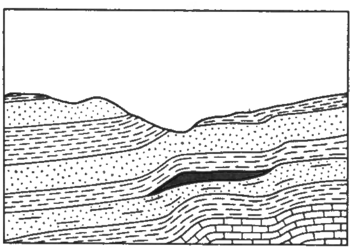
B

Dome structure; *illustrated in plan a, by contours representing the surface of the oil-bearing bed, and by vertical sections b and c*



C

Lenticular deposits; *lenses (black) of coarse sand in oil-bearing shales serve as local centres of concentration.*



D

Terrace structure; *black indicates an accumulation of oil.*

G.S.C.

FIGURE 7. Diagrams of Oil Structures (A, B, and C after L. C. Uren).

permeable rocks are sandstones, some coral limestones, and some dolomites, particularly those formed from limestones by replacement of some of the lime by magnesia, with a decrease in volume and some consequent fracturing. Even shales, the least permeable of the sedimentary rocks, contain very small pores through which liquids pass by capillarity. When oil and gas get into rocks that are sufficiently porous, or are fractured or faulted, they migrate slowly upward until the surface is reached or until relatively impervious rock prevents further movement.

Traps

There are many kinds of structural and other traps, the simplest being anticlines and domes, as illustrated in Figure 7 A and B. Under ideal conditions the gas, because of its lightness, will fill the porous beds at the crest of the fold and will be underlain on the flanks by oil, which in turn is lighter than the water that fills the pores in the lowest part of the structure. There may be departures from this sequence, even in simple anticlines. For example, natural gas moves with much greater ease than oil and, consequently, structures are found that contain only gas. Not all anticlines, even in an oil-bearing region, necessarily contain gas or oil, because water movements in the porous strata may be strong enough in some cases to flush an anticline, causing a migration of the gas and oil to another structure where the effect of water is less pronounced. Other types of traps are provided by faulting of a porous stratum adjacent to an impervious one, by a lenticular porous stratum in impervious beds (*see* Figure 7C), by 'terrace structures' (*see* Figure 7D), and by large coral reefs.

The requisites for the accumulation of oil and natural gas thus are the presence of source rocks such as oil-bearing shale or limestone, the presence of porous strata to form a reservoir, the presence of suitable structures or other traps, and a covering of impervious rock such as shale to prevent further upward migration and loss. The source rocks may not be exposed at the surface, and may not be close to the trapping structure, but careful study of the strata over broad areas may indicate their presence far beneath a favourable structure. The structures themselves can be detected by careful stratigraphic and structural mapping and by geophysical surveys and there may occasionally be an oil seep at the surface nearby, but the presence of an accumulation of oil or gas can only be proved by drilling expensive wells, often to depths of several thousands of feet.

Oil-Shales and Sands

Outcrops of shale containing organic hydrocarbon compounds are fairly common, and oil is produced from them in some countries by mining or quarrying the shale and distilling off the hydrocarbon. The hydrocarbon in these rocks is a residue left after the more volatile parts of oil-bearing shales were driven off long ago by natural processes involving heat and pressure. Several such occurrences are known in Canada, mainly in the Maritime Provinces and British Columbia, but they have not been considered workable; the better deposits may become valuable at some future time.

Canada also possesses a unique type of occurrence found over a large area near Fort McMurray in northern Alberta. The deposit consists of bituminous material in unconsolidated sand of Cretaceous age, (*see* Plate XXXII), that rests on Devonian limestone. The bituminous matter represents oil from which the more volatile material has been driven off by natural processes. It is not certain whether the oil was originally in the underlying limestone or whether it originated in the sands. The deposits form a large reserve, and methods of mining and processing have been worked out, both for producing asphalt and gasoline and other petroleum derivatives. So far it has not been possible to establish economic operations that could compete with ordinary oil from wells, but the deposits may be very important in the future.

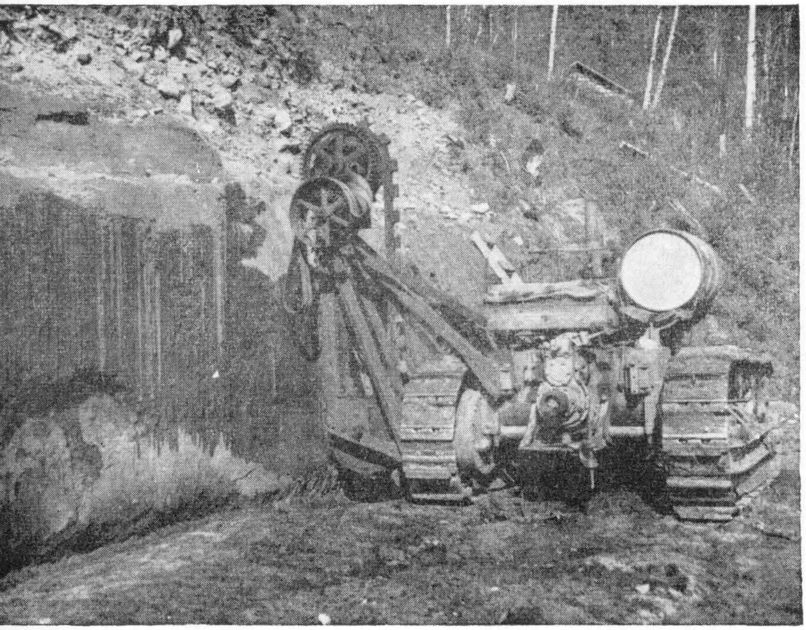


Plate XXXII

Tar sand, Fort McMurray, Alta., and an experimental machine for mining it.

Prospecting Possibilities

Prospecting for oil and gas is a difficult and complicated matter. Seepages of oil or gas sometimes give a clue for a successful discovery, but prospecting depends mainly on detailed studies of the rocks and structures exposed in areas where the geology is favourable in a general way, on detailed studies of cuttings and cores of rock from wells already drilled in a district, and on special geophysical studies that assist greatly in interpreting the structures at depth. Favourable sites are explored by drilling very costly wells; a few wells in Alberta that reached depths of about 2 miles cost about $1 million each to drill, and many shallower ones cost more than $100,000. Despite the most thorough preliminary studies, many wells are drilled unsuccessfully, either because there was no oil or gas in the structure, or because they were not present in commercial quantities, or because the well was not in quite the right place, or because the structure changed with depth.

Prospecting for oil and gas is, therefore, a highly specialized undertaking beyond the scope of the ordinary prospector. It is occasionally undertaken by trained geologists or geophysicists working on their own, but is almost entirely done by men of these professions employed by oil companies. The literature on the subject is extensive and well known to those engaged in the work, so it is unnecessary to discuss the details in a publication of this kind.

A prospector searching for metals or minerals in regions containing marine sedimentary rocks might be alert for seepages of oil or gas and for occurrences of oil-shales or sands. It should be remembered, however, that many reported oil seepages are nothing but an iridescent film on water, caused by iron compounds or decomposed vegetation, and that many gas seepages consist of coal gas or marsh gas instead of the important kind of gas that is related to oil.

In some parts of the country oil and gas rights accompany the land rights, and in other parts they are reserved to the Crown. Claims are not staked for oil and gas, but leases may be obtained from the owner of the land or from the government, as the case may be. In the provinces these matters are under the jurisdiction of the provincial governments.

Suggestions for Additional Reading

Holbrook, E. M.: Oil from the Earth; *Canadian Geographical Journal*, Oct. 1949.

Hume, G. S.: Petroleum Geology of Canada; Geol. Surv., Canada, Econ. Geol. Ser. No. 14, 1944.

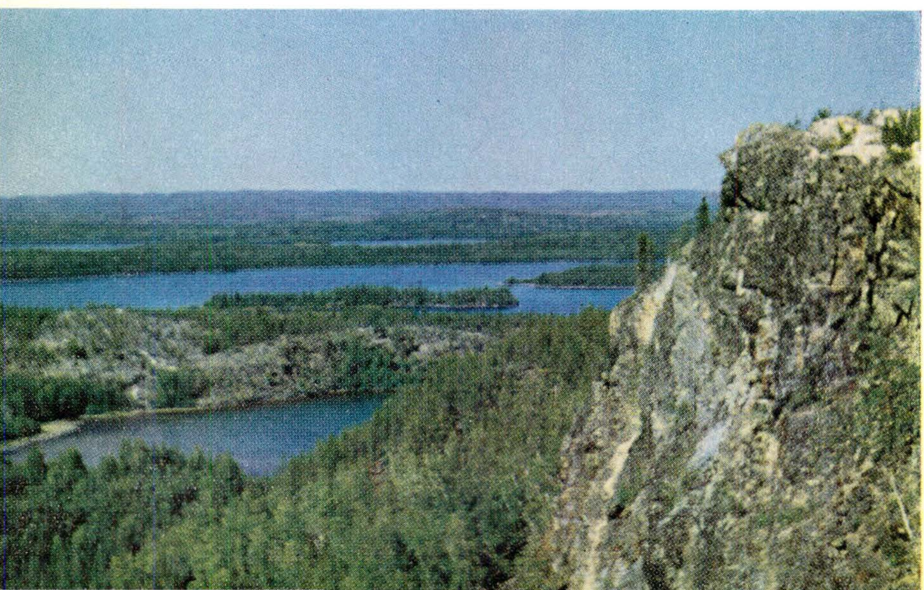
Ball, M. W.: This Fascinating Oil Business; Bobbs-Merrill Co., New York.

Natural Gas in Canada; Crude Petroleum in Canada; Reviews issued annually by Dept. of Mines and Tech. Surveys, Ottawa.

Plate XXXIII

A. Part of the Canadian Shield north of the limit of trees, southern part of Keewatin District, N.W.T.

B. View in the Canadian Shield, northern Saskatchewan.



CHAPTER V

OUTLINE OF THE GEOLOGY OF CANADA

Canada is divisible naturally into five principal geological regions, which are commonly called geological provinces (*see* Figure 8). Because the underlying rocks have a great influence on the character of the land surface, these divisions are also the main topographical units of Canada. These geological and topographical provinces are, therefore, of much importance not only for their bearing on prospecting and mining but also for their influences on agriculture, forestry, settlement, and other matters.

The largest geological province is the Canadian Shield, which constitutes about half of the country. This large area is underlain by a complex assemblage of Precambrian rocks. It is roughly shield-shaped in outline and it forms, in a sense, the core or backbone of the continent. Except along the northeast side where the Shield is bounded by the Atlantic Ocean, younger, softer strata overlap the Shield to form the Plains. The largest of these are the vast Interior Plains that are responsible for much of Canada's agricultural development and almost all its oil production. Another large plains area lies north of the Shield, in the Arctic islands. The Hudson Bay Lowland, southwest of that bay, is formed by sedimentary strata that overlie the central part of the Shield. Low-lying areas north of Lake Erie and Lake Ontario, and along parts of the St. Lawrence and Ottawa Rivers, form what is called the St. Lawrence Lowland; although relatively small, these areas are of great agricultural and industrial importance. The eastern part of Canada lies in the Appalachian System, which extends northward from the United States. It is in part a rugged region with complex geology, embracing the island of Newfoundland, the Maritime Provinces, Gaspé, and part of the Eastern Townships of Quebec. A large region in Western Canada is occupied by the Canadian Cordillera, part of a great assemblage of mountains that forms the western parts of both North and South America. Recent work in the Arctic has shown that a large area there contains high mountains and much-folded rocks. This area is now distinguished as a separate geological province and called the Innuitian Region.

These major divisions are separable into smaller geological and topographical units, most of the details being far beyond the scope of this book. The following brief descriptions are intended only to make succeeding parts of the book understandable and to serve as a foundation for the further knowledge of the geology

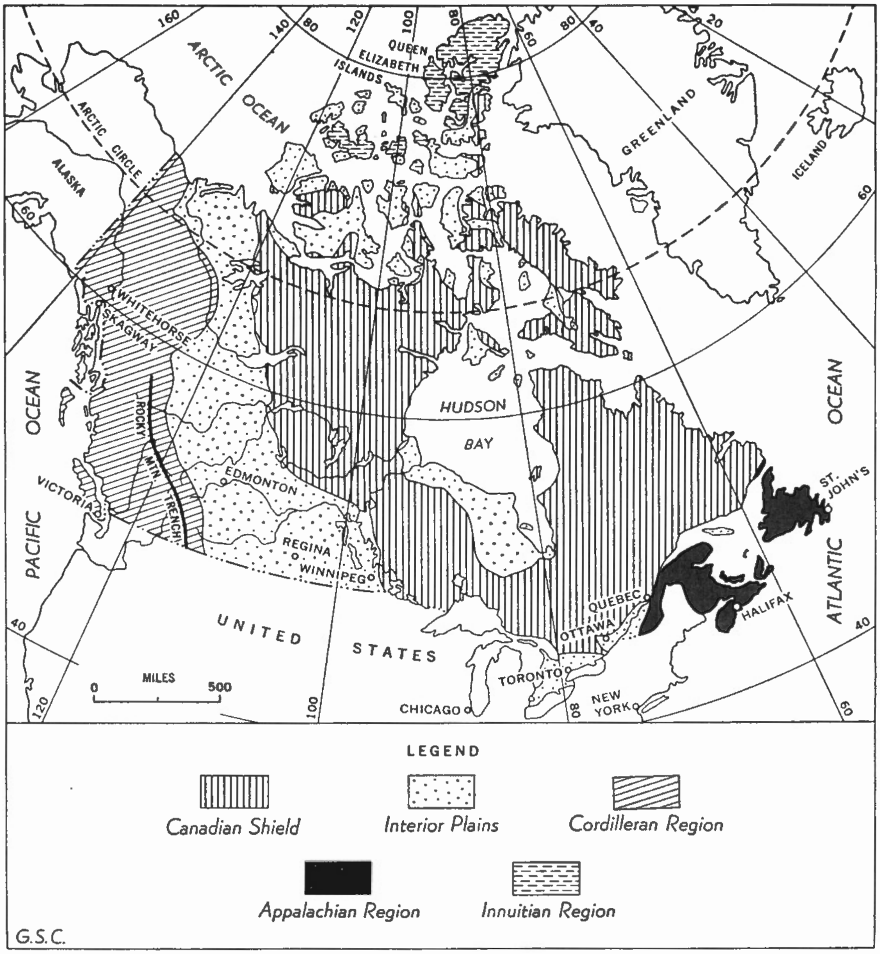


FIGURE 8. Canada showing main geological regions.

of Canada, which should be acquired not only as an essential to intelligent prospecting, but also for a better understanding of the country's varied resources and magnificent scenery. A much more extended summary entitled "Geology and Economic Minerals of Canada", and other publications listed at the end of this chapter, are recommended for additional reading.

Canadian Shield

This great area includes more than 1,800,000 square miles. The southern part of the Shield continues into the United States west and south of Lake Superior, where the principal production of iron ore on this continent has been derived from Precambrian rocks. Another part of the Shield crosses the St. Lawrence River east of Kingston, where the harder Precambrian rocks form the Thousand Islands.

The surface of much of the Shield has rather low relief, and the general height is less than 2,000 feet above sea-level. Relatively few hills and ridges rise more than 100 to 200 feet above the general surface. At places, however, such as north of Lake Superior and in the Haliburton and Laurentian Highlands, the topography is more rugged; in Labrador the Torngat Mountains have elevations of 5,000 to 6,000 feet above the sea, and in Baffin Island mountains rise to elevations of 8,000 to 10,000 feet. Because of the intense glaciation the surface of the Shield has undergone, characteristic topographical features are rounded rock outcrops and rocky ridges, separated by areas of glacially deposited sand and gravel. Another feature is the countless number of lakes of all sizes and outlines that have resulted from the effect of glaciation in disorganizing the drainage. When flying over many parts of the Shield one gets the impression that there is almost as much area covered by lakes as by dry land. There are also many patches of swampy 'muskeg' that are a further indication of poor drainage. A different type of topography characterizes a large area between Hearst, Ont., and Senneterre, Que., underlain by extensive deposits of clay that formed in large temporary lakes during the retreat of the last ice-sheet. In this 'clay belt' the surface is flatter than elsewhere in the Shield and outcrops are less numerous, a condition that has impeded prospecting in important mining areas such as Porcupine and Rouyn.

The amount of exposed rock varies greatly in different parts of the Shield. Exposures are probably poorest in the so-called 'clay belt' just mentioned. They are very abundant in certain parts of Northwest Territories and Labrador. In most areas that have been mapped geologically, rock exposures probably total less than 10 per cent of the surface. The southern part of the Shield is well wooded, with mixed coniferous and deciduous forests in the more southerly regions, and large tracts of coniferous trees farther north. Forest growth depends on climate, and because the climate varies in different parts of the country the limit of trees extends diagonally southward from the vicinity of Great Bear Lake to Churchill. East of Hudson Bay the line swings northward so that only the northernmost parts of Ungava and Labrador are beyond the limit of trees, but south of this line there are treeless mountainous tracts.

Precambrian time lasted for at least five-sixths of the entire geological past. During those long ages great accumulations of sedimentary and volcanic strata were formed; these were subjected to mountain building processes, and large bodies of granites and other igneous rocks were formed in the roots of the mountains. These ancient mountain ranges were worn down by erosion, seas encroached over the resulting low land, and the cycle of deposition, mountain building, intrusion, and erosion began anew. In at least some parts of the Shield these processes were repeated several times, and it appears that no one process occurred throughout the Shield at any one time, but that mountain building, for example, took place in one region while another was covered by sea and undergoing a stable period of deposition. Much of the Shield, particularly along the margins, was covered by the sea in Palæozoic times, when sediments that have since been partly eroded away were deposited on the Precambrian surface. It is probable that certain parts of the Shield, at different times, stood above the Palæozoic seas, and were subjected to erosion. There is no evidence of widespread submergence in Mesozoic or Tertiary times. In late Tertiary time the surface was uplifted, probably 300 to 700 feet higher than the surface of today. This uplift caused renewed stream erosion that shaped hills and valleys to more or less their present form. These events were followed by glaciation in the Pleistocene period, when great ice-sheets covered the entire Shield. As these advanced they rounded ridges and outcrops and deepened valleys, and as the ice melted, moraines of gravel and sand, and other glacial deposits, were formed. During the few thousand years that have since elapsed, there has been time for only minor changes such as slight uplifts, and a little weathering, frost action, stream erosion, and stream deposition.

The great and diversified mineral wealth of the Shield results from its long and varied past, during which rocks were made favourable for the deposition of ore minerals by faulting and other forms of deformation that accompanied or followed igneous intrusion at depth. The long periods of erosion that followed exposed these deep-seated mineral deposits or brought the surface relatively close to them. The Shield is, therefore, the most favourable large geological province in which to prospect for metal deposits. It must be borne in mind, however, that only certain kinds of rocks and geological structures within it are distinctly favourable, and that large areas probably do not contain important deposits. Moreover, deposits of metals tend to form along belts in particular areas, and the deposits along a particular belt commonly have similar general characteristics.

In many regions the oldest Precambrian rocks exposed are metamorphosed sedimentary and volcanic rocks of different kinds, the altered volcanics commonly being referred to collectively as 'greenstones'. These ancient strata occur as remnants, some of which are 100 miles or more in length, bordered by areas of granite and gneiss. It has been estimated that 80 per cent or more of the Shield, consists of granite and allied rocks, but much of what is mapped in a general way as granite consists of gneisses formed from sedimentary and other rocks that have been intimately invaded by granitic rocks or that have been partly transformed into granitic rocks. In many regions the Early Precambrian rocks are overlain unconformably by less-deformed sedimentary and volcanic strata that are usually assigned to the Late Precambrian. It is possible, however, that the conditions that produced this great unconformity and the strata above it took place at different times in different regions, and that some strata mapped as Late Precambrian are relatively undeformed Early Precambrian rocks. In some areas, Late Precambrian strata are intruded by Precambrian granitic rocks, and in most parts of the Shield the youngest known intrusive Precambrian rocks are diabase.

The unravelling of the complex geology of the Shield is made difficult by the intense metamorphism that many of the rocks have suffered, by the lack of fossils that would aid in determining the relative ages and correlation of strata, and because large areas of granitic rocks commonly intervene to prevent the tracing of the older strata from one district to another. Moreover, large sections of the Shield have not yet been mapped geologically. For these reasons, formational and other age and stratigraphic names cannot be applied with certainty over large distances, therefore groups of rocks are given different local names in different regions, or are not given formational names. In some earlier reports and maps confusion has been caused by attempts to extend formational and other names too widely.

Regional Subdivisions of the Shield

Because the Canadian Shield is so large and so complex, it is convenient to divide it into segments having somewhat distinct types of rocks and structures. There is also some evidence that the principal periods of folding and igneous intrusion took place at different times in different parts of the Shield. Moreover, particular metals and kinds of mineral deposits show strong tendencies to occur in certain segments of the Shield rather than in others. These associations, which are of great importance to prospectors, appear to be based on fundamental differences in the distribution and abundance of metallic elements in different parts of the earth's crust, and perhaps also on differences in the kinds and ages of rocks and structures in different parts of the Shield, as well as differences in the depths to which erosion has uncovered stocks and batholiths. As a rule, the mineral deposits in an individual mining camp or mineral belt contain the same important metals or minerals; if other minerals are present they are usually in minor amounts or near the edges of the camp or belt.

Geologists now agree that the Shield is divisible into separate segments or regions of the kind mentioned above, but authorities are not yet in complete agreement regarding their naming or boundaries. For some time a large region in the southeastern part of the Shield, called the Grenville, has been recognized as a separate unit because it has several distinctive characteristics; its boundary is now fairly definitely defined between Lake Huron and the country immediately east of Lake Mistassini in northern Quebec, but its position farther northeast is still uncertain. More recently, the names Slave, Churchill, Superior, and Arctic Islands have been proposed for other large segments of the Shield, as shown in Figure 9. A few other names have also been suggested, but those mentioned are the ones most commonly advocated. Some geologists call these regions sub-provinces, regarding the entire Shield as a geological province. Others call them 'provinces', because they consider that the Shield is too large to be classed as one geological province; they regard as sub-provinces still smaller divisions, several of which are now discernible.

In Figure 9 the larger divisions of the Shield that are favoured by most authorities are shown in a general way, by large lettering, but information available at present is not adequate to permit drawing boundaries for them except in a few instances. Because the problem of whether they should be called geological provinces or sub-provinces is not yet settled, they are simply referred to as 'regions'. Smaller divisions within these regions are shown by smaller lettering, and are referred to as 'sub-regions'; again, few boundaries can yet be

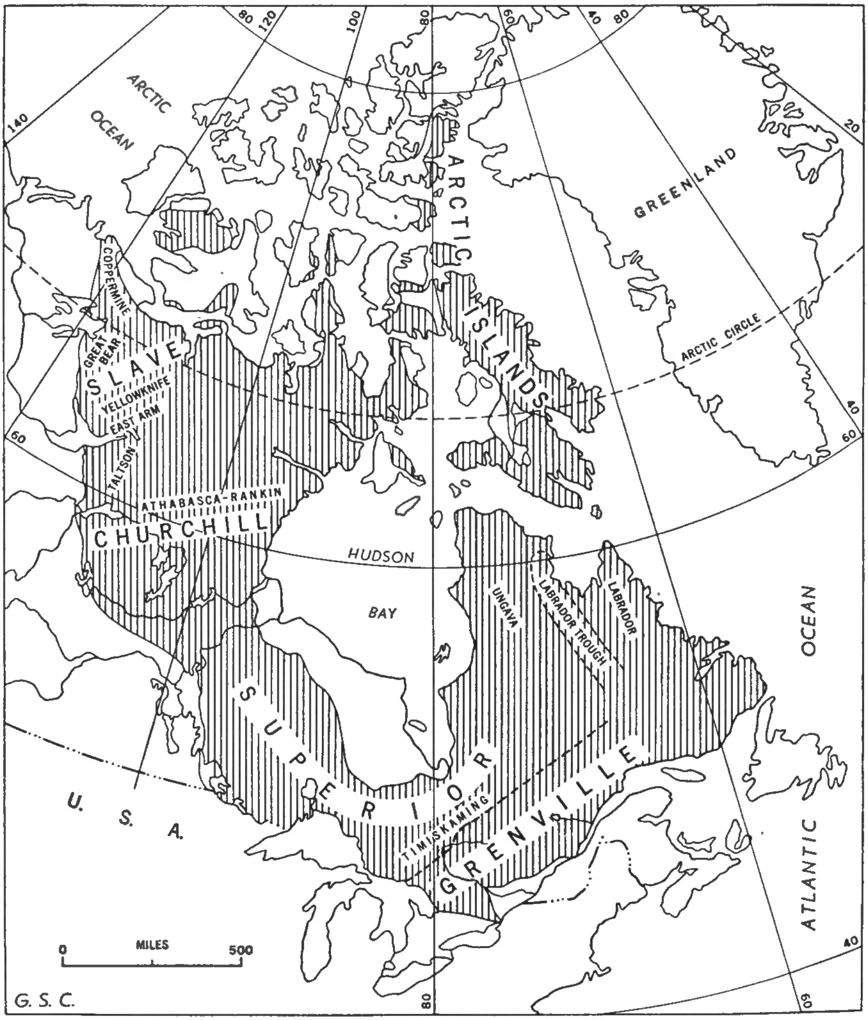


FIGURE 9. Principal geological regions and sub-regions within the Canadian Shield. Major regions shown in large type, and sub-regions in smaller type.

drawn. It is emphasized that many of the larger and smaller regions shown are not yet officially adopted and that other units or names may eventually be chosen, but they are used here to facilitate outlining the geology and characteristic mineral deposits of different parts of the Shield. It is likely that, as geological mapping and studies progress, some names will be defined. Meanwhile, there is a growing tendency for Precambrian geologists to agree that the Shield must be subdivided, and to use these or somewhat similar designations; therefore, prospectors will find them useful in understanding geological literature and in selecting fields for prospecting. In the following brief notes the divisions are discussed in geographical order, beginning with the northwestern part of the

Shield. The information is co-ordinated largely from privately-published papers by H. C. Cooke, J. E. Gill, A. W. Jolliffe, J. T. Wilson, and M. E. Wilson.

Slave Region

The name 'Slave' has been applied to the northwestern part of the Shield, in the general vicinities of Great Slave and Great Bear Lakes. It is not clear how far eastward this name should be applied, because relatively little geological work has yet been done in the territory northwest of Hudson Bay. Considerable work has been done farther west, permitting a subdivision of the western part of the Slave region into smaller units called Coppermine, Great Bear, Yellowknife, East Arm, and Taltson.

In the extreme northwestern part of the Shield the *Coppermine* sub-region is underlain by Late Precambrian strata, including the Coppermine River series, which consist mainly of shale and sandstone, with some lava flows and diabase sills. Deposits of native copper and other copper minerals have been found, but the inaccessibility of the region has so far prevented their exploitation.

The sub-region extending northward from the north arm of Great Slave Lake, and immediately east of Great Bear Lake, has been called *Great Bear.* It contains large areas of folded sedimentary and volcanic strata believed to be early Late Precambrian in age, and called the Snare River group. These strata are intruded by large amounts of granitic rocks. East of Great Bear Lake itself are strata resembling those of the Snare River group, and they also are intruded by granitic rocks. This sub-region is noted for its uranium occurrences, and it also contains several occurrences of silver, copper, cobalt, and nickel.

The *Yellowknife* sub-region, north of Great Slave Lake and east of the occurrences of the Snare River group, contains large amounts of sedimentary rocks, with lesser amounts of greenstones, that are classed as the Yellowknife group. These are older than the Snare River group, and are assigned to the Early Precambrian. The Yellowknife group is intruded in places by granitic rocks that are older than the Snare River group, but other granitic rocks in the region may be younger and correspond to the granitic rocks that cut the Snare River group. This sub-region contains two large producing gold mines, other smaller gold mines and many gold and tungsten prospects. Particularly in the eastern part, it contains numerous pegmatitic occurrences of such minerals as beryl, columbite, and spodumene.

The basin of the East Arm of Great Slave Lake contains a large northeasterly trending belt of Late Precambrian sedimentary rocks, which form the *East Arm* sub-region. Occurrences of copper, lead, zinc, uranium, nickel, and cobalt are present.

South of Great Slave Lake, the *Taltson* sub-region is mainly underlain by granitic and gneissic rocks, but it contains a large northerly trending belt of Late Precambrian sedimentary strata called the Nonacho series. A few uranium and base metal occurrences have been found in this belt.

A large area in the vicinity of Thelon River and Dubawnt Lake contains flat-lying sandstone and related rocks that are probably Late Precambrian in age.

Churchill Region

This name is applied to a large segment of the Shield extending northward from the vicinity of Nelson River, and including the territory immediately north of Lake Athabasca and that in the vicinity of Rankin Inlet. The trends of the belts of older Precambrian strata in the Churchill region are dominantly northeastward, and the region is further characterized by the presence of altered limestone or dolomite interbedded with older Precambrian gneisses such as those of the Tazin group north of Lake Athabasca and the Kisseynew gneiss near the Saskatchewan-Manitoba boundary.

Some investigators have applied the name Athabasca to a folded belt immediately north of Lake Athabasca, where important uranium deposits have been found, as well as occurrences of gold, cobalt, nickel, vanadium, and other metals. Recent work has shown that this belt probably extends northeastward to the vicinity of Rankin Inlet, therefore the writer has tentatively classed it as the *Athabasca-Rankin* sub-region. The eastern part of this belt contains large areas of greenstones, with minor amounts of sedimentary rocks, which appear to be Early Precambrian in age. They are cut by granitic intrusions. Younger, probably Late Precambrian, strata appear to be cut by younger granitic intrusions. Deposits of nickel and other metals have been found, and the entire belt is favourable in a general way for prospecting.

The remainder of the Churchill region is not yet separable into sub-regions, although a large area south of Lake Athabasca that is underlain by the flat-lying sandstone forming the Athabasca series may be designated as the Athabasca Plain. Prospecting in this area is difficult because there are few rock exposures. Farther to the south and east is a large territory containing many belts of greenstone and other strata of early Precambrian types, in which important copper-zinc and copper-nickel deposits have been found. These belts hold opportunities for additional prospecting.

Superior Region

This name, derived from Lake Superior, is used to describe a very large segment of the Shield extending eastward from Nelson River in Manitoba, through Ontario, and into northwestern Quebec. The characteristic feature of this region is that most of the numerous belts of Early Precambrian greenstones and sediments, which lie between large areas of granitic and gneissic rocks, trend almost due east and west, in marked contrast with the northeasterly trends in the Churchill region. The western part of the Superior region contains, in addition to great areas of granitic and gneissic rocks, large remnants of Early Precambrian sedimentary and volcanic strata, large areas of Late Precambrian sediments and volcanics such as the Animikie series, and sills and dykes of diabase. The principal known mineral deposits include the Steep Rock iron mines west of Port Arthur, several gold mines and prospects lying between Lake Winnipeg and Lake Nipigon, and the copper-zinc-silver deposit discovered recently at Manitouwadge.

The eastern part of what is here called the Superior region, extending from the Michipicoten district in Ontario to the Mistassini district in Quebec, is usually called the *Timiskaming* sub-province. There are grounds for considering this to be of the same rank as the Churchill and Grenville regions, instead of as a sub-region of the Superior, but the term 'Timiskaming sub-region' is adopted here because the easterly trending structures seem to continue in a general way from eastern Manitoba and western Ontario.

Much of the pioneer work in laying the foundations for Precambrian geology was done in the Timiskaming sub-region, along the north shore of Lake Huron and in the Sudbury, Cobalt, Porcupine, and Noranda areas. In many places the ancient rocks are predominantly greenstones, commonly composed of pillow lavas. In several areas these greenstones and associated rocks are classed as the Keewatin group, a name first applied to rather similar rocks farther west, near Lake of the Woods. In some areas, particularly near Timmins and Noranda, the Keewatin group is overlain by ancient sedimentary strata called the Timiskaming series. The Keewatin and Timiskaming rocks and their equivalents are intruded by granitic batholiths that outcrop over much of the region, the earlier volcanic and sedimentary strata being preserved in places as remnants in the more extensive granitic rocks. These intrusives are referred to as the Pre-Huronian intrusives by some geologists and as the Algoman intrusives by others. They were formed at depth during a pronounced period of mountain building towards the close of Early Precambrian time, and were exposed by subsequent erosion that wore down the ancient mountains. This erosion is indicated by a pronounced unconformity, found in several parts of the region, which is regarded as the line of demarcation between rocks of Early and Late Precambrian ages. Late Precambrian rocks are preserved principally in a large belt north of Lake Huron and extending intermittently northeastward through the Timagami and Cobalt districts into the territory near Noranda, Que. These younger strata are sometimes referred to collectively as the Huronian, but are given local names such as the Bruce series and Cobalt series because of differences in age or because complete correlations cannot be made from one district to another. They consist of metamorphosed sediments and minor volcanic rocks that, on the whole, have not been subjected to such intense metamorphism and folding as those of Early Precambrian age. They are intruded in places by granitic intrusions such as the Birch Lake granite north of Lake Huron, by gabbroic intrusives such as those near Sudbury, and by sills and dykes of diabase such as the Nipissing diabase at Cobalt.

The Timiskaming sub-province contains some of the largest mines of the world and, at least to date, is the most important mineral-producing part of the Shield. Within its boundaries are the great nickel, copper, and gold mines of the Sudbury basin; the gold mines of Porcupine, Kirkland Lake, and northwestern Quebec; the gold, copper, and zinc mines of Noranda and Chibougamau in Quebec; the iron mines of Michipicoten; large low-grade uranium deposits near Blind River; and many smaller mines and prospects of various kinds. Although much of the territory has been prospected intensively, it still holds opportunities for both conventional and highly technical prospecting.

Grenville Region

The southeastern part of the Shield has for some time been recognized as a separate unit called the Grenville province or sub-province. It forms a belt 150 to 200 miles wide extending from Georgian Bay of Lake Huron to southern Labrador, and it extends into the United States to form the Adirondacks. Its boundary with the Timiskaming sub-province is a line of known and supposed faults reaching at least from south of Sudbury to the territory east of Lake Mistassini in Quebec. Because of this faulting at some points, and because of scarcity of rock exposures at others, it is uncertain whether the older rocks in the Grenville region are older or younger than those to the north, or the same age.

The oldest known rocks of the Grenville region, which in general strike northeasterly, form what is called the Grenville series. It consists largely of crystalline limestone and impure limy rocks, and gneisses containing garnets and other minerals such as are formed by intense metamorphism of limy and clayey rocks. The Grenville series is intruded by bodies of gabbro and diorite, and by large intrusions of still younger granite and syenite, with which are associated innumerable dykes and masses of pegmatite.

The Grenville region contains important titanium deposits north of the Gulf of St. Lawrence, contact metasomatic iron deposits such as the large one being mined at Marmora, Ont., some zinc and lead deposits, and many relatively small pegmatitic and contact metasomatic deposits such as those worked from time to time for feldspar and mica. Metalliferous deposits of hydrothermal types have, however, been found much more rarely than in the Timiskaming sub-region.

Ungava and Labrador

Geological information is still limited for much of northernmost Quebec and Labrador. Names for segments of the Shield are here not yet well established, nor is it possible to define definitely the northern boundaries of the Superior or Timiskaming regions. To aid in description, the writer uses the name 'Ungava' for the territory east of Hudson Bay, 'Labrador Trough' for the important belt of sedimentary strata lying farther east, and 'Labrador' for the territory between the Trough and the coast of Labrador, and has classed these as sub-regions.

Most of the *Ungava* sub-region, as defined for the purpose of this publication, appears from reconnaissance surveys to be underlain by granite-gneiss, granite, and allied rocks of Early Precambrian age. A large area containing greenstones has, however, been mapped in the basin of Eastmain River, and others probably exist. Late Precambrian sedimentary rocks form the Belcher Islands in Hudson Bay, and similar rocks outcrop along the east coast of that bay, near Richmond

Gulf. Prospecting in this territory has not been extensive, and few mineral deposits have yet been found apart from large, low-grade iron deposits on Belcher Islands.

The so-called *Labrador Trough* is a belt about 60 miles wide, containing Late Precambrian sedimentary strata, with some volcanic rocks, and sills and dykes of gabbro. It is of particular importance because it includes the now well-known iron deposits of New Quebec and Labrador. The belt extends northwesterly for about 600 miles, from the headwaters of Romaine River to the west side of Ungava Bay. The rocks within the belt are folded, and cut by many faults. At the west side of the belt the strata rest with pronounced unconformity on Early Precambrian gneisses. The eastern boundary is a zone of sheared rocks that probably indicates a prominent fault.

There is relatively little information on the geology of the *Labrador* sub-region, between the Trough and the Labrador coast, but there is some evidence that parts of it contain altered rocks of the same age as those in the Trough. Rocks much like those of the Grenville series have also been found, as well as large areas of typical gneisses, and Late Precambrian sedimentary strata. Occurrences of uranium, copper, and other metals have been reported from this region, where intensive prospecting has been done only recently.

Arctic Islands

Although geological information is less complete for the Arctic Islands than for most parts of Canada, sufficient work has been done to outline the broad features, and some areas have been investigated in considerable detail. The Canadian Shield forms most of Baffin Island, where the rocks show some similarity to those of the Grenville region. The Shield is also exposed on some of the islands north of Baffin Island (*see* Figure 9). Rocks of Late Precambrian types have been found mainly on Victoria Island, north of Coppermine, and at the northwest end of Baffin Island. Little prospecting has been attempted because of the remoteness of these islands.

Cordilleran Region

The Cordilleran region of Western Canada is part of the great belt of high mountains that stretches along the west sides of North and South America. In Canada the belt averages about 450 miles in width, and includes almost all of British Columbia and Yukon Territory, and the western parts of Alberta and the District of Mackenzie, N.W.T. The mountain ranges and intervening valleys trend northwesterly, parallel with the coast of British Columbia and southern Alaska. Much of the region is forested but it also contains areas above timberline in which bare rock is exposed except where covered by snow or ice.

The Canadian Cordilleran region is divided into two main parts called the Eastern and Western Cordillera, in which the topographical features and the geology are very different. In British Columbia these divisions are separated by an unusually deep and persistent valley, called the Rocky Mountain Trench.

This remarkable valley extends northwesterly for nearly 1,000 miles, through almost the entire length of the province from the vicinity of Cranbrook almost to Watson Lake; the Canadian Pacific Railway line crosses the Trench at Golden and the main line of Canadian National Railways intersects it at Canoe River. The Trench probably owes its origin to erosion along a zone of faults.

The Western Cordillera includes ranges on Vancouver and Queen Charlotte Islands, the lofty Coast Mountains along the border of the mainland, and the still higher St. Elias Mountains along the boundary between Yukon and Alaska. Between the Coast Mountains and the Rocky Mountain Trench is a broad belt composed partly of mountain ranges, such as the Cassiar and Selkirk Mountains, and partly of rolling plateaux interrupted by deep valleys. The best known features of the Eastern Cordillera are the Rocky Mountains, composed of high ranges extending from the 49th Parallel almost to the Yukon. The entire Canadian Cordillera is frequently referred to as the 'Rocky Mountains', but without justification, as the official terminology has always restricted this name to the mountains lying east of the Rocky Mountain Trench. A belt of foothills several miles wide separates the Rockies from the Interior Plains.

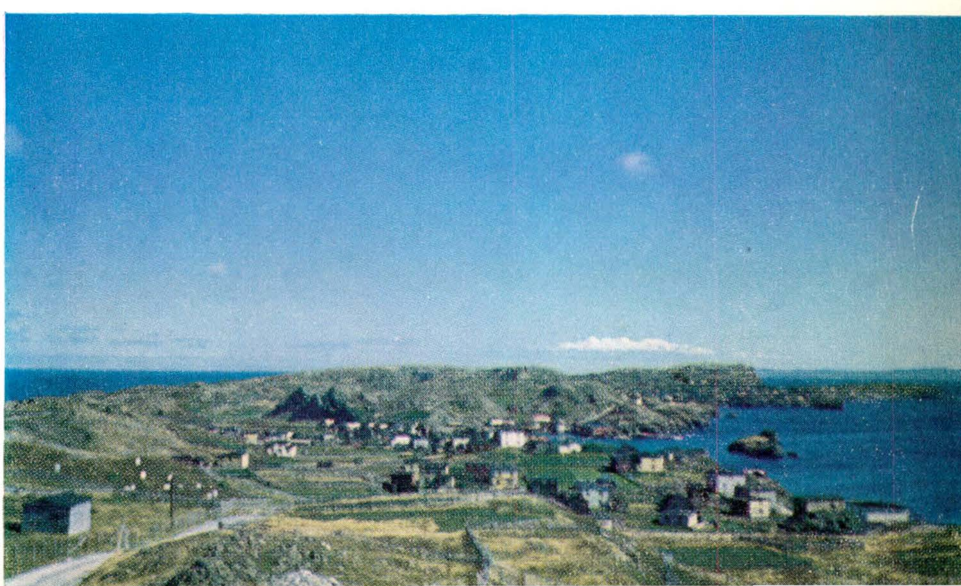
The Cordilleran region is on the site of a great basin of sedimentation where seas and freshwater basins existed during much of the time from Late Precambrian to late Mesozoic and early Tertiary. Here sediments were deposited in much greater thicknesses than on the Precambrian basement underlying the Interior Plains. The mountains of the Western Cordillera have been carved in a complex assemblage of sedimentary, volcanic, and plutonic rocks. Great thicknesses of sedimentary strata that range in age from Late Precambrian to early Mesozoic are exposed. With these are interbedded large amounts of lava flows and volcanic fragmental rocks, mainly late Palæozoic and Mesozoic in age. These strata were folded and intruded by granitic rocks at different times, mainly in the Mesozoic era. The mountains formed at that time were eroded to a fairly flat surface, exposing deep-seated granitic rocks in many places, most notably the large and complex Coast Range batholith along the western mainland of British Columbia. Later, lava flows of Tertiary age, composed mainly of basalt and andesite, spread over much of this surface. Still later, the land was uplifted, and during late Tertiary time streams eroded deep valleys in the uplifted surface and dissected it into the mountains and plateaux that today characterize the Western Cordillera.

The mountains of the Eastern Cordillera are formed from a great thickness of sedimentary strata ranging in age from Late Precambrian to Mesozoic. These strata consist chiefly of limestone, quartzite, and shale, which have a total thickness estimated at about 68,000 feet in the Rocky Mountains. Sedimentation continued, at least in places, until early Tertiary time, long after the main period of folding of the mountains to the west. The Rockies and other ranges of the Eastern Cordillera are, therefore, still in the first stage of erosion. Consequently, the peaks in general present a saw-tooth appearance without the patches of fairly level uplands that mark the ancient uplifted land surface formed by the first cycle of erosion in the Western Cordillera.

Plate XXXIV

A. Rugged topography in the southern part of the Canadian Shield, at Walker Lake, Quebec, north of the mouth of St. Lawrence River.

B. Part of the east coast of the island of Newfoundland, in the Appalachian region.



The complex geological history of the Western Cordilleran region was particularly favourable for the formation of metalliferous mineral deposits, and for unroofing them by prolonged and deep erosion. In consequence, this region has supplied much of Canada's production of metalliferous minerals, and also considerable coal; it contains some large base-metal mines, as well as many smaller mines and prospects of various kinds; and it is one of the most favourable regions for prospecting. The southern half has been fairly thoroughly prospected, in so far as ordinary methods are concerned, but the northern half contains many areas that have been prospected only in a preliminary way. The region also contains important deposits of industrial minerals. The only parts of the Western Cordillera that are definitely unfavourable for prospecting are those covered by Tertiary or younger lava flows, which are younger than the lode deposits; even under these flows, deposits may be found occasionally where valleys have dissected the flows and revealed underlying rocks.

Relatively few metalliferous deposits have been found in the Eastern Cordillera, probably because of its younger mountain-building history, which has not permitted subsequent erosion to lay bare extensive deep-seated intrusions and deposits that may underlie the region. A few small intrusive bodies and a few metalliferous deposits have been found in the Rocky Mountains near Field, B.C., and east of Cranbrook, B.C. Some of these deposits, such as those of lead and zinc near Field, may be of types that are not directly related to igneous processes. The Eastern Cordillera, therefore, offer limited possibilities for prospecting for metalliferous deposits. They do hold good possibilities, however, for the discovery of industrial minerals, and important coal deposits are present.

Plains Regions

Interior Plains

The Interior Plains are underlain by a great succession of flat-lying or gently folded sedimentary rocks deposited during the Palæozoic, Mesozoic, and Cenozoic eras. The older Palæozoic strata outcrop in the eastern part of the region and consist chiefly of limestone, dolomite, sandstone, and shale of Ordovician, Silurian, and Devonian ages. Mississippian and Pennsylvanian strata overlie the Devonian beds in a few places. The strata were laid down in seas, and later in streams, lakes, and marshes, that came and went from time to time during the many millions of years that followed the Precambrian eras. The sedimentary rocks so deposited probably also covered part of what is exposed today as the Canadian Shield, and were later removed by erosion. The older strata that have been preserved appear at or near the surface in relatively narrow bands near the exposed edge of the Shield in Manitoba and Saskatchewan, and in much broader belts in Northwest Territories in the basin of the Mackenzie River. Most of the plains areas of Manitoba, Saskatchewan, and Alberta are underlain largely by flat-lying shales and sandstones of Cretaceous age, which are partly of marine and partly of freshwater origin. Still younger strata of Tertiary age occur principally in and near the Wood Mountain plateau in southern Saskatchewan, in the Cypress Hills in southern Alberta, and in a large area in southwestern Alberta adjacent to the foothills.

The Interior Plains do not contain igneous intrusions, therefore the region is usually regarded as unfavourable for prospecting for metalliferous deposits. The region is, however, of great importance because of its resources of petroleum, natural gas, and coal, and there are also certain special deposits of economic importance, such as building stones, structural materials used for making cement, and certain salts that are recovered from brines. Deposits of lead and zinc in Palæozoic limestone near Pine Point, at the south side of Great Slave Lake, have been known for many years and have been shown to contain large tonnages that may warrant the large expenditures that will be required to exploit them. The origin of deposits of this kind is uncertain, for they are in strata not known to be intruded by igneous rocks. Such deposits may have been formed by hydrothermal solutions that travelled a long distance from deep-seated intrusives of late Palæozoic or younger age; on the other hand, they may have been formed by circulating waters from the surface, which extracted metals that occurred in small amounts in nearby rocks. Similar deposits may occur in Palæozoic limestone in other districts, but prospecting for them is made difficult by the scarcity of outcrops in the plains regions.

St. Lawrence Lowland

This name is given to the fertile plains that extend south of the Canadian Shield between Lake Huron and the Thousand Islands, and also along the St. Lawrence River from the Thousand Islands to the city of Quebec, and along the lower part of Ottawa River. These plains are underlain by flat or gently dipping sedimentary rocks, mainly limestones and shales, that were deposited in seas that occupied the region during parts of Cambrian, Ordovician, Silurian, and Devonian times. Exceptions to the generally flat character of this region are the Monteregian Hills near Montreal, which are formed by small igneous intrusions.

The chief mineral resources of this region are those typical of sedimentary strata, such as deposits of gypsum and salt, and such as the petroleum and natural gas produced north of Lake Erie. In addition, veins containing lead and zinc have been found in Ordovician strata near Carleton Place, Ont., and veins containing fluorite, also in Ordovician beds, have been mined near Madoc, Ont.

Hudson Bay Lowland

South of Hudson Bay and west of James Bay a large lowland area is underlain by sedimentary strata ranging in age from Ordovician to Mesozoic and which overlap the Canadian Shield. Because of the lack of intrusions this region is not particularly favourable to prospect for metals, although it is possible that deposits such as those of lead and zinc that occur in Devonian rocks near Great

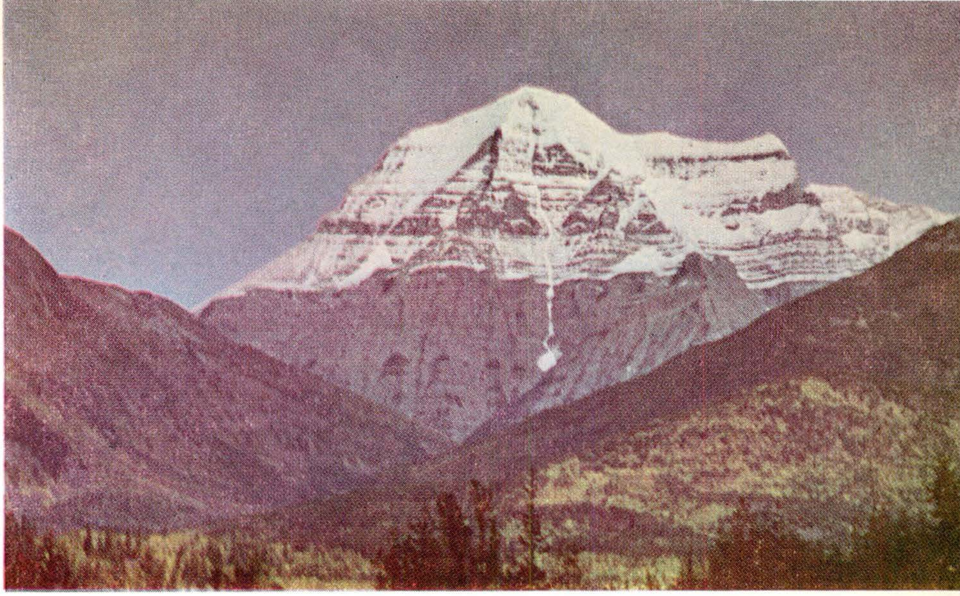
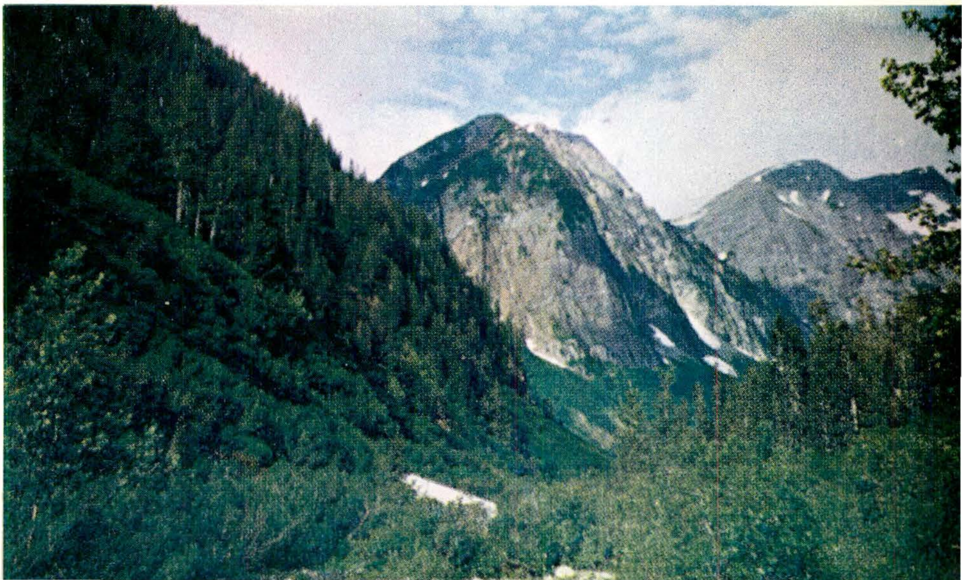


Plate XXXV

A. Mount Robson, the highest mountain in the Canadian Rockies. Erosion has carved this mountain from a flat-lying succession of sedimentary strata.

B. View in Coast Mountains near Terrace, B.C., illustrating the rounded erosion forms typical of plutonic rocks.



Slave Lake might be found here as well. The region has been investigated for oil but so far none has been discovered. The region is also of interest because of the occurrence of lignitic coals and deposits of gypsum.

Arctic Lowlands and Plateaux

Large areas in the Arctic islands consist of lowlands, and plateaux that rise to about 3,000 feet above the sea. These regions are underlain by fairly flat-lying sedimentary strata ranging in age from Cambrian to Cretaceous, therefore their prospecting possibilities are mainly limited to oil, natural gas, and coal.

Appalachian Region

The Appalachian region, which is the northern extension of a much longer belt in the United States, includes the part of Quebec lying south of the St. Lawrence River and east of a line between Quebec City and Lake Champlain, and all of New Brunswick, Nova Scotia, Prince Edward Island, and the Island of Newfoundland. In general, this region is fairly rugged because it is a tilted ancient plateau surface sloping southeast that has been carved into hills and valleys by stream erosion. In the interior of Gaspé, these hills rise to heights of more than 4,200 feet above sea-level to form the Shickshock Mountains.

Precambrian rocks exposed in western Newfoundland bear some resemblance to those of the Canadian Shield, but are separated from them by younger strata near the Strait of Belle Isle. Sedimentary and volcanic rocks, regarded as belonging to both the Early and Late Precambrian, are exposed in parts of Newfoundland, Nova Scotia, and New Brunswick. In Nova Scotia, other strata may be Precambrian or Palæozoic. The rocks exposed in much of the Appalachian region, however, are Palæozoic limestone, shale, and sandstone, ranging in age from Cambrian to Carboniferous, and there are also some Triassic strata near the Bay of Fundy. Folding occurred during the Ordovician period, and again in the Devonian when igneous intrusion was fairly widespread, resulting in numerous granitic stocks and batholiths. Parts of the region were further deformed by folding and faulting at the close of the Carboniferous period.

The line of demarcation between the much-disturbed Palæozoic strata in the Appalachian region and the flat-lying Palæozoic beds underlying the St. Lawrence Lowland is a great fault extending in the form of an arc northeastward from Lake Champlain. This fault is responsible for the sweeping curve of the south shore of the lower St. Lawrence. The faulting is attributed mainly to thrusts that occurred during Ordovician and Devonian disturbances, but there may also have been movement along it at other times.

The Appalachian region possesses great and varied mineral resources. Sedimentary rocks contain important deposits of coal, gypsum, salt, and iron, the latter being the sedimentary iron ores of Wabana in Newfoundland. The Eastern Townships of Quebec contain very important asbestos deposits. Largely because of the Devonian disturbances and intrusions, the region also contains important deposits of copper, lead, or zinc, such as those of Gaspé, Que., Bathurst, N.B., and Buchans, Nfld. In addition, many gold mines were formerly worked in Nova Scotia. The foregoing is only a brief list of the most important mineral occurrences of the region; there are also many occurrences of other minerals. The region in general is, therefore, definitely favourable for prospecting, and much of it has the added advantage of being fairly accessible.

Innuitian Region

A large part of the northern Canadian Arctic, called the Innuitian region, consists of mountains and ridges that rise as high as 10,000 feet. The Innuitian region extends from northernmost Ellesmere Island south and west to the western edge of Melville Island, and in places is more than 200 miles wide. It is underlain by moderately to intensely folded rocks ranging in age from possibly Precambrian to Cretaceous. These consist mainly of sedimentary strata, with some metamorphic and volcanic rocks.

Some strata in the region seem to have been folded before the Silurian period, some in Silurian or Devonian time, some in late Palæozoic time, and some in late Cretaceous or early Tertiary time. In the northern part granitic intrusive rocks have been found, therefore, at least parts of the region are favourable in a general way for the occurrence of metalliferous deposits. Other parts appear to be more favourable for the occurrence of mineral fuels. However, the inaccessibility will retard prospecting and the exploitation of mineral resources.

Suggestions for Additional Reading

Geology and Economic Minerals of Canada, by Officers of the Geological Survey; Geol. Surv., Canada, Econ. Geol. Ser. No. 1, 1947. Price 75 cents.

A comprehensive summary of information on the geology and principal mineral deposits of Canada. Prospectors will find it useful for extending the general outline contained in this chapter, and also for reference before studying more detailed reports on a particular area. A related publication is the large, coloured geological map of Canada, scale 1 inch to 60 miles, obtainable for 50 cents.

Structural Geology of Canadian Ore Deposits, A Symposium; *Can. Inst. Min. Met.*, 906 Drummond Bldg., Montreal, Que., 1948. Price $10.

In addition to many papers on individual mines, this book contains general geological descriptions of the Canadian Shield and the Cordilleran and Appalachian regions and several of the principal mining camps within them.

Fortier, Y. O., McNair, A. H., and Thorsteinsson, R.: Geology and Petroleum Possibilities in Canadian Arctic Islands; *Bull. Amer. Assoc. Pet. Geol.*, vol. 38, No. 10, 1954.

A recent summary of geological information on the Arctic islands, containing important information obtained since the preparation of "Geology and Economic Minerals of Canada".

Fortier, Y. O.: Innuitian Region; *Trans. Can. Inst. Min. Met.*, vol. LVIII, pp. 1-2 (1955).

Another recent summary of information on this region.

Baird, D. M.: Mines and Minerals of Newfoundland; Newfoundland Dept. Mines and Res., Information Circular No. 7, 1953.

This and the following publication include summarized information on the geology of Newfoundland, which was not part of Canada when "Geology and Economic Minerals of Canada" was prepared.

Weeks, L. J.: Newfoundland As a Field for Prospecting; *Proc. Geol. Assoc. Can.*, 1951, pp. 75-76.

A recent summary of the geology and prospecting possibilities of Newfoundland.

Many additional regional references are listed in Geol. Surv., Canada, Paper 54-1: "A List of Publications on Prospecting in Canada and Related Subjects".

CHAPTER VI

OBTAINING INSTRUCTION

The need for organized instruction in prospecting has been recognized in Canada for many years, with the result that good courses of various kinds are available in several parts of the country. Facilities of this kind may be increased from time to time, both in technical schools and in the field of adult education. The facilities available now are outlined below, and anyone who intends to prospect and who can avail himself of one of these courses is strongly urged to do so. Those who do not attend courses or take correspondence courses can, however, greatly increase their proficiency by studying independently, therefore suggestions are included for supplementing by independent study the introductory information contained in this book.

Long Courses

Several high schools and technical schools give a certain amount of instruction in elementary mineralogy and geology, but this does not usually include specific instruction in prospecting. The Institute of Mining at Haileybury, Ont., under the auspices of the Ontario Department of Mines, gives a good course on subjects related to mining, for young men who may not have the time or finances for university training. The fee at present is $25 a year for residents of Ontario; special arrangements are available for non-residents.

Short Courses

Classes for prospectors and for others who are interested in a general way are held annually in several provinces and in Northwest Territories. The importance and popularity of this means of instruction are shown by the fact that many persons repeat their attendance year after year, and that several, after attending courses, have made discoveries. The details of the courses vary from province to province and in different years, but they are usually held for a few weeks during the winter; some are held in the evenings only, and some include afternoon and evening classes; they are usually free. In some provinces the classes are held only in one city, and in others they are held at several centres. The instruction usually consists of lectures on geology, prospecting methods, and several related topics, as well as training in the identification of principal minerals and rocks by actually working with specimens supplied for the purpose.

Anyone who intends to take up prospecting would be well advised to attend one of these courses, even if it were necessary to take leave for a week or two and to travel to the nearest place where a course is held.

A few particulars regarding courses conducted in recent years are listed below. Further information can be obtained from the organizations mentioned. Classes may be held in other provinces at times; to learn if this is the case, enquiries should be addressed to the Department of Mines of the province concerned.

Alberta

Classes are held in Edmonton during the winter, under joint auspices of the Alberta and Northwest Chamber of Mines and Resources, 10060—100 Street, Edmonton, the local branch of the Canadian Institute of Mining and Metallurgy, and the University of Alberta.

British Columbia

Classes are held in Vancouver, under the auspices of the British Columbia and Yukon Chamber of Mines, 790 Dunsmuir Street, Vancouver.

Manitoba

The Evening Institute of the University of Manitoba gives a series of twelve evening lectures on minerals and rocks. The Mines Branch, Department of Mines and Natural Resources, Winnipeg, holds a one-week course in prospecting at Flin Flon.

Northwest Territories and Yukon

A course is conducted each spring at Yellowknife by the local branch of the Canadian Institute of Mining and Metallurgy. Details can be obtained from the secretary of the branch or from the Yellowknife office of the Geological Survey of Canada.

A course, sponsored by the British Columbia and Yukon Chamber of Mines, is conducted at Whitehorse, Yukon Territory. The course is conducted by the Resident Geologist, Geological Survey of Canada, and others.

Ontario

Classes are conducted by the Ontario Department of Mines in Toronto and several other centres, usually for about a week at each place. Notices giving details appear in newspapers. The classes in Toronto are held in cooperation with the Prospectors and Developers Association, 416—25 Adelaide Street West, Toronto. This association also includes classes for special instruction during some of its annual meetings, which are held in Toronto each March.

Quebec

Classes for beginners and more experienced prospectors are held at several centres, by the Quebec Department of Mines. This department also sponsors a longer course in prospecting conducted for about 5 weeks each year at Laval University.

Saskatchewan

The Mineral Resources Branch, Department of Natural Resources and Industrial Development, Regina, holds classes for prospectors at La Ronge, Sask. The course is usually held in May, and lasts 3 weeks, of which 2 weeks are devoted to lectures and 1 week to practical field training. This department also undertakes the further training of natives in prospecting, by maintaining a supervisor who travels among the natives in the northern part of the province.

First Aid Courses

Although his is not a particularly hazardous occupation, the prospector is likely to be in fairly remote places and to require more than usual self-reliance. It is, therefore, advisable for him to include a first aid course in his studies, and, if he plans a long trip far from communications, to consult a doctor beforehand regarding the handling of accidents and illnesses that require more than ordinary first aid.

Correspondence Courses

The British Columbia Department of Education provides good correspondence courses on "Elementary Geology" and "Metal Mining". They are conducted by means of easily understood, well-illustrated papers covering many different phases of these subjects. Each paper includes questions to be mailed back for correction. The geological course is an introduction to geology and mineralogy and is required to be taken before the one on mining which is more advanced and intended only for those who intend to engage in metal mining or prospecting. The courses are suitable for high-school students or adults, and are available to residents in other provinces. The fee for each course is $10. Inquiries should be addressed to: The Director of High School Correspondence Instruction, Weiler Building, Victoria, B.C.

A good correspondence course for veterans of the Canadian armed forces is conducted free of charge. Booklets on Geology and Mineralogy, Prospecting in Canada, Practical Mining, and Business of Prospecting and Mining, prepared for the Canadian Legion Educational Services, are used for this course. Application should be made to the Department of Veterans Affairs, Ottawa.

Independent Study

Those who attend classes in prospecting should be prepared to do additional studying as well. Those who do not attend classes or take correspondence courses can do much to educate themselves. Naturally, persons differ in their capacity and inclination for study, and there have been good prospectors who had little 'book learning', but they would be the first to agree that study is most desirable so long as it is combined with practical experience, common sense, and willingness to work. It is hoped that the present book will serve as a useful introduction to the subject, but it cannot possibly cover all that a competent prospector should know. The following procedure is suggested as a practical way of gaining additional knowledge by studying at home or in libraries.

(1) Study the regulations covering staking and related matters for the province concerned. Copies of regulations can be obtained from Mining Recording Offices and from the head office of the provincial Department of Mines or its equivalent. For several provinces, these regulations are explained in condensed, easily understood pamphlets as well as in the official 'acts'.

(2) Become familiar with the services of provincial and federal departments for identifying mineral specimens and assaying samples. It would be impossible for these departments to report on every mineral or rock a beginner encounters, but they can be of great assistance when an occurrence of possible significance has been found. **Much unnecessary delay in receiving replies is caused by sending specimens or samples to the wrong government agency, by requesting work of a kind that no government agency undertakes, and by addressing packages vaguely; therefore, knowledge of these matters is an important qualification for competent prospectors** (*see* Chapter XIV).

(3) Obtain one of the recommended elementary books on mineralogy, and a set of common minerals and rocks, and make a determined effort to become proficient in their identification.

(4) Gradually read other recommended publications. A good way to begin would be with one of the books on elementary geology and with "Geology and Economic Minerals of Canada". Many references for additional reading are listed in the present book, and still more are given in "A list of Publications on Prospecting in Canada and Related Subjects" published by the Geological Survey of Canada as Paper 54-1 (price 25 cents). It is not suggested that a prospector should read all the publications listed, but that he should choose appropriate ones that he is able to obtain. Many of the items listed are articles that are out of print or that appeared in technical journals, and are available only in libraries.

(5) Subscribe to at least one of the mining newspapers or magazines. They contain articles dealing specifically with prospecting from time to time, and also serve to keep a prospector posted on minerals in demand, prices of metals and minerals, and areas where prospecting and mining are active.

(6) If a prospector decides to concentrate mainly on a particular metal or mineral, even for a short time, he should study at least one publication on that metal or mineral, if one is available. Many are listed in Paper 54-1. More recent publications might be obtained by writing to the federal or appropriate provincial Department of Mines.

(7) If prospecting is to be confined to the home region, or if other fields are being considered, obtain and study appropriate geological maps and reports, or consult them in a library.

A prospector will benefit by attending meetings such as those of the Prospectors and Developers Association, at which papers on many topics related to prospecting are presented.

Training in the Field

Many features of prospecting can be mastered only by actual experience in the field. No amount of reading can take the place of practical experience; the two supplement one another and each is important. Good ways for a beginner to get experience quickly are to spend at least one season working for a company that employs and trains unskilled prospectors, or to form a private partnership with an experienced prospector. In these ways experience can be gained not only in the technical aspects of prospecting, but also in the equally important matters of travelling and living in unsettled areas.

Several companies engage prospectors. Some merely finance prospectors who work alone or in two-man teams, who work more or less where and how they like, and it is sometimes possible for a beginner to be assigned to work with an experienced man who can teach him as the season progresses. Other companies having a large concession or group of claims to prospect, or interested in prospecting a large unstaked area, organize parties to undertake systematic prospecting, surveying, geological mapping, or geophysical or geochemical prospecting. These parties are led by scientists or engineers, and they may include both experienced prospectors and students or local labourers who receive training. Persons seeking such employment can learn of companies that do work of this kind by reading mining newspapers, and can then apply directly to the companies. Also, they might obtain such a job through the National Employment Service.

Alternatively, one can gain field experience independently by intelligent observation of rocks and minerals as they occur in the home region or in the region to which one travels. It is most important to become familiar with rocks and minerals in place, not merely by studying specimens, because such features as structures and weathering are best observed in actual outcrops. It is also very important to learn what mineral deposits actually look like, how they are explored, and what size of deposit is likely to be worth further investigation. An idea of these matters can be gained by visiting abandoned prospects, whose locations can be learned from geological maps or reports, and by visiting prospects that are being explored. Producing mines are not usually open to visitors, but the owners of properties in earlier stages often permit prospectors to examine the showings.

Training of prospectors in the field has been undertaken by the British Columbia Department of Mines and by the Saskatchewan Department of Natural Resources and Industrial Development. The former operated training camps, largely in connection with small-scale placer mining, during the depression that preceded World War II, but this plan was discontinued. Since 1943 it has provided financial assistance for worthy prospectors in need of it, and has supervised their work to some extent. The Saskatchewan Department of Natural Resources and Industrial Development operates a prospectors' assistance plan, including technical advice, transportation, and loan of equipment, and, as already mentioned, it also has a separate project for training Indians in prospecting. In addition to these organized training schemes, chiefs of geological survey parties and other officials of the federal and provincial governments have helped, incidentally to their regular duties, to improve the skill of prospectors encountered in the field.

CHAPTER VII

EQUIPMENT AND TRAVEL

Equipment, provisions, transportation, woodcraft, etc., are very important considerations for prospectors. These topics cannot be discussed exhaustively in a publication of this kind because of the varied requirements for different regions and for different kinds of prospecting, and because much depends on individual preference and finances. A prospector must have at least a minimum of tools, such as a pick and an axe, and certain other items are almost indispensable. If he is prospecting near his home he may not need to travel far or to camp, and in the more settled parts of the country it is sometimes possible for prospectors to find lodging, but in general a prospector needs equipment for travelling and camping, and must know how to use it; the desirability of thorough preparation for all but the shortest trips cannot be too strongly emphasized. All that is attempted here is to provide basic information for beginners and for more experienced persons unfamiliar with certain regions or kinds of equipment. Beginners will find additional useful information in handbooks on camping, woodcraft, or hunting, even though many of these books are written from the recreational or hobby standpoint and, therefore, may contain material not applicable to prospecting.

A few general remarks will apply to all types of equipment. There is a happy medium in respect to both quality and quantity. In general, the cheaper articles do not stand up to the kind of usage they have to receive, yet very expensive articles are not necessary; good average quality is usually most satisfactory. In deciding on the amount to be taken, the aim should be to assure an amount adequate for reasonably comfortable living (which is closely connected with working efficiency) while avoiding being burdened with unnecessary gear either during the day's work or when moving camp. Another consideration is that although some articles can be bought more cheaply in cities, particularly at 'war surplus' stores, many articles that have stood the test of time for use in a particular region can best be bought at stores in the smaller towns from which one sets out on a trip. All essential articles of clothing, groceries, utensils, and ordinary tools such as picks, shovels, and axes can be bought in this way, and canoes are often available. If the cost of bringing in equipment is considered, the higher prices charged in outlying places may be negligible, particularly in view of the advice that can be obtained from local persons. When planning a trip, it might be advisable to write to a merchant at the take-off point for information on items available and their prices. The local postmaster will usually forward the letter to a storekeeper, in cases where no specific address is available.

Most prospectors cannot afford to engage local outfitters or guides, but when this is possible it would be a good way for a beginner, or anyone unfamiliar with the particular mode of travel to be used, to acquire experience.

Government agencies are not permitted to recommend firms or dealers; no names and addresses of suppliers are therefore listed here. Information of this kind can be obtained from advertisements in mining papers and magazines, or from a telephone directory under such headings as sporting goods, camp equipment, hardware, mining supplies, laboratory equipment, and scientific equipment.

Clothing and General Equipment

It is not essential to have much special clothing or general equipment. Any outdoor worker or man who engages in outdoor sports would have nearly everything required. Town clothes are not suitable, although apart from footwear, they will serve; if possible, however, it is much better to have proper outdoor clothing, of which a wide selection is available. The following list is not meant to include all the ordinary items needed, but to give advice on certain matters that may be important for beginners or persons unfamiliar with some items.

Footwear

The importance of proper socks and boots cannot be overemphasized. Socks should be woollen, of medium or heavy weight, and they must fit well. Under some conditions it is advisable to carry a spare pair of socks during the day in case of need. Three to six pairs should be taken on any but the shortest trip.

There are many kinds of boots, each of which has advantages for certain conditions, and much depends on individual preference. The main points are not to wear low shoes because of the danger of turning an ankle; to have soles sufficiently thick to protect the foot when walking on rough rocks; and to have the boot fit snugly enough at the heel to prevent the heel from moving in the boot; elsewhere there should be plenty of room for the foot to expand, as it does when doing much walking, particularly when carrying a load. High-topped boots were popular several years ago, but most woodsmen now wear boots that come just above the ankle, 6 or 8 inches high, because higher boots are unnecessarily heavy, hot, and binding. These may be desirable in a few regions in southern British Columbia and Alberta where rattlesnakes occur, and in parts of the Canadian Shield where there is much 'buck-brush' or 'Labrador tea' (dense shrubs about knee height that are hard on clothing and shins). In most parts of the Shield the favourite boots are strong, but not too heavy, leather boots reaching just above the ankle and having neoprene soles; or boots 8 inches or

A. *Typical field clothing, and a common method of back-packing, with heavier articles in pack-sacks, and lighter sleeping bags carried above them. The man at left uses both shoulder straps and a head-strap.*

Plate XXXVI

B. *Back-packing, using pack-frames on which loads are lashed instead of being placed in pack-sacks.*

more in height having rubber bottoms extending to the ankle, with leather uppers cemented and stitched to the rubber: the latter are uncomfortable in very warm weather. Some brands of this type are made of leather that is unnecessarily stiff and heavy, causing chafing of the heel or ankle, but the better ones, sometimes called hunting shoes, have soft, light-leather uppers. Boots of the last-named type require thick felt insoles, a spare pair being desirable to permit drying, as they absorb perspiration. Crepe-rubber soles wear out quickly on rock, but are otherwise fairly suitable. Leather soles are too slippery unless hob-nails are added, but nails are undesirable where canoes or aircraft floats are concerned. Neoprene soles are suitable for most parts of the Shield and many other regions but nailed leather soles are necessary in high mountains. In very hilly or mountainous country it is important to have boots with strong counters along the sides of the heel, to prevent the boots from getting out of shape when used on hillsides. Boots with moccasin-type stitching at the toes wear out quickly in brushy regions. In general, a pair of good boots will last a season in the Shield, but it is desirable to have two pairs so that one pair can be left in camp to dry. If two pairs are taken, it is often desirable to have one pair of leather and the other of the hunting-shoe type. In the mountains, two pairs of good leather boots may be worn out in a season if much time is spent in rock climbing or on talus slopes.

Boots should not be dried too close to a stove or fire, as they may be damaged or burnt. To speed the drying of the insides, warmed pebbles may be poured into them. After drying, the leather should be rubbed with dubbin or other water-proof grease or oil; as salt injures leather, greases containing it (e.g. butter, bacon-grease) should not be used.

Light footwear is desirable for wearing in camp and on long canoe trips. For these purposes many woodsmen prefer Indian moccasins obtained locally, and wear special 'moccasin' rubbers with them when necessary; others dislike moccasins because they lack a raised heel. In some regions, moccasins worn with rubbers are also popular for land travel.

Underwear

Most experienced woodsmen wear underwear of wool or wool mixture except in hot weather. Two suits of two-piece underwear of this kind are considered essential for a trip of more than a few days. In most parts of Canada it is cold at times even in summer, therefore, woollen underwear is desirable, not only for its warmth but because it does not get clammy from perspiration in the way that cotton does. Most campers err on the side of having too light or too little underwear. At times, it is advisable to carry a woollen undershirt that may be put on when required.

Trousers

In summer most woodsmen wear ordinary khaki or blue denim trousers, but in very rainy or brushy regions they often use canvas ones. Breeches used to be popular for wearing with high boots but are not worn so commonly today;

their main advantages are in being less likely to snag than are loose trousers, and in preventing flies from entering; these ends may be attained by wearing trousers tucked into the socks. During rain or when walking through wet brush, the trouser bottoms may be left open, to keep water from running down into the boots. Trousers should not have cuffs (as they may snag and trip the wearer); if trousers have cuffs they can easily be cut off.

Coats

Some sort of water-repellant and wind-resistant coat is essential; this should not be made of rubber, plastic, or oilskin because these do not permit perspiration to escape when walking or working. A light windbreaker or parka that can be carried when not needed is good for warm weather, but a heavier, canvas hunting coat or 'bone dry' is better during cool or very wet weather. It may be desirable to have both a windbreaker and a canvas coat. The numerous pockets of the hunting coat make it popular. Coats and windbreakers should be large enough to permit wearing several sweaters underneath. Parkas are desirable in the far north in summer, and anywhere in spring, late autumn, or winter; for most purposes, light ones that can be worn over sweaters are better than heavy ones.

Under some conditions it is also desirable to have a slicker or two-piece rain suit to use during heavy rain in camp, or when in a canoe or boat, or on a horse. Light plastic raincoats are suitable for these purposes because they are very light and compact; they may get torn but are so inexpensive that this is not serious.

Sweaters

One or more woollen sweaters or heavy woollen shirts are required, and in most regions at least one should be carried during the day to put on if necessary. It should be remembered that two or three light garments are warmer than one heavy one, and permit various combinations to suit requirements. Sweaters alone are not very warm because of their open weave; they should be worn under an ordinary shirt or under a windbreaker or canvas coat; this also prevents snagging.

Gloves

Gloves or mitts are required for warmth in some regions, and during some seasons in any part of Canada. Heavy gloves are useful for protection when doing rough work such as removing large pieces of rock from a trench; for such work some prefer the waterproof workmen's gloves that are now available.

Hat

Most prospectors wear a hat or cap, at least during very sunny or wet weather. Many prefer a cap because the hood of a parka can be worn over it when desired. Others prefer a light hat made of waterproof cloth.

Sewing Kit

Needles, thread, darning wool, and spare buttons should be carried on long trips.

Bedding

Sleeping bags are generally preferred to blankets because of their lightness and because the end and sides can be fastened. Blankets will serve, however, if one has them and does not wish to spend money on a bag. A good combination for summer is a light bag and a blanket that can be put under the bag in two thicknesses on mild nights, and inside the bag on cold nights. Even when using a bag, it is desirable to have a tarpaulin 6 or 8 feet square to fold under and over the bed, unless one is sleeping in a tent with a canvas floor.

Small air mattresses are now fairly cheap and add greatly to comfort, but would be an unnecessary burden on back-packing trips or canoe trips involving many portages.

When camping without a tent or with a tent that is not insect-proof, it is desirable to have a fly bar that can be placed over the bed and kept up by tapes attached to stakes driven in the ground. These bars are light and inexpensive, and can be rolled into a very small bundle.

Tents

For occasional light trips, no tent is needed in fine weather, and if necessary a shelter may be made from boughs or from a tarpaulin or tent fly. For most camping trips a tent is desirable. They are available in many sizes, shapes, materials, and prices, and the selection is largely a matter of personal preference. The most popular tent for wooded country is the "A" shape, with side walls from 2 to 4 feet high and a wedge-shaped roof; for a very small, light tent the side walls are omitted. The usual size for one or two men is 7 by 9 or 8 by 10 feet in floor dimensions. The pyramid tent, requiring only one pole, is preferred for regions where poles are hard to find or where collapsible metal ones must be included in the outfit. Duck tents are relatively cheap, but the more expensive ones made of treated cotton (so-called silk tents) are lighter and more compact. Green or khaki tents are cooler and darker than white ones; some persons find it difficult to sleep in a white tent in the far north where daylight or twilight lasts all night in summer. However, as white tents are much easier to detect from the air, they should be used if rendezvous with aircraft are to be made, unless the outfit includes other means of attracting attention. Tents equipped with sewn-in canvas floors and cheese-cloth fly doors are best for keeping out flies, mosquitoes, and other pests, but sewn-in floors are not suitable if a wood stove is to be used in the tent.

A light 'silk' fly to stretch over a tent keeps the tent from leaking and shades it, but is not essential.

Stove

A camp-fire is sufficient for light trips, but a small stove is desirable to permit cooking in the tent during rainy weather, and for warming and drying the tent. Small sheet-iron stoves come in different weights and sizes, the smallest being very light. They are of both collapsible and rigid types; the former are more compact but are sometimes difficult to assemble after they have been used for a time. A stove is usually set on four stakes or a pile of stones, and it must not be placed where any part of the tent might touch it; about 2 inches of sand or earth must be placed in the bottom of the firebox to keep the metal from burning out and to keep the stakes from igniting; if the stove has an oven, a little sand or earth should be placed between the top of the oven and that of the stove, to hold the heat.

About two lengths of stove-pipe should protrude above the tent to permit a good draft. A piece of wire netting can be wired over the top of the pipe to arrest sparks. If a tent does not have a stove-pipe hole, an asbestos or tin shield with a hole in it can easily be stitched to a tent. Some campers prefer to place the hole in the end of the tent, to reduce the danger of sparks. If this is done, pipe-elbows are required.

A gasoline or Primus stove is used in the far north where wood is difficult or impossible to obtain. Some campers prefer a gasoline stove even in wooded country.

A 'reflector' that is placed in front of an open fire and used for baking bread and other food is light and is useful if no stove is used or if the stove does not have an oven.

Saw

A saw is useful for cutting firewood and for other uses around camp. A light one can be made by fastening strong rings about 1½ inches in diameter to the ends of a 'Swede saw' blade. For use, a green pole about a foot longer than the blade is sprung between the rings to maintain tension and provide a handle.

Dunnage Bags, Packsacks, etc.

For carrying small articles during the day a haversack or rucksack is almost a necessity. A haversack is easier to get at, and is suitable if only a few articles are carried, but it has the disadvantage of being apt to catch on branches, etc., because it is slung over one shoulder. A rucksack that is carried at the back, and slung from both shoulders, is better in all respects except that it has to be taken off every time anything is taken from it.

Canvas dunnage bags or packsacks are generally used for stowing and transporting camp equipment and spare clothing. For back-packing many woodsmen find a pack frame, to which articles are lashed, preferable to a packsack.

Provision Bags

Canvas sacks are very desirable for protecting food from dampness and to prevent damage to the light cloth or paper bags in which it is packed. They range in size from 50-pound ones for a sack of flour to 1-pound ones for small parcels. They can be bought already treated with paraffin to make them more waterproof than untreated canvas, or the user can treat them, or other canvas articles, by painting with a solution of paraffin wax in pure benzine or gasoline.

Tarpaulins

Small canvas tarpaulins are useful for making shelters and covering equipment, firewood, etc. For light trips a few yards of thin plastic, such as can be bought cheaply by the yard in department stores, will take the place of tarpaulins.

Illumination

Except in the north in midsummer a flashlight is almost indispensable. For illuminating tents, candles are usually taken on light trips, and small gasoline lanterns are often included in more elaborate outfits.

Lighters and Match Safes

At least one lighter or waterproof match safe should be carried at all times. Good match safes can be bought or they can be improvised by placing matches in a tin and sealing it with adhesive tape, or by pouring melted candle wax into a box of matches. Match heads can also be water-proofed by dipping in shellac. It is advisable to stow supplies of water-proofed matches or matches in waterproof containers in several different bundles of equipment, so that if one is lost there will still be a supply.

Knife

At least one knife is a necessity, and it is well to have a spare one. The choice between a pocket knife and a sheath knife is largely a matter of individual preference. A small whetstone should be included for long trips.

Fishing Tackle

For most regions it is well to have at least a minimum of fishing tackle to obtain fish for food. Rods or other elaborate tackle are not essential. A few hooks, lures, and trolling lines are about all that is needed, but a small gill net is useful on long trips.

Firearms

There are very few parts of Canada where firearms are needed for protection. In almost all parts of the country there would be more danger from accidents with firearms than from wild animals. In some places a rifle is desirable for obtaining food or for killing black bears that may become a nuisance, rather than a menace to life.

Prospectors should acquaint themselves with local game laws. Information may be sought from local game wardens or from the provincial government departments responsible for game laws, or in the case of the Northwest Territories or Yukon from the Department of Northern Affairs and National Resources. In parts of Canada one may carry a rifle without a permit, but special permits that are usually hard to obtain are necessary for carrying a revolver or pistol.

First Aid Kits

A small kit should be carried in the pocket at all times because even the most experienced woodsmen need one occasionally. A simple one can be made by placing in a small tin a small vial of antiseptic, a small bandage, a small roll of adhesive tape, and a few Band-aids. The tin should be sealed with adhesive tape. A larger kit should be kept in camp; these can be made up to suit individual requirements or bought ready-made, but in the latter case it is usually necessary to add a few household remedies, as most ready-made kits are intended for accidents rather than illnesses. Before undertaking a long trip it would be advisable to consult a doctor or an official of a Workmen's Compensation Board regarding proper equipment. A large prospecting party with paid employees might come under the jurisdiction of a Workmen's Compensation Board, in which case obligatory first aid requirements would be specified, and in any event these Boards can give useful advice.

Spectacles

Persons who depend on spectacles should always carry a spare pair. Sunglasses are advisable in certain areas such as high mountains, where snow may be encountered during the summer. Many persons also find them desirable if much travelling on water is done.

Rope and Wire

About 50 feet of light rope, such as sash-cord, is often useful. A small coil of thin brass or copper wire, such as is sold for snaring rabbits, is useful for making repairs and for obtaining food in emergencies. A little stove-pipe wire or hay wire may also prove useful. Pliers are worth taking on all but very light trips.

Miscellaneous

A few nails and rivets are useful for repairing equipment, and a pound or so of 2-inch and 4-inch nails are helpful in making camp. A roll of friction tape is a useful addition to most kits.

Protection from Flies and Mosquitoes

Mosquitoes, black-flies, and other biting flies are a nuisance in most parts of Canada during the summer months. A person gets used to them to some extent, but in many places they are so numerous that even the most experienced woodsmen have to protect themselves. With the aids available today there is no need for anyone to hesitate about prospecting because of these pests.

In the writer's opinion, the best repellants are those containing the ingredients called '612' and '622'. The former is sold as a clear liquid and as a 'stick', which is put on exposed parts of the body except near the eyes. It evaporates or is diluted by perspiration fairly readily and has to be renewed more often than the '622' brands, which are sold as jelly in tubes or jars. To prevent repellants from running into the eyes it is advisable not to put any on the forehead; they may be smeared on the underside of the brim of a hat or cap to assist in keeping insects away.

When flies are very numerous, some men tie large handkerchiefs over their heads and necks, leaving the face exposed, or wear a head net over a hat and tucked into the neck of the shirt. These nets can be bought or improvised.

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Some men also wear shirts and trousers with zippered openings to keep flies out; others, when necessary, close these openings and the cuffs of their shirts by temporary stitching with needle and thread after dressing.

Smudges may be lit in camp or at a work site occupied for some time. To prevent a smudge from spreading it should be made in a large tin can with a few holes punched in the sides; a small fire at the bottom is covered with green leaves or grass.

Fly bars for beds or tent doors have been described elsewhere. On any but the lightest trip it is desirable to carry fly spray and a small sprayer, or a 'bomb' containing an insecticide under pressure, for use in a tent. Food and dishes should be covered before a tent is sprayed. The reader may think that a prospector should 'rough it' and that a fly spray or 'bomb' is luxury, but he should bear in mind that too much discomfort reduces efficiency.

Provisions

The choice of provisions varies greatly with the method of transportation and length of trip. For many kinds of prospecting trips supplies are no great problem and no advice is necessary beyond pointing out the need for taking a reserve for emergencies. For any kind of trip it is unwise to count on obtaining fish or game; sufficient food should always be taken, and fish or game should be considered only as extras.

For long trips it is usually necessary to avoid or restrict heavy or bulky foods such as canned fruits and vegetables, and to take only enough perishable foods to last for the first few days. An experienced man can live for a long time on a limited amount of staples that keep well, such as flour, bacon, baking powder, beans, salt, dried fruit, and tea, which provide a fairly well-balanced diet. When possible, however, a few additional items should be taken for ampleness and variety. The following list is suggested as a basis for one man for a month, when it is not necessary to reduce weight to the absolute limit, and when too much weight is not desired; substitutions can be made to suit individual requirements and preferences:

Flour	25 lbs.
Baking powder	1 "
Rolled oats (quick-cooking variety)	6 "
Beans (dried)	5 "
Rice	5 "
Potatoes (dehydrated)	4 "
Vegetables (dehydrated carrots, turnips, beans, etc.)	4 "
Bacon and ham	20 "
Cheese	3 "
Egg powder	1 "
Sugar	15 "
Tea	1 "
Coffee	3 "
Chocolate (semi-sweet, for lunches and emergency)	2 "

Milk (powdered whole milk)	3 lbs.
Salt	1 "
Fruit (dehydrated prunes, peaches, apples, apricots, figs, raisins, etc.)	6 "
Butter (canned)	4 "
Jam, syrup, honey	5 "
Pudding powders (prepared mixtures)	2 "
Dehydrated soup mixtures	1 "
Yeast	—
Oranges	1 dozen
Canned fruit	6 tins
Canned sausage or beef	6 "
Pepper, and other spices if desired	—
Lard (or substitute)	2 lbs.
Candles	½ dozen
Matches (these should be placed in two or more waterproof containers, which should be placed in different packs in case one is lost)	—
Waxed paper (for lunches)	—
Soap, including toilet and laundry soap, soap flakes or detergent	—
Pot cleaners	—
Dish towels	—

The items listed above would total about 125 pounds. Bacon and ham should be canned or of the gelatin-packed variety if they are to be kept for more than a few weeks. Dried meat can sometimes be obtained from natives, but the possibility of being able to do so cannot be depended on in most instances.

Utensils

For an occasional short trip most persons could obtain utensils at home that would serve, but for steady use several items intended especially for camping are preferable. A wide choice is available, ranging from very light one-man kits weighing less than a pound to elaborate outfits. Pots should be of tin or aluminum for lightness, and should nest to save space. Plates, cups, and bowls may be of tin, aluminum, enamel, or plastic, but aluminum cups are undesirable because they may burn the lips, and enamelware is likely to chip. Some parties find that the advantages of a pressure cooker offset its weight and expense. The following would be a moderate outfit for two men and occasional visitors:

Nest of 3 or 4 pots with lids
1 or 2 frying-pans
2 pans for baking bread, etc.
1 wire toaster
4 plates
3 cups
3 small bowls
1 large spoon
1 lifter
1 whip or egg-beater for mixing milk
1 butcher knife
1 can opener
4 each knife, fork, and spoon
Steel wool or equivalent for cleaning pots
2 yards dish towelling (dishes are more sanitary if dried in the air after rinsing in hot water, but clean dish towels are needed in wet weather).

A dish pan, flour sifter, teapot, coffee pot and one or two pails might be added if weight and bulk were not serious problems.

Prospecting Equipment

The essential pieces of equipment for prospecting, as distinct from travelling and camping, are not numerous. There is scope for a certain amount of individual preference even in the following list of more usual articles. It is not necessary to have all the items listed, or to carry all that one has at all times; a selection may be made to suit particular requirements. Equipment for preliminary exploration of a prospect is also mentioned.

Prospecting Pick

A prospector's pick or rock hammer of some kind is the essential tool. The usual type is a short-handled one for use with one hand, having a head with a hammer at one end and a pick at the other. The hammer end, used for knocking off pieces of rock, should be square sided, not octagonal, because the latter shape soon becomes rounded. The pointed end is used for picking into overburden or decomposed rock, for removing moss, for prying loose rock, and for picking out small specimens. Both the hammer and pick faces should be tempered as hard as possible without making the steel brittle. The eye should be as large as possible to reduce the chance of breaking the handle. A bricklayer's hammer is suitable for most purposes.

Some prospectors prefer a long-handled pick with a head similar to an ordinary prospector's pick, because it necessitates less stooping and can also be used as a walking-stick to assist in climbing hills. A pick of this kind can be made from an ordinary prospector's pick and a sledge-hammer handle, but the eye is likely to be too small to prevent the handle from breaking under the blows that can be struck when such a tool is used with both hands; it is therefore better to have a blacksmith make a head with a large eye.

Grub-hoe

A prospector's grub-hoe has many advantages for removing moss, roots, or shallow overburden; it is lighter than an ordinary grub-hoe and has one hammer face and one hoe face. Many prospectors have both a grub-hoe and a pick, and carry whichever seems to best suit immediate requirements.

Axe

An axe is necessary, particularly for staking and camping. The usual type has a head weighing 1 pound to 1½ pounds and a handle about 26 inches long. The 'Hudson's Bay' shape of head permits lightness with a wide cutting edge, but is not usually stocked by stores. A spare handle should be taken on long trips.

An axe sheath prevents accidental cutting of persons and equipment and also keeps the blade from being blunted or nicked. Sheaths can be bought or made from leather about ⅛ inch thick; a simple one extends for only an inch or two back from the cutting edge, and is tied by two strings attached to the leather.

It is desirable to have a single-cut flat file 6 or 8 inches long for filing down the part of the blade immediately behind the edge, as well as a whetstone for the edge itself.

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Plate XXXVII

Examples of prospecting equipment and a chip-sample. 1, large gold-pan; 2, medium-size pan; 3, steel mortar and pestle; 4, grub-hoe; 5, long-handled prospecting pick; 6, ordinary prospecting pick; 7, rock chisel; 8, chip-sample; 9, single-jack; 10, moil; 11, canvas sample-bag; 12, goggles for protecting eyes when sampling.

Some prospectors carry a small hatchet in a sheath on the belt, for incidental blazing or chopping, and leave their large axe in camp until it is needed for heavier work such as staking or clearing. Few prospectors would venture on a trip with only a hatchet unless it was necessary to reduce equipment to the barest minimum, and many woodsmen consider a two-handed axe their most essential companion next to a supply of matches.

Radioactivity Detectors and Fluorescent Lamps

These special instruments for certain kinds of prospecting are discussed in Chapters IX, X, and XII.

Gold-pan

Apart from its use in testing placer deposits, a gold-pan is very helpful in lode or 'hard rock' prospecting. Such use is by no means confined to gold. Crushed samples can be panned in the field to concentrate the heavier mineral grains, which are generally the important ones. In this way minerals that are too finely dispersed for detection in a solid specimen can often be found. Pans are of different sizes. The larger ones are generally used in placer work and smaller ones in lode prospecting.

Mortar and Pestle

Iron or steel mortars and pestles are useful for grinding samples at home or in camp; or a suitable mortar can be made from a 2-inch pipe cap or a piece of 2-inch pipe about 2 inches long with an end screwed or welded in place, or from a piece of steel hollowed out on a lathe. A short piece of steel or a prospector's pick will serve as a pestle. If nothing else is available, samples can be placed in a canvas sack and hammered against the side of an axe or a flat rock.

Sieve

A sieve is useful for screening a sample during crushing. Some authorities recommend a sieve having 60 or 80 apertures to an inch. A sieve can be improvised by punching small holes in the bottom of a small tin can, or by soldering a piece of fine-mesh screen to the bottom of a can whose ends have been removed.

Compass

A compass is an essential item that should be carried at all times to avoid getting lost, to aid in staking, and to help in making sketches and recording the strike of mineral deposits and other geological features. The best type for the purpose is a geologist's 'Brunton' compass, but it is expensive, bulky, and is more elaborate than is necessary for prospecting. Good instruments of the army marching type can sometimes be bought fairly cheaply in war-surplus or second-hand stores. A compass that will serve can be bought for about $1 in sporting-goods stores.

Because one may forget which end of the needle of some compasses points north, it is advisable to test the compass at a place where the direction is known, and to scratch a note on the back of the case.

Map Case

A waterproof map case is desirable unless the map is cut up and pasted on pages of a notebook. Cases with a transparent celluloid cover can be bought or made at home. The map can be cut in sections or folded to the proper size. It is well to have the case the size of ordinary air photographs, about 10 inches square, so that these can be carried as well.

Another method is to paste sections of a map on cardboard of convenient size, or to mount sections on a large piece of cotton, leaving spaces about ¼-inch apart to facilitate folding. The surface of the map may be sprayed with a clear waterproofing compound, but this makes it difficult to add notes or other data. To mount on cardboard, soak the map sections and the cardboard in water, then apply paste thinly while they are wet. To mount on cloth, stretch a piece of cotton a little larger than the entire map by tacking it to a smooth wooden surface, spacing the tacks 1 inch or 2 inches apart. Wet the cloth and the map sections in water, apply a thin coat of paste to both paper and cloth, and press the sections to the cloth.

Tape

A 50- or 100-foot 'metallic' tape is desirable in special cases where accurate measurements are to be taken.

Protractor and Scale

A protractor and a scale 6 inches long are desirable for plotting points on a map and for making sketches. The scale should be divided into inches and tenths, or into divisions corresponding to the scale of the map most frequently used. Inexpensive protractors and scales can be bought in 'dime stores', and it is advisable to include spare ones as they are easily lost.

Pencils, Notebook

A few pencils, perhaps including coloured ones, are necessary. A small notebook is desirable for recording general notes and particulars about discoveries and samples.

Drawing Pad

A pad of paper is necessary for making sketches, but need not be carried at all times. A convenient size is about 8 by 10 inches. A useful type is made of tracing paper and equipped with a sheet of square-ruled paper that can be placed underneath a sheet of tracing paper to aid in plotting; these are stocked by stores that sell supplies for engineers and draughtsmen.

Pocket Lens

A lens is almost indispensable for examining specimens and pannings. A single lens magnifying 4-5 diameters, and costing about 50 cents will suffice but many prefer a compound lens magnifying 8 or 10 times and costing $10 or more.

Magnet

A small magnet is usually carried for testing magnetic minerals and for removing them from pannings.

In addition to the above-mentioned tools and articles that are necessary or desirable at times for ordinary prospecting there are many other articles that are useful for specialized kinds of prospecting. These are described in other sections, where the particular method is discussed.

At least some of the following tools are required for the preliminary exposure of a discovery that seems to warrant such work and for assessment work. They might be kept at the base or in camp until needed, or one might return to do such work on another trip. A prospector might never need to do work of this kind, or he might have someone do it for him.

Shovel

A shovel is required for trenching through overburden and for removing loose rock from trenches blasted in solid rock. The long-handled, round-pointed variety is customary but a short one or even an army entrenching tool may serve if weight is being reduced.

Pick

An ordinary pick is useful for trenching.

Moils

Moils are commonly used for sampling. They are of two types. One is simply a piece of octagonal steel 8 inches or a foot long, with a four-sided point. The other has a handle and detachable bits. Both types may be tipped with a hard alloy. A large cold-chisel may be used instead. They are struck with a small sledge hammer or a prospector's pick, but most picks are rather light for this purpose.

Instead of using moils, a prospector's pick can be held in the left hand, with the point against the rock, and the hammer end can be struck by a sledge or other hammer. This method is usually frowned upon because many picks are made of brittle steel, so there is danger of a fragment striking the eye. This danger is prevented by wearing goggles.

Drill Steel

If trenches are to be excavated in solid rock, it is necessary to have a few lengths of drill steel unless a power drill is used. Ordinary striking drills are usually made from about $\frac{3}{4}$-inch or $\frac{7}{8}$-inch octagonal steel, with a chisel-shaped bit. They range in length from about $1\frac{1}{2}$ to 3 feet, the longer ones having slightly narrower bits. Formerly, such drills were always sharpened by blacksmithing, but special drills with tungsten-carbide tips are now widely used; these are sharpened by grinding and few modern prospectors require a knowledge of blacksmithing. The tops of drills and moils should be ground or forged occasionally to remove 'mushrooms' that might injure a hand if the tool slips. An iron rod with a small scoop at one end is required for removing rock cuttings from the holes drilled.

Striking Hammers

A man working alone uses a short-handled sledge weighing 2 to 4 pounds, holding the moil or drill in one hand and the sledge in the other; for this reason it is often called a 'single-jack'. When two men are working, one holds the drill and turns it slightly from time to time, and the other uses a long-handled sledge weighing about 8 pounds.

Goggles

Safety goggles that can be worn when sampling or drilling are cheap and easy to carry. Their use may prevent injury from fragments of rock or steel.

Explosives

Dynamite, caps, and fuse are required if trenching in solid rock is to be done. A merchant, or a publication such as "The Blaster's Handbook", published by Canadian Industries Limited, should be consulted for information on choice, quantity, and handling.

Portable Power Drills

Portable percussion drills powered by a small gasoline motor mounted on the drill are now widely used for drilling blast-holes for rock trenching in connection with the exploration of a prospect. They are fairly heavy and expensive, and are useful mainly for work undertaken by companies or by experienced prospectors who have reason to do fairly extensive exploration of a discovery.

Light Diamond Drills

These are used by some experienced prospectors for prospecting beneath a favourable structure or for preliminary exploration of a prospect, but because of their weight and cost, and the time and skill required to test a structure by drilling, they are not part of most prospectors' equipment. They may also be used for drilling blast-holes. They thus have important uses for some advanced independent prospectors and for companies engaged in some kinds of work. The subject of diamond drilling is discussed further in later chapters.

Transportation

For all but casual prospecting, the methods of travelling and transporting equipment are of vital concern. They vary greatly for different parts of the country, and in many regions there is a certain amount of choice. In most instances there will be at least one geological report on the area or on one nearby. This should be consulted for information on the methods of reaching the area and travelling within it. The report may have been written several years before and some changes involving easier access or deterioration of roads or trails may be expected. Supplementary information can often be obtained by writing to or visiting provincial road or forestry officials.

Southern Canada is fairly well served by railways and roads, from which much prospecting can be done by daily trips on foot or by short back-packing trips. In many places, branch roads that are unsuitable for ordinary automobiles can be travelled by truck or jeep. Also, there are steamship services on the coasts and on some of the larger lakes and rivers. Road maps and other information of this kind can be obtained from the Canadian Government Travel Bureau, Ottawa, and from provincial or local travel bureaus. Readily accessible areas are, however, likely to have been already prospected fairly thoroughly. In general, therefore, prospectors have to transport themselves and their outfits as far as they can by rail, road, steamer, or airline and then rely on one or more of the methods discussed below. These methods are usually quite different in summer and winter. Only the summer methods are discussed, because most prospecting is done then; anyone engaging in the special kinds of prospecting that can be done in winter will probably be familiar with the methods of travel or know where to obtain advice. In most parts of the country there are intermediate seasons called 'break-up' and 'freeze-up', usually lasting a month or six weeks, when the ice is leaving or forming on lakes and streams. During these periods it is either impossible or inadvisable to travel. Most prospectors set out after break-up and are careful to return before being 'frozen in', but when it is necessary to spend as much time as possible in actual prospecting they may go to their destination by winter travel, even carrying a canoe on a dog-sled if necessary. Then they would remain inactive or prospect near their base camp during break-up and freeze-up, and return in winter. The length of the open summer season varies slightly from year to year, and is progressively shorter towards the north. In the more southerly regions the best prospecting season is generally from some time in May to about the end of October. In the vicinity of the Arctic Circle the open season is usually from some time in July to some time in October, but there have been occasional seasons when the ice did not leave Great Bear Lake.

Canoes and Small Boats

In many parts of Canada the canoe is the basic method of summer travel. This is particularly true in the Canadian Shield, which is laced by a network of lakes and streams that permit access to within a few miles of most points. Furthermore, the streams of the Shield are characterized by long sluggish stretches separated by shorter rapids or falls. Canoeing upstream is therefore usually not very arduous except for the necessity of poling or hauling the canoe up the lesser rapids and back-packing on the portages at the worst ones. The Indians adapted themselves to these conditions by trial and error centuries ago, developing the birch-bark canoe, which was light to paddle and to portage, and easy to repair. The early fur traders and explorers were quick to follow their example, and used the birch-bark canoe to open up all parts of the country except the west. For many years the canvas-covered canoe, because of its greater durability and stability, has replaced the birch-bark. Aluminum canoes have recently appeared on the market but have not become popular because they are harder to repair, hot in warm weather and cold on cold days, and because one would strike a sharp blow if it overturned and hit a man. Canoes made of plywood have been used with good results.

Canvas canoes come in many shapes and sizes. The most popular for average conditions is 16 or 17 feet long and of the 'prospector' or 'cruiser' model. The former is lighter, and flatter bottomed. The cruiser is a little sturdier and has a rounded bottom that permits larger loads. A round bottom makes a canoe easier to paddle, but a flat one is best for shallow streams and for quick manœuvring in rapids. Canoes are made with or without wooden keels. Those without them are easier to paddle, except in a side wind, but this is not noticeable when outboard motors are used, and the keel protects the bottom. For carrying larger loads and for greater stability on large lakes the 'freighter' model is preferable. It is made in lengths of 18, 20, and 22 feet, but the 18-foot type is the only one that is usually portaged, and even this is an awkward load for two men. 'Semi-freighters' are also made, the construction being lighter than that of 'freighters'.

An experienced man travelling alone with a light outfit may use a canoe 14 or 15 feet long but 16- or 17-foot canoes are generally recommended, or larger ones if portages are not a problem. One man can portage a canoe up to 17 feet

A. A lone prospector and his 14-foot canoe, Chibougamau region, Quebec.

Plate XXXVIII

B. The one-man method of portaging a canoe. This photograph was taken in Yellowknife region, N.W.T. in the spring, before all the ice had melted.

long by lashing the paddles across the bars with the blades near the centre of gravity; the canoe is then turned upside down over the head, and the blades are rested on the shoulders. A head strap may be attached to take part of the weight. When two men carry a canoe they invert it over their heads, one man standing near the bow and the other near the stern, and carry the weight on their hands or their shoulders.

A spare paddle, a tube of waterproof cement, and a piece of canvas for patches should always be carried in a canoe. It is also advisable for each man to have a kapok-filled life-vest to keep near him even if he does not wear it.

A 17-foot prospector canoe weighs about 75 pounds when new and will carry about 600 pounds. An 18-foot freighter weighs 90 to 130 pounds and will carry 900 to 1,700 pounds. A canoe should be painted annually to preserve the canvas and the wooden interior. This adds to the weight, as does water that gets into the wood; an old canoe will weigh about twice as much as a new one of the same model. Canoes should be painted orange or some other bright colour to make them easy to locate. This is very important when arrangements are made to have an aircraft visit a party, or if the canoe is left at the shore while the prospector walks inland, as he will have to look for it if he does not return to the shore at the exact point from which he left.

New or used canoes of suitable kinds can often be bought locally, but it is necessary to write in advance to local merchants as they do not carry large stocks, if they stock them at all. Canoes can also be ordered from the manufacturers, who will ship them.

Plate XXXIX

A freighter canoe being lined along a rapid too swift for the outboard motor, which is out of sight at the stern.

Sectional and collapsible canoes are made for carrying in the cabins of aircraft, but are now seldom seen because they are not very satisfactory and because ordinary canoes can be carried by some aircraft. The collapsible ones can also be carried on pack-horses, but this is not commonly done. Rubber rafts are not popular because they are hard to steer.

Row-boats and car-top boats, etc., are satisfactory for use on lakes but are not suitable for portaging. In Western Canada, where the rivers are usually swift, the customary craft, if a river can be navigated at all, is a locally built,

Plate XL

Type of boat commonly used on larger rivers and lakes when the craft does not have to be portaged.

flat-bottomed wooden boat 20 to 30 feet long, used with a powerful outboard motor (*see* Plate XL); these are much like the boats called 'pointers' used on large rivers in Eastern Canada.

The use of canoes and small boats is an art that must be learned by experience. The most important points are to select canoes that are not too small or 'tippy', to keep the load and occupants low and balanced, to avoid overloading, to wait for storms to subside, and not to attempt to run rapids that are beyond one's capability. Inexperienced persons should not attempt to travel by canoe or boat unless accompanied by an experienced man who can teach them during the trip. If this is not feasible, they should get someone to give them basic instruction before setting out.

Rafts

When nothing else is available, a strong raft may be used for crossing or going down a river, or more rarely for use on a lake. The main considerations are not to attempt rafting on too swift a stream and to make the raft large enough for buoyancy and strong enough so that it will not break apart. A raft should be rectangular rather than square, to make it easier to steer. For one man, four dry logs 6 to 8 inches in diameter, preferably balsam or spruce, should be cut about 10 feet long. The raft may be built on rollers and pushed into the water, or the logs may be assembled in shallow water. They are held together by cross-bars that may be fastened by wooden pins if an auger is available, large spikes, dovetailed bars and notches, ropes, or even strong, supple roots or bark.

Outboard Motors

Outboard motors are now widely used on canoes, and almost invariably on the kinds of boats that might be used by prospectors. They add greatly to the speed and ease of travelling by canoe if much portaging does not have to be done. The question of whether or not to use a motor, aside from the expense of buying and shipping the motor and buying fuel, should be considered in relation to the saving of time and labour as against the extra time and effort required to portage the motor and fuel. A motor should not be used when actually prospecting a shoreline, as outcrops may be missed or ignored.

The selection of a motor should be based mainly on the necessity of not over-powering the canoe, lightness of weight, reputation for reliability, and ease of obtaining spare parts. Motors are too powerful for canoes less than 16 feet long. For 16- to 17-foot canoes 2- to 3-horsepower engines are generally used, and 4- to 6-horsepower ones are suitable for 18-foot freighters. Brackets for fastening motors to the sides of pointed-stern canoes are available, but canoes for use with motors are now almost invariably U-sterned and may also be paddled.

If a motor is used it is necessary to have a fuel can, generally of 2-gallon size, a funnel with a fine screen or a piece of felt or chamois to keep out grit and water, a spare starting rope, a supply of shear pins for the propeller, grease, and a few tools such as wrench, pliers, and a special tool for adjusting the 'point' that controls the ignition. On long trips a few spare parts, including spark plugs, propeller, and connecting rod, should be included; it would be advisable to consult a dealer about spare parts and making repairs. If a large party takes more than one motor, it is well for them to be of the same type, so that if one breaks down beyond repair parts from it may be used to repair another.

Aircraft

In recent years aircraft have been used more and more in connection with prospecting and mining and they are contributing greatly to the development of otherwise inaccessible regions. The Canadian Shield is particularly suited for aircraft equipped with floats, or flying boats, because of the innumerable landing places afforded by lakes and rivers. Many prospecting parties avoid long canoe trips by being flown with their outfits to the chosen area, and arranging to be

Plate XLI

The method of lashing a canoe to a seaplane now widely used when moving prospecting and surveying parties, particularly in the Canadian Shield.

brought back or moved elsewhere at an appropriate time. Charter services charging from about $50 to $100 an hour or 50 cents to $1.25 a mile operate from many towns, and advertisements in the mining press give their names and locations. The types of aircraft generally used range from small ones that carry two men and a little baggage to medium-sized ones that can carry 1,000 to 2,000 pounds, including a canoe lashed to float struts. Canoes used on trips of this kind are usually 16 or 17 feet long. Prospectors and geologists who travel by aircraft commonly develop skill in observing and sketching from the air, which assists greatly in detecting and interpreting geological features, selecting routes for travel on the ground, picking campsites, and so on.

Several prospecting and mining companies own their own aircraft or charter them for long periods. This not only facilitates the moving and servicing of prospecting parties, but also permits supervisors to visit them regularly. A few independent prospectors fly their own aircraft. This is a great advantage, and the number of such prospectors will probably increase slowly. It should not be supposed, however, that a private pilot can operate safely in this way without special instruction and qualifications. Bush flying was pioneered by a small group of skilled pilots after World War I, using aircraft that now seem very inadequate. Worthy successors to these men have brought bush flying to a high degree of safety and efficiency by learning not only the specialties of flying from water but also those of flying in regions for which there are no detailed maps or other aids to navigation.

In places where landings could not be made, particularly in mountainous parts of Western Canada, supplies and equipment have been dropped successfully by parachute, for both prospecting and geological survey parties. This method is not yet widely used but it appears to be the most suitable one for certain conditions.

Helicopters have proved successful for certain uses in prospecting and geological surveying. They can land at many places where conventional aircraft cannot, and their ability to hover facilitates close observation from the air. Their main disadvantages are their expense, and the limited range and carrying capacity of the smaller types.

If an aircraft is to return to bring supplies or to move a prospector or party, detailed arrangements should be made in advance. If possible, written instructions, including date and details of such matters as smoke signals, and a map or sketch showing the rendezvous or route to be covered on the ground, should be left with the office of the flying company or with a third party. This is advisable in case a pilot might forget oral instructions, lose written ones, or have an accident on his way to his base after placing a prospector or party in the field and after agreeing on a future rendezvous.

Horses

Pack-horses are the most suitable means of transport in many parts of the Cordilleran region. They are seldom used elsewhere because better methods are generally available. Few parts of the Shield are suitable for horses because the irregular pattern of lakes and streams makes it impossible to travel far on a direct overland route, because of the prevalence of muskegs, and because of lack of feed. In the west there are many places where trails are available or can be cut, or where trees are sparse enough to permit travel without trails, and where mountain-sides are not too steep for a horse. At some centres outfitters are available who will transport men and equipment, and at many places horses, saddles, etc., can be bought or rented from ranchers. The horses used are generally locally raised, of mixed breed and fairly small size.

Strong horses can carry 250 to 300 pounds on a good trail, but they should not be expected to carry more than about 150 pounds in rough country. The typical pack-saddle is a wooden 'saw-buck', but army pack-saddles are preferred by many. Saddle blankets usually comprise one double and one single woollen bed blanket folded to appropriate size. Side packs weighing up to

Plate XLII

Pack-horses, showing a partly packed horse at left, with a box being attached to the pack-saddle by means of the sling-rope, and a completed pack at right, with pack-cover and diamond hitch in place.

Plate XLIII

Pack-horses in Driftwood Mountains, near Smithers, B.C.

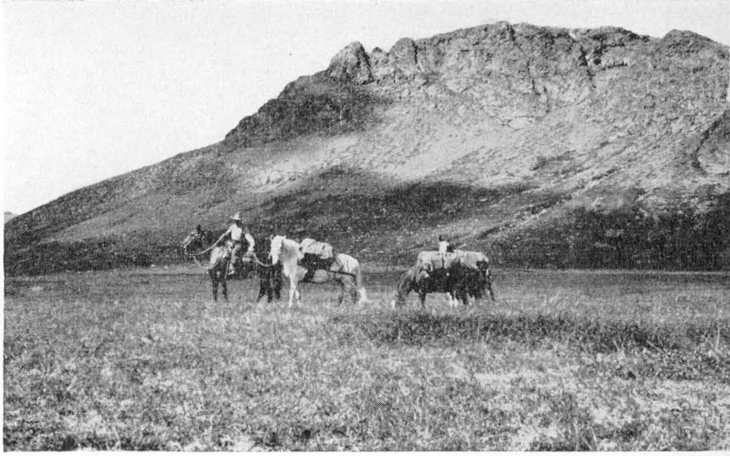
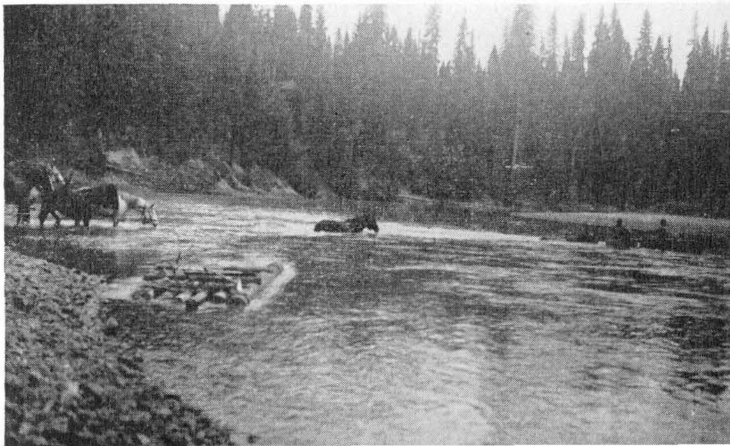


Plate XLIV

Swimming pack-horses across Cariboo River in central British Columbia. One horse is being led by the man in the stern of the row-boat, and the others are being driven into the water by a man out of sight to the left. A small quickly-built raft is shown in foreground.



about 60 pounds and very evenly weighted are lashed to the sides, and 'top packs' consisting of small articles, tents, and bedrolls are placed on top. Top packs should not be too high or heavy, to prevent swaying that may gall the horse or cause the pack to slip sideways or even under the horse's belly. The loading is completed by tying a 'diamond hitch' or 'squaw hitch' with a rope about 30 feet long attached to a canvas cinch band with a wooden hook at its end. These are complicated hitches that cannot be learned adequately from books or illustrations. Other items of equipment may include specially shaped boxes for the side-packs, a canvas pack-cover, a halter, a bell and strap, a wire-mesh nose-guard to keep the horse from nibbling grass en route, hobbles, pine tar for treating cuts and fly-bites, gall cure, colic cure, spare horseshoes and nails, and shoeing kit. A good way to prevent and treat galls is to rub old-fashioned stove polish or graphite on places that show signs of galling, and on the equipment causing it.

Riding-horses may be used as well as pack-horses, or the prospector may walk to his destination. In either case he will probably lead his pack-horse, or one of them if he has two or more.

Horses are troublesome because they are likely to stray and may cause much loss of time in searching for them, even if they are equipped with bells; many horses can travel about as fast wearing hobbles as they can without them. In some districts horses can be picketed, but elsewhere there are too many trees or the grass is too sparse. Many horses have also learned to buck off their packs and to deliberately knock them against trees. In general, however, good horses properly treated are extraordinarily docile, hard-working, and faithful, and more than repay efforts to prevent overloading and to treat them well in other ways. The selection of horses is a difficult matter, as traders have traditionally considered the detection of defects to be the concern of the buyer.

Most matters concerning the selection, packing, and care of horses, and the art of riding, must be learned by practice. If a beginner cannot accompany an experienced man on his first few trips, he can probably arrange with someone at the place where he obtains his horses to instruct him for a few days. It is not practical to discuss these matters further, but as it is sometimes necessary to swim horses across streams, and as even some otherwise experienced horsemen are unfamiliar with the technique, it seems advisable to describe it.

Most horses will wade with little trouble, carrying rider or pack, provided the ford has good approaches and the bottom is free from large boulders. Although horses are good swimmers they generally require special urging and direction to make them swim. In some places it is impossible or unwise to attempt this, because of great distance, steepness of banks, very swift current, or lack of equipment or assistants; but under favourable circumstances it is not difficult to get horses and outfit across a deep creek or river. A good saddle horse will swim a short distance without being unsaddled; the rider floats up out of the saddle, holds firmly to the pommel, keeps the reins from entangling the horse's legs, and gets seated again as soon as the horse begins to wade. For swimming

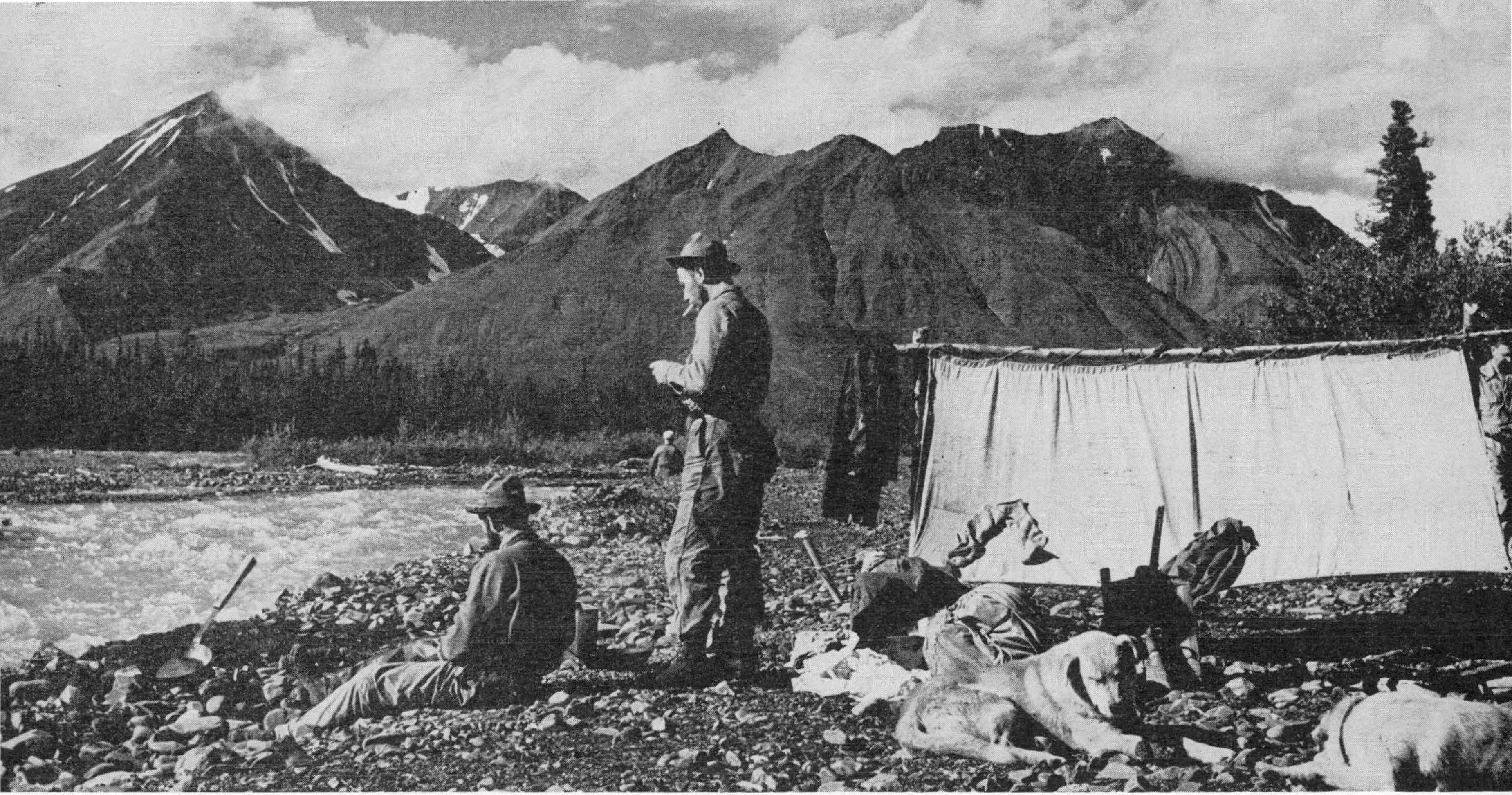


Plate XLV

A light camp in Yukon Territory. Note shelter made with canvas tarpaulin, extension placed on handle of frying-pan for use over open fire, fire-place in safe area of rocks and gravel, and dogs used to assist in packing.

longer distances some especially good horses will allow a rider to direct them in the following way. The saddle and bridle are removed, the horse is ridden bare-back as far as he can wade, then the rider holds tightly to the mane, floats or swims beside the animal on the upstream side, and encourages it to swim; if the horse tries to swim back to the wrong side it can sometimes be directed by turning its head or splashing water on it. If additional horses are to be put across, a partner may be able to chase them in immediately after the first horse, and accompany the last horse. Another method is to join ropes together until long enough to span the stream. A man then swims or rafts across towing the rope. A man on the other side then attaches the halter to the most sensible horse or the one that the others tend to follow, and with pulling on the rope and urging from behind, the horses are made to swim either one by one or in a group. The rope must be kept taut to keep the horses from becoming entangled. If a boat or canoe is available, the best way is for one man to sit in the stern guiding the most suitable horse by a halter-rope. As the craft is rowed or paddled across, the horse is led away from the shore and usually swims behind the boat or canoe willingly enough. Others may be chased into the water behind the led horse, and if they refuse to swim they can be led across one by one. Horses should not be roped together for swimming because they are sure to become entangled. Packs, saddles, and all other gear except the halter of a led horse are removed for swimming and are taken across by boat or raft. When selecting a place for swimming horses it is necessary to see that sloping bottoms and banks are available at each side, and that the leaving point is downstream unless the current is slight. Horses are usually carried downstream about as far as the width of the river.

Dogs

In the northern parts of the Cordilleran region and the Canadian Shield, sled-dogs are commonly used in summer by natives for carrying packs weighing up to 50 pounds. This method is sometimes used by prospectors and survey parties in places where trees are too dense for pack-horses or where water routes are lacking. The load is placed in pockets in a canvas pannier placed over the dog's back. The disadvantages of this method are that the dogs are inclined to stray from the route and to engage in fights, and also that they have to be provided with food.

Back-packing

Almost every prospector has to resort to back-packing at times, either for camping trips where no other method is available, for portaging, or for taking equipment to, or samples from, a discovery under investigation. With proper equipment it is not very difficult to carry enough for a trip lasting a few days, but packing heavier loads is gruelling work. For packing all day, 60 pounds is about the limit for the average man, but for short periods such as in portaging an average load is about 150 pounds and usually consists of one main pack with sacks piled above it (*see* Plate XXXVI A.). The main pack is either a pack-sack, a pack-frame, or a large sack or bale to which a tump-line is attached. The pack-sack usually has a head-strap as well as shoulder straps, so that part of the weight can be taken by the forehead. A pack-frame (*see* Plate XXXVI B.) is often preferred for the following reasons: the load can be better distributed; hard objects are prevented from pressing into the packer's back; there is an air space between the load and the back; and articles that may be needed en route can be lashed in convenient places. Pack-frames are seldom used for portaging, although they are useful for awkward loads like outboard motors. Tump-lines are long leather straps with a head-band at the centre, and are favoured by many persons who have had long experience with them and have developed special neck muscles, but others find them difficult because all the weight is carried from the forehead.

Woodcraft and Other Matters

The ability to live and travel safely in out-of-the-way places is a part of a prospector's qualifications that can best be learned under the guidance of an experienced woodsman, although much can be learned from books such as those listed at the end of this chapter. In the following paragraphs a few of the most important points are discussed briefly.

Companions

Only the most experienced men should travel alone in remote places. A prospecting party, therefore, usually consists of two or more men, but they may separate for a few hours or a day.

Camping

The main factors in the selection of a campsite are usually availability of water, firewood, and tent poles. In most unsettled regions the water of lakes and streams is suitable for drinking, but in some small lakes or in streams draining swamps or beaver ponds it is unsafe. In settled areas it may be dangerous. Doubtful water should be boiled before use.

If possible, tents should be pitched away from large trees that may blow down in a storm, and on gravelly ground that will drain readily. Tents placed in depressions or on clayey ground may be flooded during heavy rain, unless trenches are placed around them.

Camps should be kept in sanitary condition and the sites should be left clear of rubbish, preferably with the tent poles standing against a tree for future use. These points are important not only for the camper's own health but for the benefit of those who may come after; with the increasing numbers of persons travelling in even remote places, there is no excuse for leaving dirty or untidy campsites. Latrines should be covered with earth, and garbage burned, to keep down disease-spreading flies. Tin cans should preferably be sunk in deep water; if this cannot be done, they should be buried, but only after firing them to destroy any food traces, otherwise they will be dug up by bears.

Small 'meat tents' made of cloth netting are useful for suspending from a pole to keep meat cool and away from flies and animals.

Porcupines and other small animals will raid food supplies while one is sleeping or away for the day; food should therefore be kept in covered boxes or otherwise protected. Porcupines will destroy anything salty, such as leather, or axe handles or paddles that have received salt from perspiring hands, so such articles should not be left where porcupines can reach them. Black bears as a rule do not raid a camp that is only left for the day, but they often destroy everything in a camp that has been left for a few days and has lost its man scent. To protect a small amount of provisions from bears the supplies may be placed in bags or boxes protected by a tarpaulin and slung from a bar placed

Plate XLVI

Cache for storing provisions away from the reach of animals.

between two trees far enough apart so that a bear cannot climb the tree and reach the rope. A larger cache, either for supplies left at a camp or for provisions flown to a place to be visited later, is made by selecting three or four trees placed so as to form a triangle or square with sides 6 to 10 feet apart. The trees are cut off about 8 feet from the ground, and the stumps barked to make them hard for a bear to climb. A ladder is built to facilitate construction of a platform made of poles, supported by the stumps. With the help of the ladder the supplies are piled in the centre of the platform and a tarpaulin is lashed over them; then the ladder is removed. As an added precaution the platform may be made to project 2 or 3 feet beyond the stumps, so that even if a bear climbs a stump it will be difficult for him to get on the platform.

Getting Lost

Everyone who enters the woods should know how to avoid getting lost and what to do if lost or injured. These misfortunes do not happen often, but they do occur and may have serious consequences. The surest way of not getting lost is to make a pace and compass traverse right from the outset, by the method explained elsewhere, and to figure out the return course when the time comes.

This is seldom necessary, however, when roving in the way usual for prospecting. If a traverse is not made, the general direction should be noted when setting out by consulting map and compass, and by memorizing any prominent landmarks. As the day progresses, note the direction of tree shadows if the sun is out, and the position of the sun, take occasional compass readings, and if possible check landmarks or watch for new ones whenever open places are reached. When returning, if landmarks do not suffice the compass will give the general direction until familiar features are seen. It is advisable to blaze trees in the vicinity of camp or the place where a car or canoe is left to help guide one to the exact spot, as it is easy to 'overshoot' by reaching a road or shore in such a way as to miss the point desired. It is also helpful to make occasional blazes during the day; in the event of uncertainty, the fresh blazes will probably be encountered.

When using a compass it is important to keep it away from metal objects that might cause it to give inaccurate readings, as explained in connection with surveying. Occasionally a compass is affected by bodies of magnetic rock, so as to give completely erroneous readings. All that can be done to prevent this is to avoid using the compass near exposures of rocks that might be magnetic, such as gabbro or occurrences containing magnetite or pyrrhotite, and to check the evidence of the compass against that of the sun, shadows, or landmarks, and to take 'backsights' if a careful traverse is being made. In almost all cases, however, the observer, rather than the compass, is the more likely to be wrong.

If the traveller becomes completely lost, it is best not to try to travel in the dark, but to build a fire and rest. It is most important not to panic or waste energy. With daylight, calm observation may clear matters up. If two or more are concerned, the others are sure to search, and will probably detect a fire at night if it is built on a high place, or a smudge during the day; or they may themselves light a fire or smudge as a guide; it may also be possible to signal with a mirror or other reflecting surface. If there is any likelihood of a search by air or of attracting a passing aircraft, a large smudge should be prepared, ready to be lighted as soon as a plane is heard; the reflecting technique may also be useful. If at all possible, select an open place for signals so that they can be seen from an aircraft.

Men have lived on nothing but water for many days, and it is often possible to find some sort of food such as edible berries or roots, or small game. It is useful to carry a few hooks, a fishing line, and a coil of 'rabbit wire' whenever in the woods, as the line and wire have many everyday uses, and may prove invaluable. In many regions spruce partridge ('fool hens') can be snared with a wire noose on the end of a pole, and this will sometimes serve to snare fish, which may also be taken with an improvised spear. Partridge and ptarmigan can sometimes be killed with stones or sticks, and rabbits can be snared along their runways.

Fire Protection

Apart from general conservation, there are many reasons why prospectors should be extremely careful to avoid setting fires and to put out any small ones encountered. The main causes of fires are carelessness when smoking and carelessness with campfires and smudges. Fires should be built close to water if possible, on large areas clear of all inflammable material including humus, roots, moss, etc., and they should be put out thoroughly. In this connection, it is important to remember that a fire will often smoulder long after it is thought to be out, particularly if humus or peaty material is present. Partly burned sticks should be thrown into the water or heaped with earth, because they will often flare up again after water has been poured on them.

In many parts of the country no one is permitted to travel in the woods without a permit from a forest ranger or other forestry official.

Suggestions for Additional Reading

Kephart, H.: Camping and Woodcraft; Macmillan, New York. Price $3.50.

Porsild, A. E.: Emergency Food in Arctic Canada; National Museum of Canada, Ottawa.

Provencher, P.: I Live in the Woods; Brunswick Press Ltd., Fredericton. Price $4.

Roddick, J. A., and others: Symposium on the Use of Aircraft for Geological Surveying; *Can. Min. J.*, vol. 76, No. 4, pp. 51-59 (1955).

Vaeger, E.: Woodsmoke; Macmillan, Toronto. Price $3.35.

Hammett, C. T.: Campcraft; Pocket Books. Price 35 cents.

CHAPTER VIII

CONVENTIONAL METHODS OF PROSPECTING

This chapter outlines the usual methods of prospecting, as opposed to those involving specialized techniques and knowledge that are discussed later. Most of the conventional methods have been handed down for generations, with some modifications as knowledge increased and conditions changed. Although based largely on scientific principles, prospecting is an art or craft rather than a precise science, and it includes a large element of luck and much scope for individual preferences, hunches, craftsmanship, and experience. There are, therefore, no hard and fast rules for prospecting—much depends upon the individual, the metal or mineral sought, and the nature of the area being investigated.

All that can be attempted in the following discussion is to describe what appear to the writer to be logical procedures for choosing a field for prospecting and for conducting the search. An attempt has been made to strike an average, so that the discussion is not confined to the operations of prospectors who have little technical knowledge, or to those most experienced and best informed; moreover, average conditions were envisioned, with the assumption that the reader would realize that modifications would be required to suit particular circumstances. The discussion deals mainly with the search for metalliferous deposits, but much of it is applicable also to industrial minerals. The subject is treated as though the reader intends to work independently and therefore to make his own decisions, but much of what is said applies also to organized prospecting schemes. Information on the availability and uses of topographic maps, geological maps and reports, and air photographs is included because these are commonly of great importance to prospectors, both for choosing an area and in guiding their work.

Selection of Region

The matter of selection naturally does not arise if the prospector intends to work his home area. In such circumstances, he should obtain geological literature on the region, and from this and his own observations he can learn the kind of mineral occurrences known or likely to be found. Then, if the region is at all favourable, he would proceed in the manner described later. If the field is thus restricted, there is naturally not as much scope as if the prospector could travel to selected regions; the home area, nevertheless, will very often repay examination by resident prospectors.

Most full-time prospectors are prepared to make special trips lasting from a few weeks to an entire season. Such trips should be undertaken only after a great deal of preliminary study and planning, perhaps during the winter, unless the prospector is very experienced and has definite areas in mind as a result of previous investigations, or unless he decides to join a rush to the scene of a newly-reported discovery. The selection of a region is usually based on one or more of the following considerations:

(1) A particular objective, such as the search for deposits of a particular metal or mineral.

(2) General suitability of a region, because it is believed to be favourable for prospecting, but not specifically for any one mineral or metal.

(3) A reported important discovery in a new region.

(4) The accessibility of the region.

(5) Personal considerations, such as the prospector's financial resources, physique, experience, preference, and the amount of time available.

(1) *Deciding on a particular objective.* Many prospectors concentrate for the time being on a particular metal because it is in demand and 'in fashion'. If so, this is likely to be the main factor in selecting a scene of operations. For example, gold has not attracted many prospectors during the last few years because its price remains fixed while wages and the other costs of mine operation are steadily increasing. A gold discovery would have to be exceptionally good, therefore, to interest capital at present. On the other hand, much interest has recently been taken in prospecting for uranium because it has a guaranteed market, under certain conditions, until 1962, and because of a great deal of spectacular publicity. In the field of base metals, large deposits of iron ore of good quality are in demand, but the temporary decline in prices of some of the non-ferrous metals, especially lead and zinc, has made them somewhat less attractive for the time being, although good deposits of these staple metals will probably always be in demand. Further information on the demands and prospecting possibilities of many metals and minerals is contained in Chapter XII. Prices and demands for most metals and minerals are variable, therefore the prospector must allow for the possibility of changes since the preparation of any report he may be reading, and should check prices for the six months or so preceding the commencement of field work.

Every prospector should subscribe to, or in any event read, at least one of the mining newspapers or magazines to keep informed on up-to-date quotations on prices of metals, trends in the demand for different metals, and new discoveries and districts. When the choice has been narrowed down to a few metals it is advisable to study government publications such as the reviews on the metals and minerals produced in Canada issued annually by the Department of

Mines and Technical Surveys, special reports like "Manganese Deposits of Canada" published by the same department, and "Tungsten in Nova Scotia", published by the Nova Scotia Department of Mines. Reports like the two last provide much information on the demand, known occurrences and districts, and prospecting possibilities, at the time they were prepared. Many references of this kind are listed in "Publications on Prospecting in Canada and Related Subjects".[1]

After careful consideration, a particular metal may be chosen as the main objective, but the prospector should always plan to be on the alert for occurrences of other kinds. Having made such a decision, the prospector should read as much as possible on the mode of occurrence and demand for that metal, and on its uses, and also reports on some of the main areas where deposits have been found in Canada or elsewhere. If he can visit a mining library it will facilitate obtaining such information without his having to buy a number of publications that he may not use again, and it will also permit study of publications that are out of print. After reading accounts of some of the main districts, he can consult general indexes and so find references to many other occurrences of the chosen substance. He may learn that definite regions or belts are recognized as being favourable in a general way for a particular metal.

He next has to decide whether to select a region where important discoveries of the kind he seeks have been found, or one where at least minor occurrences are known, or one that is merely favourable in a general way. The old saying that "the surest place to find a mine is where one has been found before" has much to recommend it, but such districts are usually staked or, if they are abandoned ones, ordinary prospecting has probably been fairly thorough, so that the chances are mainly for special methods of prospecting. The next choice may be a less popular area where the metal has been found, in which there may be better chances for ordinary prospecting and for obtaining open ground. Another choice is a district where the metal has not previously been reported but where the geological conditions are reasonably similar to those of districts containing important deposits. Or, a district may be chosen on the basis of an independent theory or hunch.

When the choice is reduced to a few areas, it is advisable to learn how completely these are staked. This can sometimes be learned from articles in the press or from local prospectors who know the situation; otherwise, claim maps should be ordered from the government department responsible, as explained elsewhere. These maps usually cost 50 cents each and cover one township, or larger areas where a region is not divided into townships. In this way, it may be decided that a particular region is too completely staked to be desirable. In any case, it is advisable also to consult the Mining Recorder for the district while on the way to the area, to learn about the most recent staking.

(2) *Selection based on general suitability.* It is by no means necessary to have one particular metal or mineral in mind as a goal for prospecting. Particu-

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[1] Geological Survey of Canada, Paper 54-1.

larly in the case of metals, many districts contain several metals in payable amounts. Many important mining camps have certain geological features in common, although no two are alike in all respects. A field for prospecting, therefore, may be chosen simply because it is known to contain some of the geological conditions that are commonly associated with mineral deposits, although no deposits have yet been found or reported. Examples of such conditions are greenstone belts in the Canadian Shield, and areas containing prominent faults or fracture systems, contact zones of stocks and batholiths, or intrusive rocks or sedimentary or volcanic formations of the same kind or age as those in which mineral deposits have been found in other areas. Concentrations of metals or minerals in workable quantities are formed by a combination of unusual geological conditions, therefore they are generally in areas where the geological conditions are unusually complex.

(3) *New discoveries.* Prospectors and others often rush to areas where new discoveries are reported. This is understandable, but unless one "gets in on the ground floor" he will probably find that the area is fully staked for a long way around the discovery. Rushes generally result in staking bees participated in by persons who are merely speculators who hope to sell their claims promptly, as well as by prospectors who feel that they have to stake first and investigate afterwards for fear there will be no open ground left. Latecomers have to prospect on the fringes of the district or wait for claims to lapse. These are not always disadvantages, because discoveries may be made miles away from the original one, or on hurriedly-prospected claims that are abandoned. However, careful consideration should be given before joining the more popular rushes, because so many persons participate, transportation and other services may be taxed to the limit, and many of the early reports may be exaggerated.

(4) *Accessibility.* The advantages and disadvantages of accessible and remote regions should be carefully weighed. Areas near settlements and good transportation facilities are easier to reach; require less expenditure on travel, supplies, and outfit; are usually better covered by maps and reports; and permit rapid dispatch of samples and return of assay results. In an easily accessible area it is easier to induce companies to send a representative to examine a discovery; the cost of exploring a deposit is much less; and, most important of all, a deposit does not have to be as large or as rich to justify mining as it would be in a place where transportation costs were higher or where special transportation facilities would have to be provided. On the other hand, most accessible areas have been prospected already, either very thoroughly or to a considerable degree. The possibilities in these areas are, therefore, mainly for special methods of prospecting; for ordinary methods the opportunities are mainly in the off chance of finding something that was overlooked, or in changed circumstances that make some metal or mineral valuable today, whereas it was not given attention formerly.

The farther the prospector goes from established districts and easy transportation routes, the greater will be his chances of making a discovery by ordinary methods, but he will have to overcome more problems in connection with travel and work in remote places, and any discovery will have to be better, to warrant professional examination, exploration, or mining, than if it were located more favourably.

Accessibility may influence the selection of a prospecting field in another way. If a new highway or railway is to be built or has recently been built it makes the region along and near it more attractive for prospecting, and easier for the development of discoveries.

(5) *Personal considerations.* A prospector's own finances or the extent of his backing generally influences the selection of a region. Remote places may be beyond his means or his time. Also, his physique may not be suitable for very remote or mountainous places, or he may not have sufficient experience in travelling and living in such places. Finally, there is the question of preference; a man may prefer fairly settled or fairly remote places, or he may not like canoeing or flying or some other feature of prospecting in a particular region.

After Deciding on the Region

After the region has been selected the prospector should gather as much information as possible about the area to be visited. To do this he can consult lists of publications to learn what geological maps and reports are available from the Geological Survey of Canada or from the appropriate provincial Department of Mines if the region is in a province, or he may write to the government agency concerned specifying the region clearly and asking for available information. If geological maps do not suffice, he can usually obtain federal or provincial topographic maps at the addresses listed elsewhere in this book. Maps and reports should be studied carefully, if possible before going to the field. It is advisable to make notes regarding pertinent information contained in publications that are out of print or that are not being taken to the field for other reasons. Most geological reports contain information on methods of travel to and in the area, travel routes, how well the bedrock is exposed, recommendations for prospecting, and other general data besides the description of the geology and known mineral deposits. By preliminary planning of this kind it is possible to judge what equipment and supplies will be required, to decide what part of the area to investigate first, and to make a tentative plan of operation.

If possible, air photographs should be studied before going to the field. Almost all of Canada has now been photographed from the air, and for some regions different kinds or scales of photographs are available. Air photographs are particularly useful for areas for which geological maps and reports are not available, but they are also very helpful in providing supplementary information when such maps and reports are obtainable. If it is possible to visit the National Air Photo Library at Ottawa or one of the collections kept by certain provincial agencies, the photographs available for the region may be studied, and notes or tracings may be made of data that may be of interest. Otherwise, copies may be ordered through the Air Photo Library, as explained in the section on use of air photographs; many prospectors make good use of air photographs in the field, as well as in preliminary planning.

Unless one is familiar with the staking regulations for the province or territory concerned, he should obtain a copy of the appropriate regulations and study it carefully. He must also have a staking licence or its equivalent. Copies of regulations can be obtained by writing to or calling at the head office of the provincial department concerned*, or at local recording offices; licences may also be purchased from the Recorders.

On the way to the selected area, the prospector will often have an opportunity to visit the office of a resident government geologist, mining recorder, or other official who can give him information about the area, as well as about the amount of staking and the number of prospectors likely to be there; the latest claim maps may also be obtained. The newcomer may also meet other prospectors willing to give him information, and scouts or other representatives of mining companies which he may later wish to interest in a discovery. In this connection, a little advice to beginners may be useful. Prospecting and other branches of the mining industry are highly competitive, and those engaged in it are seldom given to broadcasting news of their discoveries. It is therefore not advisable to ask a man directly where he is going, where he has been, what he has found, or his opinion of someone else's discovery or property; let him volunteer any information he cares to give. It is advisable, also, to be on guard against over-enthusiastic reports; prospectors have to be optimists, but sometimes their enthusiasm gets the better of them. Another hazard is the occasional instance of specimens from an entirely different region being shown, or of wrong directions being given, either as a practical joke or with a deliberate intent to mislead.

While he is in the town from which the final stage of the journey is to commence, the prospector should make definite arrangements for the holding or forwarding of mail; the periodical shipment of supplies, if necessary; and definite arrangements for being picked up, if he is travelling by air. If there is an assay office in the town, he may wish to arrange for the assaying of samples sent from the field, and for the forwarding of assay reports.

Work in the Chosen Region

Before reaching the area, the prospector will probably have decided whether circumstances will permit him to work for some time from a fairly permanent base, perhaps making short, light trips away from it, or whether he will have to make frequent moves with his entire outfit. In the former case, he will probably spend a little time establishing a base.

Next, he will probably try to become familiar with some of the rocks and known mineral occurrences in the vicinity. He will already have done this to some extent en route, for even if he travelled by air he would have made observations, and might have arranged a reconnaissance by air instead of going

* In the case of the Yukon and Northwest Territories, address letters to: Chief, Lands Division, Northern Administration and Lands Branch, Department of Northern Affairs and National Resources, Ottawa, Ont.

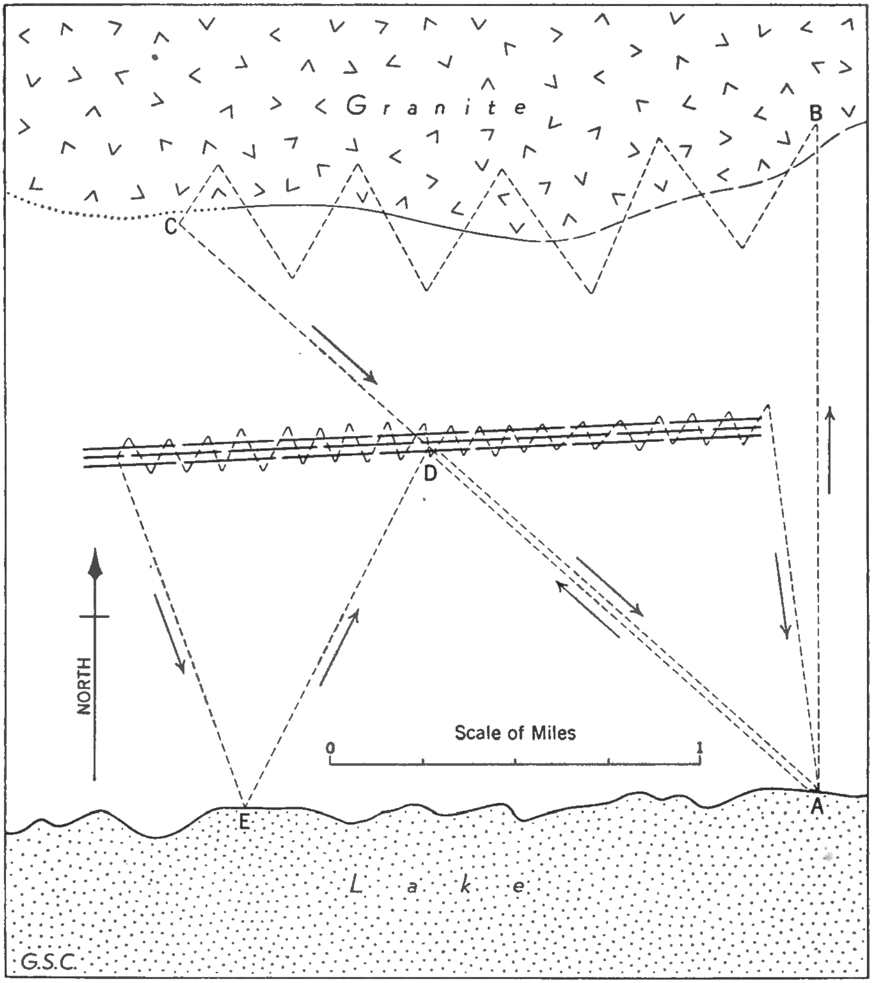


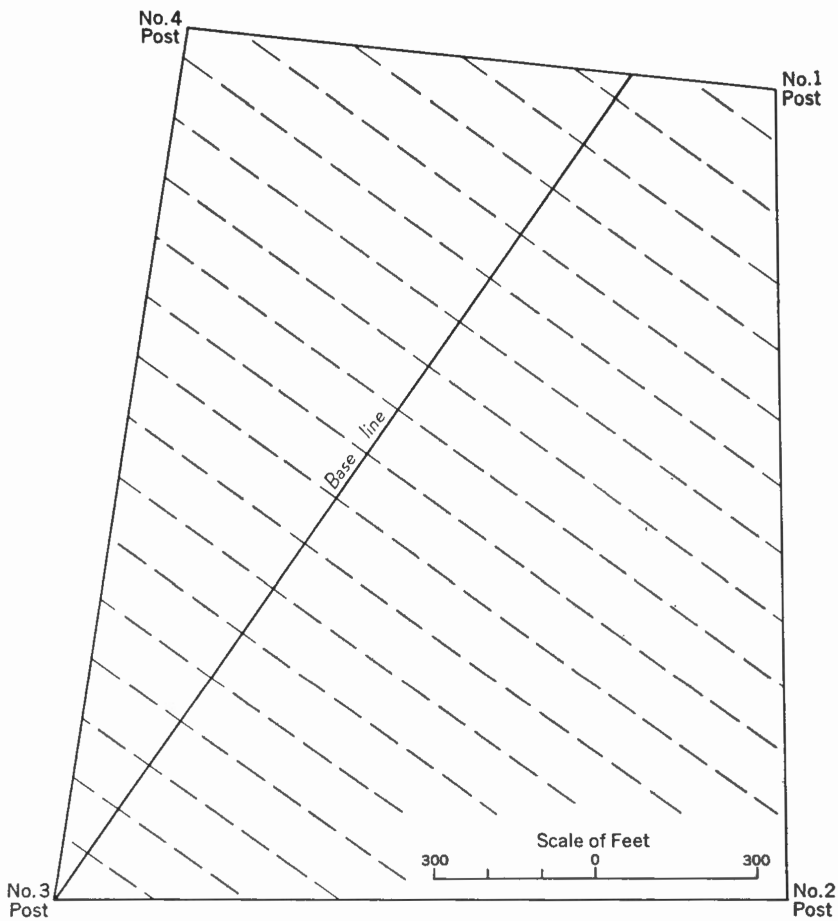
FIGURE 10. An example of prospecting traverses.

directly to his first camping-place. If the geology has been mapped, time will be well spent in examining outcrops of different formations and types of rock, and in comparing them with the geologist's descriptions. If the geology has not been mapped, the prospector will probably make a reconnaissance by canoe or on foot to gain an idea of the rocks and structures present, and so to plan his work. If abandoned mineral deposits are reported in the vicinity, he will probably visit them to learn a little about them at first hand. His ability to judge a discovery will be improved if he considers whether abandoned ones were worked out, too small, too low-grade, too 'spotty', etc. It should always be borne in mind that abandoned underground workings may be dangerous to enter, especially for inexperienced persons.

The manner of prospecting is determined by personal preference and experience. In general, the need nowadays is for patient, detailed searching, particularly if the region concerned has been previously prospected. Also, much depends on the local geological conditions, and on the kind of deposit being sought or that may occur. The prospector has probably made up his mind to investigate first some particular formation, fault, contact zone, or other feature whose existence is known or surmised. He would then proceed to cover this local area more or less systematically, by closely-spaced traverse lines if outcrops seem scarce (*see* Figure 10), or by going from outcrop to outcrop if these are visible, and in places scraping away moss or shallow overburden if necessary. Figure 10 illustrates traversing done on three consecutive days in a locality where outcrops were scarce. The prospector left his canoe at A and walked north to B, prospecting as he went, to investigate the contact zone of a body of granite shown on a geological map. He made zig-zag traverses well into the granite and away from it, and found a few outcrops but no signs of mineral occurrences. Near the end of the day he had reached point C, so he estimated the compass bearing that would get him back to his canoe. On his way back to A he crossed a gully at D and found outcrops that showed signs of shearing, so he thought this might represent a zone worth intensive prospecting. He blazed his way back to A so that he could retrace his steps. Having done so on the following day, he made closely-spaced zig-zag traverses all day, and then returned to his canoe at A. The next day he left his canoe at E and walked back to D on an estimated bearing. He then traversed the western extension of the zone. Thus in three days he not only traversed in detail two possibly favourable zones, but also made several traverses in different parts of the intervening territory, and examined the shoreline from A to E. If outcrops were observed during any of these traverses, the routes would be altered so that they could be examined.

If clues for selection of a particular area are lacking, or if the prospector is of less methodical habits, he may simply work his way through the country in any way he chooses. Almost all agree that fairly systematic coverage or 'traversing' of at least the more favourable parts of the area gives best results in the long run, although too prolonged or too stubborn adherence to one theory or one set of conditions is often unwise. Whether to go from outcrop to outcrop, or along ridges, or to run lines with a compass, is largely a matter of topography and visibility.

A third circumstance arises when prospecting claims that have already been staked. Then it is usual to cover them fairly thoroughly and methodically, paying greatest attention to what are thought to be the more favourable rocks or structures. Prospecting of claims is often done along lines 100 to 500 feet apart, in a direction more or less across the prevailing strike of formations or structures (*see* Figure 11). The lines are directed by using a compass or by sighting along pickets, as explained in Chapter XI, and they may be blazed and cleared if necessary. Geological observations are often made along such lines, if the prospector has sufficient training or if an organized group includes geological workers; the results would then be plotted to make a geological map. In some types of work, readings with special instruments such as Geiger counters or dip needles are taken along the lines. In detailed prospecting of certain areas in



In this instance a base line was surveyed by tape and compass, in a direction approximately parallel to the trend of formations or structures. Cross-lines were then run at 100-foot intervals, either by compass and pacing, or picket lines and pacing. If there were several claims in a group the lines would probably cross several claims or all of them. If one side of the claim was nearly parallel to the trend, or if there was no definite trend, a claim line might be used as a base line

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FIGURE 11. Lines surveyed for detailed prospecting of a claim.

proved mining camps, it may be desirable to do extensive stripping or trenching across the strike of particularly favourable formations or structures if the overburden is not too deep. Whatever method is adopted, it is important to keep notes and to mark on a map, if possible, the exact locations of points where notes or samples were taken.

In most areas it is possible to eliminate certain sections as being less favourable and to concentrate on others. It must be remembered, however, that such eliminations are not certainties, but merely part of a system to permit prospecting to be done on what seems to be the most favourable ground. Sections may be eliminated because they contain few rock exposures, but many important deposits occur in places where there are few or no exposures. This is sometimes because the deposits occur in fractured or faulted rocks that weather readily, or because the minerals in the deposit are of a kind that decompose easily; both conditions tend to produce depressions, which are natural places for overburden to accumulate. Low-lying areas are therefore favourable places for prospecting by ordinary methods, if the overburden is not too deep, and should not be disregarded. Large sections underlain by uniform granitic and gneissic rocks are usually considered to be among the least favourable, but deposits do occur in such environments, so they cannot be ruled out entirely; in particular it should be remembered that such sections may not be as uniform as they appear from the results of preliminary surveys.

One of the first principles a prospector has to learn is that although mineral occurrences are fairly common, deposits that will pay to mine are much scarcer. This fact should not discourage prospecting, but it is necessary for beginners to learn not to get excited about every occurrence they find. Instead, they should keep looking for fairly large occurrences or for small exposures that may prove to be more extensive under overburden or at greater depth.

The question of what to look for when prospecting is one of the most difficult matters to discuss, because so much depends on the kind of deposit sought, on local conditions, and on the prospector's individuality. All that is attempted here is to discuss briefly some of the principal clues and methods that have proved useful, particularly in the search for metalliferous deposits. It should be emphasized that all the guides mentioned probably would not be present in connection with any one deposit, although two or more might occur together.

Veins. Veins constitute one of the commonest classes of mineral occurrences and deposits. They are among the easiest to recognize, particularly if they are quartz veins, because the light colour of quartz generally contrasts with the wall-rock, and because the resistance of quartz to erosion often produces bold outcrops. The term 'vein' is used in this connection to include not only regular veins, but also stringers, stockworks, and irregular masses of quartz or other vein minerals.

Many veins and other bodies of quartz do not contain valuable minerals; quartz of this kind is often called 'bull quartz'. Most quartz veins contain little, if any, of the transparent variety typical of quartz crystals; as a rule veins consist of milky white quartz, although bluish, blackish (smoky), and pinkish varieties are not unusual. Barren quartz is commonly glassy and it may have a bluish tinge, but these are not always reliable characteristics for distinguishing worthless quartz. Many quartz veins, however, are not barren, but contain gold, sulphides, or minerals like scheelite, which may be present in either unimportant or in commercial quantities.

There are also many veins in which quartz is absent or only a minor constituent. Veins composed of one or more metallic minerals only are rare, but they do occur, as in the case of native silver. Usually, however, gangue minerals make most or all of the vein, and, if quartz is not the main constituent, calcite or other carbonate minerals are likely to be the chief components.

All veins, no matter how small or seemingly barren, should be examined closely and followed as thoroughly as if large, because small veins may lead to larger ones, and barren parts may lead to sections containing valuable minerals.

Pegmatites. Dykes or irregular bodies of pegmatite are among the most easily found occurrences, because they are usually light in colour and resistant to erosion. Most pegmatitic occurrences are unimportant, but all are worthy of scrutiny because some contain valuable minerals in workable amounts.

Favourable Structures. A prospector should watch for signs of shearing, fracturing, or faulting because, even if such structures do not contain veins or other deposits at the place where they are first encountered, they may do so at some place nearby.

Discovery of Valuable Minerals in Place. Valuable minerals may be exposed in recognizable form at the surface of outcrops, or in fragments of rocks broken off by the prospector or lying nearby, or they may be exposed in excavations such as road or railway rock-cuts. This is particularly true of resistant minerals like gold that do not erode or decompose readily, but even these minerals may be in such small grains that they are difficult to detect. Many other minerals alter readily by weathering at or near the surface, and are only found by indirect evidence such as mineral associations, or secondary minerals, as is explained later. Therefore, although important amounts of a valuable mineral may at times occur fairly conspicuously, as a rule such deposits are found as a result of careful investigation of the vicinity where a little of the mineral has been found, or where some indirect clue has been noted.

Mineral Associations. At the surface, many valuable minerals are altered beyond recognition or are completely dissolved and carried away from outcrops. In such cases a more resistant mineral that is commonly associated with the one sought may provide a clue for its presence beneath the weathered part of the deposit.

Mineral associations have already been mentioned in connection with quartz veins. Here the quartz, although generally valueless itself, is a conspicuous and resistant mineral with which valuable minerals are often associated. There are also many less obvious associations, such as gold with pyrite and other sulphide minerals, nickel with pyrrhotite, silver with lead and zinc minerals. A prospector should try to remember as much as possible of the associations mentioned in other parts of this publication and in other literature on mineralogy and mineral deposits. If sizable bodies containing minerals that might indicate the presence of more important ones are found, samples should be panned or sent for assay.

Gossans, Mineral Stains, etc. Many metalliferous minerals alter fairly readily in the presence of moisture. This matter is discussed more fully in the section on mineral deposits, but it is mentioned here because of its importance as a clue in prospecting. In some instances, metals or other elements are dissolved and carried in solution to deeper parts of the deposit or to an entirely different place. In other instances, new minerals are formed in the outcrop of the deposit. These are generally called secondary minerals because they are produced by alteration of the first-formed or 'primary' minerals. Some of the original minerals may be entirely changed to secondary products in the near-surface part of the deposit or, more rarely, at depths of 100 feet or more below the surface. On the other hand, the secondary minerals may only form a thin crust or 'bloom' on the surface of primary minerals, or they may have migrated a little way to form a stain on the surface of other parts of the deposit, on nearby rocks, in overburden, or to line cracks and cavities near the surface of the deposit. Secondary minerals occurring in any of these ways are often important indications to the prospector, because they may be the only clue to a nearby primary deposit, and because many secondary minerals are bright in colour and hence easily recognized. It must be emphasized, however, that the presence of a very small amount of some primary minerals may produce widespread staining. It should also be remembered that lichens and other growths on rocks may produce coloured incrustations that at first glance may resemble mineral stains.

The most common secondary minerals in outcrops are limonite and other secondary iron compounds, because pyrite and other iron minerals are common primary constituents of mineral occurrences. The primary iron minerals oxidize to form rusty outcroppings ranging in colour from yellow to chocolate brown or red. These rusty outcrops are generally called *gossans*, from a word used by early Cornish miners to describe them. Typical gossans consist of limonite and a cellular mass of quartz that resisted alteration, but the term is used more loosely to describe any rusty outcrops. Unfortunately, many gossans are unimportant, either because they resulted from insignificant amounts of iron sulphide minerals, or because the only primary mineral is pyrite, which is in demand only under special circumstances. However, other gossans may lead to useful deposits containing hematite, or valuable sulphide minerals, or minerals like gold that are commonly associated with sulphides. It should be noted that magnetite does not oxidize easily, except when associated with sulphides; therefore magnetite deposits may not be marked by gossans.

Many other important primary minerals alter to characteristic secondary minerals that are very useful as clues for prospecting. The principal ones are as follows. Copper produces malachite and azurite, which have characteristic green and blue colours, the former being similar to 'verdigris' and the latter to 'blue-stone'. Nickel-arsenide minerals produce an apple-green mineral or stain. Cobalt-arsenide minerals produce a characteristic pink to red 'cobalt bloom'. Molybdenite alters to a pale yellow mineral generally called molybdenum stain. Manganese minerals produce black secondary minerals that are often sooty or iridescent; this material may migrate a short distance from the deposit and form a black

Plate XLVII

Panning is useful in prospecting for and testing lodes as well as placers.

mass called 'wad' that may cement soil or gravel. Minerals containing uranium alter readily, generally to vivid yellow, orange, or green minerals. Many different yellow or orange secondary uranium minerals have been named and described, but unless they occur in large quantities it is usually sufficient to refer to them collectively as 'uranium stain'. Minerals containing lead or zinc may alter to various oxide and carbonate compounds; some of these are white, and others are of several colours; as a rule, they are not as useful guides as those mentioned previously. Many of the secondary stains and deposits are soluble in water and are removed from the surface by heavy rain or melting snow; hence at such places the surface rock must be broken to find them.

Although many gossans and other secondary deposits are unimportant, all merit investigation. This may consist of trying to pick or blast down to the primary minerals, or of panning the altered material in the hope of finding traces of the heavier, primary minerals, or of sending samples for assay.

Wall-rock Alteration. The rock enclosing many mineral deposits is altered by the introduction of solutions that preceded or accompanied the deposition of the ore minerals. These solutions commonly react with the original rock-forming minerals to form new mineral compounds, or they may produce disseminated grains or masses of some of the same minerals that occur in the deposit itself. The altered zones may extend only a few inches from the deposit or for many feet. The most common alteration minerals are white mica, chlorite, quartz or other compounds of silica, calcite or other carbonate compounds, and disseminated pyrite. By studying alteration zones beside known mineral deposits a prospector can learn to recognize the commoner types, and he should be constantly on the alert for similar occurrences of altered rocks, since this knowledge might stand him in good stead if the altered rocks around a deposit outcropped and the deposit itself was not exposed or difficult to recognize.

Tracing Float. Fragments from a mineral deposit are often transported by glaciers, streams, floods, frost action, or gravity. If carried a long way, almost all are rounded, but if they have not travelled far the majority are more or less angular. The term *float* is usually restricted to more or less angular material from a mineral deposit, the name alluding to its having 'floated' away from its place of origin. Pieces of float may be recognized in stream beds or on the surface of the land, particularly along hillsides. It may then be possible to trace float to its source by finding additional pieces. In general, the larger and more angular the pieces are, the closer they are to the source. In some cases it is possible to work up a stream and gradually eliminate tributaries that do not carry float of the particular type being sought, thereby narrowing the area of the possible source. Or, in working along a hillside, the distribution of float may be found to occur in a roughly triangular pattern with the apex at the deposit. In places where outcrops are scarce it is useful to look for float in depressions caused by the blowing down of trees, and among the roots of such trees.

Panning. In addition to its use in prospecting for placer deposits and testing them, panning is often very useful in 'hard-rock' prospecting. Several authorities have recently expressed the opinion that prospectors are not making sufficient use of the pan when searching for or testing lode deposits. Very fine float invisible under ordinary circumstances may be panned from the beds of streams or from gravels or soils. Very widely scattered grains may be evenly dispersed through glacial drift, but otherwise the discovery of float by panning is a useful aid in tracking down a deposit by the same process of elimination described above for tracing coarser float.

Another important use of the pan is in testing samples from gossans or other outcroppings, as a means of detecting heavy valuable minerals, and of estimating their quantity. This may save the time and expense of obtaining preliminary assays. Samples may be tested nearby if water is available, or at camp. The samples are crushed in a mortar, or, if no mortar is available, they may be hammered on a hard flat surface such as the side of an axe. To prevent loss of particles, the sample can be kept in a canvas bag while being hammered. The sample should be ground finely enough to free small grains of minerals. This is best done by periodically screening the sample and then continuing to crush the material that will not pass through the screen. Screens with 60 or 80 meshes to the inch are recommended, particularly if minerals are likely to be present in very small grains, but those learning the art of panning are advised to begin with coarse material.

If the concentrate obtained by panning contains sulphide minerals, it should be roasted in the gold pan or other container for four or five hours over a hot fire. This is done to liberate particles of gold or other minerals that may be included in a sulphide mineral. The time of roasting may be reduced if the concentrate is first mixed thoroughly with an equal amount of potassium chlorate. After the chlorate has decomposed, the sample should remain on the fire for several minutes at red heat. The caked residue is then pulverized, screened, and panned.

The technique of panning is more fully explained in Chapter XIII. Small pans are usually employed by lode prospectors, and some use a frying pan with the handle removed.

Any concentrate or tail obtained in the pan should be examined carefully with a hand-lens. If the prospector does not recognize the constituents, he may make tests, or send the concentrate to a laboratory for identification or analysis.

Panning is not infallible, and therefore if a large deposit is found it is desirable to have samples assayed, even if panning did not reveal the presence of valuable material.

Preliminary Investigation of a Discovery

When an occurrence is found, a prospector is faced with the problem of how much time to spend exploring the showing before going on to look for other and perhaps better occurrences. The exploration and evaluation of mineral deposits are discussed in Chapter XI, more particularly in relation to the work that is done after a prospect of some merit has been found. The present section is confined to matters that come up in the course of prospecting rather than to those arising after it is decided to do considerable work on a showing. Nevertheless, some of the later discussion regarding evaluation, sampling, and exploration applies also to the preliminary problems and will supplement the brief remarks made below.

Mineral occurrences are fairly common, but those that are large and rich enough to be mined are comparatively rare. There are no accurate statistics for this matter, but authorities generally consider that by far the majority of mineral occurrences are too small to be classed even as prospects, and that fewer than one per cent of prospects become producing mines. Therefore, if a prospector is working in a region that is at all favourable he may encounter small occurrences fairly frequently. He should take time to investigate one of these only sufficiently to satisfy himself that it apparently does not lead to something larger. He cannot always be certain of this, but when in doubt it is probably best to note the location for possible future investigation and go on to look for a more promising showing. Some occurrences are sufficiently exposed to permit rapid estimation of their size and content. Others require removal of moss or shallow overburden. Some contain primary minerals that can be seen at the surface of the exposure or in pieces of rock chipped off with a hammer, and others are capped by gossans or other secondary minerals that should be picked or scraped in the hope of reaching primary minerals without too much loss of time. If the occurrence is obviously small, the prospector might decide not to take any samples or specimens, or he might take some and discard them later if he found something more promising.

The decision of whether to spend considerable time exposing an occurrence or prospecting in the immediate vicinity, or to proceed with general prospecting is one for which there are no definite rules. There have been a few instances where seemingly insignificant occurrences marked important deposits, but there have been many others where prospectors became unduly excited about the first occurrence they found. Much depends on experience and on how difficult it would be to return on another day. In general, it seems best to recommend doing a minimum of initial exposing and sampling, making careful note of the position and other particulars, and then continuing to look for other occurrences. After several days or weeks of prospecting, if several occurrences have been found, the most promising might be selected for closer attention. Then, if the occurrence shows any likelihood of being large enough to be of interest, careful sampling and, if necessary, stripping or trenching would be done. These matters are discussed more fully in Chapter XII.

Suggestion for Additional Reading

Mertie, John B. Jr.: The Gold Pan: a Neglected Geological Tool; *Econ. Geol.*, vol. 49, No. 6, pp. 639-651 (1954).

Topographic Maps

A prospector may use three main kinds of maps, namely topographic maps, geological maps, and claim maps. He will often find that a geological map contains all the topographic data he requires, but in other cases he may require a topographic map because no geological map is available, or because a topographic map shows additional information that he requires.

Features Shown

A topographic map is a representation to scale of such features as lakes, streams, roads, railways, and towns. It may also show the relief, or height above sea-level, of the land surface. This is usually shown by contour lines, which are lines joining points that are at even elevations, such as 100 feet, 200 feet, 300 feet, etc., above sea-level. A beginner can learn to visualize the relief from a study of the contour lines, by imagining that each line represents what a shoreline or island would look like if the land were flooded at levels of 100 feet, 200 feet, etc. above the present level of the sea. The degree of accuracy of a topographic map depends on the amount of time spent in surveying, on the methods employed, and on the scale, since large-scale maps are usually made with greater precision. Another point to remember is to note the date of the map, because a map made several years previously may omit roads and other features constructed later.

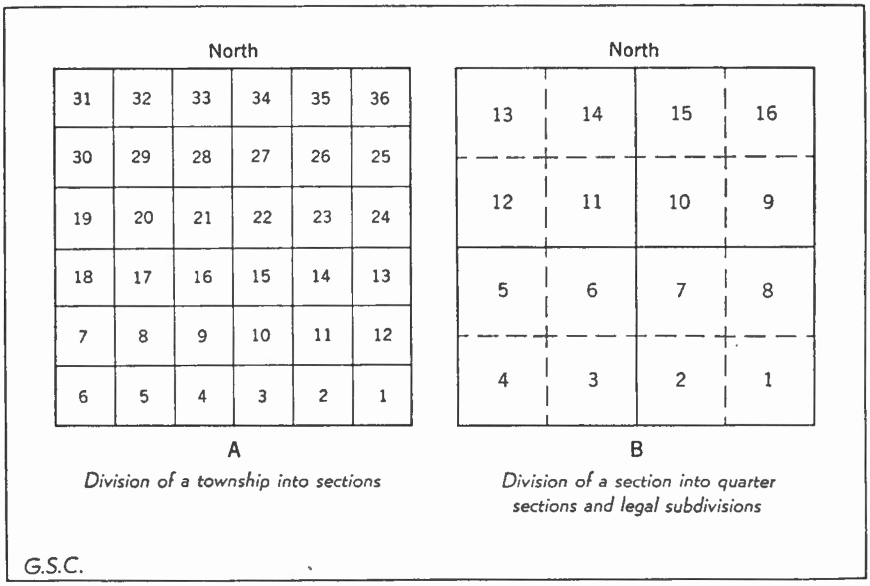


FIGURE 12. The division of a township into sections, etc. according to the Dominion Lands System.

Orientation

Most maps are drawn so that north is at the top, with the right and left borders of the map running exactly, or almost exactly, true north and south. The orientation is usually shown by lines of latitude and longitude, and also by two arrows, one of which points true (astronomic) north, and the other, magnetic north. The difference between magnetic and true north, which is called the declination or variation, varies from place to place but is usually about the same within any one map-area.

Scales

The scale of a map may be shown in three different ways, and all are often indicated. One way is to state the relationship between inches on the map and feet or miles for an equivalent distance on the ground, such as "1 inch to 1,000 feet", or "2 inches to 1 mile". Another way is to place a line, called a 'bar scale' on the map, and to mark along it appropriate distances in feet or miles. The distance between two points on the map can be marked along the edge of a piece of paper, the paper can then be laid along the bar scale, and the distance can thus be determined. The third way of showing the scale is by a fraction showing the relationship between any distance on the map and an equivalent distance on the land; thus $\frac{1}{63,360}$, the fractional scale of a map on 1 inch to 1 mile, indicates that any distance on the ground is 63,360 times the equivalent distance on the map.

Land Subdivisions

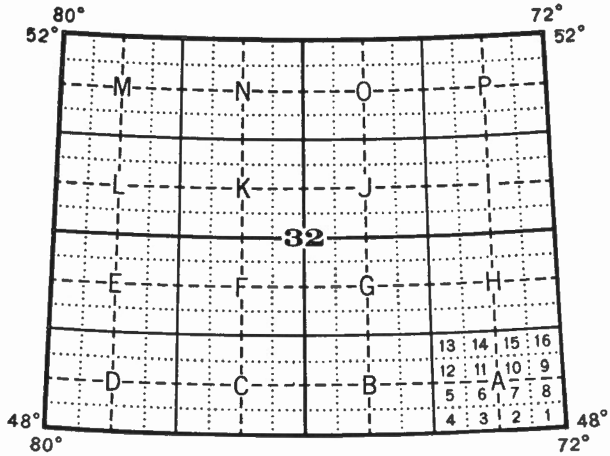
Most parts of southern Canada have been divided into units, indicated on the ground by surveyed lines and corner markings of various kinds. These subdivisions are usually shown on topographic maps, and it is important for prospectors to understand them because they are helpful in locating positions, describing discoveries, and staking claims.

In Eastern Canada the largest land units are usually called counties or districts. These are divided into townships, which are commonly 10 miles square. In districts surveyed many years ago the townships are usually laid out irregularly, but in those surveyed more recently the lines usually run north-south or east-west. Townships may be named or numbered. They are usually divided into strips one mile wide, called 'concessions' in Ontario and 'ranges' in Quebec, extending east and west, and numbered consecutively from south to north by Roman numerals. These strips are divided into lots, commonly numbered in Arabic numerals from east to west. Thus the description of a lot might read "Lot 16, Concession IV, Percy Township, Northumberland County". In some of the more recently surveyed parts of Ontario the Dominion Lands System explained below is used, and in some of the older parts of Quebec 'parishes' take the place of townships.

In the Dominion Lands System, used in most parts of Western Canada, the townships are 6 miles square. They are numbered, and their position is referred to a series of meridians extending northward. The First or Principal meridian was laid out from a starting point selected near Winnipeg; its longitude was later determined to be 97 degrees 27½ minutes west of Greenwich, to which all longitudes are referred. The other meridians are at regular intervals of 4 degrees of longitude. Rows of townships extending northward are called Ranges, which are numbered successively away from the meridians, in Roman numerals. Townships are numbered northward from the 49th parallel, in Arabic numerals. Each township is divided into sections one mile square, as shown in Figure 12A. Each section is divided into quarter sections, each of which is divisible into quarters called 'legal subdivisions', as shown in Figure 12B. Thus the description of a piece of land might read LS 14, Section 12, Township 2, Range III, west of the 1st Meridian. In British Columbia, townships are laid out in somewhat the same fashion as in the Dominion Lands System, but are subdivided differently.

Grid Reference

On some topographic maps, numbered or lettered intervals are marked along the borders, to which any place on the map can be referred by drawing lines north, south, east, or west to the edges of the map. The approximate position



The units consist of sheets, 4 degrees in latitude by 8 degrees in longitude, published on the scale of 1 : 1,000,000 (approximately 1 inch to 16 miles) shown on the index thus **32**

Each 1 : 1,000,000 sheet is quartered into sheets 2 degrees in latitude by 4 degrees in longitude, published on the scale of 1 inch to 8 miles (1 : 506,880), and referred to as N.W., N.E., S.W. or S.E., the number taking the form thus .... **32** S.E.

Each 1 : 1,000,000 sheet is divided into sixteen sheets 1 degree in latitude by 2 degrees in longitude, published on the scale of 1 inch to 4 miles (1 : 253,440) or 1 : 250,000, lettered from A to P, shown on the index thus .... **32** A

Each four-mile sheet (or 1 : 250,000) is quartered into sheets 30 minutes in latitude by 1 degree in longitude, published on the scale of 1 inch to 2 miles (1 : 126,720), referred to as N.W., N.E., S.W. or S.E., the number taking the form thus .... **32** $\frac{A}{S.E.}$

Each four-mile sheet (or 1 : 250,000) is divided into sixteen sheets, 15 minutes in latitude by 30 minutes in longitude, published on the scale of 1 inch to 1 mile (1 : 63,360) or 1 : 50,000, the number taking the form thus .... **32** $\frac{A}{2}$

Note: Some one-mile maps and most 1 : 50,000 maps are published in two halves, referred to as east half or west half, the number taking the form thus .... **32** $\frac{A}{2}$ West Half

Every sheet is given a name indicating its location by reference to the largest city or town in it, or by reference to some well known geographical feature.

A map entitled "Index Map of Canada According to the National Topographical System", showing the extension of the numbering system for all parts of Canada, may be obtained from the Director, Surveys and Mapping Branch, Department of Mines and Technical Surveys, Ottawa.

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FIGURE 13. Diagram showing method of numbering map-sheets of various scales, according to the National Topographical System.

of the point can then be described from the grid intervals intersected. Another method is to draw pencil lines across the map, through the grid markings, thus dividing the map into a series of small squares. If desired, a map that does not have grid markings can be gridded by drawing lines, say, one inch apart, and numbering or lettering them.

Federal Topographic Maps

The Department of Mines and Technical Surveys issues topographic maps at a small charge for each map. Most are in the National Topographic Series, numbered as explained in Figure 13. The earlier maps of this series were on scales of 1, 2, 4, or 8 miles to 1 inch. More recent ones are on fractional scales of $\frac{1}{50,000}$, $\frac{1}{125,000}$, $\frac{1}{250,000}$, and $\frac{1}{1,000,000}$, the first three of which are roughly the same as the corresponding 'inch to mile' scales mentioned. The scales of such maps can be converted to feet or miles by dividing the lower figure by 12, (the number of inches is a foot). For example, $\frac{1}{50,000}$ equals $\frac{1}{12 \times 4166}$.

Federal topographic maps generally should be ordered from the Director, Surveys and Mapping Branch, Department of Mines and Technical Surveys, Ottawa; branch offices of the Geological Survey of Canada can supply certain maps of areas in their general region. Delay and needless clerical work is caused by ordering topographic maps from the head office of the Geological Survey of Canada. Index maps showing maps available are obtainable, or a map may be ordered by specifying the exact locality desired and the scale preferred. The charge for most maps is 25 cents each.

Provincial Topographic Maps

Topographic maps are issued by some provincial government departments also, particularly the Departments of Lands and Forests of British Columbia, Ontario, and Quebec.

Suggestions for Additional Reading

Elementary Map and Aerial Photograph Reading; U. S. War Dept., Basic Field Manual FM 21-25, 1941. For sale by Superintendent of Documents, Washington, D.C. Price 30 cents.

An elementary handbook on the use of topographic maps and air photographs, not specifically related to prospecting or geology, but containing useful information for beginners in prospecting. There is also a more advanced manual on the same subjects (FM 21-26), price 20 cents.

Map and Aerial Photograph Reading Complete, Military Service Pub. Co., Harrisburg, Pa., 1943. Price $1.

A book on the use of topographic maps and air photographs, prepared mainly for military instruction, but useful for beginners in prospecting.

Geological Maps

A geological map shows observed and inferred information on the kinds of rocks present, and on their distribution and structure. This information is superimposed on a topographic base map, and most of the remarks made in the foregoing section of this book regarding orientation, scales, etc. are also applicable to geological maps. The kinds of rocks and their distribution are shown by different colours or different patterns. Colours are preferable, but patterned maps can be published more cheaply and more quickly. On many maps, outcrops and rocky areas are shown by symbols, and on a few detailed maps they are shown in deeper shades of the same colour as is used to depict the more extensive areas where the formation beneath overburden can only be inferred. Structural features are indicated by symbols to represent strike and dip, schistosity, faults, axes of folds, etc.

It is impossible to show all details on a geological map; one colour or one pattern therefore commonly represents rocks of several related kinds, and many minor faults, fractures, or other features are usually omitted. Mineral occurrences, mines, oil wells, and other relevant features known at the date the map was prepared are usually indicated. If an area contains many mineral deposits and occurrences, the practice is to show the more important deposits on the map and to refer to others in a report, if one accompanies the map; but it is not likely that all minor occurrences would be mentioned. If mineral occurrences of probable significance or interest are discovered during the course of a geological survey, the location and the kind are either shown on the map or mentioned in a report.

Many maps are accompanied by one or more 'structure sections' illustrating, perhaps only speculatively, the sub-surface distribution of rocks. A legend explains the meaning of colours, patterns, and symbols, and is usually arranged to show the formations in the order of their ages, the youngest being at the top. Many maps are accompanied by marginal notes that provide short accounts of the topography, geology, and known mineral occurrences of interest. The name of the geologist (or geologists) who performed the field work and prepared the map is always stated on the map, and the related report, if any, is usually mentioned.

Scales and Kinds of Geological Maps

Most of the coloured maps published in recent years by the Geological Survey of Canada are on scales of 1 inch to 1 mile and 1 inch to 4 miles, these now being standard for fairly detailed and semi-reconnaissance work, respectively. Preliminary maps may be issued on the same scales, or on 1 inch to ½ mile and 1 inch to 2 miles. Less detailed reconnaissances may be published on still smaller scales. The results of special detailed investigations are usually published on scales of from 1 inch to 400 feet to 1 inch to 1,000 feet.

The Geological Survey of Canada also prepares and publishes compilation maps that co-ordinate information published on other more detailed maps. Examples are the series of regional maps on the scale of 1 inch to 8 miles; and the geological maps of provinces, most of which are on the scale of 1 inch to 20 miles.

During its long existence the Geological Survey of Canada has mapped thousands of areas, and provincial organizations have mapped many others, but because of the vastness of Canada, and the relatively small staffs available for the work, much of the country has been covered only by very inadequate reconnaissance. A fair amount of territory has been mapped in a semi-reconnaissance way, but the amount for which mapping on 1 inch to 1 mile has been done by what are now considered adequate standards is very small indeed. With present staffs only a slight net improvement is possible each year, because maps made some time ago are becoming obsolete almost as rapidly as new 1-mile or more detailed projects are completed.

Interpretation of Geological Maps

The accuracy and amount of detail of the geological information shown on a geological map varies with the scale and purpose of the map, the number of rock exposures examined, the method used for surveying their positions, and the skill of the geologist and his assistants. Only in the most detailed forms of mapping, or in areas where outcrops are very scarce, is it possible to examine more than a small fraction of the rock exposures present. Even those that are studied may be open to more than one interpretation; for example, an area may contain two ages of granitic intrusions that are so much alike that only certain exposures can be definitely mapped as one or the other, and elsewhere the geologist has to use his judgment; or an area may contain two formations that are of the same kind of rock but of quite different ages, and in such cases errors or uncertainties in correlation can easily occur unless fossils whose ages are known definitely are found.

A geological map is, accordingly, a combination of facts and inferences. To use a map properly a prospector should be careful to observe whether outcrops are shown at or near the locality he is studying, and whether geological contacts, faults, etc. are shown as 'defined', 'approximate', or 'inferred'. A defined contact or fault, shown by a continuous line, is usually within $\frac{1}{8}$ inch of its true position on the map. An approximate one is known to occur somewhere in the vicinity shown. An inferred one is either very indefinitely located or may even not exist.

Geological or 'structure' sections, since they depict the geologist's interpretation of conditions at depth, are usually much more uncertain than the map itself, because there may be changes with depth that no amount of surface study or drilling from the surface will reveal.

Despite their inherent imperfections, geological maps are universally recognized as being of the greatest assistance to prospectors, since case after case can be cited in which mineral deposits were found with their aid. The ways of obtaining these maps are explained in the following section.

Suggestion for Additional Reading

Dake, C. L. and Brown, J. S.: Interpretation of Topographic and Geologic Maps; McGraw-Hill, 1925. Price $3.50.

A comprehensive book on the interpretation of topographic and geological maps. It is intended for fairly advanced students and a knowledge of elementary geology and trigonometry is assumed.

Geological Reports

As already intimated, a prospector relies largely on geological reports and the maps that commonly accompany them, when he is deciding what to prospect for, what area to select, and where to narrow down his search. He therefore requires knowledge of the characteristics of different kinds of reports, of how to obtain them, and of how to use them to best advantage.

The Geological Survey of Canada, as the oldest and largest geological organization in the country, has for more than one hundred years been responsible for basic geological mapping and research, for much of the detailed mapping in mining camps and other areas of special importance, for the compilation of the results of geological work done by other agencies, for the standardization of geological nomenclature, and, more recently, for the co-ordination of geological research. Many provincial Departments of Mines, or their equivalents, also perform geological research and publish excellent geological maps and reports, generally on special areas. Reports of a third kind, that may occasionally be available to prospectors, are private reports prepared by consulting geologists or geologists employed by mining companies.

The reports of the Geological Survey of Canada, of which there are several hundred, are of different kinds called 'series'. Prior to 1935, reports published annually contained the results of several different investigations bound in one volume, and designated Reports of Progress, Annual Reports, or Summary Reports. This practice has been discontinued, and publications of the Survey now appear from time to time as 'Paper Series', 'Memoir Series', 'Economic Geology Series', and 'Bulletin Series'.

What is called the 'Paper Series' consists of preliminary maps and reports, commonly issued before a field project is completed or before all the laboratory and office work is finished. These maps and reports usually cover specific areas; their object is to provide publication of the highlights of the survey results as rapidly as possible; the maps are patterned instead of coloured, to expedite publication; and the reports are mimeographed or, more recently, printed by a quick process. These reports, if in an area favourable in a general way for prospecting, provide summarized information on the distribution of formations and on the types of deposits known or likely to be found.

The 'Memoir Series' consists of full, printed reports embodying the full results of the investigation of a map-area or a special field or office project. The accompanying maps are usually coloured. The reports are generally fairly long, and include much scientific detail. These reports have to be written so that they are as useful and understandable as possible for prospectors and others who do not require all the scientific details, and at the same time so that they are of high scientific calibre. Prospectors will find that in most memoirs the introductory parts contain much information on the general characteristics of the area, on how to reach it, and on how to travel in it. These parts are usually followed by a short introductory account of the geology, written as far as possible in non-technical language. This is followed by detailed descriptions of formations, much of which is too detailed and technical for any but professional geologists. However, the prospector can ignore these parts entirely or can try to understand as much as possible of the description of a formation or intrusive rock that is especially important for prospecting. He can then proceed to the descriptions of geological structures, which may be very important to him, and to the discussion of mineral deposits. If he looks up the meanings of words he does not understand, by consulting a dictionary or textbook, he will increase his geological knowledge.

The 'Economic Geology Series' consists of reports on a particular economic topic covered in a country-wide way. It begins with 'Geology and Economic Minerals of Canada', and includes comprehensive reports with such titles as 'Lead and Zinc in Canada'. This series is not nearly as complete or as up to date as would be desirable, because there has always been such a need for geological mapping and regional studies that geologists were seldom spared to make the special studies on which the Economic Geology Series is based. Prospectors will find this series useful for obtaining basic information on the mode of occurrence and distribution of deposits of a particular metal or mineral, as well as for descriptions of many individual districts and deposits.

The 'Bulletin Series' consists of printed reports on special investigations and other matters that warrant publication in final form but which do not belong in the Memoir or Economic Geology Series.

Obtaining Geological Maps and Reports

Publications of the Geological Survey of Canada may be obtained by calling at or writing to its head office or branch offices, but the latter distribute only general and local publications, not regional publications on far-removed areas. Persons who are likely to require publications fairly frequently may obtain catalogues and indexes of publications and may be placed on a mailing list for cards that give notice of new publications. Persons who require publications less frequently should either call, or give full details in writing as to the subject or area on which information is desired. Publications are not sent C.O.D. or against later payment, and the buyer is advised to estimate the approximate amount required to cover the cost, payment being made by money order payable to the Receiver General of Canada; any over-payment will be refunded.

Inquiries for geological maps and reports published by provincial government organizations should be addressed to the Department of Mines, or equivalent, in the provincial capital. The addresses are listed in an appendix. Some of the provincial departments publish catalogues.

The principal indexes and catalogues to federal and provincial geological literature are listed in Geological Survey of Canada Paper 54-1.

Air Photographs

Air photographs have proved their worth as an aid to prospecting in many parts of Canada. Their use does not guarantee success, nor are they essential, but there are few parts of the country for which they are not helpful. Some of the ways in which they are useful to prospectors have already been mentioned, but because the subject is of growing importance it is discussed here more fully.

The photographing of Canada from the air was begun in 1920, and almost all of the country south of latitude 60° has now been covered in at least a preliminary way. Canadian aviators and surveyors were among the first in developing the techniques for this work and for applying the information to topographical mapping, and at the same time Canadian geologists adapted the use of air photographs to their requirements. It is not surprising, therefore, that prospectors were quick to realize that the photographs could in many instances be of great assistance to them.

Types of Air Photographs

Air photographs are of three main types, called *vertical*, *ordinary oblique*, and *trimetrogon* (*see* Plates VII, X, XI, XII, XV, XVIII). Any type is usually taken in a series along a carefully controlled line of flight. Recent advances in lenses, films, and papers have resulted in greatly improved photographs. Much geological detail is, however, masked by vegetation except in barren areas; for this reason the best photographs for geological or prospecting use are generally taken in early spring or late autumn. Also, in hilly or mountainous areas, details may be masked by shadows unless the photographs are taken in the middle of the day. In most instances, however, it is necessary to use pictures taken at other times, and these are generally fairly satisfactory. Virtually all prints available are black-and-white. Experiments have been made in the use of colour film for special air photographs, but so far they have not proved particularly useful for geological work or prospecting in Canada, largely because of the amount of trees, moss, or lichen that covers the rocks. Advances in techniques may, however, render colour photography more useful.

Vertical Photographs

Vertical photographs are taken with the camera pointed directly downward, the resulting picture being a plan with little distortion of scale. Each individual exposure overlaps its neighbour, so that any specific feature on the ground can be seen on two adjoining photographs, thus permitting it to be studied stereoscopically when the two pictures are placed under a stereoscope. Use of a stereoscope is particularly desirable for photographs of hilly or mountainous areas, because it provides a three-dimensional image that shows the 'depth' of the topography. It is also useful for studying pictures of some fairly flat areas, as there are commonly slight changes in the topography of interest to the prospector or geologist. Some persons prefer to use a stereoscope only in a library or at their headquarters, marking any features of interest; others use a small folding instrument in the field. Stereoscopes can be bought from dealers in engineers' and draughtsmen's supplies, at various sizes and prices. Some stereoscopes magnify the 'depth' of the topography, to assist in studying areas of low relief.

A stereoscope can be used only with vertical photographs taken so that they overlap one another and this instrument permits one eye to see one photograph, and the other eye to see the corresponding part of another photograph taken when the aircraft had moved to another position along the line of flight. The observer sees the depth or 'relief' of the land-surface photographed. There are two kinds of stereoscopes, one uses mirrors, the other uses lenses. Some of the former type are made so that they fold, and can be taken to the field for use in camp. Pocket-size stereoscopes equipped with lenses are available at about $15 each, and have the added advantage that they can be carried during the day; but their use is more difficult to learn. To use a stereoscope, two photographs, each of which shows the area or feature to be examined, are placed side by side in their proper position with respect to the line of flight. The stereoscope is then set over them in such a position that the central point of each photograph can be seen in the appropriate mirror or lens. A feature such as an island or small outcrop, that appears in each photograph, is selected, and the left and right forefingers are placed over it in the left and right photographs. The observer then places his eyes immediately over the small mirrors, or the lenses. The photographs are then moved slightly to the right and left, and up and down, with the two fingers kept in place, until the two finger-tips appear as one. The fingers are then removed, and a final slight adjustment is made to bring the two

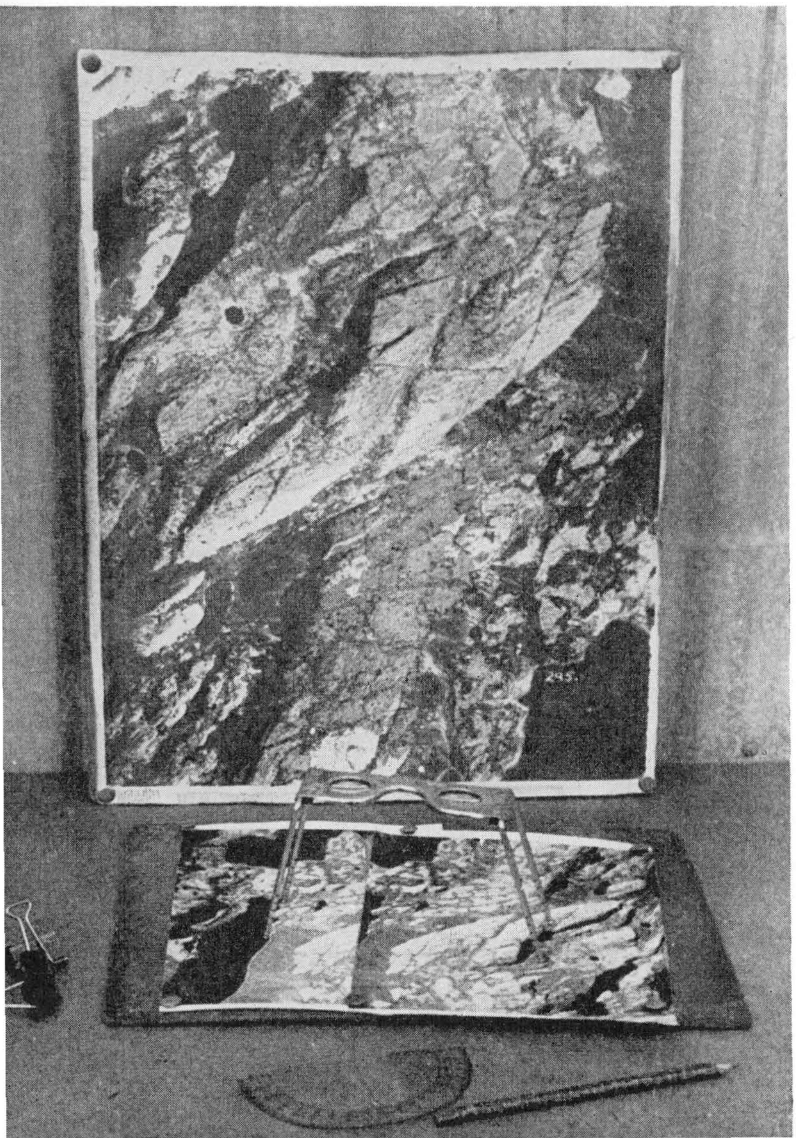

Plate XLVIII

A small stereoscope and a pair of vertical air photographs arranged for stereoscopic inspection. An enlarged vertical air photograph is shown in background.

images into exact 'stereoscopic fusion', after which the surrounding details will appear in relief. Patience and practice are required before photographs can be 'fused' quickly, and before all details can be recognized. It is recommended that a beginner in the use of air photographs should first learn the uses that do not require the aid of a stereoscope. Later, he may find it desirable to purchase a stereoscope and to practise its use.

The earlier vertical photographs were generally taken from a height of about 10,000 feet above the ground, with an 8-inch lens, resulting in a scale of about 4 inches to 1 mile; these were printed on 8 x 10 inch paper. Later, as aircraft and cameras were improved, photographs were taken from 15,000 to 20,000 feet, resulting in scales of about 2 inches to 1 mile. These photographs were printed on 10 x 10 inch paper. Since 1950 the trend has been towards ultra-high-altitude photography at 30,000 to 35,000 feet, resulting in scales of about 1 inch to 1 mile. For special purposes, such as detailed work near mining camps, vertical photographs have been taken from much lower heights, resulting in greater detail and larger scales. Some areas have been re-flown several times, with the result that photographs of different scales and qualities are available.

Vertical photographs are usually the most satisfactory type. However, because vertical photography requires more time and money, oblique or tri-metrogon types are all that are available at present for certain areas.

Ordinary Oblique Photographs

Ordinary oblique photographs were first taken from the nose of a flying boat, with the camera pointed slightly downward and at about 45 degrees to the direction of flight. Three exposures were taken from any given position of the aircraft, and were designated left, centre, and right 'obliques'. When the more modern types of cabin aircraft superseded flying boats, triple cameras were developed and mounted so that they took one 'oblique' looking backward along the line of flight, and left and right 'obliques' directed backward at about 45 degrees to the line of flight. All oblique views show perspective with gradual loss of detail towards the horizon. They are easy for beginners to interpret because they provide a more natural view than do vertical photographs, but distances are difficult to estimate. Photographs of this kind are now considered obsolete for mapping purposes, and most areas originally covered in this way have been re-flown for vertical photography.

Trimetrogon Photographs

Trimetrogon photography, begun during the last war, is a combination of vertical and oblique systems, with one view directly downward, and left and right 'side obliques' at right angles to the line of flight. Generally these are taken from about 20,000 feet above the ground, with a 6-inch lens, the vertical picture having a scale of about 3,000 feet to 1 inch.

Trimetrogon photography can be done much more quickly and cheaply than vertical photography, and is quite suitable for making topographic maps of large areas. It is not so suitable for detailed work because of the scale and the lack of stereoscopic coverage. Trimetrogon photographs do have one advantage for geological interpretation in that their broad coverage may illustrate large features such as folds, that might not be detected on vertical photographs. Because they are made with more modern equipment and at great height, they are better for this purpose than the old obliques.

Enlargements

Enlarged vertical photographs are very helpful for detailed geological work and special prospecting projects. If they are enlarged too much, however, the features become blurred. For many purposes it has been found that enlarging to scales of 400 or 500 feet to an inch is satisfactory.

Mosaics

To provide a view of an area larger than that of a single vertical photograph, several adjoining photographs may be matched together and mounted on cardboard, or photographed to permit reproduction. Such assemblages are known as 'uncontrolled and uncorrected mosaics' because there is a certain amount of distortion. They provide useful views of an area such as a group of mineral claims, but are not strictly accurate as to positions and distances. For certain areas, the Topographical Survey has prepared uncontrolled mosaics and will sell prints of them. For other areas, mining companies sometimes arrange to have a commercial organization take special pictures and compile a mosaic. Others buy copies of available photographs and make their own mosaics.

Use of Air Photographs

The main usefulness of air photographs for prospectors and geologists lies in their depiction of outcrops and features such as contacts, faults, folds, and variations in rock types. It is difficult for a man on the ground to see the broader aspects of these features unless he is on a high hill or mountain. These features may be shown on the photographs by areas of bare rock, differences of elevation, or differences in vegetation that result from changes in the rocks or soil beneath. Also, a man experienced in the use of photographs may be able to distinguish the broader rock types, such as granitic rocks, greenstone areas, thinly bedded sedimentary rocks, and light-coloured and dark-coloured dykes; these may be apparent from different tones in the photograph, or from the 'grain' brought out by weathering along fractures, shearing, and contacts. This is particularly so after he has done field work in the area; he then knows how some of the rocks of the area appear on the photographs, and can apply this knowledge to pictures of other parts of the area.

It is not suggested that a beginner in prospecting should immediately begin to master the use of air photographs, because he will have many other subjects to occupy his attention. Soon, however, he will benefit from their use, as an aid in understanding geology, in selecting areas for prospecting, in guiding the work, and in the keeping of records and the preparation of sketches. These uses are discussed briefly below.

A prospector studying geology or wishing to learn how geological features appear on air photographs would probably benefit by obtaining the "Catalogue of the Geological Survey Collections of Outstanding Air Photographs" published by the Geological Survey of Canada as Paper 47-26. These collections total about 200 photographs specially selected as illustrations of different geological features and physiographic regions. The catalogue lists the numbers by which prints can be ordered, and it contains a short description of each photograph, but it does not contain reproductions of the photographs. Most of the prints can be secured through the National Air Photo Library, but prints from a few special negatives are obtainable only from the Geological Survey.

Earlier sections have described the ways in which air photographs may be used to help in selecting a region for prospecting, in planning the work after a region is selected, and in guiding the prospector to features that are not shown on topographic or geological maps. One point that will bear repetition here is that the photographs seldom show all the outcrops. Usually, additional ones hidden by trees or other vegetation or occurring along the banks of streams can be found while traversing the ground. Therefore, localities should not be ruled out for prospecting simply because no outcrops are visible on air photographs. An experienced person can, however, detect large areas of muskeg, glacial drift, and other forms of overburden where outcrops are not likely to be found.

Air photographs are also useful as supplements to published topographic maps, because the photographs are generally on a larger scale and because it is often possible to fix an almost exact position by noting some object like a lone tree, small island, shoreline feature, bend in a stream, small outcrop, and so on. In this way, discoveries or other features, or positions from which samples or specimens are taken, can be marked on the print. Another method is to stick a pin through the point, and to place a number or note on the back of the print, beside the pin-hole.

When a prospector reports to those who employ or finance him, or tries to interest a company in sending a representative to examine a discovery, it is almost essential that he be able to furnish a sketch. Nothing is more helpful in this connection than an air photograph on which significant items are marked, or a tracing on which roads, trails, main lakes and streams, main geological features, and positions of discoveries are copied from one or more photographs. The approximate scale and northing should always be indicated on such a tracing.

Most photographs are taken along flight lines as nearly east and west as possible, one flight travelling in one direction, and the adjoining one travelling in the opposite direction. In special cases, however, photographs may have any orientation. The approximate direction of north is usually determined by selecting some feature such as a lake, road, or stream shown on both the photograph and on a map, and from these the photograph is oriented so that this feature corresponds in both photograph and map. Occasionally a photograph shows a surveyed line that has been cut through timber, in which case a more precise orientation can be made as soon as the map has indicated whether or not the photograph was being viewed 'upside down'.

The scale of a photograph, or a series of them, varies to some extent because of distortion in the lens of the camera, tilt of the aircraft, unevenness in the line of flight, and variations in the surface being photographed. These changes in scale are corrected in making accurate maps from air photographs, but they may be ignored so far as prospecting is concerned. The approximate scale is stated on the backs of many photographs. If this is not done, two points that appear on a map can be selected, and their distances on the photograph and on the map can be measured and compared. Another method is to measure on the ground the distance between two points that appear on a photograph.

How to Consult or Obtain Air Photographs

The greater part of the air photography of Canada has been done by the Royal Canadian Air Force or by commercial flying companies working on contracts for departments of the Federal Government. Much photography has been done for provincial governments also, as well as for private mining, oil, and logging companies, but in the case of the last three, prints are not usually available to the public.

Services of the Federal Government

The Department of Mines and Technical Surveys maintains the National Air Photo Library at Ottawa. Here is kept one print of each photograph taken for the Federal Government, totalling about 3,000,000 prints. Photographs for any area can be studied by visitors to the library, but they cannot be lent. Orders for prints are forwarded by the library to the Royal Canadian Air Force, which keeps the negatives and makes prints and enlargements. Photographs are designated by serial numbers, usually composed of a flight number and a number indicating the position of the photograph in the flight series. The direction of an oblique or trimetrogon photograph is also indicated in the serial description.

A map showing the type of photography available for any part of Canada may be obtained from the library free of charge.

Ordinary prints are obtainable at 50 cents each, and enlargements cost up to $12.50 for the largest size, which is 40 by 60 inches. Copies of mosaics cost about the same as an enlargement of corresponding size.

Prints may be ordered from the library by mail, by enclosing a copy of the best available map, or a tracing therefrom, on which the exact area for which photographs are desired is outlined. The following information should be given:

(1) The scale desired, if vertical photographs are requested. For some areas, photographs are available on scales of about 1, 2, and 4 inches to a mile, and for a few areas, larger scales are available.

(2) Whether matte or glossy prints are desired. The former are preferable for marking with a pen or pencil, but glossy prints may give sharper detail.

(3) Whether stereoscopic coverage is desired. If not, only half as many prints are necessary.

The library will advise the cost, and place an order on receipt of payment in advance, which should be by money order payable to Receiver General of Canada.

Services of Provincial Governments

In British Columbia, Alberta, Ontario, and New Brunswick, photographs covering much of these provinces can be inspected at, and in some instances bought from, provincial government offices. Information can be obtained from the following:

1. Air Photo Library, Department of Lands and Forests, Victoria, B.C.
2. Technical Director, Department of Lands and Forests, Edmonton, Alta.
3. Surveyor General, Department of Lands and Forests, Toronto, Ont.
4. Director of Photogrammetry, New Brunswick Department of Lands and Mines, Fredericton, N.B.
5. Nova Scotia Research Foundation, Halifax, N.S.
6. Director of Surveys, Department of Mines and Natural Resources, Winnipeg, Man.
7. Controller of Surveys, Department of Natural Resources, Regina, Sask.

Suggestions for Additional Reading

Smith, H. T. U.: Aerial Photographs and Their Applications; Appleton-Century, 1943. Price $5.80.

A book on air photographs and their uses and interpretation. It includes sections dealing with the use of air photographs in different branches of geology, including mining and engineering geology.

Outstanding Aerial Photographs in North America; Amer. Geol. Inst., Rpt. No. 5, 1951. Issued by Amer. Geol. Inst., 2101 Constitution Ave., Washington 25, D.C.

This publication gives introductory information on air photographs, a list of outstanding photographs illustrative of various geological phenomena, and a good list of references to further books and articles on the interpretation of air photographs. The publication does not include reproductions of air photographs.

Lang, A. H., Bostock, H. S., and Fortier, Y. O.: Interim Catalogue of the Geological Survey **Collections of Outstanding Air Photographs; Geol. Surv., Canada, Paper 47-26 (1947). Price 15 cents.**

A list of specially selected air photographs, with explanatory notes. Appropriate photographs illustrating particular geological features and the manner in which they appear on air photographs can then be ordered from the National Air Photo Library.

Selected Papers on Photogeology and Photo Interpretation; Research and Development Board, Washington, D.C., 1953.

A fairly comprehensive treatment of these subjects, applicable for advanced use, but one that may not be readily available.

CHAPTER IX

SPECIAL METHODS OF PROSPECTING

The preceding chapter discussed the time-honoured methods of prospecting that can be employed by anyone who learns their fundamentals, without requiring special instruments or advanced knowledge. As deposits that outcrop became harder to find, special methods were developed or attempted to aid in the search for those hidden by soil or barren rock, and for outcropping deposits that are difficult to recognize. Some of these special methods have been known for some time but are only now being widely tried; others are still in their infancy and require further appraisal or development; still other methods will doubtless be developed. In some countries, virtually all mineral deposits found in recent years have been discovered by special methods, because most outcrops had already been carefully studied. Canada is fortunate in still having much terrirory where ordinary methods can be used, but even so there is a great and growing interest in special methods, largely because they hold possibilities for the discovery of orebodies in regions already settled and served by transportation and other facilities. It has been well said that Canada's frontier for ordinary methods of prospecting is northward, and that another, downward, frontier awaits prospecting by special methods. There is, therefore, a great field for further research to discover new methods, to test the applicability of those already known, and to improve techniques, as well as for the application of those methods now well established. Indications found in these ways may be uncertain, and usually require expensive drilling or other means of proving or disproving them, but they now have an important place in the mining industry. The improving of known techniques for these special methods, and the discovery of others, offers a great challenge and a great opportunity for further research.

Most special methods are costly and are so technical that scientists or engineers must select the localities for investigation, choose the appropriate method, perform or supervise the work, and interpret the results. A few, including simple geophysical surveys such as those employing dip needles or radioactivity detectors, and some geochemical methods, can be used by well-qualified conventional prospectors working independently, but those less experienced should first become thoroughly familiar with the ordinary methods and should preferably have several years' experience before attempting special methods, unless under supervision. The only special equipment recommended for inexperienced prospectors is a radioactivity detector, if uranium is sought, and a mineral light, if tungsten is sought. Beginners are prone to suppose that modern special methods will relieve them from the necessity of learning and practising the ordinary methods, and even make requests for the name of a Geiger counter that will find gold or other non-radioactive metals.

Although several reliable special aids for prospecting are available, the lure of hidden mineral wealth and the uncertainties involved have long provided both scope for tricksters and pitfalls for the credulous. In the Middle Ages, according to Agricola, men were hanged for purporting to be able to find mineral deposits by use of sticks such as are employed in attempts to locate water by 'dowsing'. Today there are still those who allege that they can find ore by such simple means, as well as by more mysterious devices, and even by 'mental' methods requiring no equipment. Disappointment and financial loss may be avoided by buying from reputable dealers, or buying those instruments only that are recommended in standard textbooks or official reports, and by avoiding mysterious and usually secret methods or devices, unless the individual recommending them is a professional man in good standing.

Diamond drilling is not in itself a special method of prospecting, but an almost indispensable aid in testing indications and theories resulting from the use of special methods. In fact, the advances in special methods and the greater use now being made of them are largely due to the strides made by manufacturers of equipment for diamond drilling and the contractors, engineers, and drillers who use it, since they provide the means of following up these methods of prospecting.

The principal special, or indirect, methods of prospecting, which are often used in combinations of two or more methods, are outlined below. They are not discussed in detail because most of them are mainly usable by professional workers who are well trained and aware of the extensive literature on these subjects, and because a separate chapter is devoted to geophysical methods. Much research directed to the improvement of existing special methods of prospecting and to the development of new ones is being, and undoubtedly will continue to be, carried on.

Detailed Geological Studies

Mineral deposits are found at times by drilling or otherwise testing geological indications shown on standard geological maps or resulting from simple geological observations. As a rule, however, special geological investigations are required. Detailed geological studies and mapping in established mining camps are the oldest and most fundamental of all special methods of prospecting. It has gradually been recognized that it is vitally important to determine as thoroughly and as conclusively as possible the geological factors that caused known orebodies to be where they are, and to investigate mines and mining districts, including old ones, for the purpose of trying to find extensions of known orebodies and to discover similar conditions that can be explored as what are popularly called 'geological bets'. Work of this kind usually involves thorough studies of surface and underground exposures at the known deposits in the mining camp concerned, and detailed study and mapping of all rock exposures in the camp. The general principles of mineral deposition may be applicable from one camp to another, but the details vary, so that each camp has to be studied afresh. Mining companies usually do much of this work themselves, and government organizations do as much as they can when more than one mining property and ownership are involved, but because of the many demands for work of this kind, its slowness, and the high quality of work required, the present staffs and facilities cannot cope with all that might be desirable.

The conditions governing the position of ore deposits are usually structural, stratigraphic, or lithological—that is, their position depends on structures such as faults, shear zones, fracture systems, or folds that provided channels for the introduction of solutions from which the ores were ultimately deposited, or on contacts between one kind of rock and another; or the presence of ore may be controlled by the stratigraphic position of one or more beds that are particularly favourable; or by the occurrence of one or more kinds of rock that are particularly favourable. In many instances the controls involve a combination of several of these conditions. In some camps the controls can be demonstrated fairly definitely and in others they can only be surmised. In either case, it is accepted that everything possible should be done to try to solve the particular problem, including detailed mapping and thorough studies of the surrounding region, with particular emphasis on the factors pertaining to the controls known or postulated. Sometimes the results are spectacular and easily attributed to these methods, but more commonly they are only part of the slow growth of a mining camp after its initial success, and the detailed geological work is supplemented by geophysical or other studies. For both reasons, detailed geological investigations of mining camps are now considered indispensable.

An example of the efficiency of work of this kind is shown by the important developments in the mineral belt that extends from the Rouyn region to Bell River, in northwestern Quebec. Soon after the successful development of the Horne mine at Noranda, the outcrops for nearly 100 miles along this belt were examined by prospectors and geologists, and several other mines came into production. The need for more detailed geological studies to supplement the standard 1 inch to 1 mile mapping was recognized, and virtually the entire belt was remapped in detail with particular attention to rock types, tops and bottoms of beds and lava flows, and fault zones. This work, supplemented in places by geophysical studies, successfully guided the laying-out of diamond drilling projects that resulted in the discovery of several important deposits beneath drift-covered areas.

Another example is the Ace uranium mine in Saskatchewan. During and immediately after World War II, when uranium was relatively unknown and in great demand, a highly organized search was conducted in northern Saskatchewan, because one small pitchblende occurrence had been found there years before. Experienced gold prospectors were engaged and trained in the use of Geiger counters. Geologists selected the general areas of search, and checked the prospectors' discoveries. At the same time, geological mapping was done on a scale of 1 inch to 1 mile to supplement a much earlier reconnaissance map of the district, and more detailed mapping was done is some favourable areas. Within two years the prospectors and geologists found about a thousand radioactive occurrences in the district, and the more promising ones were explored by trenching and diamond drilling. The remapping proved the presence of a strong fault that was not revealed by the reconnaissance mapping. One of the radioactive discoveries was beside this fault, and the consulting geologist advised the company to explore this part of the fault and the rocks at either side by drilling, because, although this showing was not particularly impressive, the structural possibilities seemed much better than at other discoveries. As a result a large and important orebody was found, of which the surface showing was the merest indication. In spite of a great deal of work on other discoveries in the district, the Ace is at the time of writing the only large uranium producer in the district, although it is soon to be challenged by the Gunnar mine.

Special mineralogical studies are commonly helpful in determining the precise nature and distribution of ore minerals and the minerals with which they are associated. Knowledge of these matters can assist in determining the origin of a deposit, the distribution of ore-shoots in a deposit, and the distribution of deposits in a district. In recent years special equipment has been devised for experimental studies in connection with the temperatures at which minerals were formed, and for determining approximately the time that has elapsed since radioactive minerals were deposited.

The fact that many mineral deposits are surrounded by a zone of rock altered in one of several ways has already been alluded to in connection with ordinary prospecting. Special studies to determine the nature of these forms of alteration in a particular district, and to search for rocks appropriately altered, have proved effective in some instances. Because the altered shell around a mineral deposit may be as wide as, or much wider than, the deposit itself, recognition of alteration phenomena, either in surface outcrops or in drill cores, increases the chances of discovery. Investigations of these kinds may include special microscopic studies of rocks and minerals, estimates of the temperature of formation of minerals, special investigations by a method called 'differential thermal analysis' of the 'clay' minerals that commonly are formed in alteration zones, and geochemical studies as mentioned later.

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Geophysical Prospecting

Geophysics may be defined as the physics of the solid earth, its oceans, and its atmosphere. In this broadest sense it includes studies of meteorology, the internal heat of the earth, strength of rocks, and other subjects besides the magnetic, electrical, seismic, and radioactive effects that are the basis of geophysical prospecting. Many years ago magnetic methods were applied to the search for extensions of known iron deposits that contained magnetic minerals, and for other such deposits that were completely hidden. Other methods were developed, and geophysical prospecting has become a valuable and highly specialized aid in searching for and delimiting many kinds of mineral deposits. It is commonly performed as a step between detailed geological studies and drilling. Geophysics has been most successfully employed in connection with exploration for oil, probably because an oil 'pool' is usually a much larger target than an orebody.

Most geophysical work can be properly done and interpreted only by specially qualified persons. Surveys made with a dip needle, magnetometer, certain kinds of self-potential equipment, and radioactivity detectors can, however, under certain conditions be successfully carried out by experienced prospectors who do not have a great deal of technical training. These methods as well as the more complicated methods of geophysical prospecting are described in the next chapter. Geiger counters and other kinds of radioactivity detectors are forms of geophysical instruments; their use for making systematic radioactivity surveys on the ground or from the air is generally considered to be a type of geophysical prospecting, also described in the next chapter. Radioactivity detectors are, of course, also widely used in connection with ordinary prospecting for uranium.

A series of papers on different geophysical methods, written for the layman, was recently prepared by the Society of Canadian Exploration Geophysicists, and the supply was soon exhausted. The Society has generously permitted these papers to be reprinted, with some modification, as the next chapter of this book.

Plate XLIX

A portable kit for testing the metal content of stream water.

Geochemical Prospecting

Geochemical methods of prospecting are based on the fact that very small amounts of one or more of the metals present in an orebody are likely to be dispersed in its vicinity. They may be detectable in the rocks surrounding the orebody, in soil above these rocks, in water that has percolated through such soil or rock, or in plants growing in such soil. An unusual concentration of a metal occurring in one of these ways is called a geochemical anomaly. Metals dispersed in the rock surrounding a primary mineral deposit form a primary *dispersion halo* or *pattern*, and metals dispersed in weathered rocks surrounding a deposit, or in soil, water, or plants, form a secondary dispersion halo or pattern. A variable pattern of metal content, decreasing and widening roughly in the shape of a triangle and apparently pointing towards a source, is called a *dispersion fan*. Certain elements that commonly accompany a particular metal of value, and that may be detected more readily than the valuable metal itself, are called *geochemical indicators*, or *pathfinder elements*.

Geochemical methods have been used for some time in certain countries, with some success. These investigations have been most effective when employed together with geophysical and geological methods. Geochemical methods were not used extensively in Canada until recent years, because it was thought that the overburden of glacial origin overlying the rocks in most parts of Canada would not be sufficiently representative of the rocks beneath, but it is now believed that this may not be as serious a consideration as was formerly thought, at least for some regions and conditions.

Reconnaissance geochemical surveys may be made by collecting samples at random or by following and testing streams. Detailed surveys are made on grid systems at intervals depending on the detail desired, and the results are plotted accurately on a map. For some purposes, portable kits for making very sensitive chemical tests of samples are available (*see* Plate XLIX); for others, a mobile laboratory may be used or a temporary laboratory may be established in or near the area being surveyed; and for other purposes samples are sent to a permanent laboratory. Some tests can be made by experienced prospectors but, in general, geochemical prospecting probably will be most successful if performed by scientists, or supervised and interpreted by them. At least, no one should undertake these methods without careful study of some of the extensive literature. The Geological Survey of Canada does not undertake to test geochemical samples for the public. The following notes cover only a few of the main points regarding the different methods.

Surveys of Bedrock

These are usually made in connection with detailed geological investigations, special samples being taken at regular intervals. For some kinds of investigations, samples may be tested in the field by means of a portable chemical kit, otherwise they are sent to a laboratory for chemical, spectrographic, or other form of analysis.

Surveys of Soils

Samples are taken from overburden by digging pits or narrow trenches, by using a post-hole auger, or by cutting a channel in a bank. Samples should be taken to bedrock but in places where the depth to bedrock is excessive, some information may be obtained by sampling as deeply as possible. Large samples can be reduced in size by careful mixing and selection of fractions. Soil that is permanently frozen is usually unsuitable for surveys of this kind.

Surveys of Water

Geochemical surveys of this kind are usually made by following up a stream and its tributaries, in much the same way as in prospecting by panning or looking for float. Streams having a well-branched drainage pattern are preferable because they provide more even drainage of the terrain and therefore have more chances of dissolving metal from a deposit or of being representative of the metal content of the rock or soil nearby. Stagnant water is not as suitable for testing because it probably contains organic matter that would interfere with tests. Water samples are usually tested by means of field kits or in a laboratory nearby, because of the difficulty of shipping large numbers of liquid samples.

Surveys of Vegetation

Plants absorb metals from the soil and some species retain a metal in the leaves, wood, or fruit, in direct proportion to the amount of the metal in the soil.

If they do so without visible evidence of an increased metal content they are called *covert indicator plants*, whereas the few that show changes or a preference for growing in a certain kind of place are called *overt indicator plants*. Samples are usually taken from leaves or buds, and some of the principal authorities recommend sampling second-year stems. Samples are usually taken to a laboratory, where they are burned to ash for testing chemically or spectrographically. If shipping is a problem, arrangements may be made to reduce the sample to ash while in the field.

Geochemical surveys dealing with vegetation are commonly called *biogeochemical* or *botanical* prospecting.

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Fluorescence

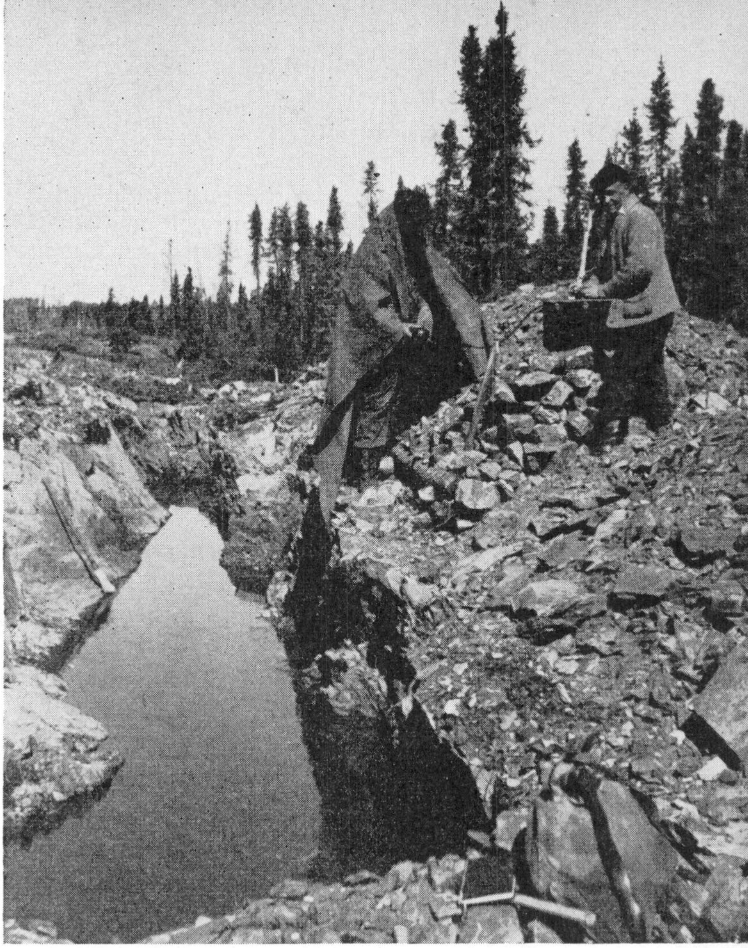
Certain minerals glow or 'fluoresce' when exposed in the dark to the beam from an ultraviolet lamp. Such lamps are also called fluorescent lamps or mineral lights. The effect is striking, and useful in detecting the presence and distribution of some minerals that possess this characteristic, but it is not a sure guide to the identification of minerals. Requests are sometimes made for a list or coloured chart of the diagnostic colours of fluorescent minerals, but the matter is far from being that simple.

Fluorescence is caused by the excitation of the atoms of certain minerals under the influence of ultraviolet rays, that is, rays whose wave lengths are shorter than those of ordinary light. This is sometimes called 'black light'. Improvements have been made in recent years in portable lamps that produce ultraviolet rays with a minimum of ordinary rays that lessen the effect, and which are lighter and more compact than earlier types. Some lamps are designed to produce rays of both long and short wave lengths.

Unfortunately, some specimens of a mineral may fluoresce visibly whereas others may not, and a single specimen may show different fluorescent colours,

Plate L

Estimating the scheelite content of a deposit by using an ultraviolet lamp under a tarpaulin. Note rock trench (partly filled with rain-water) excavated to expose deposit.



probably because of the presence of impurities. Therefore the listing of the colours is of little help in quick identification of minerals. The great use of fluorescence is in providing a simple and reliable means of distinguishing between those that fluoresce visibly and those that do not, and in making tests for fluorescence on 'beads' produced by blowpiping.

Fluorescence is probably most useful in helping in the detection of scheelite, the principal ore of tungsten, and in helping to evaluate scheelite deposits and sort scheelite ores. Scheelite resembles other minerals that do not fluoresce, therefore a fluorescent lamp is helpful in looking for it in deposits in which it might occur. This may be done at night, or under a cloth hood or canvas sheet in daytime, or at any time of day in underground mine workings. Scheelite (and its molybdian variety formerly called 'powellite') is the only ore mineral of tungsten that fluoresces.

When a great shortage of tungsten existed early in World War II, the situation was eased by scheelite recovered from a large Canadian gold mine which was found to contain much more scheelite than was formerly supposed, when a geologist examined the underground workings with an ultraviolet lamp. Another geologist devised a method of estimating the percentage of tungsten present in scheelite deposits by measuring the fluorescent areas.

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Fluorescence has also been valuable in detecting certain other minerals, such as secondary uranium minerals, but a radioactivity detector is usually much better for prospecting for uranium under Canadian conditions.

Ultraviolet lamps powered by small batteries and designed especially for prospectors, geologists, and mineralogists can be bought from several dealers in laboratory supplies and surveying instruments (*see* Plate LXV).

The following is a list of some of the principal fluorescent minerals with notes on their behaviour. New information is from time to time being discovered, so the notes should not be considered as complete or final.

Apatite usually does not fluoresce but specimens from some localities do.

Barite may in some specimens show pale bluish green or yellowish white fluorescence.

Beryl is not usually fluorescent but some specimens are said to show green fluorescence.

Calcite. Many specimens of calcite are fluorescent, the range of colours being great.

Celestite. Some specimens show blue and bluish white fluorescence.

Cinnabar is not fluorescent, but the presence of mercury can be detected by use of a quartz ultraviolet lamp and a special screen.

Dolomite. Specimens from several localities are fluorescent.

Fluorite. This was the first mineral studied in connection with fluorescence, hence the derivation of the name for the phenomenon. Most specimens show more vivid colours when exposed to 'long' rays.

Gypsum. Most specimens do not fluoresce, but some show green fluorescence.

Scheelite generally shows vivid blue fluorescence, when pure, and yellow when impure, therefore material that shows blue fluorescence is likely to be more valuable than that showing yellow.

Spodumene sometimes shows deep red fluorescence.

Uranium minerals. Many secondary uranium minerals, such as autunite and uranophane, show yellowish green fluorescence. Gummite, a variable mixture, commonly exhibits violet fluorescence.

Zircon. Some specimens show bright orange fluorescence, which might assist in detecting the mineral and estimating its quantity in rocks and placer concentrates.

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CHAPTER X

GEOPHYSICAL PROSPECTING*

Historical Summary

There is nothing new about geophysics, except possibly its popular acceptance today. As a science, it is more than three centuries old, but as an exploration tool it is somewhat younger, although not as recent a development as most people believe.

To those interested primarily in the exploration for mineral resources, the word geophysics signifies certain specialized prospecting techniques that are actually the outgrowth of the older and broader science of geophysics. Geophysics means the study of the physics of the earth, and some of the knowledge thus gained, when applied to the search for mineral deposits, becomes the science of geophysical exploration.

The story of geophysics begins in antiquity. It could be said that geophysics began with the invention of the magnetic compass. This is a geophysical instrument, because it responds to a physical force of the earth — its magnetism. There are legends that the Chinese knew the use of the compass 2,000 years before Christ, but the first authentic description of the instrument was written in the 12th century by Alexander Neckham.

Little progress was made in the study of magnetism for many centuries, probably because the ancients believed that the property of attracting the magnetic needle resided in the heavens. Not until Sir William Gilbert published his masterly study on magnetism in 1600 did it become known that the earth itself was the magnet which controlled the orientation of the compass needle. Gilbert, who has been called the "Father of Electricity" and the "Galileo of Magnetism", deserves the title of "The First Geophysicist".

The Dip Needle

Some 20 years after the appearance of Gilbert's work, Swedish prospectors were utilizing magnetized bars to assist them in prospecting for magnetic bodies of iron ore. The dip needle evolved from these early experiments, but was still so crude an instrument that it could be used only in prospecting for bodies of strongly magnetic minerals, such as magnetite and pyrrhotite. It remained the

* This chapter is a re-publication of the booklet "Elementary Mining Geophysics" prepared by Canadian Exploration Geophysicists, and is included here by kind permission of that Society. The text and some illustrations have been modified slightly by L. W. Morley, head of the Geophysics Section, Geological Survey of Canada, to conform with the needs of this publication.

principal instrument for magnetic prospecting until about the middle of the 19th century, but from then on progress was made in the refinements of magnetic prospecting, both in theory and instrumentation. The development of the Hotchkiss Superdip, the Schmidt type magnetic balance or Askania magnetometer, and the airborne magnetometer have brought about an increased versatility and expanded application of magnetic prospecting techniques.

The Gravity Method

Another physical force utilized for prospecting is that of gravity. In early times it, too, was a mystery until Sir Isaac Newton enunciated the laws of universal gravitational attraction in 1687. Small-scale, laboratory investigation of gravitational attraction did not commence, however, until the end of the 18th century, when Henry Cavendish in England designed his torsion balance.

This consisted of a bar with a lead weight at each end, balanced, and suspended at its middle by a long wire. The gravitational attraction between the weight at one end of the bar and an object brought near it would cause the bar to turn slightly on its suspending wire; the amount of torsion or twist of the suspending wire was then a measure of the gravitational attraction between the two objects.

This was essentially a laboratory instrument, but in 1880 Baron Roland von Eötvös of Hungary developed a torsion balance that could be taken into the field and used to measure the variations in gravity from place to place. Early in the present century it was discovered that differences in regional geological structures influenced the variations in gravitational attraction at different localities. By 1917 the torsion balance was being applied in Europe to the study of salt domes and anticlinal structures. It was introduced into the United States in 1922 by Everett DeGolyer, an American geologist, as a prospecting tool in the search for structures which might contain oil deposits.

For the next 15 years the torsion balance proved tremendously useful in the search for structures, especially salt domes, with which oil might be associated. Because of its slowness of operation, however, faster techniques were developed, utilizing a principle first formulated by Sir John Herschel, about 1833. He had suggested that the difference in gravitational attraction between the equator and the poles could be measured by observing the extensions of a coiled spring to which a weight was attached.

Means were not available in Herschel's day for constructing an instrument sufficiently sensitive and precise, so it was not until about 1918 that a practical instrument of this type was made by Professor Gustav Ising of Sweden. The most widely used gravity meters today follow a design developed by Kenneth Hartley in the United States in 1932, using the Herschel principle.

Essentially, these gravity meters measure the differences in density of large bodies of different types of rocks or minerals that may underlie the surface of the earth. Their greatest application has been in the field of petroleum exploration, but the possibility of their use in mining exploration deserves more intensive study.

In the preceding discussion, we have dealt with two physical forces, gravity and magnetism, that are inherent in the earth. They are fields of force supplied by nature, that cannot be modified by the geophysicist, either in degree or in point of application. He must take the force as nature provides it; he is saved the necessity of taking into the field more or less cumbersome apparatus for creating a field of force, but suffers the disadvantage of not being able to control it. However, in the seismic methods of exploration, discussed below, he creates a field of force suitable to his needs by setting off a charge of explosives. He thus imitates nature by creating a miniature and artificial earthquake.

Seismic Methods

Observations on earthquake shocks have been made for 20 centuries. Early Oriental instruments, of very crude design, were used to indicate roughly the direction and severity of earthquake shocks. The idea of using accurately measured arrival times of shocks at different stations, to determine their point of origin, was first suggested by the Reverend John Michell, of England, in 1761. Some 80 years later a distinguished Irish engineer, Robert Mallet, recognized that different geological formations might exercise different effects on the speed of travel of earthquake shocks. He actually employed an electrical detonating and timing system, in the experiments he conducted with charges of explosives, for measuring the speed at which shocks were transmitted in different rock formations. In 1888, A. Schmidt suggested that the speeds of transmission of earthquake waves, or shocks, vary with depth, a concept fundamental to seismic exploration.

It was World War I which brought to a head the practical utilization of sound or earthquake vibrations. The German army experimented with the use of vibration detectors to locate positions of big guns, and this line of investigation resulted in the Mintrop patents of 1919, basic to the refraction method of prospecting. In the same year, J. C. Karcher, in the U.S.A., took out a patent basic to the reflection method of prospecting, which had evolved from efforts by the U. S. Army to locate big guns by sound ranging, and which is explained below. In the refraction method, the detecting point is spaced at a considerable distance from the point of explosion or shot point, and the time taken for the shock waves to be refracted through the underlying rock layers to the detection point is measured.

The reflection method of seismic exploration has superseded the refraction method because of its greater simplicity and lesser consumption of explosives. In essence, it depends on timing the interval between the explosion and the reception, at the surface, of the earthquake wave which has been bounced back, like an echo, from a subsurface reflecting stratum. Accurate timing enables the geophysicists to calculate the depth to the reflecting formation. The reflection method is better for measuring reflection from a number of layers than is the refraction method.

It is in the field of oil exploration that the seismic technique has had its widest application, because it is peculiarly adapted to measuring the depth to extensive, more or less horizontal, strata such as underlie oil areas, and thus interpreting the way in which they are folded or faulted. It is not so well adapted to studying relatively small and often nearly vertical rock changes such as are presented by most mineral deposits.

Electrical Methods

For mineral prospecting, the electrical methods are particularly versatile, They include techniques in which the geophysicist creates a field of force to suit his needs, and controls its point of application, and also a technique in which nature itself furnishes the force and the geophysicist merely directs his search towards revealing its point of origin.

The natural field of electrical force for which the geophysicist searches is that which arises spontaneously in most sulphide deposits. The fact that electrical currents flow within sulphide veins was discovered by a Cornish engineer, Robert Fox, in 1830. His discoveries, made in the copper mines of Cornwall, stimulated much discussion and experimentation in England and Germany between 1830 and 1845, and during this period Robert Fox actually discovered a body of copper ore underground in one of the Cornish mines.

Electrical currents may also be applied to the earth artificially by means of a battery or generator, and from observations made on the surface with a special voltmeter the electrical conductivities of the underlying formations can be calculated.

To Robert Fox also goes the credit for suggesting, in 1843, that the natures and textures of rock formations, the saline content of subterranean waters, and the proportions of sulphide minerals in rocks would affect their electrical conductivities. Subsequent experimenters did not make much progress until Alfred Williams, an Englishman, and Leo Daft, an American electrical engineer, introduced the so-called 'flying circuit' a circuit for measuring the current in the earth which is entirely separated from the circuit introducing the electrical current into the earth. This was patented in 1902. Electrical resistivity methods of subsurface exploration took two different directions. Conrad Schlumberger, working in France, developed a direct current method, upon which he took patents about 1912. Simultaneously, Hans Lundberg and H. Nathorst, in Sweden, were developing a method of electrical prospecting utilizing an alternating current, and made important discoveries with their technique as early as 1918 and 1919.

The work of Frank Wenner of the U. S. Bureau of Standards in 1916 made these resistivity methods more quantitative, by introducing the concept of four equally spaced electrical contacts, which facilitated a simplified mathematical treatment and quantitative study of electrical conductivity.

Induction Methods

Electromagnetic methods, which depend upon electromagnetic induction to set up secondary currents in buried conductors, had their origin in the work of

Conklin, an American mining and electrical engineer, who took out basic patents on the idea in 1917.

Conklin utilized a loop of insulated wire laid in the ground, through which a current was passed, to induce secondary currents in any conductive material beneath it. These secondary currents were then investigated by observing the magnetic field which they created. This idea, in various forms, is basic to practically all such methods today.

The electrical and magnetic methods have been by far the most important in the field of geophysical prospecting for ores. In prospecting for oil, the gravitational and seismic techniques are of prime importance. These four methods represent the main ones thus far applied to the problem of detecting and differentiating subsurface changes in mineral and rock formations. They are not the only methods, however, and others are appearing which, in future, may rank with or even be better than the older techniques.

In the search for uranium, wide application has recently been made of devices that register disintegrations taking place within the atomic cores of the radioactive elements. This is the principle behind the now familiar Geiger counters, and also scintillation counters, which are more sensitive than Geiger counters for making detailed radioactivity surveys on the ground and which are being used in a largely experimental way for making airborne radioactivity surveys.

The geophysical methods of exploration serve to detect changes in the position and character of concealed geological formations, and to detect and outline certain kinds of mineral bodies. Where the changes are large enough to be spotted, they are called *anomalies.* A geophysical anomaly may be defined as a group of observed physical values of either higher or lower intensity than those in the surrounding area. There is as yet no technique so exact that it will indicate the precise nature and amount of a given metal or mineral present in a buried deposit. To what extent they may be present, and whether of commercial value, must still be determined by drilling.

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The Compass and Magnet

A magnet may be described as a piece of iron or iron alloy with the power to attract other pieces of the same material. This power is called magnetism and is the physical property applied in geophysical prospecting instruments such as the compass, dip needle, and magnetometer. Even the magnet itself is a useful aid in identifying some minerals.

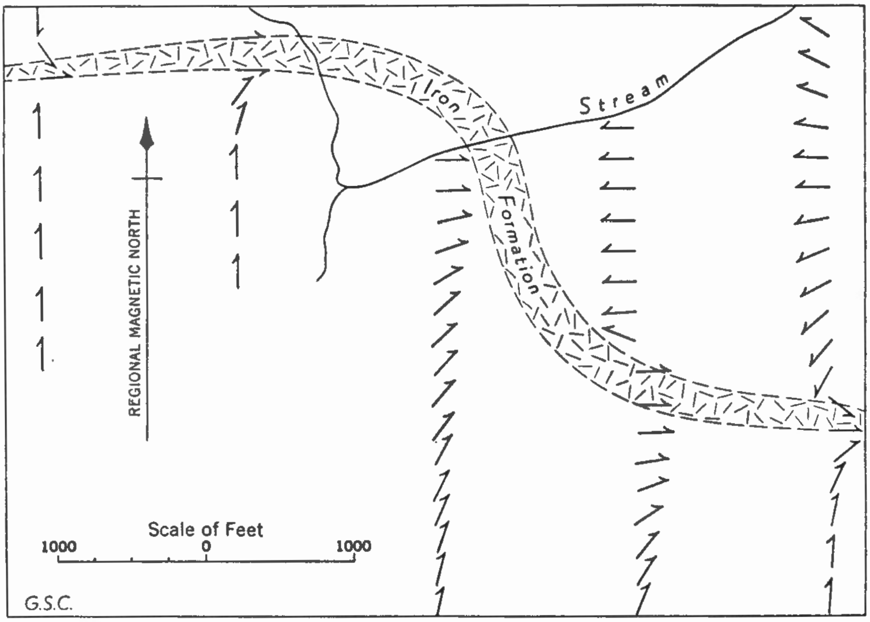


FIGURE 14. Diagram illustrating how a band of iron-formation may be defined by a compass survey.

If a needle is drawn repeatedly in the same direction across one pole of a magnet, it will be found that the needle itself becomes a magnet. If then this needle is suspended from its centre by a fine thread it will set itself in a north-south direction and point downward. Regardless of how the needle is moved it will always return to the same position, thus showing that there is a directional force acting upon it. The end pointing towards the north is referred to as the north pole and that pointing to the south, the south pole. The earth itself acts as a huge magnet, and the magnetized needle aligns itself in the direction of the earth's magnetic field. This field may be considered as having two components of force, one horizontal and the other vertical.

The needle will not point directly towards the geographic or true north because the earth's north magnetic pole is at present on Prince of Wales Island, District of Franklin, Northwest Territories.

The horizontal angle between a suspended needle which is pointing to the magnetic north, and true north is called the 'declination', or the variation of the compass. The vertical angle between a suspended needle and the horizontal is called the angle of dip or 'inclination'. A compass measures the direction of the horizontal component; a dip needle measures the inclination of the earth's field from the horizontal; and a magnetometer measures the magnitude of the earth's field, or its vertical or horizontal component.

Identifying Minerals

All prospectors should be equipped with a compass, the simplest of all geophysical instruments. With it certain minerals can be identified, and certain rock types and buried geological contacts can be located.

Magnetite, (a black oxide of iron) and pyrrhotite, (a reddish bronze sulphide of iron) are two minerals which, when placed near a compass, will readily attract the needle. Franklinite, (an iron-zinc manganese oxide); chromite, (an iron-chromium oxide) and ilmenite, (an iron-titanium oxide) feebly attract the compass needle. When testing the magnetic attraction of a mineral, it is best to set the compass on a level place and bring the specimen up to the needle several times and in several different positions.

To trace buried formations with a compass there must be a large relative difference in the magnetic attraction of the rock formations being traced and the surrounding rocks. This can be tested by bringing samples of both the rock formation and the surrounding rock up to the compass and noting the deflection of the needle. If one moves the needle a great deal and the other does not, a magnetic difference exists and it should therefore be possible to trace the formation magnetically. Even though there may not be enough magnetic material in the hand specimen to move the compass, the whole mass of a large formation may contain sufficient magnetic material to do so.

Making a Magnetic Survey with a Compass

To test the magnetic differences between large rock areas and to map formations and contacts with a compass, the following field procedure is recommended:

Cut a picket line across the contact or formations, making sure that the line is long enough to extend well beyond the contact or well within or beyond the formations to be mapped. Beginning at one end of the line, accurately take the compass bearing of the line every 100 or 200 feet and record the readings. Small changes of 5 to 10 degrees in the bearing of the line (i.e. deflection from normal) will indicate that there has been a change in the magnetic character of the underlying rock and very possibly there has been a change in rock type.

The deflection of the needle may be great, as shown in the accompanying figure. In this instance the bearing of north-south picket lines was taken at intervals of 100 and 200 feet across 'iron-formation'. The direction taken by the compass needle is shown by small arrows. Diabase dykes, gabbros, syenites, granites, slates, and volcanic rocks, as well as iron-formations, have been mapped in this manner. If very strong magnetic deflections are observed over a small area, the chances of a local concentration of magnetite are great, but whether it is of ore grade or not can only be determined by sampling.

The common magnet (either horseshoe or bar type) can be used by the prospector to great advantage. It can be used to identify the minerals listed above more readily than the compass because of its greater magnetic strength. In using a bar or horseshoe magnet to identify minerals three methods may be followed: one is to delicately balance the magnet and bring the sample up to it; a second is to suspend the magnet on a string and move it up to the sample; a third method is to powder the sample and test with the magnet. A surprisingly small amount of magnetic material can be detected in this manner. To determine roughly the amount of magnetic material present in a sample, first crush sufficient material, make a thorough separation by pulling the magnet through the sample several times, cleaning the magnet after each pass, and when no additional material is picked up, compare the amount of concentrate to the amount of tailings.

The Dip Needle

Although the compass may be used for locating contacts between bands of rock of widely different magnetic characteristics, it becomes less useful as the magnetic characteristics of the rock types become more alike. A more sensitive instrument is then required to differentiate between the two magnetic zones. For this purpose, the dip needle is more useful.

The original 'dip needle' was known as a 'dip circle', and consisted of a delicately balanced magnetic needle pivoted on a horizontal axis. If the dip needle is held so that the needle is free to swing in the vertical plane of the magnetic meridian, the needle would come to rest pointing in the direction of the earth's magnetic lines of force (magnetic field), and thus provide a measure of the angle of dip of the earth's magnetic field.

The dip needle currently used for prospecting is a variation of the dip circle, in that the needle is provided with a movable counter-weight attached to one end. The counter-weight balances the needle at an arbitrary angle to the inclination (dip) of the earth's magnetic field when the dip needle is oriented in the plane of the field. The use of the counter-weight introduces a gravitational force which acts on the needle against the magnetic force. The gravitational force is relatively constant from one area to another, while the magnetic force varies in direction and intensity from one observation point to another, thus varying the position of rest of the needle. It is possible to rebalance the needle to a nearly horizontal position for the area being surveyed, thereby increasing the sensitivity of the instrument. It is very important in using all forms of magnetic instruments that the operator exercise extreme care not to have any pieces of iron on his clothes or body, or otherwise close to the instrument, as these will affect compasses, dip needles, and magnetometers, causing them to give false readings. Therefore, while taking readings, he should be sure that his key chain, pocket knife, belt buckle, geological pick and other metallic objects are sufficiently removed from the instrument to avoid interference with the readings.

Dip-needle readings will show the relative changes in the intensity or dip of the earth's magnetic field. Therefore, it is important that an operator establish a routine procedure in making observations, so that the only relative changes the dip needle indicates are the changes in that field, and not changes in the manner of operation. For this reason, readings are taken with the instrument oriented so that the needle is swinging in the plane of the earth's magnetic field. This orientation and the reading may be obtained by the following procedure:

(1) Hold the instrument flat so that the needle is in a horizontal plane and release the needle.

(2) Observe the direction of magnetic north.

(3) Get a firm footing facing magnetic west.

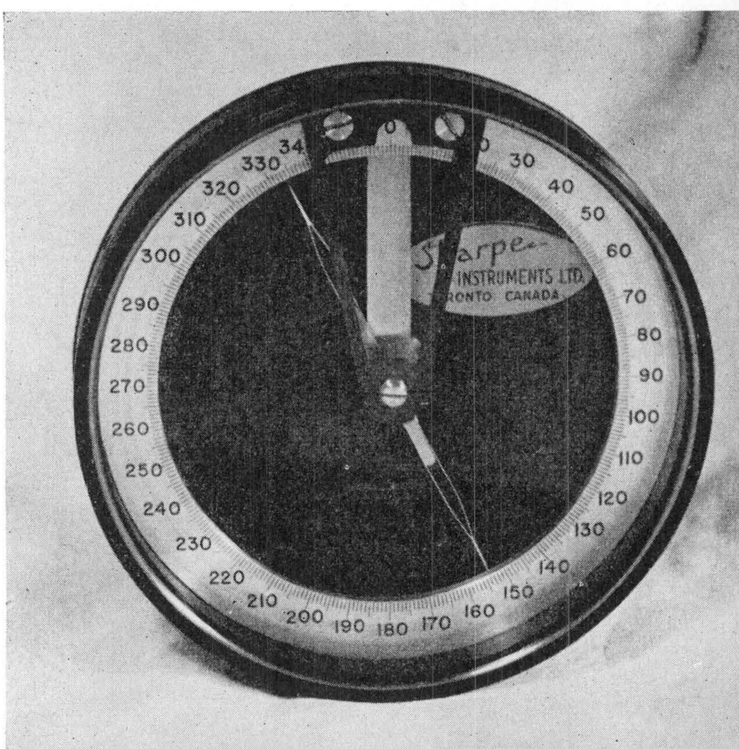
(4) Raise the instrument to a position directly in front of the face so that the needle will swing in a vertical plane, thus making sure the vertical plane of the instrument is common with the plane of the earth's magnetic field.

(5) Read the position of the north end of the needle.

(6) When the position of the north end of the needle is below the horizontal, the reading is preceded by a 'plus sign'. When it is above the horizontal the reading is preceded by a 'negative sign'.

Readings that are above or below normal are called 'anomalies'. Whether or not an anomaly has significance depends on the nature of the problem or rocks being investigated. For example, bands of magnetite will cause strong anomalies, whereas diabase dykes that contain only a little magnetite would cause a difference of only a few degrees as compared to readings over ordinary rocks cut by the dykes.

Plate LI | *A dip needle.*



Mapping the Results

If extreme care is exercised in manipulating the dip needle, the data that are observed can be plotted on a plan, and contour lines similar to those on a topographic map can be drawn to relative magnetic intensities of different parts

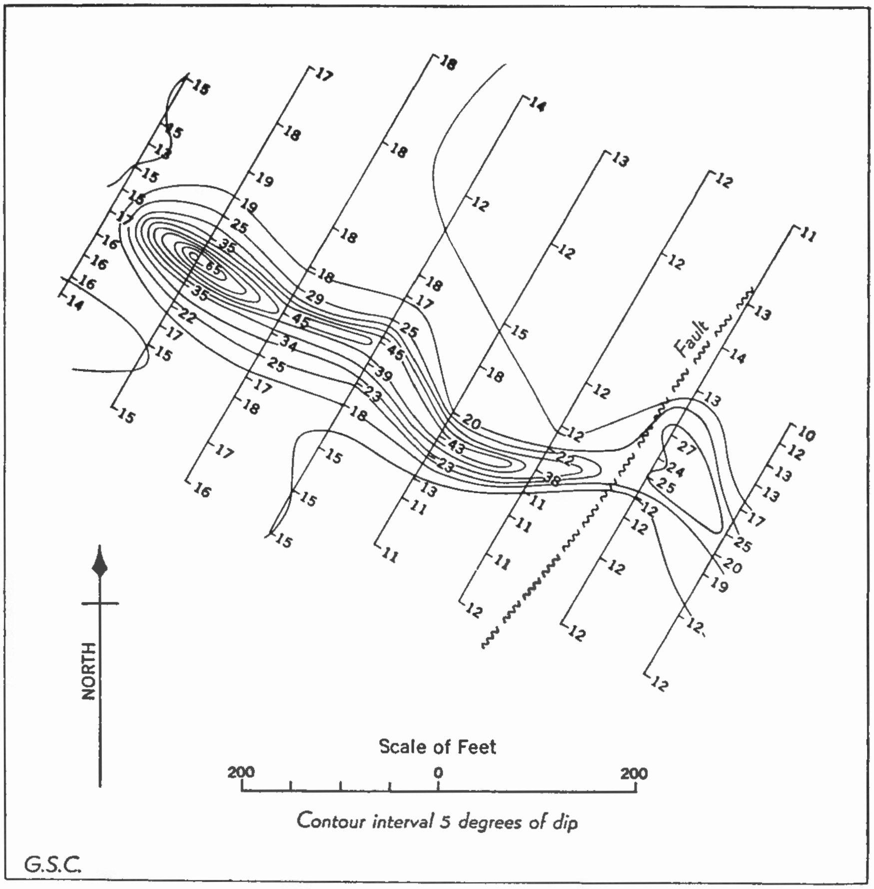


FIGURE 15. An example of a dip-needle survey.

of an area. Let us assume that dip-needle readings are observed at 200-foot intervals along picket lines spaced at 400-foot intervals and that the points of observation are carefully located. These points can then be plotted to scale on a plan and the actual dip-needle readings can be marked at the respective locations. Contour lines may be drawn to join readings of approximately the same magnitude and thus make the observations easier to interpret, as shown in the accompanying figure. One must, of course, exercise careful judgment in estimating the probable magnetic values at places between the points where readings were taken.

Many sources of error in the use of the dip needle can be minimized by testing before making a survey and by care in operating. Some of the sources of error are in the actual manipulation of the instrument, and some are caused by mechanical defects within the instrument.

Generally, the dip needle is held in the operator's hands, and its orientation and level are only approximate. Ideally, the instrument should be level, vertical, and exactly in the plane of the earth's magnetic field. Many dip needles are not provided with a level, but are intended for near-level operation obtained by hanging the instrument from a single point so that gravity can act as a means of levelling. Experience has shown that the position of the needle may vary up to 5 degrees from vertical and up to 5 degrees from being parallel with the earth's magnetic field before the readings of the dip angle are affected by as much as 1 degree. With a careful operating procedure, it is possible to place the instrument within 5 degrees of being parallel with the earth's field and within 2 degrees of vertical, thus sufficiently eliminating the effects of these errors.

Some of the mechanical factors that may introduce errors in the operation of a dip needle are:

(1) Defective bearings, such as pitted jewels or accumulation of dirt in the bearings.

(2) Defects in the pivot points such as pits, irregularities, and blunted ends.

(3) Gradual demagnetization of the needle.

The results of the above defects can be observed in the performance of the instrument. Failure of the dip needle to repeat its readings at any given location, the irregularities of the swing of the needle as it comes to rest, and any jerkiness in the needle, are symptoms of faulty operation. When such symptoms are noticed they should be taken into consideration in future use of the instrument, until such time as it can be repaired by a qualified repairman.

The dip needle is most readily applicable to rapid reconnaissance for magnetic anomalies that are associated with, or indicative of, geological structures, rock types, or mineral distribution. It is particularly applicable for locating iron-formations, tracing faults in highly magnetic material; tracing dykes and igneous contacts; and, if the rocks are suitable, for helping to map the boundaries between geological formations more accurately than can be done from scattered outcrops. It is, therefore, often useful to experienced prospectors and to geologists.

Suggestion for Additional Reading

Stearn, Noel H.: The Dip Needle as a Geological Instrument; Geophysical Prospecting 1929, American Institute of Mining Engineering 1929.

The Magnetometer

The compass and the dip needle have been used in the search for iron ore for at least three centuries. These devices are quite satisfactory for this purpose if a deposit is strongly magnetic, but a more sensitive instrument is required to

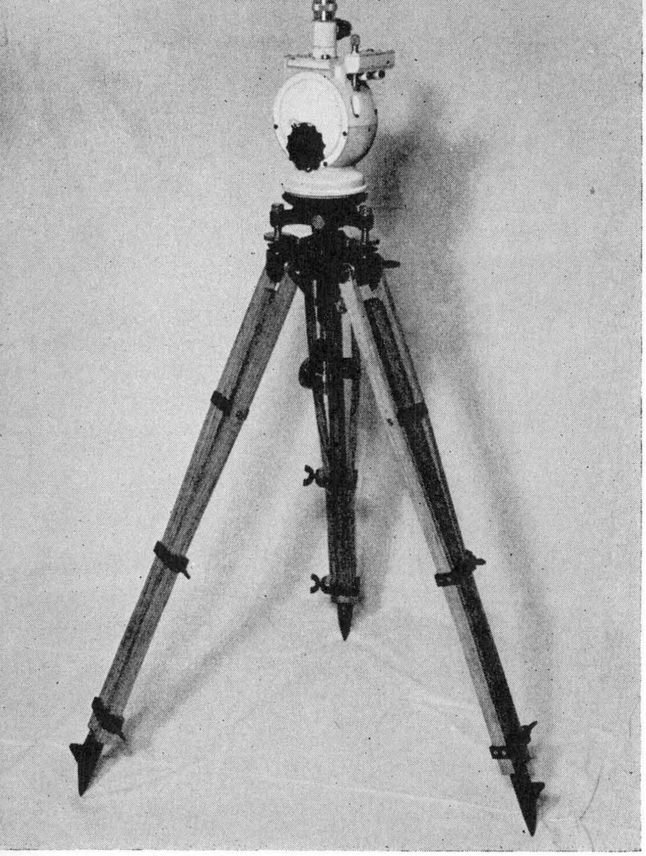


Plate LII

A Schmidt-type magnetometer.

detect weakly magnetic bodies. The extreme sensitivity of the magnetometer enables it to be used not only in the search for magnetic iron ore but also in the location of weakly magnetic rocks and ores.

Magnetometers designed for scientific observatories appeared about 100 years ago, but it was only in 1915 that the German, Adolf Schmidt, designed the first field instrument, which today still stands as the basic model for nearly all magnetometers. Schmidt called his instrument a magnetic balance. In fact, a magnetometer differs from a dip needle or other compasses because it measures or 'weighs' the intensity of the magnetic field instead of merely showing the angles of declination or inclination. The vertical-force magnetometer measures the variation of the vertical component or downward pull of the earth's magnetic field. Other magnetometers, measuring the horizontal component, or northward pull, are employed when working in equatorial regions where the vertical component is very small.

The earth's magnetic field is measured in units to which the name 'gamma' has been given: this 'gamma' should not be confused with the gamma rays referred to in radioactivity measurements.

The Schmidt magnetometer, with its later descendants, is a truly remarkable instrument; it combines precision and sensitivity with ruggedness. The magnetometer consists essentially of a pair of magnets mounted on a suspension similar to that used in precision balances, comprised of a quartz 'knife edge' resting on quartz supports. The magnets are properly counterbalanced to remain in a horizontal position when the magnetic field is normal. A microscope is used to read the deflections of the moving system. The deflections are proportional to the variations of the vertical component of the magnetic field.

The Askania, Watts, Wolfson, Sharpe, and Ruska magnetometers are all essentially similar and vary only in details of construction or quality of workmanship. All can be adjusted to give readings with a precision of about two gammas, which corresponds to 1/25,000 of the total value of the earth's magnetic field. A set of scales of equal refinement would be able to weigh one billionth of an ounce, which would be two hundred and fifty times as sensitive as the scales usually used in assaying for gold.

The Askania and other ground magnetometers of the Schmidt type have been described in all standard courses of geophysical prospecting, but it would be appropriate to single out here the "Manual on Geophysical Prospecting with a Magnetometer" by J. W. Joyce, U.S. Bureau of Mines Publication, American Askania Corporation (1937), Houston, Texas. This booklet describes in detail all the various adjustments and the specific care a magnetometer requires.

The ground magnetometer is a delicate instrument that requires servicing by specialized technicians. Quite often the magnetometer will get out of order, but this may remain undetected by the field operator. Magnetometers used by people who are unfamiliar with their construction and theory of operation should be subjected to periodical, say monthly, check-ups.

Another difficulty in making magnetic measurements with sensitive instruments lies in the fact that the earth's magnetic field is not constant, but is subject to more or less regular daily variations of moderate to small size as well as to intensive disturbances known as magnetic storms. It should be pointed out here that magnetic storms have nothing to do with the weather. They can only be detected by magnetic measurements. The strongest magnetic storms are related to periods of bad radio reception.

Geophysicists meet the difficulty by not using ground magnetometers during magnetic storms and by making corrections for daily variations by check measurements on base stations. In making accurate magnetometer maps, it is not sufficient to plot and contour the uncorrected magnetometer readings. Corrections for diurnal and temperature variations should be made as outlined in standard geophysical texts.

Comparison of Ground and Airborne Magnetometer

The airborne magnetometer is a rather complicated machine using electronic principles to measure the intensity of the magnetic field. It is bulky and therefore cannot be carried on one's back into the bush. The airborne magnetometer is slightly more sensitive than a ground magnetometer. It is normally flown at a height of from 500 to 1,000 feet above ground level.

The magnetic anomalies caused by magnetic minerals or variations of the magnetic properties or rocks diminish very rapidly with distance from the source. Therefore, aeromagnetic maps, because they are flown at a height of a few hundred feet, show only the largest features of the geology. The airborne magnetometer does not replace the ground magnetometer, and the aeromagnetic maps should actually lead to a more intensive use of ground magnetic surveys.

Interpretation of Magnetometer Readings

Ground magnetometers have been used to locate orebodies, and to outline geological conditions masked by the overburden. Generally speaking, the larger a magnetic body, whether it be magnetic ore or a rock formation which is more magnetic than its surroundings, the deeper it can be detected. Thus small deep-seated magnetite deposits are often missed by the magnetometer.

Plate LIII | *The airborne magnetometer in flight.*

The magnetometer is useful as a direct prospecting instrument in the search for orebodies that are magnetic, such as magnetic iron ore or complex sulphide deposits containing pyrrhotite, and numerous orebodies have been found by the magnetometer; probably the most widely known case in recent years was the discovery of the Quemont orebody near Noranda, Que. However, not all magnetic anomalies are caused by mineral deposits; as a matter of fact only about one per cent of magnetic anomalies taken at random are due to them. Nevertheless, in an area such as Sudbury or Noranda, where magnetic ore is known to occur, most magnetic anomalies displaying certain characteristics are worth drilling. Careful analysis of magnetic anomalies, when done by competent geophysicists, can sometimes yield information as to the depth and width of the body causing the anomaly, and the intensity of its magnetization. Such an analysis may serve to differentiate between mineral deposits and intrusives.

Valuable non-magnetic minerals may be discovered by the ground magnetometer if associated with magnetic minerals or rocks containing them. Typical examples are asbestos-bearing bodies of serpentine and quartz-diorite dykes containing gold-bearing veins.

The magnetometer can be used to locate ore-bearing structures concealed by overburden, when it is known that they lie at a predetermined distance from a belt of magnetic rocks having no economic value. Magnetometer surveys made on the ground have been used for this purpose in the Cadillac district of Quebec, where ore zones occur near bands of iron-formation. But the most celebrated case of the use of the magnetometer in such an indirect way was the discovery of the western extension, beyond a major fault, of the famous Witwatersrand gold-bearing series of strata in South Africa.

The above examples dealt with ore directly or indirectly associated with magnetic anomalies. The usefulness of the ground magnetometer is definitely not limited to such cases. In the mining districts of Canada, where most of the geological formations are upturned and concealed by glacial deposits, perhaps the main use of the ground magnetometer is to outline geological structures and formations under the mantle of overburden. Because the structures that are associated with ore deposition are usually minor structures, they can seldom, if ever, be outlined from an aeromagnetic map. It is usually the task of a ground magnetometer to locate the potentially ore-bearing minor geological structures. The ground magnetometer is an excellent geophysical instrument that has proved its worth in Canada for finding ore and detecting geological structures masked by overburden. For reconnaissance work, aeromagnetic surveys are cheaper and speedier than ground magnetometer surveys. For detail work, however, ground surveys are essential.

Aeromagnetic Surveys

Since 1947, the Geological Survey of Canada has published nearly 225 aeromagnetic maps of many parts of the country, and more are constantly being made. Each covers about 375 square miles, so that a considerable total area has already been surveyed. These maps are prepared from airborne magnetometer surveys made by the Survey. In addition, several provincial governments and numerous mining companies carry out aeromagnetic surveys under contract with aerial survey companies, and several exploration companies operate their own equipment.

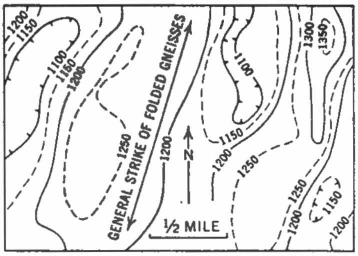
Thus, as time goes by, it becomes less likely that a geologically promising area will not have been surveyed with the airborne magnetometer. The Canadian prospector or geologist, faced with increasingly difficult problems, cannot afford to overlook any possible source of assistance, and for this reason if for no other must acquaint himself with the limitations of aeromagnetic surveys.

Although detailed interpretation of aeromagnetic maps is more within the realm of the specialist, the prospector can gain much useful information from a personal study of these maps. In this section are presented a few factors that must be borne in mind when aeromagnetic data are analysed. Instrumental details and surveying techniques are not discussed.

The airborne magnetometer was developed during the early 1940's as a submarine detector, and in this it was eminently successful. With the close of the war, no time was lost in applying the technique to petroleum exploration, and, shortly afterward, to the search for other minerals.

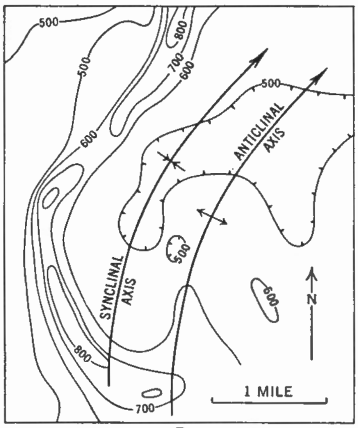
Magnetic profiles are flown along predetermined flight lines spaced according to geological requirements (in general, at right angles to the regional strike of formations) and at a specified height, usually between 300 and 1,000 feet. A continuous strip of the ground below is photographed from the aircraft at the same time, to permit later accurate positioning of the various profiles on the map. Before being plotted, the profile must undergo corrections for a number of variable factors, such as daily changes in the earth's magnetic field. In many surveys a separate stationary instrument is operated at a base station in or near the area during the survey to record magnetic storms. Surveys are discontinued during severe magnetic storms.

The corrected results are usually plotted as contour maps, for in this form they reveal information most readily. It is not uncommon to hear concern expressed regarding the accuracy of aeromagnetic maps. This results from the failure to distinguish between accuracy and degree of detail. The modern airborne magnetometer is an extremely stable and sensitive instrument, capable of measuring differences in the earth's magnetic field of as little as one part in 60,000. In this respect it surpasses the average ground instrument, but both have more than sufficient sensitivity and accuracy for their purposes. However, the airborne magnetometer is operated at an elevation of, say, 500 feet and, therefore, responds to the magnetic influence of conditions over a fairly wide area below at any given instant. For instance, two adjacent anomalies that might be well defined by a ground magnetometer survey may appear as a single combined anomaly on the aeromagnetic map. The lack of detail caused by the height of the instrument above ground is offset to some extent by the fact that a continuous profile is recorded, whereas the ground data are point measurements.



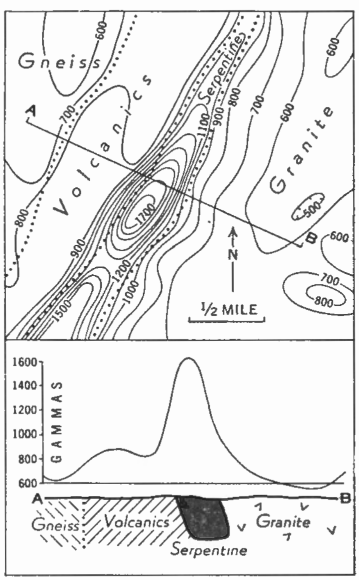
A

Despite the low magnetic relief of this area, aeromagnetic contours parallel the trend of steeply folded and contorted gneisses. The average strike is seen at a glance, but many ground observations would be required in this case to yield equivalent results.



B

A belt of relatively magnetic volcanic rocks is outlined by the aeromagnetic contours in the west half of the map. The double curve toward the south is related to known folding, as indicated by the fold axes. Recorded at a flying height of 500 feet.



C

A sharp anomaly produced by a sill-like body of serpentinized peridotite. The shoulder on the northwest side of the anomaly is caused by a belt of volcanic strata. The asymmetry of the profile is related to the southeast dip of the serpentine.

G.S.C.

FIGURE 16. Diagrams illustrating interpretation of aeromagnetic data.

'Anomaly' is an overworked term very commonly used in conjunction with the word geophysical in mining exploration. Actually, an anomaly is merely anything out of the ordinary, and as such need have no economic significance. In aeromagnetic maps, an anomaly is either a stronger or weaker zone in the magnetic field, as compared with the adjacent field.

In compiling an aeromagnetic map, an arbitrary level of magnetism is chosen so that all contour values will be positive, that is, greater than zero. It can be understood readily that the degree of magnetism represented by any contour, or as the peak of an anomaly, should not be compared as such with values from maps of another area. The intensity of an anomaly should always be expressed in terms of the deviation from the surrounding normal field, not in terms of the peak figure recorded on the map.

It is important to recognize that nearly all magnetic anomalies are related to differences in the magnetite content of associated rocks. Moreover, magnetite is one of the most prevalent of accessory minerals, particularly in igneous and metamorphic rocks, so that it is almost as remarkable in some areas to find no magnetic anomalies as to find many. Viewed in this light, a magnetic anomaly in the Canadian Shield should be treated as just that and, without further corroborative evidence, should not be considered as representing the presence of an economic mineral deposit.

Magnetic anomalies may be found associated with many geological conditions, for example:

(1) An olivine diabase dyke which cuts across folded sediments.
(2) Metamorphosed andesite bordering a granitic intrusion.
(3) Banded magnetic iron-formation.
(4) A magnetite segregation in gabbro.

Correlating Geology

If a geological map of at least part of the area being studied is available, as is usually the case, the magnetic data corresponding to known formations can be studied. The value of the magnetic field over a particular formation, its degrees of variation (technically called magnetic relief), and the texture of the magnetic field (such as trend, size, shape, spacing, and continuity of anomalies), should be determined in relation to the known geology. Areas of similar magnetic relief and texture, especially where they are on strike with known formations, may then be interpreted as the same rock type.

When few or no geological observations are available for an area covered by an aeromagnetic survey, it is nevertheless possible to interpret rock types in a general sense. Great caution must be exercised, for the magnetic behaviour of many formations is difficult to predict. The following general suggestions to assist in interpretation may be helpful. Sediments are very weakly magnetic, and tend to give widely spaced magnetic contours with poor lineation. Volcanic rocks vary from weakly to strongly magnetic, and a single lava flow generally varies from top to bottom. Basic types of lava tend to be more strongly magnetic than acidic types, and their magnetic pattern is much more irregular. Tilted or folded series of stratified rocks, particularly those which contain volcanic members, give rise to linear magnetic trends. Figures 16A and 16B illustrate this characteristic. Intrusive bodies commonly yield an irregular magnetic field, even though the rock may appear uniform on the ground. The magnetic trends show little or no lineation, although some may occur in the vicinity of and parallel to the contacts. Basic intrusive rocks are commonly strongly magnetic, as shown in Figure 16C. Acidic to intermediate intrusive rocks are commonly only moderately magnetic. In Figure 17, granodiorite forms an anomaly with respect to adjacent lavas. The outline of a geological body, as revealed by magnetic data, may offer a clue concerning the nature of the rock. Thus large igneous intrusives can be distinguished from lavas and sediments.

Exceptions to the foregoing are so common that experience tends to discourage the use of these 'rules'. For example, highly magnetic sedimentary iron-formations may occur in an entirely sedimentary series; acidic lavas may be locally very magnetic; diabase dykes may be no more strongly magnetic than adjacent sandstone; granite in some areas causes huge, positive anomalies; some serpentine is virtually non-magnetic; and gabbro sills may exhibit striking lineation, both geologically and magnetically.

Structural Determination

Modern economic geology places great emphasis upon structure in the exploration for mineral deposits. In regional structural mapping the geologist ordinarily pieces together bits of ground-observed information until a structural pattern is obtained on the basis of the evidence. It may require years of work to gain an understanding of the regional structure. Airborne magnetometer results may, in contrast, yield much information concerning large-scale structural features in a very short time, and they may supply evidence of smaller structures of importance in localizing mineral deposits. Aeromagnetic data should always be studied in conjunction with air photographs and any geological maps available when structural interpretation is undertaken; the combined data are admirably suited to the delineation of large-scale structures.

The geological interpreter must, therefore, be thoroughly aware of the dangers attending 'blind' interpretation (i.e., when no geological data are available). He should always indicate the degree to which his interpretation has been controlled by geological facts, and should make every effort to consider all these facts in his work. However, when no geological information is available, he must do without it, with the expectation that some of the interpretations will be correct, but that many will require re-interpretation in the light of subsequent geological observations.

Application to Prospecting

A prospector who uses geological information intelligently can also derive valuable clues from aeromagnetic maps. Geological common sense is undoubtedly

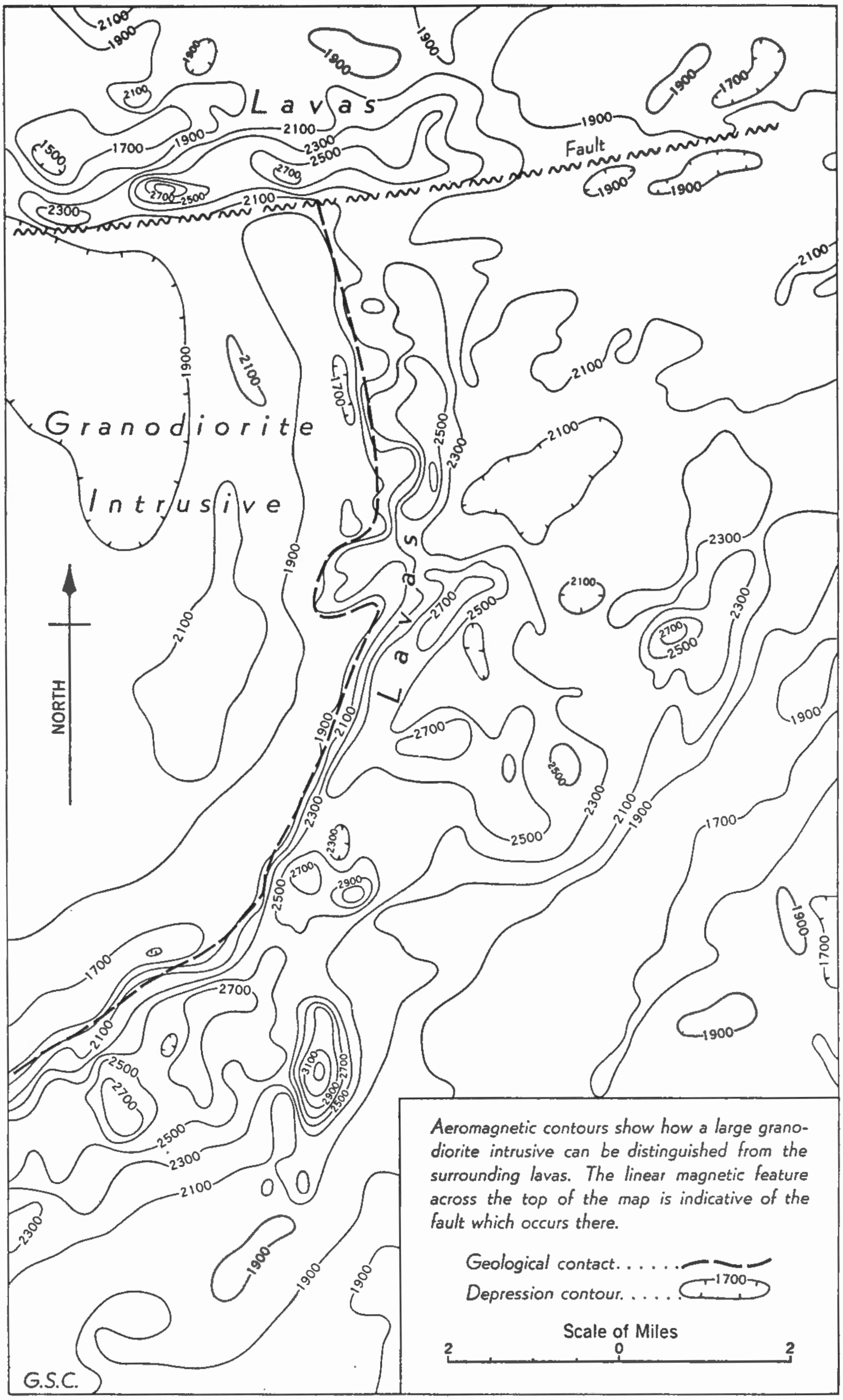


FIGURE 17. Aeromagnetic contours outlining a large granodiorite intrusive.

his best asset. Emphasis should not be so much on the strength of the anomaly, as upon its configuration. Where the evidence is suggestive, but not conclusive, the prospector must bear this fact in mind. He must be prepared subsequently to alter his interpretation if new evidence makes his conclusions seem less likely. Obviously, the prospector cannot hope to duplicate the services of an experienced geophysical interpreter, but after some practice and familiarity with the results of aeromagnetic surveys, he can derive valuable assistance from that source to guide his geological thinking.

The experienced prospector has passed through and beyond the stage of suspecting an orebody in each and every contact and shear zone, but he has not progressed so far with his geophysical thinking. He and the mining fraternity in general have just recently developed a strong interest in applied geophysics, and the anomaly (nature usually unspecified, be it electromagnetic, gamma radiation, or equipotential), is still everything. It is unfortunately true that, after being expensively 'let down' by several magnetic anomalies that failed to produce another Marmora or Bathurst, the prospector is likely to go to the other extreme, paying no further attention to the magnetometer data. Aeromagnetic maps containing valuable data that are often not utilized are being regularly made available to the public.

Aeromagnetic maps provide one of the most valuable means for securing information on the all-too-numerous regions that have not yet been geologically mapped. Their prime purpose is to help to complete the geological understanding of these areas. Then, with a more accurate and more detailed conception of the geological conditions under drift-covered areas, the prospector has surmounted a substantial part of the handicap arising from the lack of outcrops or the lag in geological mapping.

Radioactivity Detectors

Of the various methods of geophysical prospecting described in this chapter, none has equalled the present popularity of radioactivity methods as used in the search for uranium deposits. In recent years, thousands of people with various degrees of technical training have engaged in the search, using modern devices for detecting radioactivity. The reason for this popularity lies not only in the portability and low cost of some models of radioactivity detectors but also in their simplicity of operation and the direct indication they give of the presence of radioactivity. It is fortunate that this is so, for some of the principal uranium minerals are not easy to identify with the naked eye, particularly if they occur finely dispersed and without prominently coloured secondary minerals, as, for example, in the Blind River region of Ontario. Geophysical methods of detection are therefore almost indispensable and are employed to a much greater extent in searching for uranium deposits and exploring and mining them than for any other metal.

Principles of Radioactivity

The uranium atom is the heaviest in nature and is constantly trying to 'reduce' by giving off matter and energy in a process known as 'radioactive decay' or 'radioactive disintegration'. In doing this, uranium changes to elements of lower atomic weights until the stable element lead is finally reached, whereupon no further disintegration takes place.

Some of the matter and energy emitted by uranium (and, unfortunately for the uranium prospector, thorium also—the parent member of another radioactive series) are capable of penetrating considerable thicknesses of air or solid material and it is this property of the rays that makes possible the use of detecting devices.

Three types of rays are emitted by uranium, and have been named 'alpha', 'beta' and 'gamma' rays. Alpha rays are relatively large particles of matter emitted at low speeds. These are so easily absorbed that they travel only from one inch to four inches in air and are stopped by a sheet of paper, and are therefore not detected by prospecting instruments. Beta rays are electrons, small particles negatively charged with electricity that are emitted at speeds approaching the speed of light; beta rays have considerably more penetrating power than alpha rays, but are stopped by less than one-tenth of an inch of brass or aluminum; they are not detected by all prospecting instruments but can be detected by specially adapted 'beta counters', which are useful under certain conditions. Gamma rays are the armour-piercing bullets in uranium's arsenal. They are bursts of energy very similar to the familiar x-rays, which, as is well known, will penetrate considerable thicknesses of solid material. Gamma rays are even more penetrating than x-rays and will pierce up to 7½ inches of iron and up to one foot of solid rock. This is the type of ray that is normally registered by radioactivity detectors and it is therefore the most important of the three kinds in prospecting for uranium. The special beta counters detect gamma rays also.

Alpha, beta, and gamma rays are emitted directly by radioactive minerals. In prospecting for uranium, however, it should be remembered that one of the decay products of uranium is radon, a radioactive gas derived from radium, small quantities of which are present in uranium ores. This gas may migrate considerable distances from its source in a uranium occurrence through fracture zones, loose overburden, or water. The presence of uranium in the vicinity may therefore be indicated by the radioactive effects of this gas when the detecting instrument is actually far outside the range of the gamma rays directly emitted by the uranium mineral.

Detecting Instruments

Modern radioactivity detectors for prospecting, of which there are many models now available, are of two basic types, Geiger counters or scintillation counters.

The heart of any type of Geiger counter is the Geiger-Muller tube. This is a glass tube containing two electrodes, one of which is in the form of a thin wire running the length of the tube (the anode or positive electrode); the other is a cylinder, frequently of copper, lying next to the glass wall (the cathode or negative electrode). The interior of the tube contains an inert gas, commonly argon, at low pressure, with a small amount of ether or alcohol vapour. A high voltage is supplied to the tube but one not sufficiently high to overcome the resistance of the gas to the passage of current. If a gamma ray strikes the cathode, electrons are emitted by the copper, and the gas within the tube becomes ionized so that a pulse of current flows between the electrodes. This action might be compared to the passage of electricity through water; pure water resists the passage of electricity, but if a pinch of salt is added the salt solution will pass current readily owing to the presence of ions. The pulse of current thus produced in the tube may be amplified and made audible in the earphones of the instrument, or the pulses may be registered by a meter that shows on a numbered dial the number of pulses per minute. Some counters have other indicators, such as a light that flashes each time a gamma ray activates the tube.

Although the Geiger counter is an effective instrument for detection of gamma rays, it actually has a low operating efficiency, since only about one-tenth of one per cent, or one in a thousand, of the gamma rays that strike the cathode cause a 'count', that is, an electrical discharge in the tube. This apparent disadvantage becomes an advantage in some phases of exploration, such as logging diamond drill core or examining underground exposures in a mine, when it is desirable to detect beta radiation within a very small area and to exclude gamma radiation from beyond that area. For this purpose a beta counter is used. The beta counter is simply a Geiger counter in which the tube either has a very thin cathode and glass wall or an 'end-window', sometimes of mica, in a lead-shielded probe. The beta rays can therefore penetrate directly into the tube and cause a discharge. Of course, a beta counter tube also admits gamma rays, but beta rays are ten times as effective in causing flow of current in the tube, therefore of every ten counts recorded nine will be due to beta rays and only one to gamma. The beta counter has also been found useful in testing samples of low-grade uranium ores. Owing to the greater ionizing properties of the beta rays, radioactivity can be detected readily by the beta counter at very close range, when a gamma counter would show only a slight response.

The scintillation counter has become a popular detecting device in recent years. It operates on an entirely different principle from the Geiger counter, taking advantage of the fact that certain crystals emit light when struck by a radioactive ray, each ray generating a tiny spark in the crystal. To record this effect a section of a crystal is fitted very exactly to the end of a photomultiplier tube. This is a very sensitive 'electric eye' that converts light impulses into electric impulses, as do the simpler ones used in light meters and door closers, but multiplies the original voltage and delivers an amplified pulse of electricity for each flash of light. These pulses after further amplification can be recorded by a meter or made audible in earphones.

An interesting feature of scintillation counters is that certain substances used for the scintillating crystal respond only to gamma rays, and others only to alpha rays; scintillation counters may therefore be made selective for either type of ray. The alpha scintillation counter is employed much like the beta Geiger counter, for studying localized radiation. The gamma scintillation counter is a very efficient detector of radiation and is several times as sensitive as the Geiger counter. It should be remembered, however, in comparing the relative sensitivities of Geiger and scintillation counters, that the efficiency of each instrument also depends on the effective area of the crystal scintillator as compared to the cathode area in the Geiger-Muller tube or tubes which, in portable models, is much greater. The greater sensitivity of the gamma scintillation counter, together with the fact that it has a greater speed of response, makes it the best detector yet devised for use in airplane or helicopter. On the ground, the scintillation counter can detect radioactive material beneath a greater depth of cover than the Geiger counter, making it an instrument well adapted for tracing a known radioactive zone beneath drift or for detailed surveys of areas that include drift-covered sections. The sensitivity should not be over-estimated, however, since radiation drops very rapidly as the distance from the source increases, so that eventually the normal surface and cosmic radiation will mask the indication. When this point is reached, no matter how sensitive the instrument may be, it will be unable to detect the radioactive material beneath the overburden. Generally speaking, about four feet of water, or two feet of overburden, or six feet of snow will successfully mask the radiation from a pitchblende source when a scintillation counter is used. These distances are about 30 per cent smaller when a Geiger counter is used.

For general prospecting, the Geiger counter is still preferred by many experienced operators because of its lower cost, lightness, and simplicity of operation. It has been found that Geiger counters are sufficiently sensitive to pick up all the significantly mineralized occurrences, as well as many that are relatively unimportant. Greater sensitivity might only serve to increase the number of unimportant occurrences detected. Scintillation counters are desirable for detecting slight radioactivity and for making detailed surveys.

Interpretation

The interpretation of geophysical results from Geiger or scintillation counters is relatively simple and direct in comparison with other geophysical methods, in which calculations, corrections, and plotting of results are necessary. A radioactive anomaly must indicate an occurrence of some radioactive material in its vicinity, and if the anomaly seems significant it can be checked by obtaining and testing samples. It should be remembered also that what appear to be anomalies are sometimes caused by a faulty instrument. This can be checked by testing the counter at some other place where no radioactivity would be expected, such as over deep water. Then, if the counter seems to be operating properly, it can be used again at the place where the 'anomaly' was detected.

Unfortunately, "all that glitters is not gold" nor is everything that 'kicks' necessarily a uranium deposit. Sometimes a thorium mineral is the source of radiation, and thorium at present is of little economic interest. No completely reliable method of distinguishing thorium from uranium by means of a field detector has yet been devised. Thorium, theoretically, gives off a greater proportion of beta rays than does uranium and by comparing the number of beta counts to gamma counts emitted by a specimen, using a beta counter, an indication of the composition may be obtained, but this has not proved to be very practical. Usually a special type of radioactive assay, a chemical analysis, a blowpipe test, or a mineral identification is required to confirm the presence of uranium.

As already mentioned, radon penetrating fracture zones or loose overburden may give rise to radioactive anomalies although no source material can be found at the surface. If the anomaly is extensive, deep trenching or diamond drilling may be necessary to reach the source of the radon, and it may not be found immediately under the point where the reading occurs.

Since pitchblende and uraninite are soluble in acid solutions, they may be leached from the surface zone of a deposit, especially if sulphides are present. Sampling the surface at a radioactive anomaly may therefore yield negligible assays in uranium oxide. Therefore, if the anomaly is extensive, rock trenching or diamond drilling may be required to obtain a fair sample.

Low assays are commonly obtained from material that causes a marked anomaly, owing to what is called 'mass effect', whereby a large area of low-grade material gives rise to a considerably higher count rate than would a small area of the same material. This has caused many disappointments, particularly when inexperienced persons investigate large outcrops, cliff faces, and underground workings in mines.

Significant Indications

One of the most frequent queries about radioactive prospecting is "What is a significant indication?", by which is usually meant "Will a certain count-rate indicate a certain grade of ore?" There is no simple answer to this question, as may be gathered from the preceding paragraphs. Generally speaking, count-rates double the normal background are considered worth investigating further, but even this rule of thumb should not be interpreted too literally. The background count is derived from the slight radioactivity of rocks plus the effects due to cosmic rays. Therefore background may differ with the rock type. In the Beaverlodge area, for instance, it is not uncommon for the count to rise to double or more in proceeding from sediments or amphibolite into granite. The higher radioactivity of granite, especially pink or red granite, may be due to the presence of radioactive potassium in the feldspars and such an 'anomaly' is often of no significance, as the prospector quickly learns. On the other hand, within an area of one rock type a double background count may indicate that radioactive minerals are in the vicinity and that the indication simply has been diminished by distance from the source or by overburden. Therefore the vicinity of such an indication should be further investigated until it is established that no significant source of radiation is present. If a seemingly significant count is obtained, particularly over more than an isolated spot, the next step is to take some samples and to hold them close to the counter, at a place where the background is normal; this will eliminate the all-too-common mass effect. If the samples do cause a count of twice background or more, the next step is to send them for laboratory tests; if such tests repeatedly show low results, samples should not be considered worth assaying unless they show a higher count; the prospector will gradually learn by experience what to expect from his instrument and his methods of using it.

Anyone planning to work in a certain area should visit any known occurrences of radioactive minerals there and make observations with his own particular instrument, if at all possible. There is no more effective way of learning to recognize a significant indication.

It will be clear that, despite the apparent simplicity of geophysical prospecting for uranium, problems of interpretation do arise with which anyone interested in the subject should be acquainted.

In addition to the ordinary ways of prospecting with a counter, detailed radioactivity surveys, made with readings at intervals of 10 to 100 feet along surveyed lines and 'contoured' in the same manner as described in connection with magnetometer surveys, are useful for detailed prospecting and exploration. They are, however, usually made by or supervised by geologists or geophysicists.

Airborne Scintillation Counter Surveys

The possibility of flying over virgin country with a sensitive Geiger counter appeals to the imagination as a quick and easy method for locating uranium deposits. When the demand for uranium was established, scientists were not long in testing this idea, but were disappointed to find that ordinary Geiger counters were not sufficiently sensitive. They tried using a number of Geiger tubes arranged in rows to increase the efficiency of the instrument and in this way, a practical survey instrument was actually developed.

About 1947, however, a new instrument, using an entirely different principle from that of the Geiger counter, was developed for use on the ground. This was the gamma ray scintillation counter, already mentioned in the preceding section. Whereas the average Geiger tube can detect only about 3 per cent of the gamma rays striking it, the scintillation counter can detect up to 30 per cent. The sentitive part of the scintillation counter is a special transparent crystal of sodium iodide, usually cylindrical in shape, about 1 inch or 2 inches in diameter and 2 inches long. When gamma rays pass into and are absorbed by the crystal, they cause minute sparkles of light, referred to technically as scintillations. These scintillations, too weak to be observed by the human eye, are detected by a photomultiplier tube, which is simply a very sensitive photo-electric cell placed in optical contact with the crystal. The whole assembly is mounted in a light-proof case which, however, can be penetrated by gamma rays, since they are similar to the very penetrating x-rays.

The scintillation counter was soon applied to experimental surveys from the air. For this purpose the output of the photomultiplier tube, after passing through an amplifier and electronic counting circuit, is recorded as a continuous line on a roll of chart paper. The reading on the chart at any point represents the number of counts per second and can be regarded as the number of gamma rays striking the crystal during the second of time immediately preceding the point on the chart being read. This is true only if the time-constant of the instrument, that is, the period over which the instrument adds the counts before recording them, is one second. The time-constant is adjustable and a better average of the number of counts per second is obtained if the period over which the counts are made is fairly long. Because the aircraft is moving quickly, however, the time-constant should not be too long, or the counts will be averaged over too great a distance and it would be impossible to pin-point accurately the location on the ground corresponding to the reading on the scintillation chart. Thus the slower the aircraft travels, the longer the time-constant of the instrument may be set, and the more accurate the reading will be. If the time-constant were shorter than about one-half second, the record would have a meaningless fluctuation and any real anomalies would be obscured. For an aircraft travelling at 120 miles per hour at an altitude of 500 feet, the optimum time-constant is about one second. The ideal arrangement is to use an instrument with a fairly long time-constant in a slow, low-flying aircraft. More recently, high-count rate meters have become available, making it possible to operate at faster aircraft speeds and shorter time contacts.

The two naturally occurring radioactive elements, uranium and thorium, are, in minute quantities, common constituents of rocks. Thus, depending on the amount of these elements present, all rocks are to a greater or lesser extent radioactive and are gamma ray emitters. In general, most sedimentary rocks contain very little thorium and uranium in comparison to igneous and metamorphic rocks, although uranium deposits do occur within sedimentary rocks. Of the igneous rocks, granites, syenites, and pegmatites are far more active than are the darker-coloured rocks such as gabbro, basalt, and peridotite. As far as radioactivity is concerned, sand and clay overburden is usually fairly inactive, and about 3 to 5 feet of this material will effectively block most gamma radiation from underlying rocks. About 5 to 10 feet of water will absorb most gamma rays. Gamma radiation is a mixture of two kinds of rays; high-energy rays, to which the term 'hard rays' is applied, and low-energy rays called 'soft rays'. The so-called soft component of gamma radiation from rocks is absorbed by 3 or 4 feet of air, while the harder components can penetrate with diminishing intensity approximately 3,000 feet of air. Unlike the magnetometer, the scintillation counter cannot detect mineral bodies that are more than about 3 feet under the surface. Thus, for all practical purposes, it is only the surface exposures of bedrock that contribute to the amount of radiation detected by the airborne scintillation counter.

When doing airborne prospecting for uranium in areas where most of the rocks are igneous or metamorphic, such as in the Canadian Shield, it is difficult to distinguish the anomalies due to worthless rocks from those due to uranium deposits. Such rocks are never as radioactive as uranium deposits, but the cumulative radiation from a large exposure of granite, for instance, can often cause as large anomalies as pitchblende veins, which are rarely exposed over areas larger than about 4 by 100 feet. This state of affairs is expressed by saying that in areas of igneous and metamorphic rocks the background radiation is high. Also, the Shield contains numerous small and unimportant concentrations of uranium minerals, which may cause many unimportant anomalies. In areas where the rocks are predominately sedimentary, however, the difficulties of interpretation are not as great, because the background radiation does not obscure the radiation from uranium deposits. For example, the airborne method met with success in the Colorado Plateau region of the United States. Here the radioactive bodies are found lying like 'radioactive plums' in relatively non-radioactive sedimentary rocks, so that any anomalies that are found from the air are worthy of investigation on the ground. On the other hand, it has been found that surveys over the Canadian Shield produce such a profusion of anomalies, most of which are due to granite or syenite outcrops, that extreme caution is necessary in their evaluation.

In interpreting, it must be borne in mind that there are three main factors that affect the reading of the airborne scintillation counter: first, the radioactivity of the surface rocks (the quantity it is desired to measure); second, the proportion of the area below the aircraft not covered by overburden; and, third, the height of the aircraft above ground. As to the second factor, the scintillation counter 'sees' at any one time a circular area on the ground approximately equal in radius to the distance of the plane above ground. Thus the important factor in this case is the percentage of this circular area not covered by overburden. This percentage can be estimated by examining the strip photograph of the terrain taken at the time of the survey, but this can be only a rough approximation, since moss and trees often obscure the outcrops. As to the importance of the height of the aircraft above ground, the gamma radiation becomes less intense at greater altitudes because it disperses in all directions from the outcrops. Moreover, gamma radiation is absorbed by air, so that the thickness of the air layer between the source and the scintillation counter significantly reduces the reading obtained.

The airborne scintillation counter can be operated to better advantage from an aircraft flying at an altitude of 200 feet or so than from one flown at 500 feet or higher. At low altitudes, the difficulties of interpretation that have been discussed are minimized. Because the scintillation counter 'sees' a relatively small area at low altitudes, the radiation from a small exposure of a uranium deposit within this area would be proportionately greater than it would be if the aircraft were higher. Moreover, at low altitudes, the intensity of the gamma radiation is greater since it has not had as great a distance available in which to fan out and disperse. It is not necessary to worry so much about height corrections at the lower altitudes, since the ratio of rays representing an anomaly compared to background radioactivity is so much greater.

Although it is best to operate at low altitudes, there is great diversity of opinion as to the safety of low flying. It is generally conceded that heavy aircraft cannot be safely operated at altitudes below 500 feet over terrain such as that of the Canadian Shield. Some consider that light aircraft with low landing speeds can be operated in comparative safety at altitudes as low as 50 feet. Others prefer helicopters for very low flying, particularly in country where there are many lakes and few possible landing spots on the ground. Helicopter operation at present, however, is more costly than operation of small and medium-sized conventional aircraft. If, however, the cost of the follow-up ground work is included, the helicopter method may in the long run be cheaper if ground checking is done by landing the helicopter. Another advantage of the helicopter is that the significance of anomalies can be decided on the spot by hovering over the area at various altitudes and consequently it is unnecessary to keep continuous records. In other words interpretation is done during flight.

Another method of getting readings at tree-top level comparatively safely is to tow the scintillation counter in a 'bird' 400 feet or so below the aircraft. Companies operating airborne electromagnetic gear utilizing such a device find it convenient to include a scintillation counter in the installation.

It has been fairly well established that the detection of economic deposits of uranium from the air at altitudes in excess of 350 feet is possible in the Canadian Shield only in those very rare instances when the area of exposure of the deposit is unusually large.

Because commercially available scintillation counters are light in weight and reasonably inexpensive, the next few years will undoubtedly see wide use of this instrument in aircraft. Already, several occurrences are reported to have been found in Canada in this way, and improvements in instruments, techniques, and interpretation may render the method more valuable in future.

Suggestions for Additional Reading

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The Self-Potential Method

In some methods of geophysical prospecting, advantage is taken of naturally occurring fields of force, as in the magnetic and gravitational techniques. In these cases, the geophysicist relies on the magnetic attraction or the gravitational pull inherent within a mineral body itself. Some other methods require him to employ special apparatus to generate an artificial field of force, so that he can measure the reactions of mineral bodies to such a force. The seismic and electrical methods are of this type. There is an electrical method which actually falls in the first category, however, and which relies upon observing electrical fields of force, that is, electrical currents, which are generated naturally by certain types of mineral bodies. This method is known as the spontaneous polarization or self-potential technique. The term 'spontaneous polarization', means that the particular mineral body spontaneously acquires an electrical polarity, that is,

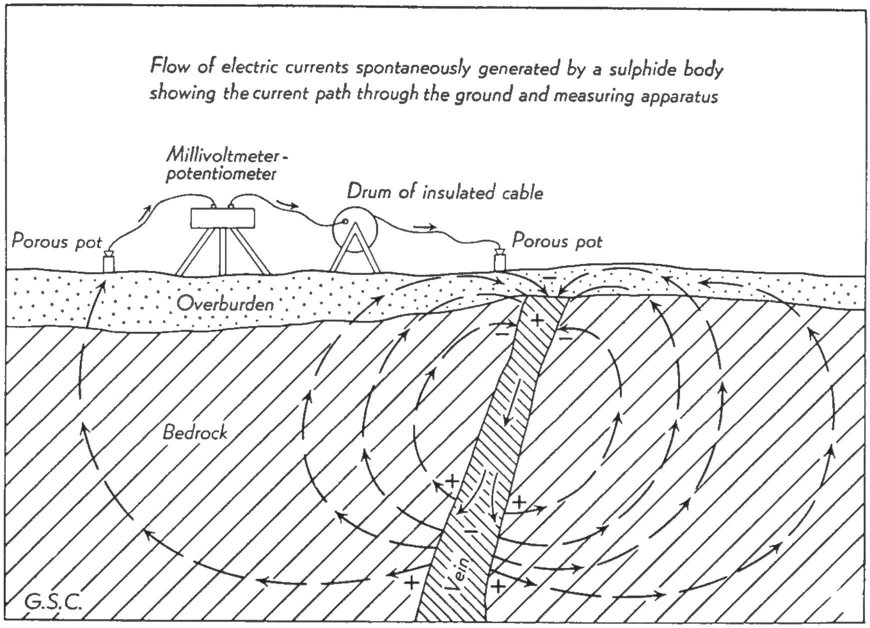

FIGURE 18. Illustration of the self-potential method.

one end becomes electrically positive and the other negative; and 'self-potential' means that the mineral body itself generates an electrical potential or force.

This description of the technique is not intended to give directions for carrying out surveys by the spontaneous polarization method, or for interpreting the results. Both require experience. Its purpose is to furnish enough background information to enable the reader to gain some idea of how and where the method can be applied, of the significance of the results, and how data are assessed for their possible importance to an exploration program. The first question to arise is naturally "What types of deposits generate these spontaneous electrical currents?" Evidently such deposits act like electric batteries, which gives the clue to what the geological requirements must be. A battery, whether an ordinary flashlight cell or a storage battery, generates electric currents because one or more metallic substances are in contact with either acid or alkaline solutions. In the ground, the common sulphides provide the metallic element like that of the battery, and such sulphide bodies are in contact with mildly acid solutions at the surface, and with mildly alkaline ones at depth. The acidity of near-surface solutions may be due to humus and to carbon dioxide absorbed from the atmosphere, and may also be augmented by the oxidation of sulphides. Rock moisture at depth is usually alkaline from reaction with rock minerals.

These solutions in contact with the metallic conductor (sulphide body) generate a current that flows down the sulphide body to depth, passes out into the wall-rocks and returns to the surface, where it completes the circuit by flowing back into the apex of the sulphide body. Almost all metallic sulphides are conductors of electricity and can serve as the metallic element in such a natural battery. The only common exception is sphalerite, and in this connection it may be noted that sphalerite does not have a metallic lustre, whereas almost all sulphides possessing metallic lustre are also conductors of electricity and can act as natural batteries. There may be cases in which even sphalerite acts weakly as a natural battery. Besides the sulphides, there are some other minerals that act in the same manner to generate natural currents. Principal among these is graphite, but anthracite coal frequently serves to generate currents, and so do the manganese oxides: pyrolusite and psilomelane. The iron oxide, magnetite, does not always possess metallic lustre, is not a good conductor, and does not normally generate appreciable spontaneous polarization currents.

Although the statement is occasionally made that these spontaneous currents are generated solely as a result of sulphide oxidation, this is quite incorrect, as is obvious from the fact that graphite, a metallic-type conductor, will also generate currents which may be even stronger than in the case of sulphides, and without any sulphides being present.

The flow of these spontaneously generated currents down the sulphide body, out into the country rock, and then back into the sulphide body at its apex, results in a point of inflow of current, or negative centre, above the apex of the deposit. The potential difference, or voltage, of this negative centre compared to that of the distant, surrounding ground, may be anything from about 0·1 volt to as much as 0·6 to 0·7 volt, and sometimes even more. It is this difference in potential that is the indicator of a buried, metallic conductor and for which the geophysicist searches by means of a systematic exploration of the ground. The apparatus employed to measure these weak potentials consists of a measuring instrument called a millivoltmeter potentiometer connected to a pair of porous (unglazed earthenware) pots, known as non-polarizing electrodes, for making electrical contact with the soil. Each pot is filled with a saturated solution of copper sulphate into which a small bar of copper projects. The copper bars are connected by wires to the terminals of the measuring instrument. One electrode is kept stationary on the ground at a base point, and measurements are taken as the other electrode, connected to the instrument by some 1,500 feet of wire, is moved out along a traverse line and placed in contact with the earth at regular intervals. The usual procedure is to take observations at intervals of 50 or 100 feet along a grid of parallel lines. The spacing between the lines of the grid is from 50 to 400 feet, depending upon the objective of the survey. Care must be taken to see that the pots are placed on fresh earth, not on decaying humus, which introduces small false potentials.

The strength of the potentials generated depends largely on the concentration of sulphides in the deposit, and not at all on the width of the deposit. The more massive the sulphides, the stronger are the potentials generated. As the percentage of sulphides within a vein structure or lens decreases, the increasing internal resistance caused by the non-conducting gangue minerals decreases the effective voltage. Interpretable reactions are usually not observed above deposits containing less than about 5 per cent sulphides. The potential generated by the deposit and that observed at the surface of the ground in a geophysical survey may not be the same. With the increasing thickness of overburden, the observer is farther and farther away from the battery which he is measuring, and the reactions at the surface may become too weak to interpret when the overburden is more than about 300 feet thick.

Another important feature is the vertical extent of the sulphide body. Pockets, short gash veins, and small lenses with limited vertical extent produce local centres of electrical activity without much breadth. On the other hand, large lenses and continuous veins extending to considerable depths produce strong, continuous bands of electrical activity which are also spread over considerable width.

Thus, the actual readings of potentials recorded at the surface, and the pattern of their distribution, furnish useful guides in evaluating the underlying, causative mineralization. This does not mean that the geophysicist can deduce the measurements of the sulphide body in feet, nor can he predict the percentage of sulphides present, much less venture any guess as to what metals are to be expected. It does mean, however, that he can obtain some indication of the type of underlying deposit and furnish a very valuable guide to a subsequent drilling program. Of all the geophysical methods applicable to the search for sulphides, the spontaneous polarization technique provides the quickest field procedure and also furnishes highly definite information as to the occurrence or absence of sulphide mineralization. The possible occurrence of graphite in the area introduces a qualification of the last statement, however, since the method also reacts to that mineral. Graphitic formations can occasionally be differentiated from sulphide bodies either because of the strength of the potentials recorded, or of their pattern of distribution. Usually such differentiation is not possible, and the results must be interpreted with the full realization that, where graphite is likely to occur, it can be responsible for the potentials observed.

With the exception of graphite there are but few and insignificant factors to lead the geophysicist astray when interpreting the spontaneous polarization results. Pronounced slopes, for example, sometimes introduce a topographic effect, usually minor, which can readily be detected and should be discounted. The method can be used to trace metallic pipelines, so naturally when operating in a district where buried pipelines are likely to be found, the operator must be on the watch for them. Water moving just beneath the surface, through sand or gravel beds, may set up weak potentials, but these are hardly to be confused with the stronger ones associated with sulphide deposits. Where sulphide deposits lie beneath lake waters, the method is not usually applicable except over the ice in the winter.

In the foregoing, the emphasis has been placed on the principal application of the spontaneous polarization technique to the direct search for sulphide bodies. For this, its speed, simplicity, and definitiveness make it very useful. In addition, the method can sometimes be used to gain an idea of the structure of concealed bedrock formations, as when the sulphides themselves, or graphitic formations, have been involved in dislocations or foldings, or have selectively followed such features. Sometimes the tracing of graphitic horizons furnishes stratigraphic or structural data which assist in locating associated formations of economic interest.

In conducting spontaneous polarization surveys, the geophysicist observes certain physical reactions that arise within a mineral deposit. He cannot see the minerals, nor can he assay them, and unfortunately the physical reactions he observes do not indicate the precise minerals or metals present. The reactions merely indicate that a certain class of minerals, the sulphides, may be present. Furthermore, there is no indication of the volume of mineral involved in the reactions. It therefore becomes necessary to correlate the geophysical indications with all available geological data, to see whether or not there is any geological basis for believing that minerals of one type rather than of another may be present, and whether the conditions are right for deposition of a large volume of mineralization.

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Gravity-Meter Surveys

Gravitational surveying today consists of measuring minute variations in the pull or attraction between a small mass and the earth. This pull is termed the force of gravity. Everyone is familiar with the action of this force. Sir Isaac Newton first stated the law governing the force of attraction in the year 1687. It may be stated thus: "Every particle of matter in the universe attracts every other particle with a force which is directly proportional to the product of the masses of the particles and inversely proportional to the square of the distance between them." This simply means that the closer two masses are to each other and the larger they are, the greater is the force between them. Each time we weigh ourselves we are actually measuring the gravitational force or attraction between ourselves and the earth. In fact, if a sensitive weighing device were employed, it would be possible to measure the attraction between ourselves and a nearby mountain.

The instruments used now for gravity surveys are capable of measuring extremely small differences in gravitational force. A good field instrument will measure to 1 part in 100,000,000; a massive sulphide orebody of 50,000 tons at a depth of 200 feet in greenstone would give rise to an anomaly of about 1/100,000,000 of the earth's total gravitational force and therefore is at the limit of detection. Lowering the height of the measuring instrument by one foot also will cause a difference of 1/100,000,000 in the measured force of gravity. As a force-measuring device, a gravity meter is therefore many times more sensitive than the finest chemical balance, and yet sufficiently rugged for field use. A single observation with it usually takes two or three minutes. One common type of gravity meter may be likened to a spring balance. With this type of instrument, a mass is suspended from a coiled spring; the amount of stretching of the spring depends upon the attraction between the earth and the mass.

Minute variations in the length of the spring are measured by optical and mechanical devices. Readings of the extension of the spring are proportional to the force of gravity at the point of observation. These readings are usually expressed in terms of 'milligals'; one milligal is approximately equivalent to one millionth of the total gravitational force at the surface of the earth. As indicated above, a good field instrument will measure to within an accuracy of about one-hundredth of a milligal.

Any subsurface structure of higher density than its surroundings will exert an extra gravitational pull that will add to the earth's normal force of gravity in its vicinity. Suppose for instance there exists below the surface of the ground a large mass of very dense material such as a massive sulphide orebody, surrounded by rock of lesser density: because of the excess mass of the orebody, the force of gravity directly over it will be slightly greater than it will be to one side. The gravity meter measures only the vertical component of this 'extra' or anomalous force.

Thus a positive gravity anomaly, that is, a region of greater gravitational force, indicates material of higher density beneath the anomaly than that surrounding it. A negative anomaly on the other hand indicates material of lower density beneath the anomaly.

In common with many other geophysical surveys, a grid or series of lines is laid out to cover the expected geological formations or ore deposits. Before

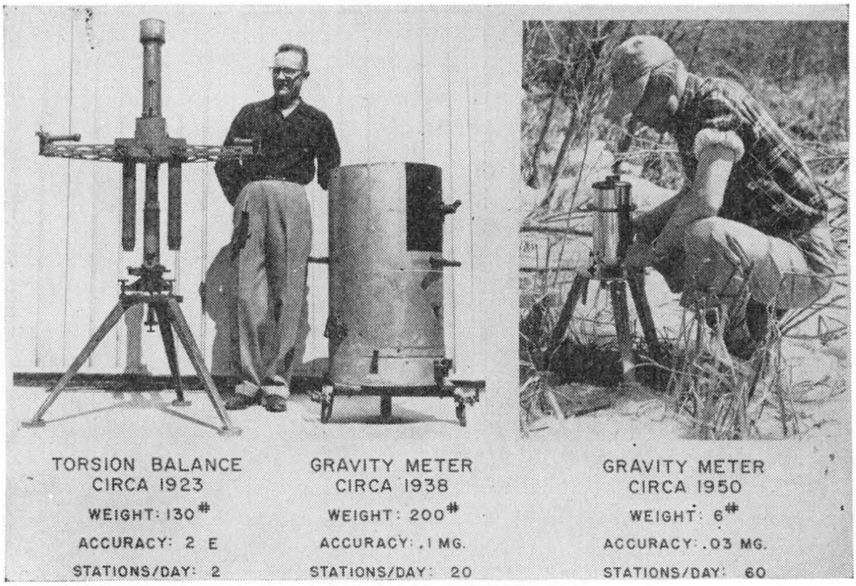

Plate LIV — *Early and recent gravity meters, showing the reduction in size and weight.*

any inferences can be drawn as to the nature of the subsurface, certain corrections have to be applied to the readings taken in the field. In the first place, the instrument is so sensitive that it is affected by the position of the sun and the moon, so that the force of gravity at any particular point changes regularly throughout the day. This difficulty and the 'drift' due to instrumental changes during the day are overcome by occupying a base station at frequent intervals throughout the day during the course of the survey so that information is obtained for applying drift and diurnal corrections.

Corrections have to be applied for differences in elevation because the farther one is from the centre of the earth, the less the force of gravity becomes, as mentioned earlier. In order to make proper corrections, each point where the instrument is read has to be surveyed accurately for elevation. Because the earth is not quite spherical in shape, and because of its speed of rotation, the force of gravity increases as one goes north and a correction is applied for this by accurately surveying horizontal positions. While the gravity meter measures only the vertical pull, it is nevertheless affected by the mass of surrounding hills and valleys and this effect must be eliminated by making what are known as 'terrain corrections'. Thus it can be seen that a gravity survey involves more than merely reading the instrument.

It is true that the magnitude of the corrections far exceeds the actual measurements, but the error in making these corrections is so much less than the quantities measured that the final result, if properly computed, is perfectly valid.

It has been suggested above that the physical quantity actually measured by a gravity survey is the density of the underlying rocks and, that, in fact, a final gravity map is a picture of subsurface densities. The preparation of the gravity map is an exact science, and the knowledge, background, and skill of the geophysicist are required to interpret these results in geological terms.

The instrument is best applied in those cases where the material being sought is of high density and occurs in reasonably large masses. For instance, a hard, high-grade hematite is a dense material. Its massiveness is one of its outstanding physical characteristics. A gravity survey can disclose the presence of a concentration of hematite, and a fairly reliable estimate of the mass can be arrived at regardless of the shape, size, or distribution of the body. Such a survey can also be used to map structure, because many rock types are distinguished by differences in density. In general the basic rocks are more dense than the acidic. However, it must be pointed out that interpretation of structure on the basis of gravity data requires close geological control.

A large mass of lesser density near the earth's surface will give rise to the same observed gravitational phenomena as a smaller mass with a greater density at a greater depth. Because of this, it is not possible to determine the exact position and shape of a mass causing an anomaly, but upper and lower limits to its depth can be determined. In this way, interpretation of gravity data is similar to interpretation of magnetic data. The depth limitation does not follow quite the same law and, generally speaking, it is possible to obtain useful gravity data from materials at greater depth than by most other methods. In fact, deep-seated heavy masses very often cause anomalies that can apparently obscure the relatively near-surface anomalies that are usually the type caused by orebodies.

In brief, gravity anomalies are caused by any mass of material the density of which is different from that of the surrounding rock. A fairly large tonnage of dense material is required before an effect is detected, therefore the instrument is best applied in the exploration for massive base-metal deposits, such as hematite, massive sulphides, and magnetite, rather than in the exploration for disseminated mineral deposits. A gravity survey often assists in structural studies.

The Resistivity Method

When an electrical voltage is applied across a specimen of a substance, a current is caused to flow through the specimen. The ratio of the voltage required to cause a certain electric current through the specimen to that current is referred to as the 'resistivity' of the substance. This 'resistivity' is so called because it is a measure of the resistance offered by the substance to the flow of current. It is measured in units of ohm-centimeters or ohm-meters.

Most rock materials, when perfectly dry, are excellent insulators. In practically all rocks, however, the individual aggregates of minerals, or grains, are separated one from another by microscopic holes called pore spaces. The ration of the volume of the solid mineral grains to the pore spaces within the entire rock mass is dependent upon the size and shape of the grains and the degree of compaction of the rock. The pore spaces contain appreciable amounts of water with salts in solution even above the permanent water-table, that is, the level below which water is always present in rock or overburden at that locality. It is because of these solutions that all rocks in their natural states conduct electricity to some extent. This type of conduction is called 'ionic'. Naturally the greater the porosity or fissuring of a rock the more water it can contain and the lower will be its resistivity. Different formations can often be distinguished one from the other by their difference in resistivity, which indicates a general difference in average porosity. However, because the physical condition of a rock mass will often vary from place to place within the mass, it cannot always be said that a specific narrow range of resistivities characterizes a particular rock type. A tenfold variation may often be encountered within one rock type.

Soils, swamps, lakes, and streams usually have much lower resistivities than the underlying consolidated rocks. In general, igneous rocks have higher resistivities than sedimentary rocks. The resistivity of sedimentary rocks frequently increases with the age of the rocks, since increasing age generally means increased compaction. Rocks of the Precambrian shields are among the most highly electrically resistive in the world, with resistivities ranging up to 100,000,000 ohm-centimeters. At the other end of the scale salty shales of much more recent age exhibit resistivities of less than 100 ohm-centimeters.

Plate LV

Conducting a resistivity survey.

There are a number of rock constituents that have the ability to conduct electricity, even in a perfectly dry state. These include graphite, a wide variety of metallic sulphides, and a few metallic oxides; they have the property of 'electronic' conduction. This is the manner in which metals themselves conduct. As a class, these minerals are much better conductors than barren rock and hence can be readily differentiated from the rocks by their greatly decreased resistivity.

General Field Procedure

Electric current may be caused to pass into the earth by connecting a direct-current or low-frequency alternating-current generator to two contact points, such as metal stakes driven into the ground. If the material between the two current stakes is homogeneous, the current will flow through it in a manner that is predictable by theory. As a result of this passage of current there will be voltage differences set up in the region about and between these current stakes.

These voltages are predictable, once again by theory, since they are dependent on the distance between the stakes, the total current, and the resistivity of the material. From measurements of these voltage differences on the surface of the earth it is then possible to derive the resistivity of the earth in the vicinity of the stakes, knowing the other factors involved. Because, in nature, no rocks are perfectly homogeneous, the value of electrical resistivity that may be derived by such measurements will depend on the region in which the measurements are made. In view of this circumstance, it is possible to carry out the same calculations as in the case of a truly uniform medium, but we then call the resultant value the 'apparent resistivity' of the medium in the region of measurement. The apparent resistivities will be decreased in the vicinity of areas of increased porosity, shearing, and brecciation, and also in the presence of concentrations of the electronic conductors referred to above.

The system usually employed in Canada is to use two current-stakes about 7,000-15,000 feet apart, the line joining these stakes being perpendicular to the regional strike of the formations. Voltage measurements are made in the central region along survey lines also running perpendicular to the formational strike, the current stakes remaining fixed throughout the survey. In another form of survey, widely employed elsewhere, both the current stakes and the voltage measuring points are moved, with fixed relative spacing, throughout the area to be surveyed. The latter system has the advantage that its 'depth of penetration' can be controlled by varying the relative spacing of the ground points. That is, it can be made selectively sensitive to effects arising at a certain depth. It is not widely used in Canada, however, because it is usually adversely affected by the relatively conductive soil mantle that is present over most of the Shield area.

Resistivity methods are used in mineral prospecting primarily for base-metal sulphides, although they have been used in the search for high-resistivity materials as well, such as certain hematite occurrences and quartz veins. These methods are finding increasing use in engineering problems, such as determining the depth of drift at dam sites and elsewhere, and also in the search for water-bearing formations.

Interpretation

The greatest limitation to a satisfactory interpretation of the results of a resistivity survey is that the variations from the normal or background values, i.e. the so-called 'anomalies', are such that these anomalies could be caused not only by the materials sought, such as metallic sulphides, but also by non-economic bodies. A narrow, highly conducting zone, such as a vein of massive sulphides, may give rise to the same type of anomaly as a broad zone of lower conductivity, such as might be expected from a shear zone. This is an instance of the 'saturation' effect to which resistivity measurements are susceptible. This no longer applies when the width of a zone is much greater than its depth below surface, for then a measure of the true resistivity of the zone can be obtained from the surface measurements, and hence the concentrated sulphides and a shear or fracture zone containing no sulphides can be differentiated. Even under these favourable circumstances it is not always possible to distinguish between concentrated sulphides and graphite, or between disseminated sulphides and a shear or fracture zone.

Valleys in the bedrock surface covered by 50 to 100 feet of overburden can also give rise to resistivity anomalies that may be of the same magnitude as those to be expected from small sulphide bodies in the bedrock.

All too often the above limitations are ignored in practice and interpretation, with subsequent disappointment when all the resistivity anomalies in an area are drilled and do not yield sulphide mineralization. It is only when these factors are understood both by those who carry out the surveys and those for whom the surveys are performed that the resistivity methods find their proper appreciation as simple, inexpensive, and relatively rapid means for base-metal exploration.

Electromagnetic Method

The electromagnetic method of geophysical prospecting, as its name implies, is based on the use of two fundamental physical phenomena, electricity and magnetism. An elementary principle of physics is that if a current of electricity is passed through a wire, a magnetic field of force is created in the vicinity of that wire. The two phenomena, electricity and magnetism, are inter-related. Early geophysicists took advantage of this fact to devise an apparatus for use in the search for massive sulphide mineralization.

In the earliest systems, a current of electricity was passed through the ground between two metal stakes spaced a suitable distance apart. By measuring the magnetic field at the surface of the earth it was possible to determine whether or not an excellent conductor of electricity existed beneath the ground surface. It was hoped that this excellent conductor of electricity might be the sulphide mineralization that was sought. Some success was achieved with the early systems, and, with recent improvements, the electromagnetic method has found wide application in areas favourable for the occurrence of base metals.

As the method developed, it was found that it was not necessary to pass current through the ground by means of metal stakes to cause current to flow within subsurface conductors, but that an alternating current flowing in a loop of wire suspended above the surface of the earth will cause currents to flow in buried conductive deposits. The process by which this takes place is termed 'induction'. The steps in this process are as follows:

(1) The alternating current flowing in the loop creates an alternating magnetic field (primary magnetic field) in the vicinity of the loop.

(2) The primary magnetic field will cause currents to flow in any subsurface conductor.

Induced currents flowing in a subsurface conductor will create a magnetic field (secondary magnetic field) that can be measured at the surface of the earth. This secondary field is absent unless an excellent conductor of electricity exists beneath the surface.

The indicating device used to measure the magnetic fields in the electromagnetic method consists of a 'search coil' connected to either a sensitive voltmeter or a pair of earphones. The intensity of the magnetic field cutting the 'search coil' is indicated by the reading on the voltmeter or the loudness of the signal in the earphones.

In a popular technique employed in Canada, a coil of wire of several turns is suspended in a vertical plane from a guyed mast. A strong alternating current is passed through this coil, which, in the vicinity of the coil, creates an alternating magnetic field, called the primary field. If a highly conductive mass, such as a massive sulphide body, is near the coil, currents are induced in this mass. Induced currents flowing in the conducting body will in turn create another alternating magnetic field known as the secondary field. If strong enough, the secondary magnetic field distorts the primary magnetic field. This distortion can be measured in terms of 'dip-angles'. An understanding of these measurements may be obtained from the following paragraphs.

Plate LVI

Apparatus used in electromagnetic surveys.

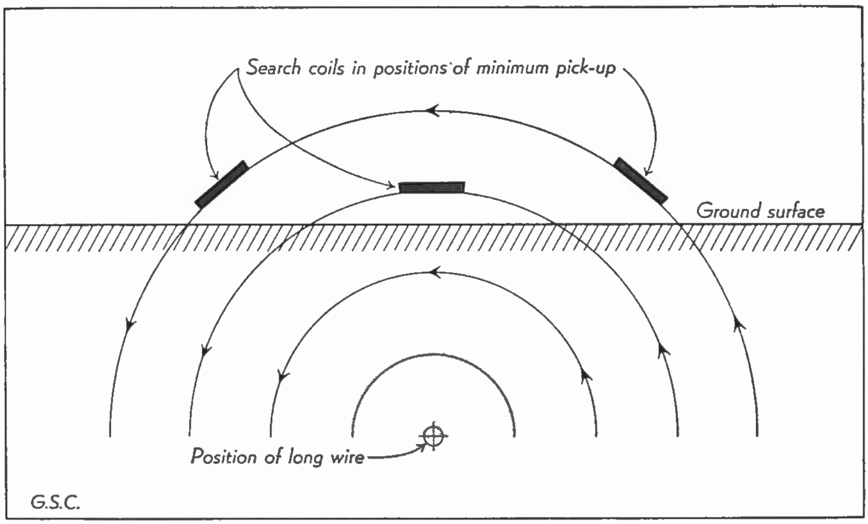

FIGURE 19. Theoretical illustration of the electromagnetic method.

The magnetic field caused by a current flowing in a long wire spreads out from the wire concentrically, as shown in section in Figure 19. At any point in the field, a search coil will have a voltage induced in it that is dependent upon the frequency of the alternating current in the transmitting coil, the number of turns of wire in the search coil, its area, and the angle it makes with the lines of force. In the accompanying diagram the search coil is shown in positions in which the voltage induced in it is a minimum. If the long wire is replaced by a large sulphide body, the same considerations apply. However, in actual practice, conditions are more complicated than this because the secondary field due to the conductor is superimposed on the primary field of the vertical coil (*see* Figure 19).

A hypothetical traverse taken along the ground above and at right angles to such a conductor is shown in Figure 19. The directions of the primary and secondary fields are indicated by arrows whose lengths are proportional to their respective field strengths. The direction and intensity of the resultant or 'distorted' field are found by employing the so-called 'parallelogram of forces' as shown. These resultant arrows are parallel to the plane of the search coil when it is rotated into a position where it is not cut by any of the lines of force of the resulting field. In these positions, no voltage is induced in the search coil and hence, if a pair of earphones is connected across the search coil, no signal is heard in the earphones. When the search coil is tilted in either direction away from the position of minimum voltage, a signal is heard in the earphones.

The angle between the resultant arrow and the horizontal at any point is termed the dip-angle, and its determination is the fundamental measurement in the search of conductors. A typical dip-angle curve is given in Figure 20 in which dip-angles are plotted along a traverse across a massive sulphide orebody.

Over barren ground, the dip-angles are almost zero. The approach to a conductor is marked by increasing dip-angles which in turn decrease to zero directly above the conductor, and then increase, but in the opposite sense, beyond the conductor. Finally, far from the conductor, they reduce to zero again.

Field Procedure

To overcome complications caused by dip-angles arising from elevations and topographical effects, the plane of the transmitting coil is oriented for each observation so as to pass through the point of observation. If the relative locations of the transmitter coil and the search coil are known to within a few feet, the transmitter coil can be oriented so as to make errors negligible, even in the most rugged terrain. Hence, the dip-angle profiles are directly interpretable and require no topographic or other correction. When the coils are properly oriented the occurrence of a dip-angle indicates a conductor.

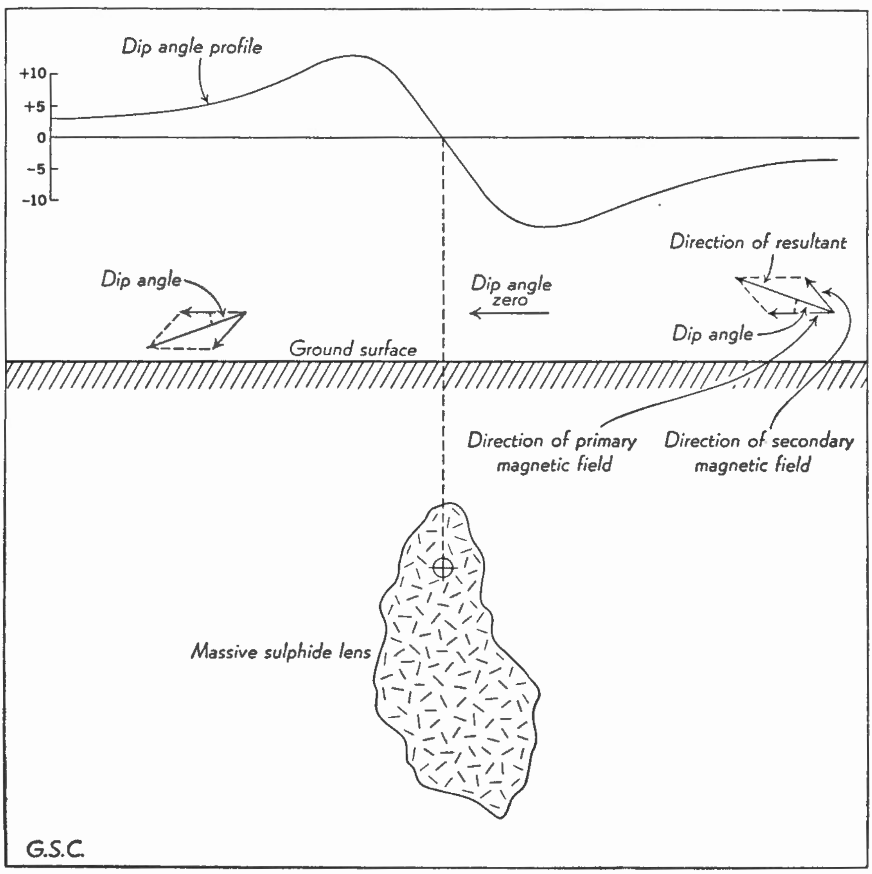

FIGURE 20. An idealized traverse across a massive sulphide lens.

In operation, the transmitting coil is erected at a convenient location and traverses are made at right angles to the assumed formational or structural strike on each side of the location of the transmitter. The traverses are usually made along lines 400 feet apart, during a reconnaissance survey, and closer together when detailed surveying is required. The distance traversed along any one line from the corresponding transmitting-coil location is seldom greater than 2,000 feet. Thus it is necessary to employ several transmitting-coil locations in order to complete the survey of a mining property.

Advantages and Limitations

The electromagnetic method described above is used chiefly in the exploration for such excellent electrical conductors as massive metallic sulphide deposits or for massive magnetite. It can, however, be used advantageously in the search for moderately-conductive materials if the frequency of the alternating current employed in the transmitting coil is chosen appropriately. As a general rule, the lower the electrical conductivity of the deposit sought, the higher must be the operating frequency of the electromagnetic unit. There is however, a specific upper limit to the useful frequencies, above which overburden and poorly-conducting shear zones, faults, etc. give rise to obscuring anomalies. Most electromagnetic surveying is performed at a frequency of 1,000 cycles per second. The most suitable frequency for the survey of any one area should be determined before large-scale application of the method is made.

Very little, if any, response is caused by swamps and other topographic features when the survey is performed at a frequency of 1,000 cycles per second. In fact, the ability to operate satisfactorily under almost any topographic conditions is one of the major advantages of the electromagnetic method over other electrical methods.

Graphitic shear zones and sedimentary horizons are frequently the cause of electromagnetic anomalies (as is the case with other electrical methods). The method using 1,000 cycles per second does not indicate contacts between two rock types unless one or other is an excellent conductor or unless an excellent conductor lies along the contact. Thus this method does not indicate structure in the manner of a resistivity method, unless such excellent conductors as sulphides, magnetite, or graphite follow structural trends. The method using 1,000 cycles per second occasionally detects faults.

The interpretation of data from electromagnetic surveys is usually based on accumulated experience and on comparison with results of scale-model experiments. The scale-model experiments are performed in the laboratory under controlled conditions and permit the geophysicist to determine the general nature of the anomalies to be expected from many typical bodies. It is often possible to estimate the size, shape, and depth of a conductor from the results of an electromagnetic survey by comparison with scale-model data. These factors then have to be assessed in light of the available geological data.

The electromagnetic method is ideally suited for the detection of massive sulphide and magnetic deposits. It can be applied satisfactorily under almost any topographic conditions. The correct operating frequency for the electromagnetic method should be determined before extensive application of the method is made in any one area. The possibility of success of the method and the determination of correct frequency often can be estimated by a study of both the general geological conditions and the types of rock and ore in the district. As will be seen from the above discussion, the application and interpretation of the method require experience.

Reference

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CHAPTER XI

EXPLORING AND APPRAISING MINERAL DEPOSITS

The full appraisal of mineral deposits and mining properties is a technical matter that may involve the expenditure of much time and money. Even if this is done, uncertainties may still remain, because many deposits have variable shapes and erratically distributed minerals. There is probably no other industry that uses more advanced engineering and scientific methods for the solution of its problems, yet many prospects and mines present problems that cannot be solved precisely until after a deposit has been completely mined out.

Except in the earliest stages, the judging of deposits is or should be the work of mining engineers with operating and geological experience or of geologists with an engineering background, and it is not the purpose of this publication to discuss these matters to that extent. Prospectors should, however, have a sound knowledge of the fundamentals, to assist them in deciding whether a discovery is worth preliminary work and what form such work should take. This knowledge also helps them to decide whether a deposit is likely to be of interest to those who buy or finance mining properties, and also whether an offer is reasonable. Knowledge of this kind is also important for those who back prospectors or participate in the financing of mining enterprises. The following is, accordingly, a discussion of the fundamentals, expressed as far as possible in non-technical terms. The general principles of the business aspects of mining are outlined first. This section is followed by one on sampling, and one on the kinds of preliminary work that a prospector might be expected to do to test a discovery and, if it seems favourable, to prepare it for its first examination. Some information on more advanced kinds of sampling and exploration is also included, because, although prospectors do not usually need to perform such work, it is useful for them to have a general knowledge of what is involved.

Appraising a Discovery

Like all industries, mining is based on economic principles, some of which are applicable to business in general, whereas others are peculiar to mining. The basic principles are, first, that mining is the business of producing and marketing minerals, ores, and metals and, second, that this business is governed by the law of supply and demand. Strictly speaking, supply is the amount that will be offered at a particular price, and demand is the amount that will be bought at a particular price. In a more general sense, supply and demand may result in overstocking or shortage of a particular product, so that prices may fluctuate considerably and at times it may be almost impossible to interest a company or financier in a discovery of a particular metal or mineral, even if the size and other factors are promising.

A condition peculiar to mining (including the oil and gas industry) is that it is based on a single 'crop'. When an orebody has been mined it is exhausted forever, therefore financing must be done with this in mind. Capital invested in acquiring, exploring, and equipping a mine can be recovered only from the profits of the operation or from sale of the property or plant.

Another peculiarity of mining is the large number of insignificant mineral occurrences as compared to the number that will repay the cost of mining. Nature made mineral deposits in all shapes and sizes, but, as a rule, only the larger or richer are valuable. The smallest can usually be dismissed at a glance, but larger ones, which are called *prospects* because they show some prospect of being of commercial size and mineral content, almost invariably require expenditure of time and money to determine if they have merit. To decide this is a complicated matter, because deposits are seldom well exposed at the surface, and even when they are their subsurface characteristics are still unknown. Mineral discoveries are therefore subjected to a process of elimination whereby prospectors choose those that they hope can be classed as prospects, and do a little work on them; then scouts, engineers, or geologists representing capital examine a large number of such discoveries, select the better prospects for further preliminary exploration, and gradually eliminate the poorer ones and continue to test the more promising ones. By the time a mine reaches production it is not uncommon for one or several million dollars to have been spent in exploring and equipping it, to say nothing of the money that has been spent in exploring other properties that did not yield favourable results. A would-be prospector should not feel discouraged at this state of affairs, for the mining industry flourishes in the face of these disadvantages; a reasonable sum can often be obtained for a good prospect, even though it does not later live up to expectations on exploration, while the return from a successful property may be very substantial. Allowance must, however, be made for the fact that many discoveries will probably be unimportant. The following sections outline the principal factors that must be considered in estimating the possibilities of a discovery. In most cases, either the size or the content will prove unfavourable, and the remaining factors need not then be considered.

Size of Deposits

Of all the factors that determine the worth of a prospect, the size and average grade are usually the most important. Productive mines range from 'pocket' deposits, from which a few tons of high-grade ore are mined, to enormous operations involving many thousands of tons of ore daily for many years. Pocket mines are usually worked by one man or a few men only, and must be conveniently located to transportation unless the product can be easily moved, as in the case of gems or free-milling gold. At the other extreme, deposits that will support the largest operations are exceedingly rare. Almost all producing mines are between these extremes of size, and are operated at rates of 100 to 5,000 tons a day; most are below 2,000 tons a day. Ores mined at these rates are usually too lean to make shipping in the raw state profitable, so it is almost always necessary to build at the mine a plant for concentrating the ore to a partly or completely processed product. The simpler plants, of 100 ton-a-day size, at present, cost about $150,000, and large complex ones may cost $1 million or more. The most conservative practice is to postpone building a plant until a sufficient amount of ore to repay the cost of the plant from estimated earnings has been proved. It is, however, generally considered to be sound practice to build a plant when sufficient ore for three years' operation has been proved, provided that the geology is sufficiently favourable to make it likely that a great deal more ore will be developed as mining progresses. In other words, if the deposit is known, or is considered likely, to pinch out at the sides and at depth, a plant would only be justified if the deposit was proved to contain enough ore to repay the cost of the plant; but if the deposit appears to continue beyond the part that has been proved to contain three years' ore, and if the geological conditions seem favourable for substantial extension, it may be reasonable to take a chance even if the three-year block of ore would not pay for the plant.

Ores that consist chiefly of quartz or other fairly light minerals average about 12 cubic feet to a ton, ores in which metalliferous minerals are fairly abundant average about 10 cubic feet to a ton, and massive metalliferous ores average still less. Three years' ore for a 100-ton plant represents about 110,000 tons, or about 1,300,000 cubic feet. If this orebody were a vein 3 feet wide, traced for a length of 1,000 feet, it would have to be proved to extend consistently to a depth of about 430 feet to comprise three years' ore averaging 12 cubic feet per ton. However, all mines do not operate on a single deposit; several smaller deposits may be mined if they are spaced within a few hundred feet of one another, but in such cases the costs of exploration and mining will be higher per ton than if the ore were in a single body.

A discovery that does not appear to have possibilities of being proved to contain at least 100,000 tons will be unlikely to merit attention unless it is very rich or possesses other unusual characteristics. This means, for example, that if the showing is 3 feet wide or more, and seems to contain a reasonable amount of valuable mineral, and its lateral extent is obscured by overburden, it is worth stripping or trenching to test whether it extends for several hundred feet, and, if so, it may later be worth exploring at depth to learn if it extends deep enough to make up the required tonnage. Some deposits pinch out or are offset by faulting a short distance below the surface, and some others persist to great depths; in general there is reason to hope that they will extend at least half as far in depth as they do laterally.

In the above-mentioned examples, widths of 3 feet were mentioned. This was done because 3 feet is about the narrowest practical underground opening, therefore most deposits have to be at least 3 feet wide to permit profitable mining. If they are narrower, some waste rock would have to be mined as well, therefore the deposit would have to be richer. A few deposits, such as high-grade gold, native silver, and pitchblende veins may be mined even if only a few inches wide, by removing 2 or 3 feet of waste rock alongside, but deposits rich enough to warrant this are exceptional.

Before a small 'showing' is abandoned, consideration should be given to the possibility that it might improve greatly with depth or laterally, or that it might be an independent outlier to an important deposit. This is always the prospector's dream, and it proves correct in some instances, but many other deposits become much smaller or die out altogether a short distance along or below the surface. Most deposits remain about the same; if they are short and narrow at the surface they will probably be short and narrow in the third dimension; if a series or cluster of small lenses is found at the surface, their downward continuations will probably be small and lenticular as well. There have, however, been notable examples in which small, relatively insignificant surface showings proved to be the upper manifestations of important deposits. In some cases the surface showing was part of a large body, barely unroofed by erosion. In other cases a cluster of deposits lay like a hill of potatoes, distinct from one another, and the surface showing was merely a small member of the cluster. Such remarkable discoveries are comparatively rare, however, and it would be absurd to do expensive exploration along or under every little mineral occurrence in the hope of obtaining marked improvement. It is a justifiable gamble only when the general geological conditions in the vicinity of a small showing are particularly favourable: for instance, if the showing is in or near a strong fault or shear zone, or in a large zone of alteration of a kind that is associated with important deposits elsewhere, or in a particular rock such as a bed of limestone in which important deposits are known to occur in another part of the district.

Mineral Content

Those who have never seen a mineral deposit usually think of one as composed of solid, pure metal or of a solid mass of some mineral such as galena. Nothing could be farther from the truth, for even the richest deposits almost invariably consist of a mixture of minerals. In most deposits the valuable mineral or minerals constitute but a fraction of the whole, and are usually distributed unevenly, in small grains. In many deposits these grains are microscopic in size, and fairly large masses of what appear to be a pure mineral are seen, when examined under a microscope, to contain minute portions of other minerals.

The valuable content of a deposit is called its *tenor* or *grade*. The former term is preferable because 'grade' also refers to slopes, but 'grade' is more generally used. The content of gold, or other precious metals is expressed in 'ounces per ton' of ore, whereas the amount of base metals is expressed as a percentage.

Some industrial minerals are expressed as percentages, and for other kinds of deposits special terms are used. Because deposits are variable, the grade can only be estimated properly by averaging the results of many samples that have been taken in one of the ways mentioned later, and that have been carefully analysed or otherwise tested.

Most deposits are far from uniform. Some consist of low-grade and high-grade parts that, in the aggregate, have sufficient value to permit mining the entire deposit. Others contain parts, called *ore shoots*, that pay to mine, whereas the intervening parts are too sparsely mineralized to be minable. For deposits of this kind, an average value that permits profitable mining is determined, and because there usually are parts whose content is greater than this, other parts that are leaner than the average can be mined for blending with the higher-grade material. The tenor of the lowest-grade material that can be mined economically in that particular deposit is called the *cut-off point*. Ore whose grade is just at the cut-off point or slightly better is called *marginal ore*, and material that is slightly below the cut-off point is called *sub-marginal material*. An improvement in price or operating costs will sometimes cause sub-marginal material to become ore. One of the first matters that a beginner must learn is not to get excited over minute quantities of metals or other elements reported in assays or analyses. Most rocks and minerals contain many elements in small quantities, usually too slight to be significant.

Estimating the grade of a deposit fully is a highly technical matter. It is generally done with more and more precision as exploration advances. The estimates made by a prospector on a discovery, and on a raw prospect by an engineer or geologist, must be adequate, but they do not need to be as precise as those on a prospect that has responded to exploration and is being evaluated as a possible producer. A prospector needs to know enough about the subject to permit him to decide whether a discovery is worth further consideration. He can form an idea of this from the ore grades of producing mines. As a rule, the larger deposits permit the mining of lower-grade ores, because costs decrease as the volume of business is increased, and a large uniform deposit of moderate or even fairly low grade is usually preferable to a small rich one, particularly if the latter contains erratically distributed minerals. Today some large Canadian mines treat ores averaging $5 to $10 a ton in value, but most of these were established when prices of supplies, equipment, and labour were lower, and all or part of their capital expenditure has been written off. Under conditions prevailing in 1955, deposits averaging as little as $10 a ton would probably be brought into production in exceptional circumstances only.

It is impossible to give simple rules regarding the grades that can be worked at different scales of operation, but the following examples chosen at random from mines producing in 1954 will give an idea of the grades and costs for operations of different sizes. It must be emphasized, however, that the details of each prospect have to be worked out separately, because no two deposits are entirely alike or have entirely similar problems of transportation and ore treatment.

The following examples are gold mines, chosen because their grades are quoted in dollars:

Mine	Average Daily Rate Tons	Value per Ton $
Kerr Addison	4,546	7.32
Dome	1,975	8.41
San Antonio	495	8.37
Leitch	108	29.21

The following base metal mines are cited as examples, but in these cases the grade is not quoted in dollars because of fluctuations in metal prices:

Mine	Product	Average Daily Rate Tons	Approximate Content per Ton
Copper Mountain	Copper (minor silver & gold)	5,128	0·80%
East Sullivan	Copper	2,500	1·3%
	Zinc		1·21%
	Gold		0·015 oz.
	Silver		0·44 oz.

Other Geological Characteristics of the Deposit

Besides size and grade, and besides the non-geological considerations mentioned later, other features of a deposit may influence its possibilities. These are chiefly related to the geological type of the deposit and to its structural features.

Some types of deposits have a good reputation for size and persistence, and others have not. For example, stratified deposits such as coal seams, sedimentary iron ores, and bedded rocks used as industrial minerals are likely to have a fairly even grade and to be persistent. Replacement deposits have a good reputation because, although many are small, many others are large. Also, they may occur in clusters, so that if one is found, others may lie nearby. Veins are of many sizes; small ones are not likely to have a great extent, but large ones have a good chance of extending both laterally and downward. Pegmatitic deposits are generally fairly small, and any valuable minerals they contain are likely to be distributed erratically. Although there are exceptional pegmatitic deposits, most are worked on a small scale, if at all. If other deposits of the same type as the one being considered have been explored or mined in the same region, the conditions encountered there should be ascertained and considered.

It may be vitally important to consider whether a surface showing represents primary or secondary mineralization. Secondary minerals do not, as a rule, extend far below the surface in Canada. These minerals may be concentrated at or near the outcrop of a primary deposit, as a result of long-continued solution and deposition by surface waters, with the result that the near-surface part of the deposit is much richer than the main, primary, part. On the other hand, the upper parts of a few deposits have proved to be misleadingly lean, because primary minerals were dissolved and carried away by surface waters.

Structural features often influence the economics of a deposit by determining its dip, by causing weakness of the deposit itself or of its walls, or by causing it to be displaced by faults. The lowest mining costs are obtained in large deposits that have considerable lateral extent, thus permitting them to be mined by open-pit methods employing power-shovels, draglines, or bulldozers. The ore is removed from the pit by large trucks, by aerial tramways, or, in the largest operations, by standard-gauge railways that spiral around the sides of the pit. Examples of deposits worked by open-pit methods are flat-lying coal seams and other sedimentary deposits, and the upper parts of large replacement and contact metasomatic deposits. Fairly cheap underground mining can be done on deposits that are large in all three dimensions. Bodies such as veins, that are relatively narrow compared to their other two dimensions can be mined fairly cheaply if they dip steeply (say, 50 degrees or more), because mined ore then moves by gravity in the stopes and ore passes, until it is collected at a convenient point for haulage or hoisting. On the other hand, it is usually more costly to mine a fairly flat-lying vein because the broken ore has to be handled by some mechanical method such as scraping. Structural features that affect the strength of ore or wall-rock may add greatly to the cost of mining because much timbering and back-filling may be required to support ore or rock weakened by fracturing or faulting. In the same way, timbering may be required if the rock immediately above an orebody is inherently weak, apart from structural conditions. If a deposit is displaced by faults, costs of exploration and mining will probably be greater.

Location and Transportation

As is to be expected, location has an important bearing on whether or not a prospect can be explored readily and whether a mine can be operated economically. Apart from the question of transportation, if a deposit is in a settled area it is easier to obtain labour, and any amenities available make it easier to hold labour and lessen the need for housing, recreation, and other facilities to be provided by the company.

Topography plays an important part in determining the cost of exploration and mining, because adits (tunnels) cost much less than shafts. If a deposit occurs in a mountainous or very hilly setting, the entire deposit or its upper part is usually explored and mined from an adit. This is customary in the Cordilleran, but shafts predominate in other parts of Canada because the relief is usually too slight to make adits practical.

Transportation facilities and availability of developed or potential electric power are most important considerations, both in the exploration stage and in the event of production. Any but the most preliminary exploration requires considerable supplies and equipment, and before substantial production can be begun large amounts of heavy machinery, building materials, and other supplies are needed. In addition to these, an average of about thirty-five pounds of supplies is required for each ton of ore produced. Finally, there is the problem of getting the product to market. In the parts of Canada served by railways, highways, or established water routes, transportation is fairly easy, although freight charges may add appreciably to the costs of exploration and mining. Beyond established routes, where exploration must be serviced by air or by tractor trains, costs rise greatly; to be attractive, therefore, a prospect has to be better than it would be if it were in a more favourable location. A few, chiefly gold mines, have become productive in remote places without the provision of highway or rail transportation, because they were sufficiently profitable to warrant transport of heavy equipment by sleighs and tractors during the winter, and the shipment of the output by air. In almost all instances, however, it has been necessary to provide road or rail links before production could begin. This has meant that deposits even a few miles from major transportation facilities had to be considerably better than if the facilities had been available already, and that deposits in very remote places have had to be good enough to warrant extension of facilities; if such facilities could not be provided, the deposits have been left unworked.

Treatment

In special circumstances ores may be shipped to market in the state in which they are mined, or after sorting by hand. In by far the majority of instances, however, treatment plants are required. This applies even to most coal mines, which are equipped with screening and washing plants, and to many iron mines, where preliminary treatment is carried out before the ore is shipped. Most mines have elaborate plants for crushing, grinding, and concentrating the ore, and some are equipped with special chemical or smelting plants which carry the processing through all stages except final refining. In some instances a plant already operating in a district will accept suitable ore from neighbouring mines. In view of the great differences in ores, however, it is usually necessary to provide individual plants, after careful research has been done on bulk samples. The kind of treatment necessary, the percentage of recovery that can be expected, and the ease or difficulty of treatment all affect the cost of operation and influence the decision as to whether mining is practical. If other factors are favourable, a satisfactory method of treatment can usually be worked out, but if a deposit is in a remote place, or seems just large and rich enough to be minable if there were no complications, or if its ore is costly to treat, or permits only poor recovery, it is likely to be regarded unfavourably. One should not be too pessimistic about treatment, however, because advances in methods may become available. For example, a large Canadian mining organization instructs its field staff never to turn down a property on the ground of treatment alone. If other factors are satisfactory, but treatment presents a problem, it will try to develop an improved method of treatment.

Present and Future Demand

The state of the market for a particular metal or mineral is an important consideration. Gold has a fairly assured market, and its price is relatively stable. Many of the base metals, such as iron, copper, lead, and zinc are normally in such demand that good deposits are almost certain to be valuable, although their prices fluctuate considerably. Demand and prices for other mineral products for which there is a more limited market need to be considered very carefully. In other instances, there may be no present market, but there may be hope that a market will be available in future, or that a market could be developed if a large deposit were shown to be available.

The ways of obtaining information on markets and prices from the press and from government publications, have already been explained. It should be emphasized that for many metals the prices usually quoted are trade prices for products of smelters and refineries. When ores or concentrates are shipped to a treatment plant the prices paid for the contained metal are considerably lower. In the first place, nothing is paid for metals that cannot be profitably extracted, and a penalty may even be charged for the presence of objectionable components that make the extaction of others more difficult. Plants deduct a certain amount as a treatment charge, and privately owned ones must try to make a profit. Finally, the prices for many metals are based on the New York or London markets, so a Canadian plant may have to allow for the cost of freight, duty, insurance, selling, and perhaps refining. Such matters must be considered carefully by engineers in appraising a deposit. A prospector does not have to consider all the details, but when judging a new discovery he should make allowances for the probable demand, and for the possibility of considerable spread between the value of ore and the published quotations for metals and minerals.

Prospectors sometimes form misleading opinions of the value of discoveries by assuming that all the constituents shown in an assay or analysis can be recovered profitably. For some ores it is possible to count on obtaining payment for, say, gold and copper, or lead and zinc, but only in exceptional cases is it possible to recover metals or minerals occurring in subsidiary amounts. The possibility should be investigated eventually, but it is seldom important at the outset, when the decision to do preliminary work should be based on one or two principal constituents.

Exploration of Deposits

A discovery that shows signs of being of possible importance must be 'explored' before its worth can be judged. Apart from the fact that nothing can usually be learned about the conditions at depth without some form of subsurface exploration, few deposits are sufficiently exposed to allow appraisal of their width, length, and possible mineral content without the removal of overburden and products of weathering from parts of the deposit. Work done to reveal the extent and content of a deposit is properly called 'exploration'. The term 'development' is sometimes used instead, but it is more properly used in connection with the preparing of a mine for production, after an orebody has been proved.

The earliest exploration is usually done by the prospector himself on any occurrences that he thinks warrant it. This is done so that he can judge their importance, and to facilitate examination by an engineer or geologist. Further work is usually financed by companies on recommended prospects. This is part of a process of elimination, whereby prospects that respond to exploration are examined, and further work is recommended or not as the case may be. After each favourable report, more advanced exploration is done, until finally a few mines are brought to production, out of a large number of prospects on which money was spent but which did not respond. This process usually requires several years; few mines reach production until at least three years after the initial discovery. The aim is not to risk too much in the early stages, but to re-appraise the situation periodically, and to risk more and more money on those prospects that seem to warrant it.

Exploration by the Prospector

After a discovery that may have promise has been found, the first step is usually to try to get a general idea of its width and length. Before any work with tools is done, other than picking into the outcrop to try to obtain fresh specimens, it is usually advisable to make a reconnaissance, because the width and length may be determined well enough from other exposures to avoid the need for removing overburden, because the reconnaissance may indicate where work can be done to best advantage, and because a better deposit may be found nearby.

The true width or thickness of a deposit for any particular place in it is the distance at right angles to both the strike and the dip (*see* Figure 3). If the deposit dips vertically, the width measured horizontally and at right angles to the strike will be the true width. If the deposit dips at an angle, the width measured horizontally will be greater than the true width. This is an important consideration because the surface showing of a deposit often gives an exaggerated impression of the width, particularly if the dip is fairly flat. Also, few deposits maintain regular width. Most of them widen and narrow, and it is then necessary to determine their average width.

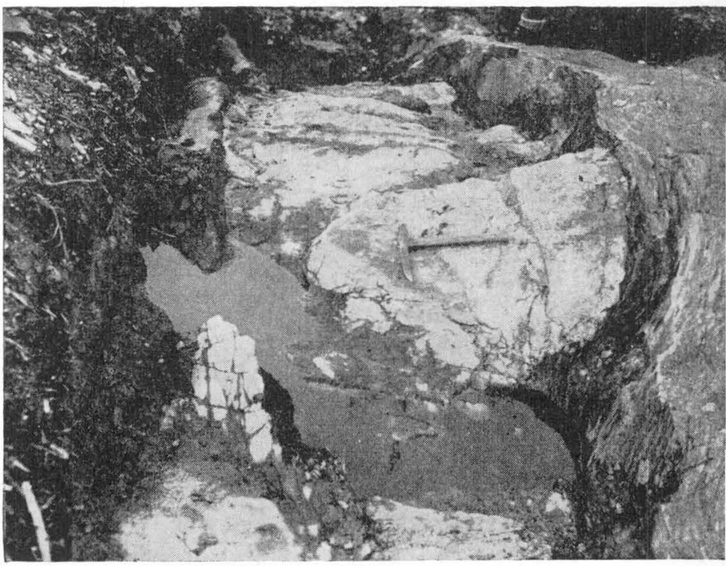
The length of a deposit is the distance it extends along its strike. When attempting to trace the length it is important to understand the way in which the outcrops of a dipping deposit are distributed with respect to a sloping or irregular land surface. If a deposit dips vertically, its outcrops will occur in a straight line regardless of how irregular the surface is. If the dip of a deposit is inclined at an angle, and the land surface is flat, the outcrops will lie in a straight line; but if the land surface is sloping, the outcrops will trend down the slope in the direction of the dip of the deposit. This is difficult for a beginner to visualize, but after a little practice he learns to think in three dimensions and to take into consideration the slope of the land surface. It is useful to experiment with a model made of sand or mud or plasticine—a sloping surface or a series of hills and valleys can be shaped on the model. Then, if a piece of flat cardboard is taken to represent a vein or bed of rock, it can be thrust into the model at different angles. The line of juncture of the cardboard and the surface of the model will then illustrate the manner in which the outcrops of a vein or bed are distributed with respect to the surface.

When attempting to trace the length, if the dip or surface is such that the outcrops should follow a simple line, it is easy to take a bearing and follow it in the hope of finding other outcrops. If not, allowance is made for the 'swing' of the outcrops and a search is made in appropriate places. In open country, a row of pickets or piles of stones can be set in line by sighting along two already in place. In wooded country it is useful to blaze a line, and clear it if necessary, as this will not only assist in directing the search for other exposures, but will be useful later when making a rough survey of the showings. All that has been said above regarding the trend of a deposit assumes that the deposit has a regular strike. Many deposits, however, are inherently curving or irregular in strike, apart from any swinging of outcrops due to dip and land surface.

If the width and lateral extent of the deposit are not sufficiently exposed in the natural state, a limited amount of work is usually done by a prospector to try to improve the exposures. In the simplest cases this may only involve the scraping away of moss or thin overburden (*see* Plate LVII). If necessary this is supplemented by digging trenches to try to reach bedrock. Preliminary trenching is commonly done at intervals of 25 or 50 feet, the trenches being placed at right angles to the strike. If bedrock cannot be reached at a depth of about 5 feet, it is customary not to go farther, at least in the early stages of

Plate LVII

A quartz vein with the overburden stripped off, and a little rock blasted out where the depressions are filled with rain-water. Note shearing of wall-rock at side of vein.



exploration. In some instances an iron bar or pipe, or a post-hole auger, can be driven into the ground to learn the depth of bedrock, but this is not practical if the overburden contains large boulders. Special bars with a device at the end for holding fragments of rock are sometimes used to learn the character of the

Plate LVIII

A portable fire-fighting pump used to cut trench through over-burden and to clean bedrock.

bedrock without the necessity of trenching. Probings of this kind, or the presence of nearby outcrops, sometimes permit reaching bedrock more readily by placing a trench at a different place than that dictated by the even spacing previously decided on.

If the deposit is revealed in an outcrop or trench, it is useful to place a stake, picket, or pile of rocks to mark one of its walls, or the centre of a narrow deposit; and to place others along the strike, to assist in placing other trenches.

Trenching is usually continued, if the exposures thus found show reasonable widths and mineral content, until the prospector believes that he has established enough length to interest an examiner. He would not have to establish a length of many hundreds of feet at the outset, if the width and mineral content are impressive. If the deposit seems to end in one direction, it is desirable to do some further stripping or trenching in the vicinity to try to learn if it actually dies out, or if it is faulted, or if branches or parallel bodies can be found.

Trenches should extend a foot or more beyond the walls of the deposit, to indicate the nature of the wall-rocks. If a deposit is very wide, all preliminary trenches do not have to extend the full width. Instead, pits can be spaced at intervals across the width.

In places that are favourably situated, stripping of overburden can sometimes be done to advantage by using water under pressure from a portable fire pump (*see* Plate LVIII). In another method, known as ground sluicing; a small stream of water diverted to the desired place by a ditch can be allowed to flow until it washes off the overburden. If the amount of water is small the effect can be increased by what is called 'booming' (*see* Plate LIX). A small dam is improvised at a convenient place and a gate a foot or two in size, made out of boards or hewn logs, is placed in the dam. The gate is opened from time to time by the prospector, to allow the pent up water to rush out, or an automatic gate may be built by hinging the gate and arranging a latch that is opened by a lever, at the other end of which is a box into which water flows when the pond is full.

If the deposit contains radioactive minerals it may be possible to trace it beneath a few feet of overburden by using a Geiger counter or other detector. Similarly, if a deposit contains magnetite or pyrrhotite in sufficient quantity, it may be traced by using a dip needle.

As trenching proceeds, the deposit should be constantly reappraised as there is no point in continuing to do work if the deposit seems to be too small or of too low mineral content. Preliminary panning may be done as exploration proceeds, and samples should be sent for assay if possible.

Next, it is necessary to consider whether the prospector should blast into the rock. Many deposits are too weathered to permit the prospector or examiner to obtain a satisfactory idea of them unless openings are made by blasting.

Plate LIX

A crib-dam and boom-gate used as an aid in removing overburden.

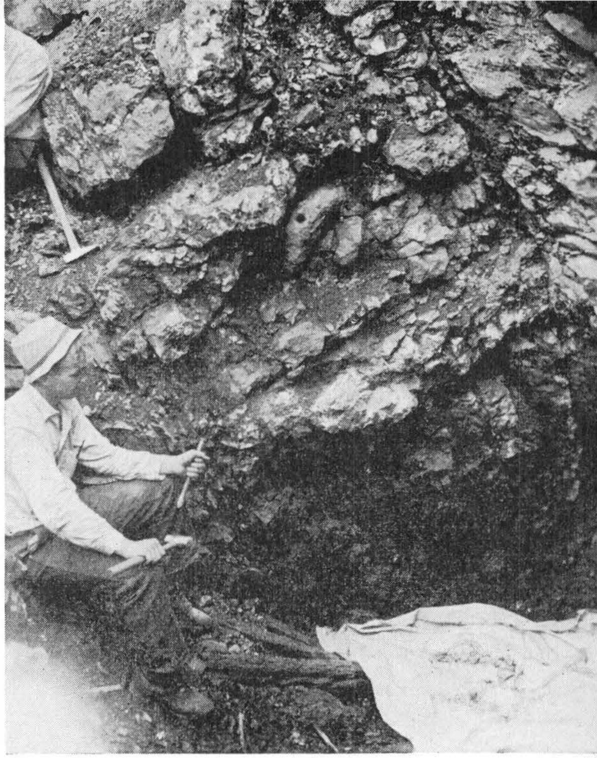
On the other hand, many prospectors do not know how to use explosives safely, or do not have the necessary equipment, and it is not necessary that all competent prospectors should be able to undertake 'rock work'. If the surface is badly weathered, and if the knowledge and equipment is available, it is, however, often desirable to blast into the surface of the deposit at a few places, using the methods described in another section. This can be done by placing a few 'pop holes' or rock trenches in a few outcrops of the deposit, or in the bottom of a few trenches dug in overburden. It should be emphasized, however, that in general only enough removal of overburden, or blasting, should be done at first to provide sufficient information to interest possible backers or buyers and to facilitate the first professional examination. Examiners often find that a prospector has not done enough work, and that their trip has been largely a waste of time; but they also often find that a prospector has done too much misdirected work, such as extensive trenching in a poor place, or unnecessary surface blasting, or even unnecessary tunnelling.

The last preliminary step, often overlooked, is to make a rough survey and sketch showing the position and nature of outcrops of the deposit and nearby rocks, the position of trenches, if any, the numbers and positions of specimens and samples, and the locations of trails and other features.

This completes the preliminary work. The next step is usually to try to interest capital, or to go on with general prospecting until an examination can be arranged. In some instances, an examiner who did not recommend that his principals acquire the property or finance further work, might suggest that the prospector do further work of a certain kind himself. In other cases, the prospector might need to do assessment work on the claims in another year, and so would do further exploration on the deposit. He would then proceed with some of the earlier stages of advanced exploration, as described later. If possible, he should obtain professional advice before undertaking such work, unless he is very well qualified, because mistakes at any stage beyond very limited preliminary exploration are costly, and because he might better occupy his time in trying to find other deposits.

If a deposit contains significant amounts of radioactive minerals, blasting usually scatters fragments in such a way that Geiger counters or other radioactivity detectors cannot be used dependably for further prospecting in the vicinity or for testing showings. It is, accordingly, better not to blast until after any desired radioactivity surveys have been made, or, if it is necessary to blast to try to expose primary parts of the deposit, logs may be laid above the part to be blasted, to minimize scattering.

Examiners who turn down properties are usually generous in giving advice on work the prospector might do to improve his showings. Also, several provincial government departments employ engineers or geologists who do as much as possible to advise prospectors, although they cannot visit all properties in their districts each year. Furthermore, geologists of the Geological Survey of Canada are glad to advise prospectors and claim owners when they visit properties in



A. *Sampling surface exposure with moil and hammer, and canvas sheet used for catching the sample.*

Plate LX

B. *Channel-sampling with moil and hammer (underground). The channel has been outlined by chalk marks. Note that the channel is at right angles to the quartz vein, and that samples of wall-rock, as well as of the vein, are taken. Note also canvas sheet for catching the sample, and mask worn to prevent breathing rock dust.*

an area being mapped at the time, or when making special studies. Federal agencies do not, however, make special trips to examine properties at the request of, or on behalf of, the owners. Failing any of these ways of obtaining advice, a prospector or his grubstaker should consider the advisability of engaging the services of a consulting geologist or mining engineer. Some prospectors cannot afford this, but others who can will spend thousands of dollars on their claims in other ways, without spending a hundred or so on professional advice.

Sampling

One of the most important skills of a prospector is to be able to take samples that are sufficiently representative of a deposit. Almost always, one or more samples must be taken from each discovery that seems to have any merit, and additional samples must be taken as exploration proceeds. The only exceptions are the rare cases where abundant valuable minerals are exposed, such as a vein containing a great deal of visible gold, or a vein containing massive pitchblende. Thorough sampling is a complicated procedure usually done or supervised by an engineer or geologist, who decides on the best method for the type of deposit and other circumstances, and the number of samples necessary to provide a proper estimate of the average grade of the deposit or of ore shoots in a deposit.

The various methods of sampling and of estimating the grade of a deposit used by engineers and geologists need not be discussed fully, but a short description of sampling methods in general is given below, because some knowledge, even of the methods that are not applicable to prospecting, is desirable. Prospectors and the general public often read about samples in reports and news items, without understanding what is meant. The methods described below apply mainly to lode deposits, but some apply to placers. The types of samples with which prospectors should be almost exclusively concerned are *chip*, *channel*, and *grab* samples, but some prospectors may use light diamond drills, or may need to take a *bulk* sample.

Channel Samples

These are taken from a channel at least 2 to 4 inches wide and $\frac{1}{4}$ to 1 inch deep, cut at right angles to the strike of the deposit, usually with a moil and hammer, but a pick or bricklayer's hammer may be used, especially for fairly soft or brittle material. The surface should first be cleaned with a broom or brush. There is no definite rule for the size of channel or the amount of material removed, so long as these are kept as nearly uniform as possible for any one sampling project. The larger channels are generally recommended when the minerals are distributed fairly unevenly. If the valuable minerals are very spotty, channel sampling may not be practical. The sample should be as uniform and representative as possible, and care should be taken not to include more of the better or more easily broken material. If a large piece is broken off accidentally, it may be broken up and a piece of appropriate size used. Care must be taken to obtain the finely broken material, as some of the metalliferous minerals are broken to dust during the cutting of the channel. The material cut from the channel may be caught on a sheet of canvas or oilcloth, in a box, gold pan, or large can, or in a sample sack kept open with a wire loop, and great care must be taken to see that these are not contaminated by fine material from previous sampling. A pound or more is usually obtained for each linear foot of channel. If it is impractical to ship large amounts of samples, the individual samples may be carefully reduced in size, in the way explained in connection with bulk samples.

It is useful to outline with crayon the places to be channelled. If the deposit contains bands of different material, they should be sampled separately. If it is more or less uniform, a length of not more than 4 feet of channel should be regarded as one sample; separate samples should be taken if a deposit is more than 4 feet wide. Separate samples should be taken of a few inches of the wall-rock at each side of the deposit, in case it also contains valuable minerals. If a deposit is less than 3 feet wide, separate samples of wall-rock should be taken for lengths sufficient to make a total of 3 feet, this is done because mine openings would have to be at least 3 feet wide, even if the deposit is narrower. Distances should be measured in tenths of a foot rather than inches, for ease in calculation.

Separate channel samples are usually taken at even intervals of 5, 10, or 20 feet, depending on the size of the deposit, regularity of mineral distribution, and the time and money to be spent on sampling. If trenches or other exposures do not permit evenly spaced sampling, the channels are placed to suit circumstances, and this is taken into consideration when calculating the results.

Chip Samples

These are similar to channel samples, except that instead of cutting a channel, chips are knocked off at intervals of an inch or a few inches. A moil or pick is used, as in channel sampling. If a large piece is broken, it is split and an average piece is put with the sample. This is a cheaper and quicker method than channelling, and it is often sufficient, particularly for preliminary sampling, when it is seldom worthwhile to take careful channel samples from weathered or oxidized exposures. All the other matters referred to under 'channel sampling' apply to chip sampling as well.

Panel Sampling

Panel samples are taken in the same ways as channel or chip samples, but from a larger area instead of a strip. They may be taken from areas 1 foot or several feet square, in an attempt to obtain a more representative sample. Lines may be laid out in the form of a grid, and alternate squares may then be sampled.

Grab Samples

Grab samples, sometimes called character samples, are pieces that are more or less representative of a deposit, taken at random from the deposit in place, or from a dump or mine car. If several such samples are taken with reasonable care to obtain average material, they may provide fair samples of deposits whose minerals are distributed fairly evenly, particularly in preliminary samples, but as a rule channel or chip samples are much preferable. In many instances what are said to be grab samples are really selected samples.

Selected Samples

Selected, or 'picked', samples are not really samples at all, because they are not representative of any sizable part of a deposit. They are specimens or small chips of the best parts of a deposit, and assays from them are of little use. Selected samples are desirable for purposes of mineral identification, because they provide better material with which to work. Also, a selected sample may be useful in the case of a deposit that appears to be of low grade; if such a sample gives only a low assay, it can be confidently assumed that the deposit is of still lower grade. Otherwise, selected samples should be avoided, yet many assay reports based on such samples are presented, either because the sampler had little knowledge of prospecting or mining, or in an attempt to attract attention. This has been done so often that the informed public discounts sampling reports that do not state the method of sampling and the width that the sample represents, and all high assays said to be from grab samples.

Bulk Samples

As their name implies, bulk samples are substantial amounts of a deposit, taken as representatively as possible. They range from a few hundred pounds to several tons in weight, and may be blasted from pits or trenches at the surface, or from underground workings. They are warranted only after a deposit of fair size and grade has been outlined, and are rarely needed by prospectors. They are taken for one of two purposes, or a combination of the two. One is to provide a more representative estimate of the grade of an unevenly mineralized deposit than can be obtained by averaging the results of several smaller samples. The other is to provide sufficient material for laboratory tests to determine whether the deposit can be treated economically and to learn the best method of treatment and the percentage of recovery that can be expected. If material is taken from more than one trench or underground location each sample is usually kept separate for assaying purposes, as this permits comparison of the grades of different parts of the deposit. Later, the samples may be combined for treatment tests. If transportation is not a serious problem, best results are obtained by shipping the entire sample or samples. Otherwise, the amount can be reduced in such a way that a smaller quantity is fairly representative of the entire sample. This can be done by shovelling the whole sample into a cone-shaped pile, perhaps after breaking the larger pieces with a hammer. Each shovelful is placed on the peak of the pile, so that small pieces roll down in a more or less even manner. When all is in place, the top of the pile is flattened by spreading the material as evenly as possible into a pile whose height is about one-tenth its diameter. Then two opposite quarters of the pile are shovelled into a new pile and it is quartered in the same way. This process is repeated until a sample of convenient size is obtained. It is best if the piles can be placed on a canvas or wooden floor, to prevent loss of the 'fines'. For very large samples, a portable crusher is sometimes used to reduce the pieces to fairly small size, after which the sample is reduced to a suitable size by coning and quartering, as described above, or by using a special sample-splitting device that gives more accurate results.

Muck Samples

'Muck' is the name popularly applied to rock or ore broken from a pit, trench, or underground working. While it is being shovelled out, a portion may be set aside to constitute a sample. Fractions commonly used are one shovelful in every five, ten, or twenty. In much the same way, 'car samples' are taken from a car of muck or ore, sometimes by setting aside pieces taken at random as the car is being loaded, or placing in separate boxes material similar to that at the bottom, middle, and top of the load.

Dump Samples

When properties are examined after exploration or mining has been done, the dumps at trenches or from underground workings may be sampled in one or several ways. Small dumps may be coned and quartered, or a number of grab samples may be taken. Large dumps are commonly sampled by excavating pits or trenches in them at systematic intervals. If dumps have been exposed for a long time to rain and melting snow, some of the content may have been lost by the washing away of 'fines' or by solution.

Borings

Various methods of boring, which are explained in the section on exploration of deposits (*see* page 243), are used to obtain samples, usually at carefully spaced intervals. Drive pipes or post-hole augers may be used for testing placers or other soft deposits that are not too deep and where large boulders do not interfere. Another method that is sometimes desirable is to drill holes with hand steel or pneumatic drills, and collect the cuttings, either as a mud called sludge or as a dry powder. Larger holes are often put down with churn drills, the cuttings being pumped out and collected. Because churn drilling can only be done vertically, this method is generally used only for flat-lying or very large deposits such as placers and some iron deposits. Diamond drilling is widely used as a means of exploration and sampling. This method permits drilling in any direction and it provides a core that can be studied and sampled readily. Except in the case of core of very small diameter, cores that warrant assaying are usually split longitudinally with a special tool, one half being assayed and the other kept for further study should that be desired. In addition, the drilling sludge for separate intervals is often collected and assayed. Sludge samples are particularly useful for sections where core cannot be recovered, as sometimes happens when the rock is too soft, friable, or fractured.

Composite Samples

After parts of samples have been used for assaying, the unused parts are sometimes lumped together to form a composite sample that may be assayed as a check on the individual results or used for treatment tests.

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Prospectors' Samples

Many of the techniques described above are not applicable to the sampling done by a prospector when he first makes a discovery or when he does preliminary exploration. He might take chip or grab samples at first, choosing them so as to be as representative as possible. Later, if the deposit seemed to warrant it, he might take channel or muck samples. The utmost refinements are not necessary in the early stages, because the interest is in the possibilities of the deposit, rather than in careful calculations of tonnage and grade. The early sampling should, however, be done reasonably carefully and systematically. Deposits having valuable minerals distributed irregularly require a greater number of samples, and the samples themselves should be larger than for a uniform deposit.

The question of whether it is worthwhile sampling altered material at the surface of a deposit always presents a problem. Such material may give too high or too low results, or the assays may be almost the same as those obtained later from unaltered material. Often, nothing but partly altered material can be obtained during early exploration, and this has to suffice. If the deposit seems to be of fair size and if the geological conditions are favourable, further work is often warranted so long as the assays show reasonable content, even if the samples cannot be relied on completely because of near-surface alteration or of imperfect sampling.

A rough idea of the content of samples can at times be obtained on the spot by panning, or, in the case of radioactive samples, by testing them with a field radioactivity detector. Accurate results can be obtained only by sending samples to a laboratory for fire assay, chemical or spectrographic analysis, or special tests. The most reliable results are obtained if the entire sample is sent, but if this is not practical samples may be reduced before shipment. The method of quartering large samples has already been described. Smaller samples can be reduced in the same way, preferably by crushing them fairly fine, then placing the sample on a cloth or paper sheet, and mixing it thoroughly during successive stages of coning and quartering.

Samples should preferably be placed in small canvas bags specially made for the purpose. The bags should either be new, or be freshly laundered after being turned inside out, to avoid contamination by previous samples. If such bags are not available, any clean, strong, tight container will serve. Sample numbers should be written on a slip of stout paper which is rolled up to prevent the number from being obliterated, and is then placed in the container; alternatively, the number may be placed on an attached tag or on the outside of the container, preferably by some means that will not be affected by water. Careful notes on samples should be recorded in a notebook or on a map or sketch.

Most provincial departments of mines will make a limited number of free assays and other tests on prospectors' samples. In the federal Department of Mines and Technical Surveys, the Geological Survey will make up to six free tests for uranium or thorium on samples from a new discovery or property, and the Mines Branch will test samples from deposits of industrial minerals and bulk samples of metallic ores without charge, and will also perform assays and chemical analyses for which a charge is made: except for preliminary reports on samples of industrial minerals, the Mines Branch work is done only in certain circumstances, and samples should not be submitted before arrangements have been made. It is particularly important that samples and covering letters be clearly addressed to the proper branch, and that the type of test desired be clearly marked on the outside of the parcel (e. g. 'radiometric test', 'radioactive mineral identification', or 'ordinary mineral identification'). Unless this is done, delay and confusion may result.

In Northwest Territories and Yukon, free assay coupons are provided to holders of mineral claims. Applications for these should be addressed to the local Mining Recorder, from whom information may be secured.

Except for the above-mentioned cases of services rendered by government departments, prospectors requiring assays or analyses, or tests of bulk samples, should apply to one of the commercial concerns doing such work. Such firms advertise regularly in the mining press, and the prospector must decide for himself where to have the work done. It is not permissible for government agencies or employees to recommend any particular firm.

If in doubt, the prospector may send a sample to an assayer and ask to have the powdered sample or 'pulp' returned. This can then be carefully divided into two or three parts, which may be sent to other assayers. It is unlikely that the results will correspond precisely, both because there may be slight variations in the samples, and because analytical methods are accurate within certain accepted tolerances only, and different methods may give slightly different results. If, however, one set of results differs markedly from the others, a further check is probably called for.

The reports on assays and analyses frequently list minute quantities of metals or other elements present, but such components should not usually be regarded as valuable constituents of the deposit, as they are seldom economically recoverable.

Surveys and Sketches

It is desirable for prospectors to make rough surveys and to record the information on air photographs, tracings, or sketches. This information is valuable as a record of geological observations, mineral discoveries, locations of samples and specimens, and geographical features. These do not need to be surveyed or plotted with professional precision, but they should be shown with reasonable accuracy, and this can be done fairly simply and quickly after a little practice. The results are useful to the prospector himself in providing a record and often by indicating trends that he might otherwise overlook. They are also invaluable when reporting or when trying to interest a possible buyer or backer. The kinds of surveys and mapping that a prospector might do fall into two classes. The first covers a fairly large area, such as a region being prospected, or a large group of claims. The second covers a smaller area such as a single claim, or part of a claim where a deposit has been found or where trenching has been done.

Large Areas

As mentioned elsewhere, one of the best ways of recording information is on an air photograph or on a tracing therefrom. Another method, if suitable maps are available, is to mark points and make notes on a copy of the map or on a tracing made from it. The positions of some points can be estimated sufficiently closely by eye. Others can be fixed by taking bearings, pacing distances, or taking altitudes with a barometer. These methods are discussed later.

In areas where timber is too thick to permit fixing positions by eye or by taking bearings to known points, and in detailed prospecting of a group of claims or a particularly favourable area, it is often desirable to prospect along parallel lines at intervals of 100 to 500 feet. To do this it is usual to mark off the intervals on a base line, which may be the side of a claim or a special line selected for the purpose. The prospecting lines are run at intervals from the base line, and are usually arranged to cross the general trend of formations or structures. They may be kept straight by taking repeated sights with a compass, or after being begun by compass, they may be run as 'picket lines'. To make a picket line, a picket is placed at the starting point and another by taking a compass bearing from the starting point. Then, if two men are available, one man may sight along the two pickets and wave the second man into position for the third picket, and so on. If a man is working alone, he can move sideways until he is in line with the pickets already in place, and then place another. Pickets are usually placed at even intervals, such as 100 feet, so that observations can be referred to these fixed points, but if this is not necessary the pickets may be placed at any convenient places, generally on high points to permit visibility. After the lines have been run they may be plotted on ordinary paper or graph paper, to make a plan on which observations can be recorded. Such a plan is illustrated in Figure 11. As well as aiding in ordinary detailed prospecting, such lines may be used for the recording and plotting of geological, radioactivity, or dip-needle surveys.

Smaller Areas

For smaller areas such as might embrace a mineral deposit or a group of trenches, a plan on a larger scale is desirable. Suitable scales range from 1 inch to 10 feet to 1 inch to 100 feet, according to circumstances.

If the points to be located are fairly close to one another, say within 1,000 feet, a base line may be run in a convenient place, as illustrated in Figure 11. The points to be located may then be measured by 'offsets' at right angles to the base line. The direction of the offsets can usually be determined with sufficient accuracy by eye, but if the distance is great a bearing can be taken from the point to the base line. If two 50-foot or 100-foot tapes are available, it is convenient to lay one along the part of the base line being used at the time, and to employ the other for measuring offsets. If only one is available, the

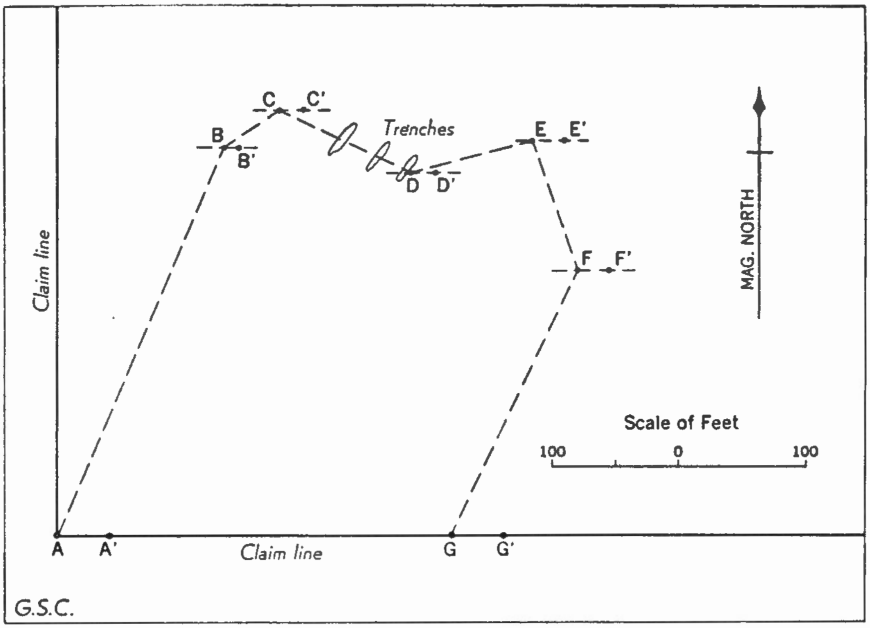

FIGURE 21. A closed traverse and a method of adjusting it.

offsets can be measured first, the points where they intersect the base line may be marked, and the positions along the base line may then be measured. For rougher surveys, pacing is sufficient.

If the distances are too great, or if timber is too large and too thick to make a base line practical, points may be located by making a 'traverse' composed of several bearings and distances, from a point of origin such as a corner of a claim. If a traverse consists of only two or three courses (bearing and distances) these can be plotted merely by using a scale and protractor and assuming that the bearings were properly taken and not affected by local attraction. For more accurate results, particularly if a traverse consists of three or more courses, it is better to make a 'closed traverse' as illustrated in Figure 21. This is done as follows:

Suppose that the first point to be located is a vein exposed in an outcrop at point C. The nearest point of reference was the claim corner A, from which a bearing was taken in the general direction of point C. As the prospector measured along the line of this bearing, when he reached a place represented by B he could see the outcrop C, so he took another bearing, B to C, and measured this distance. From C he took course C-D, to cross three trenches whose distances from C were measured. From the trench at D, he took course D-E to another outcrop, then E-F to the last point he wished to locate. He then took course F-G to strike the claim line, and finally a course down the line to close the traverse at A. The courses were then plotted on paper, to a convenient scale, using a protractor and measuring scale. Any point was taken to represent

A, and a side of the paper was taken to represent a north and south direction. When such a closed traverse is plotted, it would be most unlikely that the last course would end exactly at the point of origin, A. It is more likely to end at another point illustrated by A^1. If it is badly out of closure, there must either have been one or more serious errors in bearing or distance, or a serious magnetic disturbance at some point. If the traverse is re-run, an error will probably be detected, permitting reasonable closure. If the closure is only slightly out, a line is drawn between points A and A^1, and short parallel lines are drawn through the other points of the traverse, along which the other points are adjusted proportionately as shown in Figure 21. The letters with the strokes after them represent the first positions, and the others the adjusted positions. A special method of measuring the amount of adjustment is used by surveyors, etc., but for rough purposes the adjustments can be estimated by eye. After the traverse has been adjusted, it may be used as a skeleton around which details such as lakes, streams, outcrops, contacts, sampling positions, etc., are sketched. Usually, the more important details are fixed to the traverse by measured offsets, and the remainder are drawn by eye.

Fixing Positions

Positions are located by bearings, distances, or elevations above sea-level or by combinations of these.

For simple surveys, bearings are usually taken with a compass, in which case it is necessary to consider the possibility of local attraction, and perhaps to consider the declination. The compass does not point to the true or astronomic north, but to the magnetic pole. The angle between true and magnetic north, called the declination, varies from district to district and is noted on the legends of most maps. A special map showing declinations for all parts of Canada is published by the Dominion Observatory, available from the Surveys and Mapping Branch, Department of Mines and Technical Surveys, Ottawa. The declination can also be learned by sighting along a surveyed line whose true bearing is known, and noting the difference between this bearing and the compass reading. Local attraction may be caused by metal objects carried by the observer or lying nearby, or by magnetic minerals in nearby rocks. It can usually be avoided by holding the compass well away from belt-buckles, knives, hammers, rock outcrops, etc., but at a few places magnetic outcrops may cause confusion.

If bearings can be taken to two points shown on a map, the position of the observer can be located by plotting on the map the reverse bearings from the known points, whereupon the intersection will fix the observer's point. The points of reference must not be too close together, or too nearly in line with one another.

Distances can be measured by pacing, using 2½ feet as an average pace, or by means of a tape measure. 'Metallic' tapes in lengths of 50 or 100 feet are most practical. Some prospectors use a measured length of heavy cord, such as trolling line or cod line; these stretch, but are good enough for approximate surveys. A 6-foot steel tape is useful for measuring short distances, such as the widths across which samples are taken.

In mountainous country a small aneroid barometer is useful for locating positions on contoured maps, because distances measured by pacing or other means are not useful in locating points on steep slopes. A bearing to a known point, together with a barometer reading, generally gives a fairly accurate location. Because a barometer is influenced by change in weather, its reading should be noted frequently at points whose elevations are shown on a map; then when a reading is taken at a point to be fixed, an adjustment can be made on the assumption that the weather has not changed much since the last check-reading was taken.

Plotting

Traverses and sketches can be plotted on ordinary paper. However, graph paper, or tracing paper laid over graph paper, is convenient, because right-angled lines do not then need to be plotted, and because the divisions on the paper can be used instead of measuring with a rule or scale. Bearings can be plotted with a protractor. Special rules can be obtained for different scales of plotting, but these are not essential, because the distances can be estimated from whatever divisions the rule available happens to have. For example, if the scale is 1 inch to 50 feet; ½ inch is 25 feet; and ¼ inch is 12½ feet, which is almost the same as 10 feet on the sketch. Rules and protractors that are suitable can be bought in 10-cent stores. A sharp pencil should be used for plotting and sketching, and it should be of moderate hardness, such as F, or H, to prevent smudging and frequent sharpening.

Prospectors' Reports

A prospector commonly has to write a report on the results of his work because he is employed by a company that requires him to make a report, has to report to one or more backers, is trying to interest an individual or company in buying his property or in financing further work, or has to report a discovery or the results of exploration to a government agency, as in the case of uranium discoveries. If the prospector is in the employ of a company, the kind of report required will be specified; otherwise the following suggestions may be useful.

The report need not be long or written in learned language, but it should give essential information in as clear and neat a manner as possible, because these matters affect a reader's reaction. The following outline may be followed to prevent overlooking some important consideration.

Heading

State the name of the discovery or claim group, the province or territory, and the name of the writer.

Location

State the number of claims concerned, describe the location and means of reaching the discovery or property, including all important details such as how to get in touch with a guide, and recommended boat or air service, if applicable. The report should be accompanied by a regional map or tracing showing the location, and also by another more detailed map, tracing, sketch, or air photograph showing with reasonable accuracy the position of claim boundaries (if staked), discoveries, trails, geological observations, sampling positions and numbers, buildings, camps, and so forth. From a properly prepared report and its accompanying maps, etc., it should be possible for an engineer or geologist to reach the property and find the showings without a guide.

Ownership

The name of the discoverer or owner should be stated, together with any pertinent information such as ownership of surface or mineral rights, date of staking, assessment work done or recorded, etc.

History

The date and manner of discovery should be stated. If all or some of the discoveries were made by others at some previous time, a note of the earlier history should be included. If the ground was staked previously by others, the date and previous ownership should be mentioned, and if systematic prospecting or any exploration was done by previous owners or others, as much as is known regarding the character of such work and the availability of records or drill cores should be stated.

General Information

Give a short account of the topography, amount and kind of timber, local labour supply, power supply (if available), length of summer season, and any other matters that might affect an exploration or mining program. If important mines or interesting prospects occur in the district, they should be mentioned and their distances, similarities, or differences to the property being described should be outlined.

General Geology

Describe the main features of the local geology as well as of the claim group or the immediate vicinity of an unstaked discovery. This may be taken from geological reports and maps, or described from personal observations if reports and maps are not available.

Description of Discoveries

State the number of separate deposits apparently present; their type, such as pegmatite or quartz vein or shear zone, as nearly as the prospector is able to judge; the lengths and widths for which the deposits have been traced, stating the distances between exposures (for example, say that one vein has been traced for a total distance of 250 feet, by means of three outcrops and four trenches which are from 10 to 40 feet apart, and that in these exposures the vein varies in width from $2\frac{1}{2}$ to $3\frac{1}{2}$ feet). State the number of strippings, pits, or trenches, and specify which pits or trenches are in overburden without reaching bedrock, in overburden to the rock surface but with no deposit visible, in overburden to the surface of the deposit, or blasted into the deposit. The depths to bedrock or into the deposit should be stated. In some cases there might be diamond drill holes to describe.

The locations of specimens or samples, either submitted with the report, or tested previously, should be described, or mention should be made that they are noted on an accompanying map, etc. The type of samples and the widths across which they were taken should be stated. Assay reports should be attached, or, if the information is quoted, care should be taken to see that the figures are correctly copied and that the name of the assaying firm is included.

In describing distances, care should be taken to avoid exaggeration, because experienced mining men quickly detect it. Misleading statements are often made quite sincerely by inexperienced prospectors. For example, they may find a few small exposures of quartz or pegmatite, which represent only small veins or dykes scattered over a considerable distance, and may then state that the deposit is 100 feet wide and 2 miles long.

Closing

The writer should sign the report, give the date, his permanent address, and, if advisable, his temporary address. If he is unknown to the person to whom the report is going, it would be well to state his experience and qualifications.

Advanced Exploration

If preliminary examination by a mining engineer, geologist, or very experienced prospector indicates that further work is warranted, this may take the form of additional removal of overburden, rock trenching, boring, or underground exploration. Such work is usually beyond either the means or the ability of prospectors. It is usually laid out by an engineer or geologist, who reappraises the results from time to time and either recommends that another step be taken, or that work be stopped because the results are unfavourable. The prospector may be engaged to do some of the work under supervision, or he may have to do some further exploration himself, as assessment work, if he cannot dispose of his discovery and thinks it is worth holding. However, advanced work is usually done by experienced men hired by a company, or by a contractor who has the experience, staff, and equipment for surface work, boring, shaft-sinking, or tunnelling. A short account of the subject is given in the following paragraphs, because prospectors and those who finance them should have a general knowledge of such matters.

In most instances, exploration if carried through all stages consists first of surface work, then diamond drilling, and finally of openings driven from an adit or shaft to confirm the results of drilling. This is not always so, however. A deposit may be so well exposed at the surface that no removal of overburden is necessary. Or, if the geological environment, size, and exposed minerals are sufficiently attractive, the engineer or geologist may decide that little or no pitting or trenching into the surface of the deposit is necessary, and instead may recommend that drilling be begun at once. In rare instances, a prospect adit or shaft may be recommended without preliminary borings, particularly in the case of a deposit that seems so irregular that borings would not give suitable information. In the early days, particularly in the Cordilleran region, prospectors were prone to drive adits and sink shafts, alone or with a partner, on meagre showings. Sometimes a man would work for wages until he had saved enough to finance another spell at his 'mine', and this was repeated year after year. Occasionally the objective warranted such devotion, but often it was little more than a dream that grew into a conviction as the prospector continued his long and lonely task. Today, better organization of the mining industry has led to a distinction between prospecting and the exploration of prospects, and prospectors are normally not expected to do more than very preliminary work on their discoveries. Although it is generally desirable for companies to confirm results of borings by making underground excavations, some deposits are sufficiently regular and their valuable minerals are sufficiently evenly distributed to permit acceptable calculations of tonnage and tenor based on the results of borings alone. On the other hand, some deposits are so erratic in extent and in mineral distribution that diamond drilling may not be recommended. In such cases, if the surface showings are promising, an exploration adit or shaft may be driven immediately after the completion of surface exploration.

Removal of Overburden

If advanced exploration requires the removal of overburden to trace a deposit and to permit inspection or sampling, the most usual way is to employ labourers to dig pits or trenches at designated places. Years ago, such excavations were carried to considerable depths by shovelling onto successive benches or by using a windlass and bucket. With the availability of other methods of exploration, pits or trenches are now rarely excavated deeper than 4 or 5 feet. When trenching in frozen ground, it may be necessary to work in stages to permit natural thawing, or to hasten thawing by using fires, warm water or steam from a boiler, or by using a ground sluice.

Bulldozers are used to remove large areas of overburden or to dig large trenches across deposits, in districts where it is feasible to do so and when it is desirable to remove considerable overburden. Water under pressure may be used to clean the rock after bulldozing has been done, or even to remove large areas of overburden.

Rock Trenching

Under certain circumstances considerable trenching into the deposit itself may be desirable to study and sample relatively unaltered material. Such work requires the drilling of blast holes. Although this may be done by hand drilling, in most instances today any drilling beyond that done by a prospector at an early stage of exploration is done by portable percussion drills powered either by a self-contained gasoline motor, or by a movable air compressor. In addition to trenches, test pits may be sunk in rock to depths of from 10 to 50 feet, to

Plate LXI

Using a portable percussion drill with self-contained motor for drilling blast-holes in connection with rock trenching.

determine the dip of a deposit and the amount of minerals present at these depths. Today, however, the efficiency to which the art of diamond drilling has been advanced, and the high cost of manual labour, have resulted in a tendency to rely less on surface trenching or pitting, and to proceed with borings if a deposit seems at all promising.

Diamond Drilling

Borings or drill-holes have already been mentioned in connection with sampling. They are such important aids in exploration of deposits and in special methods of prospecting that further description is desirable. The most common methods in use today are diamond drilling and churn drilling. The former has the advantages of providing a core for study and sampling, and that holes can be drilled in any direction, but churn drilling is usually cheaper.

The diamond drill was first used in 1864 for drilling blast holes in a railway tunnel in the Alps. The method was quickly adapted for obtaining cores in connection with mining exploration. The first use in Canada was in 1871, for

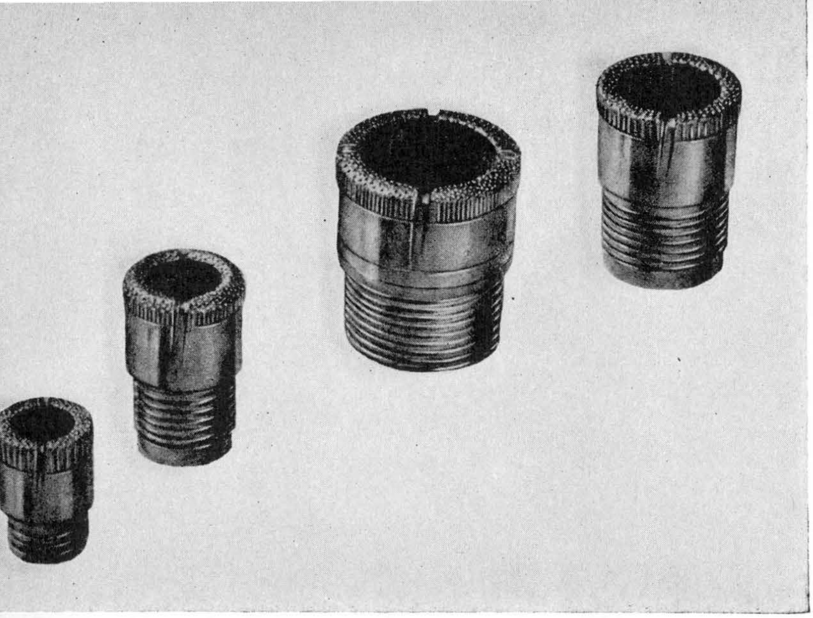

Plate LXII

Diamond drill bits of various sizes.

exploring a coal deposit in Nova Scotia, and in the following year diamond drilling was done at the Silver Islet lode mine in Ontario. Equipment and techniques improved gradually, and diamond drilling became widely used in many parts of the world, revolutionizing mineral exploration. In Canada today, many large mining companies each own several diamond drills that are used for exploration, for drilling long blast holes, and sometimes for drilling holes for cementing off strong flows of underground water. Most diamond drilling in Canada, however, is done under contract by large drilling companies. A few years ago the total amount of diamond drilling done in Canada was estimated to be one thousand miles a year.

The principal parts of a diamond drill are the bit, reaming shell, core barrel, drill rods, and power unit. The bit is a ring-shaped piece of metal in which diamonds or fragments of diamonds are set to form a cutting tool (*see* Plate LXII). Early bits contained a few, fairly large commercial diamonds, whereas modern bits usually contain many small ones. Above the bit is placed a cylin-

Plate LXIII

A diamond drill beginning an inclined hole, before the erection of the tripod used for hoisting out the drill rods.

drical reaming shell, also containing diamonds, which trims the hole to a constant size. As the bit is rotated the core of rock passes upward through the centre of the bit and shell, and enters a tube called the core barrel. The barrel is attached to a threaded hollow steel drill rod which is rotated by the power unit. For use in drilling from the surface, the core barrel and drill rods are usually 10 feet long, and for drilling from underground workings they are generally 5 feet long. When 10 or 5 feet of core have been drilled, as the case may be, the apparatus is withdrawn from the hole, the core is removed, and an additional length of drill rod is screwed on. This operation is repeated until the desired length has been drilled.* The lengths drilled range from very short holes drilled under surface showings mainly as a means of sampling, to several thousand feet, but most are between 100 and 1,000 feet in length. Until recently, drilling from the surface was usually powered by portable steam engines, but these have been almost entirely superseded by gasoline engines (*see* Plate LXIII). Drilling from underground workings is usually powered by compressed-air motors because of the danger of fumes from internal-combustion engines. Pressure is applied to the drill by a screw actuated by the motor, or by a hydraulic system. When short holes are drilled from the surface, with light equipment, the rods are

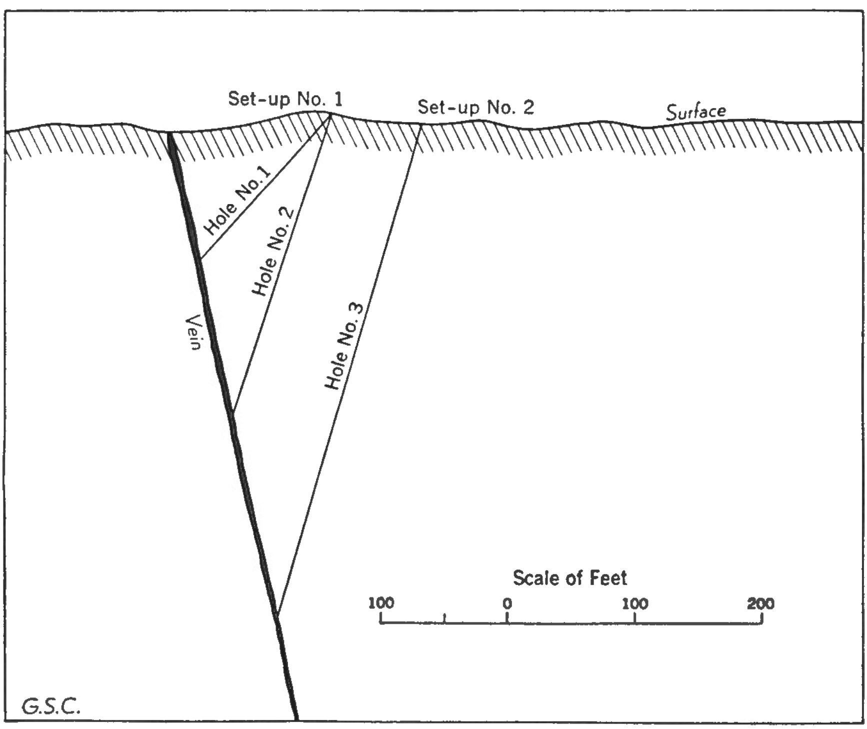

FIGURE 22. A common arrangement of diamond drill-holes.

* A 'wire-line' core barrel, that permits removal of core without removing the drill rods from the hole, has recently been developed for use in connection with BX core ($1\frac{5}{8}$ inch diameter), and experiments are being carried on in connection with other core sizes.

usually pulled out by hand, but for standard operations a tripod is erected to carry a pulley and cable, the cable being wound on a power winch attached to the drill motor. A separate motor is almost always used to power a pump, which circulates water down the hollow drill rods, to cool the bit and to flush out its cuttings, but 'dry drilling' in places where water is scarce has recently been reported to have been successful. The drill and other equipment are usually skidded into place and moved from hole to hole by a light tractor or a winch.

The most usual core diameter was formerly $\frac{7}{8}$ inch, called EX core. This has recently been changed to $\frac{29}{32}$ inch, called EXT. A slightly larger size, called AX, has a diameter of $1\frac{3}{16}$ inches, and this has recently been changed to $1\frac{9}{32}$ inches and called AXT. AX or AXT core is favoured under certain conditions, to provide a larger sample or in an attempt to obtain better recovery of core. Some authorities advise beginning with this size, and if good recovery is obtained, switching to EXT if satisfactory results are attained, because the smaller size is a little cheaper. Cores larger than AXT can be obtained; they are seldom used in exploration for metalliferous deposits but are commonly specified for exploring coal deposits.

Light drills weighing about 200 pounds are available for drilling short holes in places where transportation is difficult, and for use by independent prospectors. They usually produce core $\frac{5}{8}$ inch or $\frac{3}{4}$ inch in diameter, which is called 'x-ray' core although it has nothing to do with x-rays. These drills can be modified to produce EX or EXT core, and doing so is said to result in better core recovery. Another type of light diamond drill that can be dismantled for back-packing has recently come on the market.

One of the problems of diamond drilling is to obtain good core from fractured, soft, or brittle rock or ore. This is particularly true when drilling through zones containing abundant metalliferous minerals, for which the best recovery of core is desired. A main cause of poor recovery is too rapid drilling, but it can result from other causes. Experienced drillers and reliable contractors are the best assurances of satisfactory results.

Diamond drilling is usually done at even intervals of from 100 to 500 feet along the strike of a deposit, favourable stratum, or favourable structure. Later, if encouraging results are obtained, intervening holes are usually drilled to provide more thorough information. The final spacing depends on the irregularity of the deposit and the amount of accuracy desired, holes sometimes being spaced as closely as 25 feet to obtain detailed information. To intersect a zone at two different depths without having to move the drilling rig, a common practice is to incline the holes at two different angles, as illustrated in Figure 22. Then, if another deeper hole is desired, the rig is 'stepped back' to a second position on a line perpendicular to the zone or vein and passing through the first 'set-up'. In large drilling programs it is desirable to space holes so that they will coincide with the direction and position of co-ordinate and section lines that would be used if underground operations are undertaken later.

Diamond drilling is not usually done by ordinary prospectors because it is mainly a fairly expensive form of advanced exploration or of special prospecting. A drilling project is almost always planned and supervised by an engineer or geologist because location of drill-holes and the study and sampling of core are highly technical matters. Some experienced prospectors do, however, successfully use light diamond drills for early exploration of discoveries or for assessment work.

The cost of diamond drilling varies with the location, kind of rock, amount and kind of overburden, size of core, number and length of holes, availability of water, and other factors. It is therefore pointless to discuss costs here, beyond stating that for average contract jobs they are probably between $2 and $4 a foot. Drilling from underground workings is considerably cheaper than drilling from the surface, because the equipment can be moved on the mine tracks, and because water and compressed air services are already installed.

Diamond drill cores should be carefully studied and recorded, and securely stored in a dry place. Special boxes and strong racks should be used, and boxes should be clearly marked with the hole number and footage. Good permanent markings are made by stamping or inscribing numbers on a metal tag and nailing this to the end of the box.

Other Types of Boring

A form of drilling now largely supplanted by diamond drilling is called 'shot drilling'. Chilled steel shot is fed into a bit to act as the cutting agent. The method still is sometimes used for obtaining core with diameters of 3 inches or more, for holes not more than 100 feet long, drilled in rock that is uniform and unfractured.

Churn drills similar to those used for drilling wells for water are also used for exploring some kinds of mineral deposits. The hole is dug by a bit attached to a cable, which may be jerked up by a spring pole, but more usually is actuated by a motor-driven wheel; the bit drops down the hole to strike a series of chopping blows on the rock at the bottom. Water is circulated in the hole to flush up the cuttings. Particles from upper parts of the hole may drop down and contaminate the sample, particularly when drilling soft deposits such as placers. To prevent this, casing pipe is driven down the hole, the bottom of the casing being kept as close as possible to the bottom of the hole. In Canada, churn drilling is done mainly for testing placers, and when many vertical holes are required to test lode deposits. An example of the latter use is the drilling done at some of the iron deposits in the Labrador trough. Another type of drill used for testing placers is the Empire drill, which uses either a rotary steel bit or one like that of a churn drill.

Underground Exploration

Although borings may be said to be forms of underground exploration, this phrase invariably means the sinking of shafts or driving of horizontal openings to explore a deposit. Some of the terms used to describe such openings require explanation. To the layman, any horizontal opening is a tunnel. Strictly speaking, however, a tunnel is open at both ends, like a railway tunnel. One that is driven into a hillside and open at one end only, as is usual in mining, is properly called an *adit*. Horizontal openings driven from an adit or a shaft are given the group name of *laterals*, but are further designated as *drifts* if they follow along a vein or other deposit, and *cross-cuts* if they are driven to probe a deposit at right-angles to its strike. An opening driven upward from an adit or lateral is called a *raise*, and one driven downward is called a *winze*.

Before diamond drilling became as usual a method of exploration as it is today, exploration shafts and adits were more common during initial stages than they are now. They were often driven with hand steel, and many were just wide enough for a man to work in or crawl through. Small workings of this kind are popularly called 'gopher holes' or 'coyote holes'; they are now almost a thing of the past, because machinery is cheaper than labour. Nowadays, if underground exploration is required, shafts are usually made fairly large and laterals are driven wide and high enough to permit use of air drills and mine cars. Present costs of a prospect shaft, including timbering, are about $100 a foot, and for an adit or lateral 6 feet high and 4 feet wide, about $40 a foot.

After laterals have been driven, the surrounding rock may be explored by diamond drill from 'stations' along the lateral. This is commonly called 'underground diamond drilling'. It is similar to diamond drilling from the surface except that the drilling rods used are only 5 feet long, for easier handling in confined spaces, and the drills are rotated by compressed-air motors because the danger of fumes prevents the use of internal-combustion engines underground.

Drilling and Blasting

Pitting and trenching into solid rock to reveal unweathered parts of a deposit are not done as commonly as formerly because of advances in diamond drilling; but they are necessary at times, and under some circumstances work of this kind is done by prospectors. It is now often done by use of portable power drills and detachable bits; the arts of drilling by hand and of sharpening drills are therefore required less than formerly, but as some prospectors may require to practise them, the following notes are included. They have been modified from the booklet "Prospecting in Canada" formerly issued by the Canadian Legion Educational Services. It must be emphasized, however, that it is difficult to learn these skills merely by reading, and that practical instruction by experienced men is almost essential.

Equipment

The drills most commonly used for hand drilling are made of ¾-inch octagonal steel. They are prepared in sets of three or four, having lengths of about 1½ to 4 feet. They are usually sharpened chisel fashion, but the edge may be slightly curved for drilling very hard rock. The width of the face on the longest drill in the set is slightly more than ⅞ inch, which is the diameter of the sticks

Plate LXIV

Drilling by hand at a pegmatite deposit, with two men striking and one man (seated) holding the drill. A longer drill, for use when the hole is deepened, stands in the pit.

of explosive used in this work, and each succeeding bit in the set is $\frac{1}{16}$ to $\frac{1}{8}$ inch wider. The shortest drill, called the starter, is used first, and is widest to permit the next to be placed readily in the hole, and so on. Nowadays, drills having inserted tungsten-carbide cutting edges are popular because of their hardness.

A 4-pound hammer, called a *single-jack* is commonly used when a man is drilling alone, and an 8-pound one with a long handle is used when one man holds the drill and the other strikes.

A *scraper* 3 to 4 feet long, pointed at one end and with a small flange projecting at right angles from the other end, is made from an iron rod $\frac{3}{8}$ inch in diameter. This is used for removing cuttings from the hole.

The blasting explosive most commonly used is "Forcite 60%". Appropriate detonating caps and fuse will be recommended by the dealer. It is most essential that all explosives be stored in a cool dry place. Detonators and blasting explosives must never be stored in the same building. Government regulations controlling the handling and storage of explosives should be obtained, studied, and rigorously followed. The remainder of the equipment required for blasting comprises a wooden mallet and wedges for opening boxes of explosives, a pointed

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hardwood stick half an inch in diameter and 3 to 4 inches long, for making holes in sticks of explosive, a wooden tamping rod three-quarters of an inch in diameter and 6 inches longer than the longest drill hole, a pair of cap crimpers, and a sharp knife.

Drilling

The spacing of holes depends on the depth to be drilled and on the kind of rock and amount and angle of fracturing. It can be learned only from instruction or experience.

A hole is begun with the shortest drill, and the drill is rotated about 45 degrees after each stroke of the hammer. Goggles may be worn to prevent chips of steel from entering the eyes, and gloves may be used to protect the hand or hands holding the drill. If the head of a drill is 'mushroomed' it should be smoothed by forging to prevent damage to the hands. Most holes drilled during surface exploration are directed downward, and in such holes the cuttings interfere with the drill unless they are kept in suspension by water poured into the hole as required. A small piece of sacking or similar material is kept around the drill at the top of the hole, to keep mud and water from being expelled when the drill is struck. If all the cuttings are not flushed out, the hole may be cleared with the scraper. As the hole is deepened, longer drills are used.

Blasting

The blasting that a prospector might have to undertake would probably be either drill-hole blasting or what is called bulldozing, mud-capping, or sand-blasting. In blasting, the charge is detonated by means of a primer cartridge made up in the following manner. A piece of fuse, never shorter than three feet, is trimmed squarely across one end with a sharp knife, and that end is inserted gently and without twisting, the full distance into a blasting cap. While it is held in that position, the upper part of the blasting cap is firmly fastened to the fuse by means of the crimper. A double crimp with the latest type of crimper will give a virtually water-tight joint, but under wet conditions a special water-proofing compound, soap, or cup-grease may be applied. The paper fold at one end of a stick of explosive is then carefully opened, and a hole $2\frac{1}{2}$ to 3 inches deep is made in the end of the stick by means of the wooden tool described above; the fused cap is inserted in this hole, and the paper is then drawn closely around the fuse and tied tightly with string. This assembly of cap, fuse, and stick of explosive, is called a 'primer cartridge' or 'primer'. Great care must be taken to avoid kinking safety fuse, as this might result in a misfire. When several shots are to be fired in one blast the fuse for all primers should be cut to the same initial length, no matter what trimming is done after the holes are loaded.

Before loading, the holes are carefully cleaned out with the scraper and tested with the tamping rod to see that there is no obstruction. Usually the primer is loaded first; it must never be tamped but merely pushed to the bottom of the hole, care being taken to ensure that the cap is not pulled out. Sticks on top of the primer are tamped in firmly, but not pounded, and great care must be taken to avoid damaging or kinking the fuse. It is usually not good practice to load the hole for more than $\frac{2}{3}$ of its length. The use of some stemming material such as clay in bags or even earth, old pieces of sacking, etc., pressed firmly into the collar of the hole on top of the explosive, will help considerably.

If a number of holes are to be fired (called a 'round' of holes) this is arranged so that the holes fire in a regular order. This is necessary for two reasons; first, the holes have usually been drilled so that it is necessary for one to break a certain amount of ground in order to give the next an opportunity to break; second, so that a count can be kept of the number of shots. "Rotation Firing" is accomplished by trimming the various fuses to different lengths. After the holes have been loaded (with fuses of equal lengths) a piece is cut from the fuse in the hole to be fired first. The length cut off will depend on the number of holes in the round. This piece of fuse is used to adjust the length of fuse for the number two hole, which must be at least 2 inches longer. The number 3, number 4 holes, etc., are treated in a similar manner. When this has been done the ends of the fuses are split longitudinally for about one-half inch with a sharp knife. The fuses are then lit in the order in which thay are to go off.

Fuses are lit by two standard methods: the spitter and the hot-wire lighter. The spitter is simply a length of fuse with notches in it, the notches being sufficiently deep to cut the powder train and spaced 1 inch to 2 inches apart. As the fire travels along the fuse, flame blows out of each notch in turn and this is used to ignite the fuses in the round. As the spitter burns, it keeps the blaster informed of the length of the first fuse that has burned, and so tells him the amount of time he has left to gain a place of safety before the charge explodes. The use of matches, candles, miners' lamps, etc., to spit a round is an unsafe practice that should never be permitted, because the igniting fuse will as often as not extinguish the flame. The use of the hot-wire lighter is recommended: this is simply a piece of wire coated with a hot-burning compound that may be ignited by a match. The fuse is ignited by placing the burning part of the lighter in the split end of the fuse.

Too much emphasis cannot be placed on the importance of using fuses of a sufficient length. In most provinces a minimum of 3 feet is specified by law, and if more than one hole is to be blasted, a longer fuse must be used. The burning speed of the standard fuse is 40 seconds to the foot, so that 3 feet allows less than two minutes for lighting a round. The fuse manufacturers state that their product has an allowable variation of 10 per cent in burning speed and, for this reason, as liberal a trim as possible should be used; a good rule is to allow $\frac{1}{2}$ inch per foot of fuse.

Bulldozing, mud-capping, or sand-blasting is the method used when rocks are to be broken without drilling a hole. A place on the rock, preferably a small hollow, is selected and a charge, composed of three or four sticks and primer, is placed on the rock at this point. It is then covered with mud or clay and fired as in the case of a drilled hole. The effect of the blast is not nearly so great in bulldozing as it is in a drilled hole, but the factors of time and the expense of drilling sometimes justify the use of this method.

It should be unnecessary to state that every precaution must be taken to see that all approaches to the locality where blasting is being done are carefully guarded. Immediately after the round or charges are lit warning must be given by shouting 'fire' several times. Drillers and others take cover until the 'all clear' is given.

No discussion of blasting or blasting methods is complete without speaking of the treatment of misfires. If the rules and precautions given above are adhered to, very little trouble should be experienced from this cause. However, if a misfire does occur, no one should be allowed to return to the scene of the blast until a period of at least thirty minutes has elapsed. After that time the holes can be examined with comparative safety. If it is found that for some reason the charge has not exploded, no attempt should be made to remove the old charge; it should be fired by means of a fresh primer in the hole on top of it. Another precaution against misfires: never cut fuse until ready to use it.

Sharpening Drills

Several years ago it was customary for prospectors to sharpen their own drills, moils, and picks, but the decline in hand drilling, improvements in transportation, and development of tungsten carbide bits have almost made field blacksmithing a thing of the past. If prospectors need to do drilling by hand, they can nowadays often take with them a sufficient supply of sharpened drills and moils, send dulled ones to a blacksmith for sharpening, or carry a carborundum grinder for sharpening tungsten-carbide bits.

Estimation of Tonnage and Value

Estimates of the tonnage and value of a deposit are made by mining engineers or geologists after detailed exploration has been done. The subject is not discussed extensively here, but it is desirable for prospectors to have knowledge of the general principles involved, to help in obtaining an idea of the worth of a deposit on which they have done preliminary exploration, and to assist in understanding mining reports.

When several representative samples are taken the results are averaged to provide an approximation of the average tenor. If the widths across which the samples were taken are similar, the assay results may be added together and divided by the number of samples, to give what is called an 'arithmetical average'. If, however, the sampling widths are different, each assay result is multiplied by the width for that sample, the figures so obtained are added, and the total is divided by the sum of the widths. Such an average, called a 'weighted average' is more reliable than a mere arithmetical average. The following example shows how such averages are computed, and their difference:

Suppose that five samples taken at 10-foot intervals from a vein of variable width gave assays in gold that had the following values and corresponding widths:

$20 across 5 feet; $10 across 10 feet; $15 across 7 feet; $22 across 3 feet; and $40 across 2 feet. The values multiplied by the widths are:

Width	Assay	Width x Assay
5	$20 per ton	100
10	10	100
7	15	105
3	22	66
2	40	80
—	—	—
27	107	451

The average width is 27 ÷ 5 = 5·4 feet

The weighted average is 451 ÷ 27 = $16.70

On the other hand, the arithmetical average is 107 ÷ 5 = $21.40

When assays are being averaged, if a few are much higher than the remainder it is generally assumed that the high ones are 'erratics' that are too high to be used because they would greatly affect the average. They are generally reduced to a more conservative figure. An average calculated after erratic assays have been reduced is called a 'cut' average.

To calculate tonnage, if samples were taken at close intervals, each line sampled may be assumed to represent the width of the deposit for a block extending half way to the adjacent sampling lines, and this length is multiplied by the width. If samples have been obtained at depth, by drilling or underground exploration, widths and assays may be assumed to be representative for half the downward distance between sampling places. This distance multiplied by the width and horizontal distance give the estimate of volume for that particular block. The volume is multiplied by a factor representing the number of pounds per cubic foot for that type of rock or ore, and in this way the tonnage is calculated. The results are sometimes stated in terms of the entire block, and sometimes as tons or dollars per vertical foot. For detailed estimates the calculations are usually much more complex than the examples outlined above.

It should be remembered that the widths used must be the true widths, at right angles to the dip and the strike of the deposit. If an outcrop or trench slopes so that the true width cannot be sampled, or if a drill-hole or underground working intersects the deposit at an angle, a correction for true width must be made. Diamond drilling may give misleading results in this regard, for if the hole intersects the deposit at a considerable angle from the perpendicular, a long intersection may be obtained from a relatively narrow deposit.

Various terms are used to express the degree of certainty of estimates of tonnage and value. The following definitions have recently been approved by the United Nations Educational, Scientific and Cultural Organization and are used by the Department of Mines and Technical Surveys.

Ore is a mineral substance that can be mined at present at profit to the operator or to the benefit of the nation.

Measured (Proven) Ore: — Ore for which tonnage is computed from dimensions revealed in outcrops, trenches, workings, or drill-holes, and for which grade is computed from adequate sampling. The sites for inspection, sampling and measurement are so closely spaced, on the basis of defined geological character, that the size, shape, and mineral content are well established.

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

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

Suggestions for Additional Reading

Canadian Industries Limited: The Blaster's Handbook; price $3 from any C-I-L Explosives Division branch (1955).
A 500-page book containing instructions for the handling and use of explosives, with many diagrams and photographs.

Cumming, J. D.: Diamond Drill Handbook; J. K. Smit & Sons of Canada Ltd., Toronto (1951).
A comprehensive book giving details of diamond drills and their use.

Gunther, C. G.: The Examination of Prospects; McGraw-Hill, 1912.
A pocket-size book on the examination of mineral deposits and on their form and origin.

Jackson, C. F. and Knaebel, J. B.: Sampling and Estimation of Ore Deposits; *U. S. Bur. Mines*, Bull. No. 356, 1934. Price 25 cents.
A useful summary of information on methods of sampling mineral deposits and estimating their tonnage and value.

Reid, J. A. and Huston, C. C.: The Practical Examination of Mineral Prospects; *Trans. Can. Inst. Min. Met.*, vol. XLVIII, pp. 270-283 (1945).
A paper on appraising prospects and preparing reports thereon. Besides providing information that may be useful to engineers and geologists engaged in such work, the views expressed would assist prospectors to form a better idea of the kinds of discoveries that may be important, and to understand the viewpoint and problems of the examiner.

Stevenson, J. G. A.: Trends and Practices in Diamond Drilling. *Bull. Can. Min. Met.*, Oct. 1955, pp. 639-653.
A comprehensive article covering modern tools and techniques.

CHAPTER XII

NOTES ON SPECIFIC METALS AND MINERALS

This chapter is intended to provide brief information to permit prospectors to decide on the metals or minerals most worthy of attention, and to provide some data on their modes of occurrence and the manner in which some of the principal mines were found. A few points should be emphasized at the outset. First, it is not possible to list all the metals or minerals that may be of interest; therefore a selection has been made. Second, it is impossible to include many details; therefore the notes are intended as summaries, followed by references to fuller information, although it is realized that many may be difficult to consult, except in large libraries. Third, prices, demands, and other conditions are subject to change, sometimes quite abruptly; the notes therefore contain only the most authoritative information available as of early 1955. More recent information may be obtained from the mining press and such publications as the annual reviews on particular metals and minerals issued by the Mines Branch, Department of Mines and Technical Surveys. In any event, an outstanding discovery is likely to be attractive even if the buyer has to wait for a favourable market or has to develop one.

First considered are those metals and minerals being produced in Canada to a value of five million dollars or more a year. Aluminum is included in this category for the sake of completeness, although Canadian aluminum production comes entirely from ore brought to this country for treatment. These notes are followed by shorter ones on many of the metals and minerals produced in lesser quantities, and on some of those not produced in Canada but of present or potential economic significance.

The notes deal mainly with metals because these are of interest to most prospectors. Several industrial minerals are also discussed, as well as gems and meteorites. Industrial minerals comprise a large and important part of Canada's mineral production, but in general they are not of so much concern to the average prospector as are metals, because they commonly have low unit values and because the specifications are commonly so exacting that it is difficult for anyone but a specialist to judge whether a particular deposit is suitable. In many instances a company, knowing of a demand for a certain industrial mineral, will send a specially trained man to search in localities where the geology is favourable and which are close to transportation. Therefore, although prospectors should not ignore industrial minerals, most will be concerned mainly with prospecting for metalliferous deposits.

Main Products

Aluminum

Canada is the second largest producer of aluminum, turning out more than one billion pounds a year, most of which is exported. Yet not one pound of aluminum ore is mined in Canada, or is likely to be in the foreseeable future.

This paradoxical situation is easily explained. Aluminum is the most abundant metal in the earth's crust, but occurs chiefly in the form of silicates, such as the feldspar minerals that are a main constituent of granitic rocks and the sedimentary rocks and clays that result from the alteration of the granites. While methods of extracting aluminum from clays and feldspars have been developed in the laboratory, these minerals cannot be treated economically under present conditions. The commercial ore of aluminum is bauxite, a hydrous oxide of aluminum formed by the slow surface weathering of rocks, chiefly in tropical countries. It is most unlikely that bauxite will be found in Canada, for if any deposits had been formed before the Ice Age they would almost certainly have been destroyed by glacial action, since bauxite is a very soft mineral.

It is the combination of abundant and cheap hydro-electric power and economical water transportation that has enabled Canada to build up its aluminum smelting industry, as bauxite from British Guiana and West Africa and alumina from Jamaican bauxite can be landed directly at the smelters in Quebec and British Columbia, and the metal can be shipped out by the same economical method.

Until recently most of the aluminum produced in Canada came from Arvida, Que., where the largest single aluminum smelter in the world was built to utilize power generated in the basin of Saguenay River. As demands for aluminum increased, a new smelter was recently built on the coast of British Columbia as part of the Kitimat project, whose combined dams, tunnels, underground generating station, transmission line and smelter constitute one of the greatest engineering achievements of all time.

Reference

Aluminum in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Asbestos

Canada is the world's leading producer of asbestos, the uses of which are well known. Asbestos, of the variety called chrysotile, is the principal industrial mineral mined in Canada, the value of the production in 1954 being more than $86 million. Most of the Canadian output comes from the Eastern Townships of Quebec, mainly from the vicinity of Thetford Mines and Black Lake, where mining has been continuous since 1878. Several large mines are worked, both by open-pit and underground methods, and large reserves remain despite the great amounts produced for many years. During the last few years these mines have been greatly expanded and modernized. In addition, a mine in Ontario and another in British Columbia have recently begun production. Many other Canadian occurrences of different varieties of asbestos are known, but to be productive an asbestos deposit must be of proper quality and must occur in large quantity.

Chrysotile asbestos is a fibrous variety of serpentine formed by alteration of ultrabasic rocks. Occurrences of such rocks, which are fairly common in parts of the Canadian Shield, and of the Cordilleran and Appalachian regions, are therefore the logical places to prospect for asbestos.

Quebec

Asbestos was found near the Des Plantes River in the Eastern Townships about 1862, but attempts to work the small deposits there failed. In 1877 the mineral was found near Thetford, and mining on a small scale was begun the following year. It was difficult to find a market at first, but as the quality became known and as new uses were developed, rapid expansion took place over the next 12 years.

The chrysotile is found in peridotite that has been altered to serpentine, which occurs with pyroxenite in sill-like and stock-like masses in a narrow interrupted zone, commonly referred to as the Serpentine belt, which extends northeastward for about 150 miles from the Vermont border. Still farther northeast, small areas of similar rocks occur but have not yielded commercial grades of asbestos. In the Thetford area the peridotite lies mainly within the Caldwell group, of Cambrian age, but it also intrudes strata of Ordovician age; the age of the intrusions is therefore probably late Ordovician and related to the Taconic period of mountain building.

The chrysotile is of two types, called cross fibre and slip fibre. The former, which accounts for most of the production, occurs in veins with cleancut walls, the fibres arranged parallel to one another and at a high angle to or normal to the walls. The veins are generally from a fraction of an inch to 3 inches wide. Vein matter that is more than $\frac{3}{8}$ inch wide is called 'curde', and is hand selected, whereas shorter material is milled, the rock being crushed, beaten, and screened and the asbestos separated by overhead suction. The milled variety amounts to more than 99 per cent of total production. The cross-fibre veins are of two types, one containing a single set of fibres running from wall to wall, and the other containing fibres extending from each wall and meeting at a central fissure that may contain serpentine similar to the wall-rock, and magnetite. Both types occur throughout the deposits. The walls of the veins consist of serpentine that grades into the ordinary partly serpentinized peridotite. This border zone is lighter in colour than the surrounding rock, and the edges are sufficiently sharp to enable the rock to split readily along them. The width of the altered zone, including the asbestos vein in the middle, is commonly from 6 to 8 times the width of the vein itself.

The slip fibre type occurs in much-sheared serpentine, the fibres being matted and lying more or less lengthwise along the shear planes.

F. J. Alcock has summarized the probable origin of the deposits as follows:[1] "It is probable that the rocks were serpentinized originally at a late stage in their consolidation, as a result of reaction between the mineral constituents and associated magmatic water. Though associated with the peridotite the asbestos is quite clearly of later origin. Veins cut across pyroxenite dykes and across masses of chromite in the peridotite. At one place a granite dyke was found to contain inclusions of peridotite, and in one of these inclusions was a vein of asbestos 3 feet long and with a maximum width of $\frac{3}{4}$ inch running out from the peridotite into the surrounding granite. Evidently this asbestos was formed after the intrusion of the granite. The veins are related to fault fissuring, and apparently were formed by vapours travelling along the fissures, converting the walls into serpentine. The presence of magnetite suggests that this alteration took place at high temperatures. From the fault fissures the vapours penetrated the pores of the rock, and wherever they encountered incipient fractures they reacted with the peridotite, converting the walls into serpentine and carrying some of the excess material into the fissures to be deposited as asbestos. It is probable that this second period of serpentinization and the production of the asbestos are related to the Devonian orogeny and accompanying intrusions."

Ontario

Production began in 1950 from a large deposit of chrysotile asbestos in Munro and Beatty townships, 10 miles east of Matheson, in the region north of Kirkland Lake.

The fact that chrysotile occurred here was noted in reports of the provincial and federal departments of mines issued in 1915 and 1931 respectively, and a map by J. Satterly of the Ontario Department of Mines, published in 1945, showed a belt of serpentinized peridotite, and related rocks. In 1948 A. Heffren, whose home was in the vicinity of Matheson, worked at one of the Quebec asbestos mines, where he became familiar with the commercial grades of asbestos. This reminded him of an occurrence he had seen in Munro township several years earlier. He revisited the area and secured samples, which he showed to engineers of the mine in Quebec. This led the company to examine the showings and to acquire claims. Diamond drilling and dip-needle and magnetometer surveys begun in 1949 outlined large bodies containing veins of chrysotile in serpentinized peridotite in a large differentiated sill-like mass of basic and ultra-basic rocks. A large open-pit operation began production in 1950, after a mill for treating the ore had been built; the present capacity is 2,200 tons a day. This operation has led to several other discoveries in the region and in the vicinity of Timmins, but none has yet been brought to production.

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[1] *In* Geology and Economic Minerals of Canada, Geol. Surv., Canada, Econ. Geol. Ser. No. 1, Third Edition, pp. 140-141 (1947).

British Columbia

The Cassiar asbestos mine on McDame Mountain in the northern part of this province began production in 1953.

The deposit contains chrysotile in a basic rock, probably Jurassic in age, which is so altered to serpentine that its original nature is doubtful. After a large body of chrysotile-bearing rock was outlined by the company optioning the claims from the prospector, and tests had shown that the mineral was of such high quality that the deposit would pay to work despite the distance from markets, a branch road was built to join a road leading to the Alaska Highway, and a mill with an initial capacity of 150 tons a day began operation in 1953. This was increased to 500 tons a day in 1954.

References

Cassiar Asbestos Expands Production; *Western Miner*, vol. 26, No. 11, 1953, pp. 68-69.
A summary of the geology of the Cassiar asbestos deposit in northern British Columbia and an account of recent developments there.

Asbestos in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Cooke, H. C.: Asbestos Deposits of Thetford District, Quebec; *Econ. Geol.*, vol. XXXI, 1936, pp. 355-376.
A description of the geological and structural setting of the asbestos deposits of the Thetford district, and a discussion of the theories of origin of these deposits.

Hendry, N. W.: Chrysotile Asbestos in Munro and Beatty Townships, Ontario; *Trans. Can. Inst. Min. Met.*, vol. LIV, 1951, pp. 28-35.
This account of the discovery and exploration of a deposit that was recently brought to production in Ontario is of interest to those searching for or testing asbestos deposits.

Hewitt, D. F. and Satterly, J.: Asbestos in Ontario; Ont. Dept. Mines, Industrial Mineral Circular No. 1, 1953.
This report describes asbestos minerals and their mode of occurrence, gives information on economics and marketing, and describes the principal occurrences known in Ontario.

Ross, J. D.: Chrysotile Asbestos in Canada; Mines Branch Rept. 707, 1931 (out of print).
A comprehensive report on mining for asbestos in Canada up to 1931. It includes information on asbestos minerals and deposits known in Canada up to the time of publication.

Stephens, F. H.: Asbestos in Southern B. C.; *Western Miner*, vol. 26, No. 7, 1953, pp. 44-46.
A short account of exploration on asbestos occurrences in southern British Columbia.

Copper

Copper is one of Canada's principal mineral products, the value of the output in 1954 being about $174 million. In that year, twenty large mines, chiefly in the Canadian Shield, were in production. Copper is used in great quantities by industry, and in recent years supply and demand have tended to remain about balanced: additional commercial deposits are therefore likely to be in demand. At the time of writing, late in 1955, there is considerable interest in prospecting for copper and in exploring promising showings.

Deposits in the Canadian Shield

Copper mining began in Canada in 1847 at the Bruce mine on the north shore of Lake Huron, where copper-bearing quartz veins in diabase were worked until 1921.

The main production comes from several large copper-nickel mines in the Sudbury region, described in the section on nickel. In 1954 Ontario supplied over 46 per cent of the copper produced in Canada.

Quebec supplies about 30 per cent of the total, mainly from mines in the Shield but also from several in the Appalachian region. The former are mostly in western Quebec, and the largest of these, the Horne, is described briefly below. In addition, copper deposits in the Chibougamau region farther to the northeast, that have been known for many years, have recently been brought into production, and a railway is being built into the area.

The Horne mine is the parent mine of Noranda Mines Limited, a company that, after the initial success of the Horne, has played a leading part in the exploration and development of several large gold and copper mines in Ontario and Quebec. The discovery of the Noranda deposits in what was then a part of Quebec difficult of access was a result of the spread of prospecting after the gold discoveries in northern Ontario. One prospector, E. H. Horne, made several trips in 1911 and following years into the region that later became known as the Noranda or Rouyn camp, and was impressed by the presence of greenstone there. He found and staked an occurrence containing pyrite, chalcopyrite, and gold in 1920. Further prospecting showed that these minerals were fairly widespread, and in 1922 the claims were optioned to a syndicate that later became Noranda Mines Limited. In 1923, trenching revealed a large body of sulphides, and after diamond drilling from the surface, a shaft to explore this was begun. When the results seemed to warrant production, and a branch railway line had been built, a concentrator and smelter were erected and production began late in 1927. This mine is one of the rare examples in which great improvement with depth was found, for as exploration was continued below the upper levels, even more important orebodies were found. These and others in the district are large, irregularly shaped replacement masses, usually in rhyolite agglomerates, tuffs and flows shattered by folding or faulting. The sulphide minerals are mainly pyrite, pyrrhotite, and chalcopyrite, and at some of the mines in the district there is also considerable sphalerite. Some of the bodies also contain important amounts of gold. In 1954 the Horne produced 21,881 tons of copper and 168,067 ounces of gold, as well as much silver and pyrite; use of the last-named for the production of iron oxide sinter, sulphur, and sulphur dioxide began late in the year. The principal ore reserves at this mine are reported to average 2·28 per cent copper and 0·187 ounce of gold a ton.

Another important copper producer is the Flin Flon mine of Hudson Bay Mining and Smelting Company Limited, which is in the southern part of the Shield and on the boundary between Saskatchewan and Manitoba. Here replacement bodies in sheared volcanic rocks on the limb of a large drag-folded anticline contain pyrite, chalcopyrite, sphalerite, and pyrrhotite. Ore reserves are reported to average 0·075 ounce of gold and 1·02 ounces of silver a ton, 3·25 per cent copper, and 3·9 per cent zinc. In 1954 the mine produced about 45,000 tons of copper. Important zinc-copper deposits are being developed in the Manitouwadge region, Ontario, following recent discoveries there.

Cordilleran Region

For many years British Columbia has been an important producer of copper, chiefly from large mines in the more accessible regions near the coast and the boundary with the State of Washington. Some of these, such as the mines at Rossland, Phoenix, and Anyox, have been exhausted for several years, but several others continue to be productive. The principal of these are the Copper Mountain, Britannia, and Tulsequah Chief-Big Bull. The principal producer at present is the Copper Mountain mine of Granby Consolidated Mining, Smelting, and Power Company, near Princeton. The ore is in and near a stock that varies from gabbro at its margin to copper-bearing syenitic pegmatite at the centre. None of the rocks contain quartz. The different types show evidence of having differentiated in place from a single magma. The orebodies, which differ from most Canadian ones by containing bornite as the chief copper mineral, occur principally in fragmental volcanic rocks of Mesozoic age, close to the intrusive stock. The ore is reported to contain about 1 per cent copper, as well as some silver and gold. In 1954 the mine produced about 12,000 tons of copper.

Considerable exploration of copper deposits is currently proceeding in northern British Columbia and Yukon Territory.

Appalachian Region

Copper has been produced for some time from mines that usually produce other base metals as well, in Newfoundland, Nova Scotia, and the Eastern Townships of Quebec. The principal mines are the Buchans in Newfoundland, the Stirling in Cape Breton Island, and the Suffield, Weedon, and Huntingdon in the Eastern Townships.

The large mine of Gaspé Copper Mines Limited came into production early in 1955. The principal orebodies are replacements containing chalcopyrite, bornite, chalcocite, and cubanite as the copper minerals, in altered limestone of Devonian age. A granitic intrusion that caused both the alteration and the ore is believed to lie beneath the deposits. Ore reserves were reported to be 67 million tons averaging 1·3 per cent copper.

The orebodies now being explored at Bathurst, N.B., which are described briefly in the section on zinc, will also yield copper, as two of them contain about 0·5 per cent of that metal.

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Gold

Gold is one of Canada's chief mineral products, the annual value of production in recent years being about $150 million. The gold mining industry has, however, been going through a difficult period because of international monetary problems and because the price of gold is more or less fixed while the cost of mining has risen greatly. Interest in prospecting for gold and in bringing new gold mines into production is therefore at a low ebb at the time of writing, and only the most favourable gold discoveries are likely to attract attention under present conditions.

Historical

As explained in more detail in the chapter on placer deposits, the first large production of gold in Canada was in the Appalachian region of Quebec, where placer mining began in the basin of the Chaudière River in 1847. A few years later discoveries of rich placers in British Columbia caused the beginning of a large production of placer gold in the Cordilleran region. This kind of mining reached its peak at the turn of the century as a result of the Klondike discoveries in Yukon Territory. Since 1900, when gold to the value of $22 million was taken from the Klondike alone, Canadian production of placer gold has gradually declined.

During the period of great interest in placer mining in the west it was natural that some men would turn their attention to prospecting for lodes, and that many quartz veins and other gold-bearing lode deposits would be found. Even before the placer rush, a little lode gold was mined on one of the Queen Charlotte Islands in 1852. Twenty years later an arrastra was used in an attempt to work a lode gold deposit in central British Columbia. A stamp mill was built in the Cariboo district of British Columbia in 1876 but this attempt to work gold-quartz deposits had little success. Near the end of the century, however, important gold-bearing lodes were brought to production in southern British Columbia, largely as a result of the impetus given by the building of the Canadian Pacific Railway. Most important were the replacement veins containing gold and copper in the Rossland camp, where production began in 1894 and a large output was obtained from 1897 to 1916. Another important producer, the Nickel Plate mine at Hedley, began production in 1903 and is still operating; for a time it was the largest Gold mine in Canada. The Nickel Plate ores are gold-bearing contact metasomatic deposits in limestone, containing much arsenopyrite. These mines, together with several smaller ones, made British Columbia the leading province in the production of lode gold during the early years of the present century.

Important gold mining was carried on in Nova Scotia for many years on gold-quartz veins in slates, generally along the crests of anticlines. These veins occurred in the Gold-bearing series, a thick succession of quartzites and slates considered to be late Precambrian by some geologists, and Cambrian by others. The veins are believed to owe their origin to granitic intrusions of Devonian age. Production began in 1862 and declined after about 1904, but reached a new high in 1939, largely as a result of the 1934 revaluation of gold by the United States from $20.67 to $35 an ounce. Output has since declined greatly.

The first discovery of gold in the Canadian Shield was in 1866 not far from Madoc in southeastern Ontario. Other discoveries soon followed in this region, and, after the building of the Canadian Pacific Railway in 1886, in the region between Port Arthur and Winnipeg. Small mines were brought into production in both regions, but they did not challenge the lead then held by British Columbia.

After Sudbury and Cobalt became established respectively as great nickel-copper and silver camps, the importance of the Canadian Shield as a source of minerals began to be better realized. Prospectors and financiers turned their attention to the area in greater numbers, thus beginning a succession of important gold discoveries that has continued to the present. The first of these was what became the Porcupine camp. A geologist of the Ontario Department of Mines had found traces of gold in quartz veins there as early as 1896, and in his report recommended the area to prospectors. The first discovery by a prospector was in 1906, but the important discoveries that became the Dome, Vipond, and Hollinger mines were made in 1909. Regular production began at the Hollinger in 1912 and has continued to the present, with gradually increased scale of operation. Other important mines came into production in the district from time to time, making the Porcupine camp one of the great gold producers of the world.

The Porcupine discoveries caused prospecting to spread eastward and westward in the more accessible parts of the Shield. The first great gold camp discovered after Porcupine was Kirkland Lake, where early finds were made in 1911 and 1912. Production began in 1915, and as additional mines began operating and tonnages were increased, the camp gradually came to rank with Porcupine as a major gold area.

The depression that began in 1929 and lasted until about 1939 caused an extraordinary expansion of gold mining, at first because gold had a steady market at a fixed price at a time when prices of other commodities fell, and later because the official price of gold was raised by the United States in January 1934 from

$20.67 to $35 an ounce. Many new mines were brought into production in Quebec, Ontario, Manitoba, Saskatchewan, and the Northwest Territories; the last great camp to be developed was Yellowknife, where production began in 1938. Some of these were new discoveries and others were known formerly but were not sufficiently attractive at the former price of gold. In addition, many of the mines that operated successfully at the old price had substantial amounts of low-grade material that could be mined profitably at the new price. Canadian gold production reached its peak in 1941, when 5,345,179 ounces valued at $205,789,392 were produced; this included about $2,700,000 worth of placer gold. During these years gold held an envied place in the Canadian economy.

After 1941 gold production dropped, at first because of difficulties in obtaining supplies and labour during World War II, and since then because of rising costs and labour problems. Despite substantial cost aid paid to gold mines by the federal government through the Emergency Gold Mining Assistance Act to offset these difficulties, a number of important mines have been forced to close. By 1954 production had fallen to 4,366,440 ounces valued at $148,764,611, but Canada maintained her position as the second greatest gold producer, ranking next to South Africa, which produced about 12 million ounces. There was little prospecting or exploration for gold and no new mines were added. That a gold mine with ore of high grade can be exploited even during such unfavourable times was, however, shown in 1949 when a deposit averaging about one ounce a ton, in a fairly inaccessible part of the Northwest Territories, was brought to production at a rate of about 100 tons a day.

Because the amount of gold used in industry and the arts is slight compared to that used as money, stored as backing for paper currencies, or used for settling international obligations, the future of gold mining depends largely on future policies, of other countries as well as Canada, which are difficult to predict. So long as present conditions prevail, a substantial production will probably continue to come from most mines already established, but prospecting and exploration for gold will probably be less attractive than for some other metals.

Deposits in the Canadian Shield

At present the Canadian Shield accounts for about nine-tenths of the Canadian production of gold, the remainder coming mainly from the Cordilleran region. For many years Ontario has been the principal producer, followed by Quebec. In 1953, mines operating at 100 tons a day, or more, amounted to thirty-two in Ontario, sixteen in Quebec, three in Northwest Territories, and two in Manitoba, not counting mines that produced gold as a by-product. Thirteen of the mines operated at rates of more than 1,000 tons of ore a day, the largest being Kerr-Addison, in the Larder Lake area of Ontario, with an average rate of 4,485 tons a day.

The gold deposits of the Canadian Shield differ greatly in details, but they fall into three broad categories. One type, naturally enough, consists of gold quartz deposits that may be large quartz veins or aggregates of many irregular veinlets and lenses; in some the gold is visible and free milling, but much of it is of microscopic size and often occurs in grains of sulphide minerals. Another type consists of altered rock, often schist, containing disseminated gold, frequently associated with sulphide minerals. Many mines contain bodies that are mixtures of both these types; gold occurring both in stringers and lenses of quartz and in the intervening rock, so that large bodies can be mined economically. The third type consists of large sulphide orebodies mined mainly for copper and other base metals (such as the orebodies of the Sudbury and Noranda districts) that yield substantial amounts of gold.

The principal gold deposits of the Shield occur in belts of early Precambrian greenstones or sedimentary rocks, or both. Although gold mines are scattered widely in the Shield, the main ones are in three belts. One of these extends through the Porcupine camp, is represented by a few additional deposits farther east in Ontario, and extends into Quebec, where it contains the Beattie mine and other deposits. Another belt, about 100 miles long, includes the mines at Kirkland Lake, several of which are worked on what is really a single long orebody. This belt continues, with deposits spaced intermittently, through the Larder Lake district in Ontario and for many miles in Quebec, where it includes the Noranda, Malartic, and Val d'Or regions. Many of the orebodies in each of these belts are associated with bodies of quartz-feldspar porphyry, syenite porphyry, or other intrusive rocks, and the orebodies are commonly related to prominent faults and shear zones that provided access for the intrusions and the ore-bearing solutions. A third belt, called the Yellowknife Gold Belt, includes the important Giant Yellowknife and Con-Rycon orebodies in the Northwest Territories, which lie in large shear zones displaced by a prominent post-mineral fault.

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Gypsum

Gypsum (hydrous calcium sulphate) is an important commodity used mainly in the manufacture of plaster, plaster board, and cement. In 1953 gypsum to the value of about $7 million was produced in Newfoundland, Nova Scotia, New Brunswick, Ontario, Manitoba, and British Columbia. About half of this production was used in Canada and the remainder was exported.

Gypsum is formed by the evaporation of water in shallow basins, the deposit being incorporated as lenses or beds in sedimentary formations. Anhydrite (anhydrous calcium sulphate) is commonly associated with gypsum deposits, but it has relatively few uses. Most Canadian deposits of gypsum are in Palæozoic formations. Gypsum is not likely to be of concern to prospectors for the following reasons: (1) many occurrences are already known; (2) should additional deposits be desired they will probably be developed by diamond drilling along zones outlined by geological studies; and (3) it is necessary to distinguish carefully between gypsum and anhydrite, which resemble one another.

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Iron

Iron is one of the most vital and largely used commodities because, in the form of steel, it is a foundation of our industrial life. Iron ore has been produced in increasing amounts in Canada since 1939 because of the economic growth of the country and because depletion of high-grade deposits in the United States has spurred development of new sources of supply. Three important new mines have come into production since the end of the war—the Knob Lake deposits in Quebec-Labrador, and the Steep Rock Lake and Marmora deposits in Ontario—and a number of prospects are being actively explored. At present Canada ranks eighth as a producer, but this status will rise sharply within the next decade as present sources come into full production and new ones are developed. There can be little doubt that iron ore will be required in increasing amounts by world markets, but it should nevertheless be stressed that only large deposits with a high iron content, and such that the ore can be mined and treated cheaply, are likely to be of commercial importance.

History

Many years ago early settlements in Quebec and Ontario were supplied with iron by small local charcoal furnaces that smelted limonite from bog iron deposits and magnetite from small deposits in the southern part of the Canadian Shield. As soon as transportation facilities were improved it became cheaper to import iron and steel from other countries, so these early mines were abandoned.

Small iron mines have been operated intermittently in the Appalachian region since 1848. Ore from the large Wabana deposits of Newfoundland, which have been mined since the turn of the century, has for many years been smelted at the steel plant at Sydney, N.S.

Shipments of iron ore from the Texada Island mine in British Columbia were made to the United States from 1886 to 1908, and this mine and another at Quinsam Lake in the same province have recently begun shipping magnetite concentrates to Japan.

Iron deposits have been found in many places in the southern part of the Canadian Shield in Ontario, but most have been too small or too poor for profitable mining. The first to be worked successfully on a large scale was in Michipicoten district, where the Helen mine was worked from 1900 to 1918. This deposit was found in 1898, by a prospector named Goetz, who staked a gossan as a possible gold discovery; it turned out to be an iron mine. No iron ore was produced in any part of Canada from 1925 to 1938 inclusive. In 1939, large operations were resumed in Michipicoten district and have continued as a source of iron ore for the steel plant at Sault Ste. Marie.

Large deposits of high-grade ore, averaging about 60 per cent iron, were brought into production at Steep Rock Lake, 120 miles west of Port Arthur, in 1944 after an interesting history and an outstanding engineering achievement. Boulders of hematite were found on the shore of Steep Rock Lake during geological mapping in 1885, and it was concluded from their unglaciated appearance that they had not travelled far and probably came from a source later covered by the lake. The notes accompanying the map, published in 1897, contained the statement: "An iron-bearing horizon with hematite of good quality, appears to be generally covered by the waters of the lake". This report caused much prospecting and staking in the area, but these early endeavours were unsuccessful. Further studies called attention to promising occurrences found in place, and thereafter a great deal of prospecting was done. A persistent prospector, Jules Cross, made a dip-needle survey of a part of the lake from the ice in 1930, and his backers provided funds to diamond-drill from the ice the anomaly his survey indicated. The first important drill intersections were found in 1938. When a large body of good-grade iron ore had been outlined, the Seine River, which drained into Steep Rock Lake, was diverted by several dams and cuts, and the lake was pumped out to permit open-pit mining, which began in 1944. In 1953 development of an underground mine was begun, to obtain ore from parts of the main deposit that are too deep for open-pit operations. Production exceeded 2 million tons in 1955, and is expected to reach 10 million when development is complete.

The history of the development of the Quebec-Labrador deposits also shows the importance of geological studies, the long time often required before discoveries can be exploited, and the large expenditures and extensive engineering work involved. From 1892 to 1895, A. P. Low of the Geological Survey of Canada carried out geological explorations in Ungava and Labrador and reported the presence of large deposits of iron-bearing material in the basins of Hamilton and Koksoak Rivers, which he thought might be of economic importance at some future date. In 1929 a company undertook exploration of these and found deposits of good grade close to the scene of the present mining, but the location in relation to the demand for iron ore at that time did not favour exploitation.

In 1936 another company, Labrador Mining and Exploration Company Limited, was formed to search for gold and base metals in this general region. Systematic geological studies and prospecting were done under the direction of J. A. Retty, who was the first to find iron ore on the Quebec side of the Labrador watershed. This work was continued by the company and after 1942 by Hollinger North Shore Exploration Company Limited and The M. A. Hanna Company. When sufficient ore had been proved to warrant the building of a 358-mile railway from Seven Islands on the north shore of the St. Lawrence, Iron Ore Company of Canada was formed in 1949 by the three above-mentioned companies and several large steel companies in the United States, for the purpose of building the railway and bringing the deposits into production. This was accomplished after an expenditure of about $250 million on exploration and construction, and in 1954, 60 years after Low's explorations, the first shiploads of iron ore left Seven Islands bound for steel mills in Canada, the United States, and Europe. Production in 1955 amounted to 7 million long tons.

This successful development has caused other companies to acquire concessions throughout the Labrador iron belt, which extends northwestward for about 500 miles and southward for 150 miles from Knob Lake. Much systematic prospecting, geological mapping, and exploration are being done, and other mines may eventually be brought to production.

In 1949 an aeromagnetic survey carried out by the Geological Survey of Canada for the Ontario Department of Mines revealed a strong anomaly near Marmora, close to the southern boundary of the Canadian Shield. Soon after the map was published, Bethlehem Steel Corporation acquired the ground and drilled it, revealing the presence of a large deposit of magnetite in much-altered Precambrian limestone, overlain by a thickness of about 140 feet of nearly horizontal beds of Palæozoic limestone. This was removed to expose the ore and permit open-pit mining. An output of 500,000 tons of pelletized concentrates a year is expected. Production began in May 1955.

Iron Minerals

The principal minerals of iron ores are hematite (Fe_2O_3) and magnetite (Fe_3O_4), which are oxides of iron that occur together in some ores and separately in others. Also important in some ores are limonite ($2Fe_2O_3 \cdot 3H_2O$), the hydroxide of iron; siderite ($FeCO_3$), the carbonate of iron; and chamosite, a hydrous aluminum silicate of iron. The presence of even small amounts of phosphorus or sulphur in iron ores is very detrimental and may make them unsuitable for blast furnace use. Sulphides of iron such as pyrite and pyrrhotite, which are very common and sometimes are found in large bodies, are not usually worked for their iron content alone but rather for their sulphur content; such operations occasionally provide by-product iron oxide, suitable for use as an iron-ore raw material.

Deposits

Iron deposits are of several kinds. The origin of some of these seems clear, but the details for some of the others are still open to question.

One type appears to have been formed by magmatic segregation. All basic igneous rocks contain magnetite or other iron minerals in accessory amounts, and these have been concentrated, seemingly while the rock was still molten, to form masses, some of which are fairly large and rich in iron. It is possible, however, that the origin may not be as simple as outlined above, and that the iron minerals may have been introduced as a later phase of the intrusive process, which partly replaced the earlier-formed rock. Deposits of this kind have not been worked to any extent in Canada for iron alone, although some ultimately may be. Iron is obtained as a by-product from titanium ores of this general type, mined on a large scale in eastern Quebec for titanium dioxide.

Many contact metasomatic deposits containing magnetite have been found in Canada and some of the larger ones have been worked, e.g. the recently opened deposit at Marmora. These deposits are usually found in limestone, but also in other rocks, close to the margins of intrusive stocks or batholiths of granitic or more basic composition. As a late phase of the intrusive process, magnetite appears to have been carried by hot solutions into the intruded rock, where it crystallized in veins or masses that are commonly surrounded by a border of altered rock called 'skarn', containing garnet and other typical contact metasomatic minerals. Therefore, prospecting for deposits of this kind should be done in rocks intruded by stocks or batholiths, and particular attention should be paid to the vicinities of the contacts of limestones and other carbonate rocks with intrusives that contain magnetite as an accessory mineral. Altered zones carrying garnet or other lime silicate minerals would be particularly favourable.

Sedimentary Deposits

Unconsolidated placer deposits containing magnetite derived from the weathering of rocks in which it was an accessory mineral are common. They occur as stream placers in the Cordilleran region and as beach placers along the Pacific Coast, the Gulf of St. Lawrence, and Lake Superior, but have not been successfully mined for iron ore. Occurrences formed in this way are also found as magnetite-bearing beds in consolidated strata.

Bog deposits of limonite are formed in stagnant water. Everyone has seen small patches of iridescent bluish scum on the surface of pools of water. Some of this material is composed of iron hydroxide, the iron being leached from nearby rocks or sands by surface water or springs; some may be caused by fatty material released from decayed vegetation. If sufficient iron hydroxide accumulates and settles, a deposit of limonite is formed. Small deposits of this kind have been found in several parts of Canada, but they are not likely to be of commercial value.

The Wabana ore consists of layers containing small round 'ooliths' composed of concentric shells of chamosite and hematite, interbedded with sandstone and shale of early Palæozoic age. The iron-bearing minerals appear to have been deposited directly as a sediment, and the iron they contain seems to have been derived from the weathering of rocks that contained this metal only in accessory minerals. The iron probably was dissolved in sea water and re-deposited in the form of ooliths and iron carbonate.

Keewatin Iron-Formation

Thin alternating layers of cherty quartz or jasper, and magnetite or hematite, are fairly common as interbeds in Keewatin lavas and other early Precambrian rocks. Deposits of this kind are generally called iron-formation. Some may be simple sedimentary deposits, but their common association with lavas suggests that the iron may have been contributed to the water that deposited it, not by weathering of rocks exposed on land, but from volcanic sources.

The important deposits at Michipicoten and Steep Rock Lake differ from the ordinary type. At Michipicoten much of the ore consists mainly of siderite, and at Steep Rock the ore consists chiefly of goethite (hydrous iron oxide) with some irregular zones of hematite. It is believed by some that these ores were formed by replacement of pre-existing rocks, the iron being introduced by solutions, but others believe that the Steep Rock ore is the result of weathering of iron-bearing rocks in Precambrian time.

Animikie Iron-Formation

This name is given by United States geologists to the typical iron deposits found in Proterozoic rocks. Deposits of this kind have been the principal source of iron ore mined in the United States in Minnesota and nearby states. The Quebec-Labrador deposits are also of this general type. Similar deposits, but not of ore grade, have been found in Canada west of Port Arthur, on the Belcher Islands in Hudson Bay, and elsewhere.

This younger type of iron-formation is much like the Keewatin type, but has a granular appearance like sandstone. Wavy or concentric banding is common in such deposits, and they commonly contain slaty rocks.

Most deposits of this type are low in grade. Those that have been worked are ones that have been enriched by natural processes, either by circulating surface waters or by ascending hydrothermal solutions. The Quebec-Labrador deposits appear to have been enriched by solutions that removed some of the silica in the original iron-formation, so that iron remained in relatively greater amounts; although the richer deposits show a relationship to the present erosion surface, it is not yet clear whether the solutions were of surface or hydrothermal origin.

Great advances have been made in the United States in recent years in research on methods of treating the low-grade, unenriched iron-formation that is available in large quantities in that country and in Canada.

Sulphide Deposits

Many large deposits of pyrite, pyrrhotite, or other iron-bearing sulphides are known but these are usually not suitable as sources of iron because of their sulphur content. However, the exploitation of large deposits of this kind by special processes, as sources of both sulphur and iron, was recently undertaken by Noranda Mines Limited and the International Nickel Company of Canada Limited, in conjunction with their other operations.

Economics

Iron and steel plants are usually located near the markets for iron and steel products. The principal plants in Canada are at Sydney, N.S., and Hamilton and Sault Ste. Marie, Ont. Ores that contain 50 per cent or more of iron are usually shipped direct or after washing; ores of lower iron content are usually treated at the mine by some method such as gravity concentration, magnetic separation, or sintering, to bring them up to shipping grade.

Because iron ore has a relatively low unit value, compared to other ores, only large deposits of high iron content can be worked profitably. An iron ore mine must be capable of supplying daily, for a long period, thousands of tons of material sufficiently rich to warrant shipping, or of a type suitable for concentrating. Therefore, although iron occurrences are very common, only the best ones are likely to be of value in the near future. Because prospecting for iron is usually done with the aid of geophysical instruments and in conjunction with geological studies, and because it would be difficult for the average prospector working on his own account to distinguish between important and unimportant deposits, it seems likely that most important iron discoveries in future will be made by scientists or prospectors working for companies, rather than by independent prospectors unless they are well trained.

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Lead and Zinc

Lead and zinc are grouped because they commonly occur together in ores. For many years these metals have been produced in important quantities in Canada. In 1954 the Canadian output was 221,000 tons of lead valued at nearly $59 million, and nearly 374,000 tons of zinc valued at more than $89 million.

Lead was one of the metals first used by man. Lead water pipes, joined by a lead-tin solder, were in extensive use by the Romans, and our word 'plumber' is derived from 'plumbum,' the Latin name for the metal. Zinc was not used until comparatively recent times.

The principal uses of lead today are in storage batteries, in sheathing for electrical cables, in ethyl compounds for adding to gasoline, in plumbing, and in many alloys; zinc is used mainly for galvanizing, die-casting, and in the manufacture of brass.

The principal minerals from which lead and zinc are produced are galena and sphalerite, respectively. The metals are also produced to some extent from other minerals, mainly of secondary origin, that occur as a result of reactions between surface waters and galena or sphalerite. Such minerals do not occur in large quantities in Canada.

Deposits containing galena or sphalerite are numerous and widely scattered in the Cordilleran region, the Canadian Shield, and the Appalachian region. Production, however, is mainly from large orebodies that can be mined relatively cheaply. Certain smaller mines are able to operate during periods of high prices, but the great majority of small occurrences of galena and sphalerite, which are not hard to find, cannot be operated economically except under special conditions.

The Sullivan Mine

The Sullivan mine at Kimberley in southern British Columbia is the largest source of lead and zinc in Canada. It is the largest lead-zinc-silver mine in the British Commonwealth and is also the largest single producer of these metals in the world. Therefore, although there are other important lead-zinc mines in the Cordilleran region, the short space available here is devoted to a few notes on the Sullivan, which has played a very important part in the development of mining in Canada and in the economy of this country, and still has ore reserves sufficient for many years.

Prospecting in the East Kootenay region, where the Sullivan mine is located, began about 1860 with the discovery of placer gold near Fort Steele. In 1892 a high-grade galena deposit was found by two prospectors in the hills west of Fort Steele; this, later known as the North Star mine, produced considerable lead and silver. In the same year, four prospectors named Sullivan, Smith, Cleaver, and Burchett became discouraged with their efforts in the vicinity of Kaslo and decided to travel across the Purcell Range and try their luck at Fort Steele. After an arduous back-packing trip of more than a month's duration, prospecting as they went, they reached Fort Steele, with their supplies exhausted, just when the North Star discovery was causing excitement. They decided to search on the hill across a small creek from the North Star, and Burchett soon found galena float which he followed until he found a deposit in place. They staked claims which they explored for 4 years and then sold for $24,000 to a group operating the Le Roi gold-copper mine at Rossland. This group began systematic development of the Sullivan deposit in 1900, after a branch of the Canadian Pacific Railway was built from Cranbrook to Kimberley. Ore was first shipped to small smelters at Trail and Nelson, and in 1903 to a smelter built near the mine. These early efforts met with little success, however, because the intimate mixture of the galena and sphalerite was not well suited to direct smelting. In 1909 the property was optioned to the Consolidated Mining and Smelting Company of Canada, which operated mines at Rossland and the smelter at Trail. This option was confirmed in 1910 and the new owners began selective mining and sorting to improve the quality of the ore shipped. At this same time, deep diamond drilling showed that the orebody was very extensive. The problem was to find a means of utilizing the large amounts of material that were not suitable for direct smelting. By this time a process called 'selective flotation' was coming to the fore as a means of separating the constituents of fine-grained ores. In this process the ore is ground to a 'pulp' and this is fed into cells in which the pulp is agitated mechanically or by air blown into the cells, small amounts of frothing oils and various chemicals being added. By using different oils and controlling the process in various ways, certain mineral grains can be made to adhere to the bubbles, which rise to the top of the cell and are skimmed off. The company saw the possibilities of this method for producing lead and zinc concentrates from the Sullivan ore, and after considerable research succeeded in adapting the process to the ore. The first unit of a concentrator was built in 1923, and since then the operation has been gradually expanded.

The huge Sullivan deposit is a replacement body along a zone in beds of early Proterozoic argillite. The whole zone is up to 300 feet thick. It occurs on a limb of a broad anticline, the ore zone dipping about 30 degrees northeast. The hanging-wall is quartzite and the foot-wall is in most places conglomerate composed of pebbles of argillite. The ore is banded and contorted. Galena, sphalerite, pyrrhotite, and pyrite are the principal sulphide minerals. Individual orebodies in the zone are up to about 1,000 feet long, and more than 200 feet thick at right angles to the dip. The vertical range of the ore zone is at least 1,300 feet. A zone consisting chiefly of pyrrhotite underlies much of the ore.

Sills and other bodies of gabbroic composition, called the Purcell sills, intrude the sedimentary rocks in the vicinity of the mine. The available evidence is that these are of Proterozoic age. Granitic rocks, apparently Cretaceous or early Tertiary in age, are exposed about 10 miles from the deposit and may exist at depth closer to the mine.

Because of the importance of the deposit, its geology and origin have been studied intensively. There seems no doubt that the orebodies formed in the particular belt of argillite where they are found because it was favourable for the circulation of solutions, probably because it was more permeable than other bands and was flanked by less-permeable strata. Faults that displace the strata may have played a part in providing access for the solutions. In spite of prolonged investigations, conclusive evidence has not been found that would date the period of replacement. Most of the evidence, in the district as a whole, seems to point to replacement associated with the Cretaceous or Tertiary period of granitic intrusion, but it may instead have been related to the earlier Purcell intrusives, or separate phases of the mineralization may have been related to each of these intrusive epochs.

The ore is treated 2 miles from the mine in a large modern concentrating plant with a capacity of 10,000 tons a day. The concentrates are shipped by rail to the company's smelter at Trail, B.C., which is the largest metallurgical plant in the British Commonwealth.

The importance of the Sullivan mine has caused a great deal of prospecting and study in its neighbourhood, but nothing comparable has been found. The possibilities for ordinary prospecting in the vicinity have probably been exhausted, but there may still be possibilities for further specialized investigations.

Deposits in Other Regions

Large amounts of zinc and considerable lead are produced from mines in the Canadian Shield. The zinc is derived chiefly from large copper-zinc deposits such as those of the Flin Flon mine on the boundary between Saskatchewan and Manitoba, and the Waite-Amulet, Normetal, and East Sullivan mines in northwestern Quebec. The part of the Canadian Shield in Quebec also contains several zinc-lead mines such as the Golden Manitou. In the Northwest Territories extensive exploration has been done during the last few years on large zinc-lead deposits in limestone of Devonian age at Pine Point, Great Slave Lake, that were found long ago but whose development has been retarded by the distance from a railroad. The results of exploration have been encouraging, and the possibility of building a railroad to serve the area is said to be under investigation.

A large zinc-copper deposit was found late in 1953 near Manitouwadge Lake, north of Lake Superior. The events that led to this discovery have been described as follows. A geological map made by J. E. Thompson of the Ontario Department of Mines, published in 1932, showed an occurrence of sulphide minerals near Manitouwadge Lake. In 1953 two prospectors named Barker and Dawidowich formed a team with a pilot named Forster, who owned a small airplane; one of the places they decided to investigate was the Manitouwadge area. On their first visit they took samples that were found to contain up to 1·5 per cent copper. When they returned to stake claims they found that the ground had been staked by others; these claims were allowed to lapse, however, apparently because the stakers were not aware of the copper occurrence, and Barker and his associates were able to stake the ground. The property is being developed by Geco Mines Limited and is expected to be in production in 1957. Ore reserves are reported to be more than 14 million tons averaging 3·55 per cent zinc and 1·72 per cent copper.

Several important zinc-lead and zinc-lead-copper mines are operated in the Appalachian region in the Eastern Townships of Quebec and in New Brunswick, Nova Scotia, and Newfoundland. The Buchans mine in central Newfoundland was discovered about 1907 and for many years has operated at a rate of 1,300 tons a day, producing lead, zinc, and copper concentrates. Since 1952 there has been great activity near Bathurst, N.B., as a result of disclosures by diamond drilling of large zinc-lead bodies. A large deposit of magnetite, apparently of replacement type, was found here in 1902 and has been worked intermittently for iron. The presence of a little galena and other sulphide minerals, known for some time, caused a company to explore the periphery of the deposit by diamond drilling and to have geophysical surveys made. Several anomalies were found, and diamond drilling at places where magnetic and electromagnetic, as well as geochemical, indications coincide has revealed at least two large zinc-lead bodies with some copper; total ore is in excess of 50 million tons.

Outlook for Prospecting

Lead and zinc are staple commodities that will probably be used in large quantities for years to come. During the last war the need for them caused considerable expansion of production, which has been reflected in lowered prices during the post-war years. Because large deposits are already available, there is not a great incentive for ordinary prospectors to concentrate on these metals at present, but any discoveries of fair size and grade would probably be of interest to mining companies.

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Nickel

Canada produces over 70 per cent of the world's nickel. In 1954 the Canadian production was more than 160,000 tons valued at over $180 million, the highest value of any metal produced in Canada.

Canada's nickel comes chiefly from numerous mines of the International Nickel Company of Canada Limited and Falconbridge Nickel Mines Limited in the Sudbury district of Ontario. The other principal producer is the Lynn Lake mine of Sherritt Gordon Mines Limited in northern Manitoba, which began full-scale operation in 1954.

In view of the importance of nickel to Canada's economy, a brief historical note on the metal seems justified. In the 18th century, miners in Saxony found that certain ores of copper, when treated by the usual smelting methods, yielded, instead of the expected red metal, a very hard and intractable metal, of a very light colour, to which they gave the name of 'kupfer-nickel' or 'Old Nick's copper'. In 1751, the Swedish chemist, Cronstedt, succeeded in isolating the mysterious element, which he named 'nickel' after the Saxon nickname for the metal. About 1877 a company was organized to acquire nickel and copper discoveries near Orford in the Eastern Townships of Quebec. Difficulty in treating the nickel ore caused the company to devote most of its attention to copper mining. In the following year the company was reorganized as the Orford Copper and Sulphur Company, and a refinery was built in New Jersey, U.S.A. The manager of the refinery, R. M. Thompson, discovered a practical method of separating nickel and copper from the smelter product by what was called the Orford process.

In 1883 a blacksmith named Flanagan, working on the construction of the Canadian Pacific Railway near the village of Sudbury, found copper sulphides along the right-of-way. He did not record a claim and others staked the ground a few months later. Several discoveries that later became important were found in 1884 by prospectors who were searching for gossans. In 1886 the Canadian Copper Company, forerunner of the International Nickel Company, was incorporated to acquire several properties. Mining began at the Copper Cliff mine in that year, and the construction of the first smelter was completed in 1888. The smelter product was sent to the Orford refinery in New Jersey, but the presence of nickel caused trouble and led to the development of the Orford process, which made it possible to separate the metals economically. A great deal of research during the years that followed has resulted in greatly improved treatment methods and in developing new uses for nickel, mainly in special nickel-steel alloys that are now indispensable in peace and war.

The International Nickel Company operates large mines and plants, and produces about 140,000 tons of nickel annually, as well as large amounts of copper, platinum metals, gold, silver, cobalt and small amounts of seven other elements. These mines and plants, together with those of the former Mond Nickel Company, acquired by the International Nickel Company in 1929, and those of Falconbridge Nickel Mines Limited, make the Sudbury region one of the great mining and metallurgical centres of the world.

The history of the discovery of the Falconbridge mine is interesting because it is connected with early successful applications of geophysical exploration and diamond drilling for base-metal mines. In 1901 the late Thomas A. Edison made a dip-needle survey in Falconbridge township, because he needed nickel for making a storage battery he had invented. Geological mapping had shown the vicinity to be favourable in a general way. He obtained indications that were followed up by sinking a shaft, but the attempt was abandoned because quicksand was encountered. Diamond drilling later revealed an orebody at this place. The property was acquired by the present company (a subsidiary of Ventures Limited) which completed a smelter to treat the ore in 1930.

The typical orebodies of the Sudbury district are large irregularly shaped masses containing massive and disseminated sulphide minerals, mainly pyrrhotite and chalcopyrite. The nickel is contained in the mineral pentlandite and the platinum in 'sperrylite', an arsenide of platinum. Several years ago the average grade of the ores was about 3·5 per cent nickel and 2 per cent copper, but in recent years with operations on an expanded scale ore of lower grade has been treated. This is reported to average roughly 1 per cent nickel and the same in copper. The orebodies occur at and near a body of basic intrusive rock that was described in 1897 by T. L. Walker as grading from a more basic type called norite to a more acid type called micropegmatite. A few years later A. P. Coleman mapped the region for the Ontario Department of Mines and showed that the intrusive is in the form of a large basin-shaped mass 37 miles long and 17 miles wide, with the micropegmatite towards the centre and the norite outermost, and that the orebodies are near the outside of the basin. He proposed the explanation that the two kinds of rock and the ore segregated by settling from a molten magma that was intruded in the form of a great sheet. This explanation was accepted until about 1917. Detailed investigations by company geologists between 1940 and 1950 showed that the ore commonly is closely associated with quartz diorite masses resembling dykes, that are probably younger than the norite. These geologists also showed that the orebodies are generally localized where fault and breccia zones cross the diorite and nearby rocks. Thus, the simple theory of magmatic segregation in place does not fit the evidence. It appears, rather, that the ore is the last, perhaps hydrothermal, phase of a long sequence of events that began with the intrusion of the basic sill-like mass and was followed by the diorite, after which faulting and brecciation occurred before the emplacement of the ore.

The first large nickel mine to be brought to production in Canada outside the Sudbury district is the Lynn Lake mine in northern Manitoba. The deposits, found in 1942, consist of massive and disseminated pyrrhotite, pyrite, pentlandite, and chalcopyrite in basic intrusive masses having variable composition. The ore reserves were reported to amount to about 14 million tons averaging 1·223 per cent nickel and 0·618 per cent copper. The demonstration that a substantial operation was possible here came at about the same time as the exhaustion of the original Sherritt Gordon copper-zinc mine at Sherridon, Man., so the company transported almost all the buildings and mining and milling plant from Sherridon to Lynn Lake, a distance of about 150 miles. Buildings were placed on large sleighs and hauled by tractors during the winter, on a route that made use of frozen lakes and muskegs and cleared winter roads where necessary. A branch railway line 147 miles long was completed by the end of 1952. Underground development and a large concentrator were completed, and a refinery using a new process was built near Edmonton to take advantage of supplies of natural gas. Full-scale operation of the mine and concentrator began late in 1953, the first nickel concentrates being produced in November. The first concentrates were treated at the Fort Saskatchewan refinery in Alberta in July 1954.

The present outlook for nickel is good. Demand is strong, and the recent price trend is upward. The largest individual buyer is the United States Government, which is making large purchases by contract for the national stockpile. Even without this, it is virtually certain that the market can absorb all the metal that can be produced. Considerable interest is therefore being shown in prospecting for nickel and in exploring promising showings. The principal activities, apart from the Sudbury and Lynn Lake areas, have been at Rankin Inlet, on Hudson Bay, at Mystery Lake in Manitoba, at two deposits in Yukon Territory, at Choate in British Columbia, north of Kenora in western Ontario, and south of Quebec City in the Eastern Townships. Some of these concern recent discoveries, and some deposits that have been known for several years.

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Platinum

Platinum and other metals of the platinum group—palladium, rhodium, ruthenium, iridium, and osmium—are produced in fairly large quantities as by-products of Canada's nickel mines. In 1954 this production amounted to 343,706 ounces valued at nearly $21 million; of this, platinum accounted for 154,356 ounces valued at $12,950,469. For some time Canada has been a leading producer of these metals, accounting for about half the world output.

In the Sudbury ores, platinum occurs in the mineral sperrylite, which is sparsely scattered among the sulphide minerals. Small amounts of native platinum have been produced in the Cordilleran region as a by-product of gold placers.

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Silver

Canada is the third largest producer of silver. In 1954 she produced over 31 million ounces valued at nearly $26 million. Although the Cobalt district, before its decline, was an outstanding producer from native silver veins, almost all the silver now produced in Canada is a by-product of mining for other metals. Silver is a common constituent of lead, zinc, and copper minerals, and some silver is nearly always present in native gold. In 1954, nearly all the silver produced in Canada came from the refining of base-metal ores; about half of this came from the Sullivan lead-zinc-silver mine in British Columbia and about 11 per cent from cobalt-silver operations in Ontario; only about 2 per cent came from the refining of gold.

About half the silver used in Canada goes into coinage, the remainder is used in various arts and industries. Canada produces far more silver than she needs. The remainder is exported, mainly to the United States.

Ores important for silver alone are not so likely to be found as are ores from which silver may be recovered with other metals but if such deposits were found they would probably be attractive, particularly at the present price of about 90 cents an ounce for silver.

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Structural Materials

Clay, sand, gravel, and crushed rock used for making brick, tile, cement, or concrete, together with building stone, are produced in great quantities and constitute a large part of Canada's mineral production. These materials are of little interest to ordinary prospectors because many sources of supply are known and because special knowledge of the specifications of usable material is generally required. Several publications on occurrences, uses, or treatment of various structural, road, and ceramic materials may be obtained from the Mines Branch and the Geological Survey of the Department of Mines and Technical Surveys, and from provincial authorities.

Uranium

Canada is one of the world's leading producers of uranium, the 'fuel' from which atomic energy is derived. During the last few years many prospectors and companies were engaged in prospecting for uranium and in exploring prospects, and at times uranium was the most-sought metal in Canada. Because large amounts of uranium ore are now available in Canada and in other countries, and because of a recent curtailment in the provisions for buying uranium at special prices, interest in prospecting and exploring for uranium has declined. The subject is, however, discussed at some length here, because limited possibilities remain for the discovery of deposits that would be economic under present conditions, and because an increase in the demand for uranium may again make prospecting and exploration for this metal more attractive.

History

Pitchblende, the principal uranium-bearing mineral, was recognized in the ores of Joachimsthal in Bohemia in 1727, but its composition was not understood until 1789 when analysis of the mineral resulted in discovery of the element uranium. A century later, radioactivity was discovered accidentally by Becquerel, a French scientist, who found that pitchblende affected a photographic plate. As it was found that pitchblende was much more radioactive than pure uranium, he deduced that pitchblende must also contain some unknown, strongly radioactive substance. The discovery of radium in pitchblende by the Curies in 1898 showed that this was the case. Prior to the discovery of radium, pitchblende was in little demand, although small quantities were used to produce the small amounts of uranium required in the chemical trade and as a pigment for colouring pottery glazes. As the important and now well-known uses of radium were developed, the demand for pitchblende and other uranium minerals increased because there are no separate radium minerals, radium being simply one of the products of the radioactive disintegration that is characteristic of uranium and other radioactive elements. Mines in Bohemia and other parts of Central Europe were the chief source of pitchblende until rich discoveries were made in the Belgian Congo in 1921. Radium was also produced from carnotite (uranium vanadate) deposits in Utah and neighbouring parts of the United States. In 1930 a large and rich deposit containing pitchblende was found by Gilbert LaBine and E. C. St. Paul at Great Bear Lake, and this became an important producer of radium in 1933. Occurrences of uranium minerals in insignificant amounts had been found in several parts of Canada many years before, but this was the first to warrant production.

Rutherford's research on radioactivity and the nature of the atom, about the beginning of the present century, demonstrated that immense energy is locked up in the atom. Experiments were performed in different countries to try to release and control this energy. Under the urgency of World War II this experimental work was intensified, and atomic fission on a practical scale was attained by the use of uranium, thus causing a pressing demand for the metal. The Eldorado mine at Great Bear Lake became the principal source on this continent, and as a security measure the Canadian Government bought the Eldorado company, prohibited private staking and mining for uranium, made widespread studies of known uranium occurrences, and succeeded in finding many new ones, mainly in the Beaverlodge region of Saskatchewan. Here the Ace mine was brought into production by Eldorado in 1953.

Late in 1947, as the need for greatest secrecy had passed, the ban on private staking and mining was removed and the Canadian Government guaranteed a base price for uranium oxide, which has been extended until 1962. Staking and mining are done, as for other metals and minerals, under the laws and regulations of the various provinces and territories. However, under the regulations of the Atomic Energy Control Board, a Federal body, discoverers of radioactive occurrences are required to report them to the Geological Survey of Canada, which acts for the Board in compiling information on resources of radioactive minerals. Exploration permits, which may be secured free by applying to the Board, are required before advanced exploration such as diamond drilling is done, and mining permits are required before production is undertaken. Restrictions are placed on publication of figures for production and ore reserves, and uranium ores and concentrates can be sold only to Eldorado. As soon as private staking was permitted, many persons and companies began prospecting for uranium and exploring deposits, with the result that several thousand occurrences are now known in Canada, although most appear too small or too low in grade to be minable. A few privately owned properties have been in production on a relatively small scale in the Beaverlodge region since 1954. Large production from the Gunnar deposit, found in that region in 1952, was begun in the autumn of 1955. Huge tonnages of low-grade ore are reported in the Blind River region of Ontario, where the first plant came into operation in October 1955. Deposits are being explored in several other parts of Canada. The greatest activity at present, apart from the regions already mentioned, is in the Bancroft region of southeastern Ontario. It has been estimated that by the end of 1957 the annual gross value of the uranium produced in this country will be at least $100 million.

During the period 1950-55, interest in uranium caused more prospecting and staking than ever before. Many experienced prospectors quickly acquired the relatively small amount of additional knowledge required, and a larger number of beginners swelled the ranks. Over-simplified publicity caused many of the latter to believe there is little more to prospecting for uranium than acquiring a counter. It is true that such a prospector has an outside chance of finding an important deposit, but events have shown that knowledge and experience are almost essential. So far, all the producing uranium mines in Canada, and almost all the prospects that have merited attention, have been found by experienced prospectors or by men employed on organized prospecting schemes.

Mineralogy

Many minerals contain uranium, but most of them are comparatively rare and are difficult to identify by field methods. The uranium-bearing minerals fall into three main classes: (1) primary minerals found in veins and other hydrothermal deposits; (2) primary minerals found usually in pegmatites and related types of deposits; and (3) secondary minerals formed by near-surface alteration of primary minerals of classes (1) and (2).

The most important uranium mineral is uraninite and its variety pitchblende. Uraninite is a definite mineral species composed of uranium oxide. In its typical crystalline form it occurs as cubic and octahedral crystals, and sometimes in small rounded masses, scattered sparingly in pegmatites and other deposits formed at high temperatures. Pitchblende has about the same composition, but occurs in masses and disseminations instead of as distinct crystals and is typical of veins and related types of hydrothermal uranium deposits. Although pitchblende is officially classed in Canada as a variety of uraninite, its mode of occurrence is distinct and it is usually considered for practical purposes to be a separate mineral. As such it has been the most important Canadian source of uranium. A substance called 'thucholite', found occasionally in hydrothermal and other deposits and formerly considered a separate uranium mineral, consists of a non-radioactive hydrocarbon containing minute grains of pitchblende. Brannerite, an oxide of uranium and titanium, is an important constituent of conglomerate ores in the Blind River region, and may ultimately rival pitchblende as a source of uranium.

The most common uranium mineral of the general pegmatitic class is uraninite. Others include uranothorite, euxenite, fergusonite, and pyrochlore.

The secondary uranium minerals are usually bright yellow, although some are orange and green. In outcrops in Canada they generally occur as thin coatings on or near primary uranium minerals, and as a rule do not extend far beneath the surface. The only exception so far in this country is uranophane (silicate of calcium and uranium) which occurs in fairly large quantities to depths of several hundred feet at the Gunnar pitchblende deposit in porous or fractured rock that permitted unusually deep circulation of artesian water.

Most uranium minerals are difficult to distinguish by ordinary means. Fortunately it is not usually necessary for prospectors to learn how to do so, because a Geiger counter properly used will indicate the presence of a radioactive mineral or minerals, and special radiometric assays or chemical analyses of samples indicate their uranium content, which is the essential information. The general mineral association will usually make it apparent to a prospector whether he is dealing with a hydrothermal deposit, a pegmatitic or related type, or a secondary occurrence, without the need for identification of the uranium mineral or minerals. In most instances there is no need for precise identification of the minerals unless and until exploration shows that a large deposit may be present, in which case the question of treatment would arise and it would then be necessary to have full mineralogical information. Therefore, it is mainly necessary for prospectors to be able to recognize pitchblende and uraninite, and collectively to recognize the yellow secondary minerals that can be grouped as 'uranium stain'. During the boom of 1950-55, government agencies have complied with hundreds of requests for identification of radioactive minerals that required extensive laboratory work, but in most instances the discoveries did not prove to be either large enough or rich enough to justify the work.

An important point in connection with uranium-bearing pegmatites and related types of deposits, if they show indications of being of commercial size and grade, is that those carrying uraninite are usually less difficult to treat than those carrying other uranium minerals such as euxenite, pyrochlore, etc.

Types of Canadian Deposits

Uranium has been found in Canada in many different kinds of deposits. These are described in other publications and are not discussed in detail here. The economic deposits found so far are of three kinds: hydrothermal deposits ranging from simple veins to complex systems of stringers and disseminations; uranium-bearing conglomerate for which the origin of the uranium-bearing minerals is not yet known definitely; and certain pegmatitic deposits.

In the hydrothermal deposits the uranium mineral is pitchblende, occasionally accompanied by 'thucholite'. Many pitchblende deposits consist of veins, stringers, lenses, or pods, composed of relatively few minerals. Some consist of pitchblende alone, but most contain hematite, quartz, chlorite, calcite, and other gangue minerals. Some contain other metallic minerals in addition to pitchblende and hematite. In individual stringers or masses, gangue minerals may be in minor amounts, or the stringers or masses may consist chiefly of gangue with a little pitchblende. Most deposits are complex zones of mineralized lenses, stringers, and streaks within a much larger volume of altered rock; at some deposits the rock contains pitchblende in both disseminated and concentrated forms.

In the Blind River region north of Lake Huron, uranium-bearing quartz-pebble conglomerate has been found at several places at and near the base of the Huronian group of formations, resting unconformably on pre-Huronian granitic rocks and greenstone. The matrix of this conglomerate contains considerable pyrite, scattered grains of brannerite, uraninite or pitchblende or both, and small amounts of other minerals. The uranium minerals can usually be seen only with a microscope, and although a good deal of research has already been done it is still uncertain whether the uraninite is mainly in the form of broken or eroded crystals of uraninite or of fragments of pitchblende. Many factors suggest that the uranium minerals resulted from the erosion of older rocks and were concentrated as placers that later became hard conglomerate. However, uranium minerals are found in only a few placers of recent age, presumably because most of them are fairly soluble in water. Some geologists therefore believe that the Blind River deposits are probably the result of hydrothermal replacement. Others believe that the uranium minerals were deposited originally as placers, and later were re-distributed by hydrothermal solutions.

The most abundant general types of uranium deposits are pegmatites and related deposits, but in almost all of these the uranium minerals are present in small scattered amounts only. Before 1955, pegmatitic deposits had not been proved to be commercial sources of uranium, but a few of the Canadian deposits of this kind are sufficiently large and of sufficient average uranium content to have warranted thorough exploration, and plans for production from some of these, in the Bancroft region of Ontario, were announced in 1955.

Associations

For prospecting, it is important to know as much as possible about the ages and kinds of rocks in which deposits are likely to be found, the structures that are most favourable, and the minerals commonly occurring with the ores. This is particularly important for the hydrothermal deposits, although many of the questions cannot yet be answered as definitely as is desirable. In the case of the conglomeratic uranium deposits, favourable rocks are the conglomerate at and near the base of the Proterozoic strata in the region north of Lake Huron. It is not yet known to what extent conglomerates and other sedimentary rocks of other ages or in other districts are favourable.

Uranium deposits of the general hydrothermal class, containing pitchblende, have been found in rocks of many ages, from Archæan to Mesozoic, and they have been found associated with Tertiary intrusives in the United States. On the basis of present information the most favourable areas in Canada are those near the border of the Shield that contain folded Proterozoic strata, but in such areas the deposits are not confined to the Proterozoic rocks.

Hydrothermal deposits have been found in rocks of so many different kinds that it is impossible at present to give definite rules regarding favourable host rocks. In some places for instance, dark-coloured, basic rocks such as basalt, diabase, and the more basic sedimentary rocks are particularly favourable, but in other places granitic and gneissic rocks contain important deposits. In an area where pitchblende is known or likely to occur, no type of rock can be considered completely unfavourable at present.

Many of the more important pitchblende deposits in Canada occur in or close to prominent faults where the adjoining rocks are fractured, sheared, or crushed to provide favourable sites for the emplacement of deposits. Zones of this kind may be easily eroded and, therefore, underlie low-lying areas.

Pitchblende is usually accompanied by considerable iron, generally in the form of hematite and less commonly as magnetite and sulphide minerals. Silver, cobalt, and copper minerals, and to a lesser extent those of lead and zinc, accompany pitchblende in some deposits. None of these minerals, however, can be considered as definite guides to the presence of pitchblende. The principal known deposits of hematite, magnetite, iron sulphides, silver, cobalt, and copper have been tested and have shown no evidence of uranium. The matter is therefore far from simple, and any deposits of the general hydrothermal class are worth checking on the chance that pitchblende may be present, for this can be done fairly easily. Hematite in the form of red wall-rock alteration commonly accompanies pitchblende in hydrothermal deposits.

Pegmatitic deposits are common in areas where granitic intrusions are abundant and where erosion has been sufficiently deep to expose the deposits. They are particularly abundant in the Grenville region of the Canadian Shield. It is hoped that studies now being conducted in the Bancroft region will throw light on the factors that caused certain deposits there to contain larger tonnages and better average uranium content than most pegmatitic occurrences.

Distribution

Uranium occurrences and deposits are now known in many parts of Canada, mainly in the Canadian Shield. The occurrences in the Shield have so far been found mainly within about 100 miles of its western and southern borders, but this does not necessarily indicate that other parts of the area should be neglected. The principal areas containing pitchblende deposits of hydrothermal types are the Great Bear Lake, Hottah Lake, and Marian River regions in the Northwest Territories, and the Athabasca region in northern Saskatchewan. The better accessibility of the last-named makes it the most attractive of these. A number of pitchblende occurrences have been found north of Sault Ste. Marie, Ont., but these have so far proved small and unimportant. A few deposits of hydrothermal type have been found a relatively short distance north of the Grenville boundary and pitchblende deposits have recently been found in Labrador on the continuation of this general trend. Pitchblende has been reported from one deposit in British Columbia, and pitchblende and thucholite have been found at several places in New Brunswick and one in Gaspé; therefore the western Cordilleran and the Appalachian regions offer possibilities for the uranium prospector.

Uranium deposits in conglomerate have been found in many places between Sault Ste. Marie and Sudbury, but those that have shown the best possibilities so far are in an area a few miles east and northeast of Blind River.

Radioactive pegmatites are widespread in the Canadian Shield and fairly common in the Cordilleran region. They have been found principally in the Grenville division of the Shield and in the Charlebois Lake and Lac la Ronge regions of Saskatchewan. A few deposits in Saskatchewan contain large tonnages, with uranium contents reportedly averaging between 0·05 and 0·1 per cent U_3O_8.

Economics

Until March 31, 1962, there is a guaranteed market for all uranium ores and concentrates that are amenable to treatment and that contain not less than 10 per cent uranium oxide (U_3O_8). The price payable is based on a price of $2.75 per pound of contained uranium oxide, plus an allowance to help pay for the cost of concentrating, plus a special allowance for the first three years of production to help pay for the cost of development. On this basis, ores averaging 0·1 per cent U_3O_8 would be worth about $15 a ton for the first three years and $12 thereafter; those averaging 0·2 per cent U_3O_8 would be worth $29 a ton for the first three years and $24 thereafter; those averaging 0·3 per cent U_3O_8 would be worth about $41 for the first three years and about $34 thereafter. However, these prices are based on the total value of the uranium in the ore; in practice it is never possible to recover all the metal in making concentrates, so the value of concentrates would be reduced by an amount depending on the percentage of recovery.

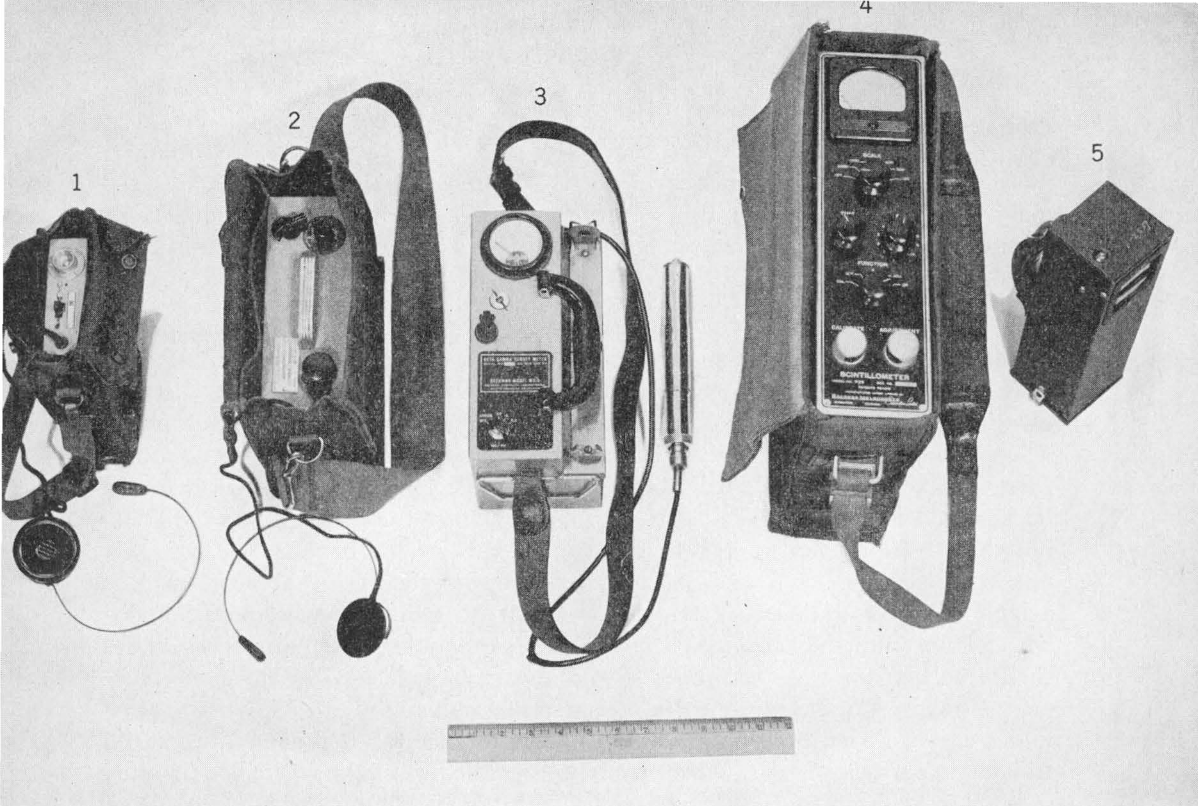
Ores or concentrates may be sold only to Eldorado Mining and Refining Limited, which pays the cost of rail transportation, if any, to its plants. This company was authorized to make special price contracts in certain circumstances, such as the case of a property containing a large proved tonnage of material that was below the average grade that would permit profitable operation at the guaranteed price, or a property that planned to produce a high-grade product from a plant that would require large expenditures to build. The terms of such contracts were not disclosed, and the guaranteed schedule of prices was considered to be sufficient for early estimates of the value of a deposit. In August 1955 the Rt. Hon. C. D. Howe announced that "there is a limit on the amount of uranium which will be purchased under the special price arrangement. On the basis of our present information, Eldorado will not be able to negotiate special price contracts after March 31, 1956". This was confirmed later. As the private properties brought to production in Canada have required such special contracts, the possibilities for further prospecting and exploration, at least for the present, are more limited and depend on deposits that would be economic under the guaranteed schedule of prices. On the basis of present knowledge, these would be unusually rich, well situated deposits that could be treated fairly readily to produce a marketable concentrate.

Authorities believe that there will be considerable demand for uranium after 1962, but are unable to predict what prices may prevail or whether the market will be guaranteed. The following authoritative summary of the situation in 1955 was given by the President of Atomic Energy of Canada Limited:

"It is impossible to say at this time what the demand for uranium will be after March 31, 1962, the present expiry date of the guaranteed market. The military demand may continue at the present rate or may cease altogether. On the other hand, we may have a situation in which there is still government buying but on a reduced scale. Whatever happens, it can be safely predicted that there will be some requirement for uranium for use in atomic power programmes in the early sixties. It is evident, however, that the demand for uranium in the early stages of a Canadian atomic power programme will take up only a small part of our potential production. Consequently, if the military requirement ceases or is cut back substantially, Canadian producers may have to look to export markets and should expect to meet the same conditions which prevail in the case of other base metals which are not in short supply."

General Hints on Prospecting for Uranium

Although anyone, with the aid of a counter, has a chance of finding a uranium deposit, experience in Canada thus far has shown that considerable knowledge and experience are almost essential. In this country there are many bodies of weakly radioactive rocks and many small mineral occurrences that may be confusing to those without a fair knowledge of the subject. Beginners should therefore consider that they have only an outside chance of finding an important deposit unless they are prepared to spend a good deal of time and



NEG. NO- 107328

Plate LXV

Geiger and scintillation counters and a 'Mineral Light'. 1: small Geiger counter with earphone; 2: medium-size Geiger counter with earphone; 3: large Geiger counter equipped with meter and probe; 4: scintillation counter; 5: 'mineral light' or ultraviolet lamp.

effort in studying and gaining experience. Although several very important uranium deposits have been found in Canada and although many others have warranted exploration, most discoveries have proved small and insignificant. Therefore, prospectors need knowledge, not only of where and how to prospect to best advantage, but also of how to decide which occurrences are worthy of attention. The general principles explained in Chapters VIII and XI are applicable to uranium as well as to other metals. However, in addition to aiding in the search where formations and structures are theoretically favourable, the counter permits testing places not in this category and it is possible that important deposits may be found under conditions not yet known to be favourable.

Almost all important discoveries in recent years have been found with the aid of Geiger or scintillation counters. A list of Canadian dealers in Geiger counters and other radioactivity detectors may be obtained from the Mines Branch or the Geological Survey of Canada, Department of Mines and Technical Surveys. These branches do not, however, recommend specific instruments or dealers. In general, the experience in Canada has been that the cheaper instruments are satisfactory for ordinary prospecting but that the cheapest get out of order more often than those of moderate price. The most expensive models are used mainly for special purposes. It is sometimes possible to rent counters from dealers, but because the situation varies, it is impossible for Government organizations to advise regarding rentals.

As mentioned in Chapter X, in using a radioactivity detector it is important to remember that the instrument can detect thorium as well as uranium, and that large exposures of weakly radioactive material cause misleadingly strong reactions. The recommended procedure is first to use the counter to seek places where counts of two or three times the background count or more are obtained, then to take samples of the radioactive rock or mineral to a place where the background is normal and hold each sample against the counter. Any that do not then cause a count of two or three times background or more are probably not worth sending for tests. Those that do cause such counts should be sent to a laboratory for radiometric or other tests, at least until one becomes familiar with his instrument, after which he will be better able to judge which samples should be sent for tests. Samples should always be held against the same place on the counter, and as near to the Geiger tube as possible, to allow for testing under uniform conditions and to afford maximum counts. It is sometimes useful to include one sample selected from the most radioactive spot, if it is designated as a selected sample. If this gives only a low assay, the deposit is probably of little value, as its average content will almost certainly be still lower. Also, it is easier to identify minerals in high-grade samples. Samples should, however, ordinarily be taken to represent as nearly as possible the average content. Each sample should weigh a pound or more.

Special radiometric tests distinguish adequately between the uranium content and the total radioactivity of preliminary samples. Prospectors who do not wish to wait for laboratory results can, with the aid of an ultra-violet lamp and a blowpipe, make field tests to indicate whether a mineral contains mainly uranium or thorium. A special kit for this purpose, including a small lamp, can be bought from dealers in instruments and laboratory supplies for about $10.

References

Brief Information on Prospecting for Uranium in Canada; Geol. Surv., Canada, Pamphlet Misc. G. 100-7 (1955).

A short pamphlet describing regulations, government services, and other matters.

Prospecting for Uranium in Canada; Geol. Surv., Canada, Prospector's booklet, 1952. Price 50 cents.

This booklet contains general information on prospecting and staking for uranium, regulations of the Atomic Energy Control Board, types of radioactive minerals and deposits found in Canada, use of Geiger counters and other instruments, and prices and marketing of uranium ores and concentrates. The booklet is accompanied by supplementary notes bringing the information more up to date.

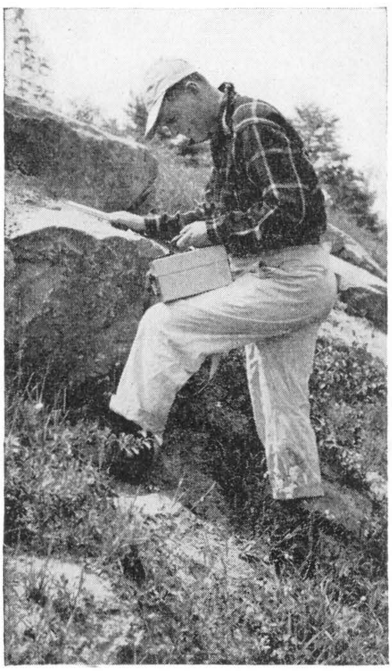
Information on Services for Testing Radioactive Samples; Dept. Mines and Tech. Surveys, Circular, 1954.

This circular explains the services of the Geological Survey of Canada and the Mines Branch for making radiometric tests, chemical analyses, mineral identifications, and treatment tests on samples from radiocative discoveries and deposits.

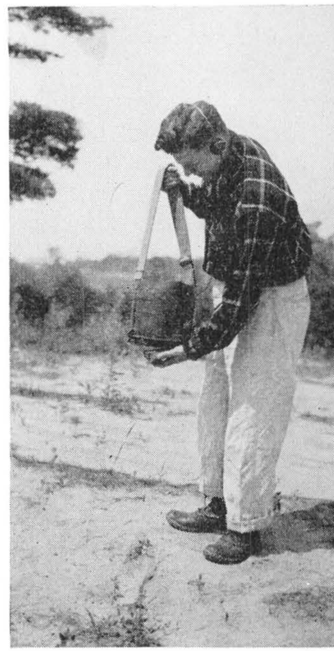
Plate LXVI

How to use a counter.

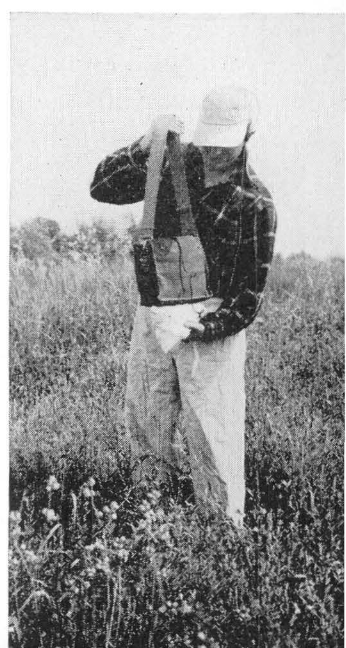
A. Using counter with earphones to test outcrop.



B. Using counter with probe to test outcrop.



C. Testing specimen, at a place where the background is normal.



D. Testing a sack containing a chip or channel sample, at a place where the background is normal.

Eichholz, G. G.: Data on Portable Geiger Counters Available in Canada; Mines Branch, Pamphlet, 1953.

This pamphlet lists Canadian dealers in Geiger counters and scintillation counters, and gives specifications and prices of the various instruments sold.

Buffam, B. S. W., Gillanders, E. B.: The Exploration and Development of Canadian Uranium Deposits; *Trans. Can. Inst. Min. Met.*, vol. LIV, 1951, pp. 434-437.

A paper on the methods of prospecting, exploration, and development used by Eldorado Mining and Refining Limited.

Lang, A. H.: Uranium Orebodies—How Can More be Found in Canada? *Can. Min. J.*, June 1952.

An analysis of the problems of searching for uranium orebodies, with some suggestions.

Annotated List of Publications Related to Uranium; Geol. Surv., Canada, Pamphlet, 1953.

This pamphlet lists other general publications on uranium and thorium published by the Geological Survey of Canada, and publications on many of the areas where uranium has been found.

Nininger, R. D.: Minerals for Atomic Energy; van Nostrand (Toronto) 1954). Price $8.75.

A comprehensive book dealing with the world-wide occurrence of uranium, thorium, and beryllium, and containing much general information on prospecting for these metals.

Cooper, M.: Selected Bibliography on Uranium Exploration and the Geology of Uranium Deposits; U. S. Atomic Energy Commission, 1953. From Office of Technical Services, Dept. of Commerce, Washington 25, D.C. Price 35 cents.

This lists many general publications on uranium, in addition to those above.

Uranium in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Other Metals and Minerals

Abrasives

Several hard minerals and rocks, such as corundum, garnet, pumice, and sandstone are used as abrasive powders, grindstones, sandpapers, and other aids to cutting and polishing. However, artificial products such as carborundum and alundum have replaced many of the former uses of natural abrasives. For this reason no natural abrasives are produced in Canada except a small amount of grinding pebbles, and several known deposits of various kinds are not being worked. Therefore it is not likely to be profitable to prospect exclusively for abrasive materials, but large deposits encountered incidentally, particularly of corundum, might be of interest.

References

Eardley-Wilmot, V. L.: Abrasives: Products of Canada; Mines Branch, Reports Nos. 673, 675, 677, 1927.

Carlson, H. D.: The Origin of the Corundum Deposits at Craigmont, Ont.; *Proc. Geol. Assn. Canada*, vol. 6, pt. 1, pp. 19-27, 1953.

Abrasives in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Antimony

Occurrences of stibnite (antimony trisulphide) and various sulphantimonide minerals are fairly common in the Cordilleran and Appalachian regions but at present are not mined because an adequate supply of antimony is turned out as a by-product of the smelting and refining of lead and other ores, and the world supply is greater than the demand. Canadian production is in the form of lead containing up to 25 per cent antimony, produced at Trail, B.C. This plant can also produce metallic antimony but has not done so since 1944.

References

Antimony in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Dawson, A. S.: Antimony in Canada; *Can. Min. J.*, vol. 68, 1947, No. 1, pp. 20-21.

A short account of the economics and sources of antimony, and of known Canadian occurrences and the possibility of further developments in Canada.

McClelland, W. R.: Notes on Antimony Deposits and Occurrences in Canada; Mines Branch, Mem. Ser. No. 108, 1950.

A summary of information on antimony occurrences in Canada up to 1950.

Arsenic

Virtually all the arsenic used is a by-product of the treatment of metallic ores containing arsenic. Several mining and smelting plants in Canada have to recover arsenic to prevent dangerous fumes from escaping. As the supply is greater than the demand there is no incentive to prospect for arsenic or to consider it an asset in ores mined for other metals.

Reference

Arsenic in Canada: Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Barite

Barite (barium sulphate) is produced in large quantities in Canada, mainly for export. The heaviness of this mineral makes it especially useful as an ingredient in the mud required during the drilling of oil wells and for other uses such as fillers in paint, rubber, linoleum, and paper.

The principal Canadian production is from Walton, N.S., where a replacement deposit in limestone-conglomerate of Mississippian age is reported to contain a large reserve. Two deposits are also worked at Parson and Brisco, B.C., and there are other occurrences in several parts of Canada. It is, therefore, unlikely that prospecting specifically for barite would be worth while at present, but if a large deposit were found close to transportation it would probably receive attention.

References

Spence, H. S.: Barium and Strontium in Canada; Mines Branch Rept. No. 570, 1922.

Tenny, R. E.: The Walton Barite Deposit; N. S. Dept. Mines, Ann. Rept. 1951, pt. 2, pp. 127-143.

Barite in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Bentonite

Bentonite is a kind of clay formed by the alteration of volcanic ash. Some kinds of bentonite swell to eight times their volume when soaked in water, while others do not swell but have great absorptive properties. Therefore bentonite has many uses as a filter, bleaching clay, and filler in numerous manufacturing processes.

The main producing deposits are near Morden, Man., where beds in different formations of Mesozoic age contain sufficient bentonite to be mined commercially; there is also a small production from beds near Drumheller, Alta. Other occurrences are known in these provinces and in British Columbia and Saskatchewan, therefore bentonite is not of great interest to prospectors, but large well-situated deposits should be investigated.

References

Spence, H. S.: Bentonite; Mines Branch Report No. 626, 1924 (out of print).

Bentonite in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Beryllium

Beryllium is a light metal that is very desirable for certain special alloys. Also, although it is not a source of atomic energy, it would be useful in connection with atomic reactors if it could be produced in reasonable quantities and at reasonable cost. There has been no significant Canadian production, and the small amounts produced in other countries have come mainly from beryl (a silicate of beryllium and aluminum) obtained from pegmatite deposits that were being mined also for mica, feldspar, lithium, or niobium. Few pegmatite deposits contain enough beryl to be worked for it alone. Beryl is occasionally found in the gangue of tungsten and tin deposits.

Several pegmatite deposits containing beryl have been found in Canada, mainly in the Canadian Shield in Quebec, Ontario, Manitoba, and the Northwest Territories. Attempts have been made to mine some of them, mainly along with other valuable pegmatitic minerals, and some deposits are being explored further with this objective. Prospectors should be on the alert for additional beryl occurrences in pegmatites, but should remember that a few sporadic crystals do not constitute a beryl deposit, although they might be worth saving if the deposit were being worked for other minerals. It should also be kept in mind that some beryl crystals are not noticeably green and may be confused with quartz. Several field tests for distinguishing beryl are described in different publications. Two of these are explained by Rowe in Paper 52-8, listed below. A prospector paying particular attention to beryllium would do well to obtain the necessary supplies and to learn these tests.

Helvite, a mineral somewhat like garnet, contains beryllium and might be found in commercial quantities. It may be found in contact metasomatic deposits, such as skarn deposits containing garnet and pyroxene in altered limestone.

Helvite is not easily distinguished from garnet without making tests. Therefore any large deposits of the kind mentioned above might be worth the trouble of making tests in the field or the expense of having a few samples analysed for beryllium. A deposit of helvite was recently reported from the McDame region, northern British Columbia, where it is said to occur in skarn between limestone and granite.

Chrysoberyl and phenacite also are beryllium-bearing minerals, but they have not yet been found in commercial quantities.

References

DeLury, J. S.: Beryllium Prospects in Manitoba; *Precambrian*, vol. 10, No. 8, 1937, pp. 3-4.
A summary of information on beryl deposits in southeastern Manitoba, up to 1937.

Gruner, G. W.: Simple Tests for the Beryllium Mineral Helvite; *Econ. Geol.*, vol. 39, No. 6, pp. 444-447 (1944).

Jolliffe, A. W.: Rare-Element Minerals in Pegmatites, Yellowknife-Beaulieu Area, Northwest Territories; Geol. Surv., Canada, Paper 44-12, (1944).

Kulcsan, F.: How Prospectors Can Detect Beryllium in Ores; *Precambrian*, vol. 17, No. 6, 1944, p. 11.
A short account on methods of identifying minerals containing beryllium.

Rowe, R. B.: Pegmatitic Beryllium and Lithium Deposits, Preissac-Lacorne Region, Abitibi County, Quebec; Geol. Surv., Canada, Paper 53-3 (1953).
This report contains information on beryl occurrences in this region.

———: Pegmatitic Mineral Deposits in the Yellowknife-Beaulieu Region; Geol. Surv., Canada, Paper 52-8 (1952).
This paper includes description of some beryl occurrences, and describes a field method of distinguishing beryl.

Spence, H. S.: Notes on Beryllium and Beryl; Mines Branch, Mem. Ser. No. 40, 1930 (out of print).
A summary of information on the uses and properties of beryllium, beryllium minerals, and Canadian occurrences known up to 1930.

Springer, G. D.: Cat Lake-Winnipeg River Area, Manitoba; Man. Dept. Mines and Nat. Res., Pub. No. 49-7, 1950.
This report includes descriptions of pegmatitic deposits containing beryl.

Warren, H. V. and Thompson, R. M.: Beryllium; *The Miner*, June 1943, pp. 32-34.
A summary of information on the uses and economics of beryllium, the more important minerals and foreign occurrences, and of tests for beryllium.

Bismuth

Bismuth is a minor metal used chiefly as a constituent of certain alloys, mainly where low melting-points are desired, as in fuses. All commercial supplies of the metal are recovered as a by-product in the refining of certain lead and molybdenum ores. No commercial ores of bismuth alone are known.

Reference

Bismuth in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Cadmium

Cadmium is used chiefly for plating other metals, particularly to prevent corrosion. It is closely related to zinc and occurs in small quantities in most zinc ores, which are the only commercial source of cadmium, the metal being recovered as a by-product from zinc refineries. No commercial ore of cadmium alone is known.

Reference

Cadmium in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Chromium

Chromium is very important as an alloying ingredient in stainless and corrosion-resistant steels, and also for electro-plating. The only source is the mineral chromite, an oxide of chromium and iron. The relative amounts of chromium and iron vary in different deposits, and this chrome-iron ratio is an important factor in determining the economics of an occurrence, because deposits low in chromium are uneconomic unless the material can be treated to bring it to market specifications. Good ores and concentrates contain about 50 per cent chromic oxide and have a chromium-iron ratio of about 3 to 1.

Most of the chromite used in Canada is imported from Africa and the Philippine Islands. A little is produced in the United States, and during World War II some was produced from deposits in the Eastern Townships of Quebec.

Chromite is associated with ultrabasic igneous rocks, such as dunite, peridotites, and pyroxenites, and with the serpentines to which they alter. Masses or scattered grains of chromite may be found, usually in the rock called dunite, that is sometimes mistaken for chromite. Grains of the latter, however, are shiny, whereas dunite is a fine-grained, grey-black, iron-magnesian rock of a dull appearance, which when scratched leaves a pale grey streak. Usually the only other metallic mineral present is magnetite, which closely resembles chromite but is easily distinguished by its strong magnetic property and black streak, whereas the streak of chromite is chocolate-brown.

Discovery of a large chromite deposit of good grade in Canada would be important, and many efforts have been made to find one, especially in wartime. Places of interest to the prospector are the serpentine areas, especially those of the Eastern Townships, Quebec, and of central British Columbia, and parts of the Canadian Shield where ultrabasic rocks occur. Southeastern Manitoba became an area of special interest in 1942 with the exploration of deposits in the Bird River region, where chromite is found in peridotite. This chromite has a low chrome-iron ratio and research is being carried out to try to develop a commercial method of treatment that would make an acceptable product.

References

Craig, J. W.: Chrome for Canada; *Trans. Can. Inst. Min. Met.*, vol. XLIII, 1940, pp. 762-780.
This paper summarizes the world-wide occurrences, uses, and treatment of chromium ores, as well as the Canadian occurrences and trade as they were in 1940.

Stockwell, C. H.: Chromite Deposits of the Eastern Townships, Quebec; *Trans. Can. Inst. Min. Met.*, vol. XLVII, 1944, pp. 71-86.
This paper describes the geology and chromite deposits of the Eastern Townships, where most of the small Canadian production of chromite has been obtained. It includes notes on prospecting possibilities.

Downes, K. W., Morgan, D. W.: The Utilization of Low-Grade Domestic Chromite; Mines Branch, Mem. Ser. No. 116, 1951.
This report describes the results of research on several methods of utilizing low-grade chromite deposits such as have been found in Canada, and it discusses possibilities for further exploitation of such deposits.

Chromite in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Cobalt

Cobalt is an important metal used mainly for making special alloys. Most of the world's supply now comes from copper-cobalt mines in Belgian Congo and Northern Rhodesia. The Cobalt camp in Ontario, formerly a large producer, still supplies a large part of the Canadian production, which was valued at nearly $6 million in 1954. Cobalt is also recovered from ores of the Sudbury district and concentrates from the uranium mine at Great Bear Lake, and a considerable amount is obtained from the Lynn Lake nickel-copper deposits.

There is a demand for cobalt at present and prospecting for minable deposits offers attractions. Several small occurrences are known in the Canadian Shield and the Cordilleran and Appalachian regions, generally associated with occurrences of nickel, copper, or native silver. Prospecting in the general areas where such occurrences have been reported is probably the most practical plan. The pink colour of cobalt bloom is a good guide and anyone attempting to search for cobalt should familiarize himself with this mineral, properly called ***erythrite***.

References

Cobalt in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Drury, C. W.: Cobalt; Ont. Dept. Mines, Ann. Rept., vol. XXVII, pt. III, 1918.
This report contains information on cobalt minerals, descriptions of the principal occurrences in other countries, and descriptions of occurrences in Ontario.

Jones, R. J.: Cobalt in Canada; Mines Branch, Report No. 847, 1954.
This report contains information on Canadian occurrences, production, metallurgy, uses, and world trade.

Diatomite

Diatomite is a sedimentary deposit resembling chalk, composed of silica in the form of the 'shells' of microscopic organisms called diatoms. It has many industrial uses as a filter, absorber, and insulating material. About half of the diatomite now used in Canada is employed as a coating on grains of chemical fertilizer, to keep them from sticking together.

More than 400 deposits of diatomite are known in Canada, but the small and sporadic production has been virtually confined to deposits of Recent age in Nova Scotia, and Tertiary age near Quesnel, B.C. The Canadian types are not competitive under present market conditions, and practically all the diatomite used in this country is imported from the United States. Diatomite is therefore not likely to be of great concern to prospectors.

References

Diatomite in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Eardley-Wilmot, V. L.: Diatomite: its occurrence, preparation, and uses; Mines Branch Rept. No. 692, 1928 (out of print).

Feldspar and Nepheline Syenite

Feldspar is used mainly in the manufacture of pottery, glass, porcelain, enamelware, and cleansing powders. It is obtained from pegmatite dykes which are usually worked in rather a small way by open-pit methods. In 1954 about 16,000 tons valued at about $300,000 were produced, all from the Grenville region of the Canadian Shield, and mainly from the Province of Quebec. Many known deposits near transportation are not being worked, therefore, feldspar is not of great interest to prospectors at present. However, if pegmatites are important because of the presence of some other mineral, the possibility of disposing of the feldspar as a by-product would be worth considering.

A large deposit of nepheline syenite in Peterborough County, Ont., yields an important product used in the ceramics industry.

References

Feldspar in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Nepheline Syenite in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Spence, H. S.: Feldspar; Mines Branch Rept. No. 731, 1932.

Fluorspar

Fluorspar or fluorite (calcium fluoride) is an important mineral for the manufacture of flux used in smelting aluminum, as a flux in the making of steel, and as a raw material for producing certain chemicals. In 1954 Canada produced about 119,000 tons of fluorspar valued at nearly $3 million. This came almost entirely from six mines in Newfoundland, where large reserves of ore are reported. The remainder of the production, about 1,000 tons, was derived from a mine near Madoc, Ont. Other occurrences are known in various parts of Canada, but only large deposits in accessible places are likely to be of commercial importance.

References

Wilson, M.E.: Fluorspar Deposits of Canada; Geol. Surv., Canada, Econ. Geol. Ser. No. 6, 1929. Price 50 cents.

Fluorspar in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Gems and Rare Minerals

The more valuable gems, such as diamonds, rubies, and emeralds have not been found in Canada in commercial deposits, but specimens of some of the minor gems, semi-precious stones, and minerals desired by lapidaries and collectors have been found in several parts of the country. It is rather surprising that the more important gems have not been found, because geological conditions more or less similar to those in which some of the principal gem deposits of the world are found, do exist. It should be noted, however, that the market and value of some gems are not as attractive as they once were, because methods of making synthetic stones of high quality have been developed in some cases. These are not imitations, but true synthetic stones of the same compositions as natural ones, and the relative ease and cheapness of their production have affected the demand for the natural stones.

Diamonds are found in other countries in 'kimberlite', a breccia composed of rock fragments in a matrix of serpentine and carbonate. This is an unusual rock, and it must be remembered all rocks containing serpentine are not necessarily favourable for the occurrence of diamonds. Most other gems occur originally in pegmatites, particularly those pegmatites relatively high in lithium and sodium. Several semi-precious stones such as lapis lazuli and jade are found in contact metasomatic deposits in limestone, schist, or gneiss.

A large part of the world production of gems comes from placers, because most gems are hard and resistant to erosion even if they are not particularly heavy. Therefore gems originally contained in deposits of the kinds mentioned in the previous paragraph tend to be concentrated in beach and other forms of placers. Often they are derived from sporadic occurrences that could not have been worked economically in their primary state, and have been concentrated by slow natural processes, just as many important gold placers are derived from very lean gold-bearing rocks. Gems may therefore be found in Canadian placer deposits, particularly in the Cordilleran region.

No discussion of the possibility of finding gems in this country would be complete without mention of the many attempts to discover the source of the famous Wisconsin diamonds. At least seventeen diamonds were reportedly found in glacial drift in Wisconsin and nearby states before the end of the last century, and there is good reason to believe that they were transported from one or more occurrences in the Canadian Shield. Repeated attempts have been made to find the source, sometimes by fairly elaborate expeditions and after careful study of the probable directions of glacial flow and deposition. All attempts have failed, but it is not impossible that by luck or by further knowledge of glacial processes diamonds may be found in the Canadian Shield. Articles on this subject are listed below. The only other suggestions of diamond occurrences in this country are reported occurrences of microscopic-sized diamonds in the Bridge River and Tulameen regions of British Columbia, but later work showed that the supposed diamonds were synthetic periclase formed by heating samples of rock.

Minor gems, and semi-precious stones such as amethyst, occur in several parts of the country, and material suitable for ornamental purposes, such as agate, can be found in many places, either in bedrock occurrences or as pebbles and boulders.

On the basis of present information it would not seem that prospecting for gems alone is likely to be very rewarding, but prospectors may find it to their advantage to learn something of the characteristics and modes of occurrence of gems and semi-precious and ornamental stones, and to be alert for occurrences of them when prospecting for other metals and minerals. At least they should learn to recognize garnets and small transparent crystals of quartz, rutile, etc. which are common and almost always valueless, and which are often submitted to government agencies by persons who think they are rubies or diamonds. Another point to be noted is that the quality of gem minerals varies greatly. Therefore it is far from sufficient merely to have a mineral identified as a species that is sometimes of gem quality; it is often necessary to have the quality estimated by a jeweller or a mineralogist who specializes in gems.

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Kunz, G. F.: Gems and Precious Stones of North America; Scientific Publishing Co., New York, 1892.
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Poitevin, E.: Gems and Rare Minerals of Economic Value; Prospecting in Canada, Geol. Surv., Canada, Econ. Geol. Ser. No. 7, 2nd Ed., 1935, pp. 91-99.
Contains information not included in the present edition which would be useful for serious searchers for these minerals. This edition, although out of print, is available in several libraries.

Smith, Arthur: Semi-precious Stones; Penguin Books, 1952.
A small inexpensive book with illustrations in colour.

Germanium

Much publicity has been given to germanium in recent years because important uses have been found for it in the manufacture of transistors, which replace vacuum tubes for some electronic purposes. Consequently, there has been considerable interest in the possibility of discovering workable germanium deposits. Present indications are, however, that germanium will continue to be turned out as a by-product of other operations and that it is not a metal to be searched for independently.

Germanium occurs in germanite and argyrodite, sulphides of silver and germanium, but these minerals are not common and they have not been found in Canada.

Germanite and other minerals containing germanium have been found in other countries in ores mined for zinc, lead, and copper, germanium being recovered from the flue dusts of certain smelters that treat these ores. It is believed that germanium might also be found in small amounts in titanium and tin deposits. It occurs in small quantities in certain coals, and in the United Kingdom is recovered from the flue dusts of producer-gas plants. Reports suggest that adequate supplies can be obtained from these by-product sources.

Small amounts of germanium have been detected in zinc ores of the Sullivan, Kicking Horse, and Monarch mines of British Columbia and it is reported to occur with hematite at the Gaspé zinc and lead mine of Federal Metals Corporation. It was reported recently from a zinc discovery in Cape Breton Island, N.S. Investigations at Canadian smelters are said to have shown that germanium did not occur in the flue dusts in sufficient quantities to make recovery worthwhile.

Many samples of coal from different parts of Canada have been and are being tested for germanium by the Department of Mines and Technical Surveys and other organizations. The results to date indicate only scattered occurrences even within a single mine.

Graphite

Graphite is widely used for making heat-resistant and corrosion-resistant articles, pigments, lubricants, pencils, and stove polishes. It is also used in the construction of certain types of atomic reactors. Graphite is a common mineral, but concentrations that pay to work are uncommon, and none is at present mined in Canada.

The Black Donald mine near Calabogie, Ont. produced large amounts of 'small flake' and 'amorphous' grades of graphite from a contact metasomatic deposit in Grenville limestone until work was suspended in 1954. Smaller amounts of the same grades were produced several years ago from deposits in and near the Ottawa valley in Ontario and Quebec. The possibility of finding other workable deposits in Canada is worthy of the attention of prospectors, but they should not be misled by the numerous small occurrences that are common in many parts of the country.

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Graphite in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Iron Oxides (Ochres)

Relatively small amounts of iron oxides are mined in the St. Lawrence Lowland of Quebec for use in purifying manufactured illuminating gas, for pigments in paints, and as polishes. These deposits have been worked since 1886, and appear adequate for all demands.

Reference

Iron Oxides in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Lithium

The development of new uses has caused an increasing demand for lithium, the lightest of all metals, during recent years. It is used for making special lubricants, in refrigeration and welding, in the manufacture of storage batteries, and for other purposes. It is reported to have limited uses in connection with atomic energy. The principal sources are spodumene (a silicate of lithium and aluminum), lepidelite (a lithium-bearing mica), and amblygonite (a fluo-phosphate of aluminum and lithium). These materials are found in pegmatites, and several occurrences, particularly of spodumene, have received attention in western Quebec, southeastern Manitoba, and the Northwest Territories. Occurrences in Lacorne Township, Que., which have been known for some time, have been explored further during the last few years and one property is nearing production following the negotiation of a contract for the sale of lithium concentrates in the United States. A large tonnage of ore grading 1·3 per cent lithium oxide is reported to have been shown by diamond drilling a series of parallel pegmatite dykes on this property. These developments have caused increased interest in exploring other spodumene occurrences in which this mineral occurs as more than occasional scattered crystals. Several deposits in Ontario and Quebec received attention in 1955, and prospectors reported additional discoveries in several parts of the Canadian Shield favourable for the occurrence of pegmatites.

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This report describes lithium and other deposits in southeastern Manitoba.

Rowe, R. B.: Pegmatitic Beryllium and Lithium Deposits, Preissac-Lacorne Region, Abitibi County, Quebec; Geol. Surv., Canada, Paper 53-3 (1953).
This report is mainly descriptive of lithium occurrences in this region.

———: Pegmatite Lithium Deposits in Canada; *Econ. Geol.* vol. 49, No. 5, pp. 501-515 (1954).
An up-to-date summary of information, with discussion of economic possibilities.

Magnesium

Because of its lightness and strength, metallic magnesium is now used in large quantities, mainly for alloys used in the aircraft industry. Canada is an important producer, the ore being obtained from deposits of dolomite (magnesium carbonate) in Ontario and brucite (magnesium hydroxide) in Quebec. Magnesium compounds used extensively for making refractory materials such as furnace linings and for various chemical purposes are produced from brucite and dolomite deposits in Quebec. Suitable deposits of brucite are in demand, but those of dolomite and other magnesium minerals such as magnesite are not sought at present. Brucite is not easy for unskilled persons to recognize. Useful information on its detection is included in the first publication listed below.

References

Goudge, M. F.: Preliminary Report on Brucite Deposits in Ontario and Quebec, and their Commercial Possibilities; Mines Branch, Dept. Mines and Tech. Surveys, Mem. Ser. No. 75 (1939) (out of print).

Magnesium in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Magnesite and Brucite in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Manganese

Manganese is an important metal used mainly in the manufacture of steel, about 12 pounds being used for every ton of steel produced. The other principal use is in making dry batteries.

Small amounts of 'bog' manganese ore have been produced at times in the Appalachian and Cordilleran regions, but none is produced in Canada at present, except as the manganese content of certain iron ores. Workable deposits of manganese would undoubtedly be attractive, but geological studies and considerable prospecting have not disclosed any, although a New Brunswick prospect is being explored.

The most important manganese minerals are pyrolusite (manganese oxide), psilomelane (hydrous manganese manganite) and manganite (hydrous manganese oxide). Most commercial deposits are a mixture of all three minerals, together with varying amounts of sand or clay, iron oxide, and barite. Wad or bog manganese is an earthy substance formed by precipitation from surface waters which have passed through rocks containing manganese. It commonly occurs as basin-shaped deposits a few feet deep or as small benches on gently sloping hillsides. Many such occurrences have been found in Canada, especially in the Maritime Provinces, Manitoba, and British Columbia, but their grade is variable and of low average.

Manganese minerals are also found in Canada in limestone of Carboniferous age, in red shale, conglomerate, granite, and sandstone, the commonest occurrence of this kind being replacements in limestone. They generally consist of irregular deposits of manganese oxide that follow the bedding of the limestone and often branch into pipes and veins. Overlying many of these deposits is soil, gravel, or residual clay up to 20 feet in depth in which occur nodules and larger masses of manganese minerals. Less common occurrences are veins and breccia fillings composed of manganese minerals.

References

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Messervey, J. P.: Manganese in Nova Scotia; Nova Scotia Dept. Public Works and Mines, Pamphlet No. 17, 1931.

A summary of information on manganese and of manganese occurrences in the province.

Manganese in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Mercury

Mercury is widely used, and is especially necessary in wartime because of its use in making detonators. It is produced from the mineral cinnabar (mercury sulphide) that usually occurs in hydrothermal deposits formed at fairly low temperatures and pressures. Cinnabar occurs at several places in British Columbia, particularly along a fault zone that extends for about 150 miles northeast of Fort St. James. Besides several minor occurrences, this zone contains the large Pinchi Lake deposit which was found and reported by a party of the Geological Survey of Canada. This mine produced much mercury during World War II but ceased operation when cheaper supplies from Italy and Spain became available. Although considerable ore is said to remain in the Pinchi Lake deposit, large deposits of high mercury content would be attractive. The fault zone mentioned above and other parts of the Cordilleran region appear to offer the best possibilities for prospecting.

References

Stevenson, J. S.: Mercury Deposits of British Columbia; B.C. Dept. Mines, Bull. No. 5, 1940 (out of print).

A comprehensive report containing general information on the occurrence of mercury and descriptions of the known deposits in this province.

Armstrong, J. E.: Geology of the Pinchi Lake Mercury Belt, British Columbia; *Trans. Can. Inst. Min. Met.*, vol. XLV, 1942, pp. 311-323.

A paper on the geology, mercury deposits, and prospecting possibilities of the Pinchi Lake mercury belt.

Mercury in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Meteorites

Although fairly rare and not strictly within the realm of prospecting, meteorites are of interest to prospectors both because of the fascination aroused by these bodies from outer space and the fact that they are salable. Because of the similarity in names, there is a good deal of confusion between meteorites and meteors. Meteors, the so-called falling stars with which everyone is familiar, are tiny particles that probably come from comets. They become white-hot and therefore visible when they enter the earth's atmosphere and are heated by the friction caused by travelling at great speed through the air; they are completely burnt up in this way and do not reach the earth. Meteorites are larger bodies that seem almost certainly to have resulted from the breaking up of small planets or 'asteroids' of which there are thousands between the orbits of Mars and Jupiter. Meteorites become molten on entering our atmosphere in the same way as meteors do, but are large enough for some of the material to reach the earth. They are usually pitted and have the appearance of having been molten. They range from small pieces to masses weighing several tons. The largest ones form craters, but at some craters believed to be of this origin no meteorite is found, perhaps because it disintegrated explosively when it struck.

Meteorites are of three main kinds called 'stony', 'stony-iron', and 'metallic'. Stony meteorites consist mainly or entirely of material much like rocks of the earth's crust, but may also contain particles of nickeliferous iron. They are difficult to recognize except in places where ordinary stones are not likely to be found, such as on top of snow or ice, or in soil devoid of other stones. In such cases, if a stone is smooth and covered with a dark crust it may be a meteorite, but if it is jagged and bright it is probably an ordinary rock. Stony-iron meteorites contain both stony matter and iron in large amounts. Metallic meteorites consist mainly of nickeliferous iron, and their recognition is assisted by their unusual weight. Meteorites are bought by the Geological Survey of Canada; small suspected specimens may be submitted for appraisal, and large ones may be reported.

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Singer, S. F.: The Origin of Meteorites; *Sci. American*, No. V, pp. 36-41, (1954).

Mica

Although mica is used in relatively small quantities, it is an important commodity used mainly in electrical appliances because it splits into thin, insulating sheets. The name is applied to a family of silicate minerals with different compositions and properties. Muscovite, the clear mica, is the most important type, and phlogopite, sometimes called amber mica, is used for many purposes. Mica is a common constituent of pegmatite dykes, but only those containing muscovite or phlogopite in unusual size and quantity are likely to be important. There is a small Canadian production, chiefly from several small operations in Quebec and Ontario, but under present economic conditions the greater part of the supply is imported, as it is difficult to compete with cheap mica from other countries. Probably, therefore, prospectors should concern themselves only with phlogopite or muscovite in sheets 6 inches or more in size. It should be noted that some muscovite appears to be dark brown or black when in thick crystals, but individual sheets are transparent.

Vermiculite, which resembles mica, is a black, brown, or green mineral sometimes formed by alteration of mica. It expands remarkably under strong heat, which makes it useful as a heat insulator. All vermiculite used in Canada is imported as no domestic occurrences of sufficient size and quality have been found.

References

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———: The "Bonanza" Mica Operation of Purdy Mica Mines, Limited, Mattawan Township, Ontario; Tech. Pub. No. 2154, *AIME* 1947.

An account of the history, geology, and processing of the product from what was probably the most successful muscovite property in Canada.

Bruce, C. G.: The Stanleyville Vermiculite Deposit; *Bull. Can. Inst. Min. Met.*, August 1952, pp. 489-493.

A description of a vermiculite deposit in Ontario, with general information on the properties, uses, and economics of the mineral.

Mica in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Molybdenum

Molybdenum is an important metal used mainly in special kinds of steel. Its principal ore is molybdenite, a sulphide of molybdenum. Most of the world's production comes from large deposits in which molybdenite is disseminated in relatively small quantities, such as one in Preissac township, Quebec, where the ore is in a wide zone between granite and granite porphyry, and the Timothy mountain deposit in central British Columbia, where molybdenite is scattered in a wide zone in brecciated quartz-diorite. Many occurrences of molybdenite in pegmatites and quartz veins formed at high temperatures have been found in the Canadian Shield and the Cordilleran and Appalachian regions. Several deposits have been worked in Canada during periods of strong demand and high prices, but the only one in production at present is that of Molybdenite Corporation of Canada Limited, north of Val d'Or, Que. This property was recently expanded to permit milling at a rate of over 400 tons a day. In normal times only the most favourable deposits can compete with large molybdenite deposits in the United States, therefore prospecting for molybdenite is not particularly attractive at present. In times of special demand known deposits can be re-opened or explored further, and there would probably then also be a revival of interest in prospecting for additional workable deposits.

References

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A comprehensive report on uses, occurrences, mining, and treatment of molybdenum and its ores. It includes descriptions of many Canadian deposits known up to 1925.

Claudet, H. H.: Molybdenite in Canada; *Trans. Can. Inst. Min. Met.*, vol. XLVII, 1944, pp. 87-98.
A summary of information on Canadian occurrences of molybdenite and on uses and treatment of molybdenum ores.

Stevenson, J. S.: Molybdenite in British Columbia; B. C. Dept. Mines, Bull. No. 9, 1940 (out of print).
A comprehensive report giving general information on the occurrence of molybdenum, and descriptions of the deposits known in British Columbia.

Molybdenum in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Niobium (Columbium) and Tantalum

Niobium and tantalum are two closely related metallic elements that commonly occur together in the same minerals and are separable only by complicated chemical procedures. Niobium is the official name for the element more commonly known in this country as columbium. Niobium is particularly important for making special corrosion-resistant and heat-resistant alloys in wide use today. Tantalum is used mainly for alloys having high resistance to wear and corrosion, and also in special kinds of optical glass.

Neither niobium nor tantalum is produced in significant quantity in Canada at present. The principal source of niobium and tantalum has hitherto been a mixture of two minerals, columbite and tantalite, which chemically are niobates and tantalates of iron and manganese, found in pegmatites and in placers derived from weathering of granites. At present, niobium is obtained chiefly from cassiterite-columbite placers and decomposed columbite-bearing granite in Nigeria.

During the last few years prospectors for uranium have, with the aid of Geiger counters, discovered several occurrences of radioactive minerals that contain niobium and tantalum. These are mainly minerals of the pyrochlore series (titanates and niobates of calcium, rare earths, uranium, etc.), columbian perovskite, betafite, and polycrase. Deposits near North Bay and Nemegos, Ont., and Oka, Que., have had considerable exploration, and research is being carried out to develop improved methods for treating material from them. There is hope that these deposits will become productive and considerable interest in searching for and exploring other deposits of this general kind, some of which appear to be contact metasomatic or replacement deposits. A feature of several deposits is their association with rocks high in alkalis, that is, sodium and potassium, as pointed out by R. B. Rowe in the publications listed below. Some deposits are in alkaline igneous rocks and others are in limy sedimentary or metamorphic rocks near bodies of alkaline intrusions. The deposits near Nemegos are complexes containing iron, apatite, niobium, tantalum, and uranium. Placers containing pyrochlore and euxenite-polycrase are being explored in southeastern British Columbia.

References

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Jolliffe, A. W.: Rare-Element Minerals in Pegmatites, Yellowknife-Beaulieu Area, Northwest Territories; Geol. Surv., Canada, Paper 44-12 (1944).
A paper describing pegmatite deposits containing niobium, tantalum, beryllium, lithium, and tin minerals.

Rowe, R. B.: Notes on Geology and Mineralogy of the Newman Columbium-Uranium Deposit, Lake Nipissing, Ontario; Geol. Surv., Canada, Paper 54-5 (1954). Price 50 cents.
A preliminary report of a special study of the deposits near North Bay.

———: Notes on Columbium Mineralization, Oka District, Two Mountains County, Quebec; Geol. Surv. Canada, Paper 54-22 (1955). Price 50 cents.

———: Association of Columbium Minerals and Alkaline Rocks; *Can. Min. J.*, March 1955, pp. 69-73.
Contains suggestions for prospecting.

Jones, R. J.: Columbium and Tantalum in Canada; Mines Branch, Dept. Mines and Tech. Surveys; Special Report (1954).
A useful summary of information on uses and Canadian occurrences.

Radium

Radium exists in minute quantities in all uranium-bearing minerals, roughly one part of radium to 3,000,000 parts of uranium. There are no separate radium minerals. Uranium minerals were formerly mined for their radium content, but now uranium is the prime object, and adequate supplies of radium are obtained from certain uranium operations. The value of the radium in a ton of ore or concentrate is small, and the price paid is on the basis of the uranium content, the value of the radium not being considered.

Radium has important medical and industrial uses, but for some of these it is now replaced by cheaper and more suitable radioactive substances produced in atomic reactors.

Rare Earths

The so-called 'rare earths' are a series of fifteen elements having closely related chemical and physical properties. The name 'rare earths', applied many years ago, is rather inappropriate, and the name 'lanthanons' has recently been proposed instead. The elements are not particularly rare, although they are usually dispersed in small and unimportant quantities. They were called earths because their oxides are earthy, but they are actually metals. The element 'yttrium' is customarily discussed with the rare earths because some of its properties are related to them. The elements are grouped in various ways by different authorities, a common method being as follows:

Lanthanum	Cerium group
Cerium	
Praseodymium	
Neodymium	
Promethium	
Samarium	
Europium	
Gadolinium	Yttrium group
Terbium	
Dysprosium	
Holmium	
Erbium	
Thulium	
Ytterbium	
Lutetium	
Yttrium	

With the exception of yttrium, the elements are listed above in the order of their atomic weights; those of the cerium group are commonly referred to as the light rare earths, and those in the yttrium group as the heavy rare earths.

The cerium group are used in the manufacture of carbon-arc electrodes, special alloys, and for other uses, and some of the heavier rare earths and yttrium are reported to be in demand for special uses. The cerium group are obtained from monazite concentrates obtained from beach sands and placers in Brazil, Ceylon, India, the United States, and other countries, and from bastnaesite (fluo-carbonate of rare earths, etc.) produced in United States from a body of carbonate rock. The cerium group is also present in such minerals as allanite and pyrochlore. This group is said to be in plentiful supply in world markets. Occurrences of monazite and allanite are fairly abundant in Canada and deposits containing bastnaesite have been found at the Rexspar property, in British Columbia.

On the other hand, the heavier rare earths are reported to be in short supply and there is understood to be a good demand for them, and particularly for gadolinium. These elements occur in xenotime, gadolinite, fergusonite, euxenite, samarskite and a few other minerals, which are found usually as accessory minerals in some pegmatites and related types of deposits. Some of these minerals also occur as accessories in granitic rocks, erosion of which might produce placer occurrences. Several occurrences of these minerals have been found in Canada, chiefly in pegmatites in the Grenville region of the Canadian Shield. Most of these are listed in "Canadian Deposits of Uranium and Thorium", listed below, because they contain uranium or thorium as well as rare earths. Their radioactivity permits use of radioactivity detectors in prospecting.

Prospectors and companies are showing increasing interest in the rare earths, particularly gadolinium and other members of the yttrium group. They are faced by the problems that the minerals are difficult to identify except by laboratory methods; that specimens for study are difficult to obtain (they cannot be obtained in sufficient quantity for sale by the Geological Survey of Canada); workable deposits would probably need to contain a fair amount of the appropriate mineral or minerals; and chemical analyses are costly and difficult. The Mines Branch of the Department of Mines and Technical Surveys makes analyses for total rare earths and for cerium (*see* Chapter XIV); semi-quantitative spectrographic or other kinds of analyses can probably be obtained at less cost from certain provincial and commercial laboratories, but these usually report only certain of the elements, particularly cerium, lanthanum, yttrium, and ytterbium.

To date there is little literature on the geology of deposits of rare earths. More information will probably be published during the next few years.

References

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Lang, A. H.: Canadian Deposits of Uranium and Thorium; Geol. Surv., Canada, Econ. Geol. Ser. No. 16, 1952. Price $1.

Olson, J. C. and others: Rare-earth Mineral Deposits of the Mountain Pass District, San Bernardino County, California; U.S.G.S. Prof. Paper 261, 1954.

Vickery, R. C.: Chemistry of the Lanthanons; Academic Press, New York, 1953. Price $6.
Contains chapters on the history of rare earths, and on rare-earth minerals.

Selenium

Canada is one of the leading producers of selenium, which is used mainly in the electrical and electronics industries. The demand is reported to be increasing. The metal is recovered as a by-product of the refining of copper and does not seem likely to be found in deposits workable for selenium alone.

Reference

Selenium in Canada; Mines Branch, Dept. Mines and Tech. Surveys, Annual Review.

Thorium

Thorium has limited industrial uses but there is no market for it at present in Canada and the markets in other countries are well supplied. Great interest has been taken in thorium minerals in recent years because they, like uranium minerals, are radioactive, and because thorium is being studied as a possible source of atomic energy. Although no large demand for thorium seems likely to arise in the near future, some companies are interested in acquiring and exploring exceptional deposits in the hope of an increased future demand.

The principal thorium-bearing minerals are thorite, uranothorite, and a group of minerals containing thorium and rare earths, of which monazite, pyrochlore, bastnaesite and allanite are examples. The principal sources of thorium at present are pyrochlore deposits in Africa, bastnaesite deposits in the United States, and monazite beach sands and other forms of placers in India, Ceylon, Brazil, and Malaya. Thorium-bearing minerals are commonly more resistant than uranium minerals, and therefore are preserved in placers in several parts of the world.

A number of occurrences of thorium-bearing minerals are known in Canada, and many of these are listed in publications. They are principally accessory minerals in pegmatites and related types of deposits; others are in placers and sedimentary rocks. It does not seem likely that these will be workable for thorium alone unless there is a marked change in the demand for thorium, but if a large deposit with substantial thorium content were found, or if it were practical to save thorium minerals as a by-product of mining for some other metal or mineral, the matter would bear careful investigation.

Some of the references listed under 'uranium' also contain considerable information on thorium.

Tin

Tin is widely used, mainly for making tin plate and solder. Large amounts are imported into Canada. During World War II, when tin was in very short supply, considerable prospecting failed to disclose deposits that could be worked for this metal alone. However, it is possible that economic deposits may yet be found. The only tin produced in Canada at present is as a by-product of the treatment of ores of the Sullivan mine in British Columbia; a few hundred tons, as metal or concentrates, have been turned out annually in recent years.

The principal tin-bearing mineral is cassiterite (tin oxide); stannite (sulphide of copper, iron, and tin) is less important. Tin lodes are usually high-temperature veins or pegmatites, and the latter usually contain unimportant amounts of of cassiterite. Both vein and pegmatite deposits are usually found in or near bodies of granite. Because cassiterite is heavy and resistant to erosion it often occurs in placers, although in Canada it has so far been found in small amounts only. Tin-bearing lodes and placers are most likely to be found in this country in a belt extending northwest through the interior of British Columbia, west of the Rocky Mountain Trench, and continuing through Yukon Territory into Alaska. In the past, considerable tin was discarded in operations for placer gold, particularly in the Yukon, and it is likely that steps will be taken to save it in future from gold placers that contain appreciable amounts of cassiterite.

A large base-metals orebody in New Brunswick, being developed by Brunswick Mining and Smelting Corporation, has been found to contain from 0·1 to 0·2 per cent tin. However, because of the complexity of the ore, the possibilities of recovering tin from it have not yet been determined.

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Titanium

Titanium has become increasingly important in Canada in recent years because one of the largest titanium-bearing deposits in the world is being worked at Allard Lake in Quebec, and because of the acceptability of the concentrated titanium dioxide produced as a raw material for the United States titanium dioxide pigment industry. In 1954 the Canadian production of titanium oxide was valued at nearly $4 million. Although titanium metal is being used for certain special applications, both as pure metal and as an alloy, the total amount consumed is relatively small as it is difficult to extract the metal cheaply from its ores, and metallurgical problems in melting, rolling, and forging the metal and in reclamation of scrap still remain to be solved. Much research is being done on these problems and a successful outcome will probably cause increased demand for titanium metal. However, as large deposits are already known in Canada and elsewhere, a new discovery would probably have to be large in size, have a high titanium dioxide content, be conveniently located for cheap transportation, and be amenable to concentration, in order to compete with those already known.

The principal ore minerals of titanium are titaniferous magnetite and ilmenite (both oxides of iron and titanium), and rutile (oxide of titanium). In the industry, ores are classed as titaniferous magnetite ore if they contain less than about 20 per cent titanium, and as ilmenite ore if they contain more than that.

Occurrences of ilmenite and titaniferous magnetite are fairly common in the southern part of the Canadian Shield in Quebec, and some have been known for many years. These deposits are classed as magmatic segregations in anorthosite, a rock composed almost entirely of plagioclase feldspar which commonly carries ilmenite and magnetite in small amounts as accessory minerals. Some of these deposits, notably one near St. Urbain, Que., have been worked for many years on a relatively small scale.

The presence of ilmenite in what is now known as the Allard Lake region was first reported by J. A. Retty, then of the Quebec Department of Mines, as a result of a geological reconnaissance in 1941. This led to the staking of claims that were acquired by two large American mining companies which, from 1944 on, carried on much prospecting, geological exploration, aeromagnetic surveys, and diamond drilling, that resulted in the discovery of eight separate ilmenite deposits. By 1947 large tonnages of ore were indicated, particularly in one deposit, and in the following year construction of a railway from Havre St. Pierre to the main deposit was begun. A plant for treating the ore was built at Sorel, Que.

The Allard Lake deposits are in the northeast corner of a large intrusive body of anorthosite. The orebodies are black dykes, lenses, and sill-like bodies containing masses and disseminations of ilmenite in the anorthosite. They are believed to be related in origin to the anorthosite, but to have been introduced, after it was solidified and fractured, as a late stage of the general intrusive process. The ore is reported to average 35 per cent titanium oxide and 40 per cent iron.

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Tungsten

Tungsten (also called wolfram) which is important for making certain kinds of steel, is obtained from the minerals scheelite (calcium tungstate) and wolframite (tungstate of iron and manganese). Scheelite occurs usually in quartz veins, silicified zones in granite, replacements, and contact metasomatic deposits. It has been found in many places in the Canadian Shield and the Cordilleran and Appalachian regions, and a few occurrences of wolframite have also been found in Canada. Tungsten minerals are also found in relatively small amounts in placers.

In 1954 Canadian production amounted to 1,085 tons of tungsten trioxide valued at about $5,800,000. This came almost entirely from the Emerald and related mines near Salmo, and the Red Rose mine near Hazelton, B.C. These mines have contracts for the sale of tungsten concentrates, but it is not likely that other properties will be put in production at present unless exceptional deposits are found, because the world requirements for tungsten are being met. If the demand should increase, prospecting for tungsten may again become attractive, in which case the ease with which scheelite can be detected with the aid of a fluorescent lamp will be a great advantage.

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Vanadium

Vanadium has important uses, mainly as an alloying ingredient in certain kinds of steel and for improving the quality of cast-iron. Vanadium has not been produced in Canada, and few occurrences are known here. The chief minerals from which it is produced in other countries are patronite (a complex mineral containing large amounts of vanadium sulphide), roscoelite (a vanadium-bearing mica), carnotite (hydrous vanadate of uranium and potassium), and vanadanite (lead vanadate). The following summary of vanadium occurrences and Canadian possibilities is quoted from "Prospectors Guide for Strategic Minerals in Canada", a publication of the former Department of Mines and Resources, which is out of print.

"Vanadium is recovered as a by-product from other metal mining, from vanadates in the oxidized zones of some lead mines, and from vanadium ore in the western United States, Peru, and some other countries.

"In the western United States the ores consist of carnotite, roscoelite, vanoxite and other less common vanadium minerals. They are replacement deposits along certain beds of Mesozoic sandstone and along brecciated zones in the same rocks. The ore is associated with gypsum and carbonized wood. In Peru a highgrade and very productive deposit of vanadium ore occurs as a lens along the bedding planes of Mesozoic shale. There, the ore is a complex sulphide called patronite associated with gypsum and greenish black masses of a hydrocarbon. The association with gypsum, carbonized wood, and hydrocarbons supports the generally held view that the ores were deposited from surface waters of the sulphate type and were aided in deposition by reaction with carbon or hydrocarbons in the sedimentary rocks.

"The outlook for finding vanadium-bearing sediments or asphalts in Canada is not particularly promising, though the possibility of such occurrences should not be overlooked. Tests so far made of what appeared a most promising possibility, namely, the bituminous sands of Alberta, were disappointing, as also were those of the Upper Carboniferous sediments of New Brunswick and Nova Scotia, which held out promise because of their appreciable content of copper in various forms concentrated around carbonized wood or coaly matter.

"A small exposure of a shallow bed, varying from 1 inch to 4 inches in depth, of very hard, black, vanadium-bearing rock lying between two lava flows of the Valdes group, probably Triassic, is known on the north end of Quadra Island, about 6 miles northeast of Vancouver Island. Samples of this rock averaged 2·16 per cent V_2O_5, too low to be of commercial grade except possibly in the case of large ore-bodies.

"All titaniferous magnetite ores, of which there are several deposits in Canada, contain small amounts of vanadium. The recovery of the vanadium as a by-product, is, however, a metallurgical problem which has not yet been solved commercially, except in ores in which the titanium oxide (TiO_2) content is less than 2·5 per cent.

"As regards finding carnotite sandstones in Canada, so little is known of the origin of this mineral that no definite statement can be made one way or the other. Sandstones containing carbonized matter should be closely scrutinized, especially if showing evidence of any yellow stain or incrustation."

During the last few years vanadium has been found in relatively small quantities in several hydrothermal uranium deposits in Goldfields region, Saskatchewan. It has been shown to occur here in a new iron vanadate mineral named 'nolanite'.

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Zirconium

This metal is especially resistant to heat and corrosion. It is said to be desirable for use in certain components of atomic reactors and for other specialized purposes. Therefore the possibility of finding economic deposits in Canada is worthy of some attention, although zirconium is not in short supply on the world market.

The principal source is the mineral zircon (zirconium silicate) which, although widely distributed in small quantities as an accessory mineral in granitic rocks and pegmatites, has not yet been reported in quantity in Canada and is produced in a few countries only. It is found in beach placer deposits which also contain ilmenite, rutile, and monazite. The most likely places to examine are therefore beach and stream deposits. Some specimens of zircon are fluorescent, and this property might assist in detecting and evaluating occurrences.

Zirconium is also produced in Brazil from a mineral called baddeleyite which is said to occur here in large quantities connected with pegmatite dykes.

Anyone interested in the possibilities of finding a workable zirconium deposit should realize that many occurrences are known where it is possible to obtain specimens of zircon, and to obtain what seem significant analyses from selected samples. Search would have to be made for exceptional deposits, or ones where zircon might be recovered as a by-product. The 1954 price for zircon concentrates containing a minimum of 65 per cent zirconium oxide in the United States was $48 a long ton.

CHAPTER XIII

PLACER AND SMALL-SCALE LODE MINING

Placers

As was the case in most countries, the first important mining in Canada was placer mining for gold, which reached its peak about the end of the last century. Since then, no important new placer districts have been found, although additional productive deposits have been discovered from time to time in known placer districts in the Cordilleran region. Other workable deposits will probably be found in some of these districts, and some known occurrences that could not be exploited before may become workable in the future. Furthermore, new placer districts containing economic deposits of gold or other minerals may be found, although the widespread search that went on during the great periods of placer mining has naturally reduced the chances. Therefore, although prospecting and mining are now chiefly concerned with lode deposits, some prospectors still specialize in placers. All prospectors should be acquainted with the basic principles of placer mining, and should not neglect the possibility of locating worth while placer deposits if the territory is favourable.

The subject of placer (or alluvial) deposits is extensive, and a large literature is available for those who wish to specialize. The following pages treat the subject more fully than was appropriate in the general chapter on mineral deposits (Chapter IV). They include brief accounts of the history and distribution of the principal Canadian placer districts, and short descriptions of the methods of prospecting, testing, and mining, particularly those applicable to prospecting by individuals and to small-scale mining methods. A few large placer operations are still conducted by companies in Western Canada. Companies interested in initiating new placer operations would do well to consult engineers and geologists specially experienced in various phases of placers and placer mining. The following sections refer mainly to gold placers, but much of what is said is applicable to concentrations of other heavy minerals if they should be found in workable quantities.

Origin and Types of Placers[1]

Placers are deposits of sand, gravel, or other alluvium containing particles of gold or other valuable heavy minerals. Gold was and is the most important

[1] This section is modified from the account prepared by W. A. Johnston for previous editions of this publication.

placer mineral in Canada. Platinum has been found with gold in the placers of the Tulameen district and at a few other places in British Columbia and in the Yukon, but not as a rule in paying quantities. Most of the platinum was recovered in the early days of mining when the price of this metal was low.

Three conditions are necessary as a rule to form commercial placers: (1) occurrence of valuable mineral nearby; (2) release of this mineral from the bedrock by weathering; and (3) its concentration by stream or wave action. Residual placers may be formed by the weathering in place of mineral deposits, but are of rare occurrence. Most rich placers are concentrations from large volumes of rock occurring in regions that were first uplifted, then dissected by streams, and later worn down for many thousands of feet to terrains of relatively low relief. As placers containing gold are the only deposits of this type of great importance in Canada the following account refers to them.

The occurrence of placers in any region may or may not indicate that workable lode deposits occur in the region. For example, both placer and lode mining for gold have been successful in the Cariboo district of British Columbia. On the other hand, the gold in some placer districts may have existed in the oxidized upper parts of sulphide deposits or in veins that were entirely removed by erosion, or the remnants may be too small to mine. No important lode gold deposits have been found, for example in the Klondike, where the placer gold was derived from gold-bearing quartz veins; the remnants of these so far discovered have not been worth working. The great quantities of quartz-rich gravels produced by erosion of soft rock containing scattered veins show that many cubic miles of bedrock have been eroded from the region. Some of the gold in residual placers may have been formed by deposition from solution, but nuggets in stream gravels do not appear to have formed in this way. Most nuggets are well water-worn, and the gold crystals and unworn fragments that are occasionally found in some placers were doubtless protected by burial or were released from their enclosing matrix shortly before being found.

The distribution of gold in placers is irregular. Coarse gold, usually accompanied by some fine or moderately coarse gold, may be scattered through the lower 10 or 15 feet of gravels, especially if they contain much clay or other fine material, but usually it is concentrated on or near the bedrock. Paystreaks may occur at any elevation in a gravel deposit on a false bedrock of clay or other impervious bed. They may or may not occupy the deepest part of a stream channel. Pay gravel may occupy the whole width of the stream bottom in narrow, V-shaped valleys; in broad, flat-bottomed valleys the paystreak is likely to be much narrower than the valley floor and its course may be quite different from that of the present stream. Most paystreaks in broad valleys were originally formed in narrow valleys of fairly high gradients. As the gradient became less and the valley was widened by the meandering stream, the paystreak became buried beneath alluvium. A stream of low gradient tends to meander and the bends tend to move downstream, so that the materials in the valley bottom are reworked many times by the stream. A paystreak may be shifted in location by this process of reworking by the stream, or, if the deposit consists of coarse material or becomes somewhat cemented or hardened after the shifting of the stream, it may remain in its original position. Paystreaks are not continuous and may split or terminate abruptly, because gold is concentrated chiefly at such places as the inside of bends, where alternate deposition and erosion take place and where the bedrock forms good 'riffles'. Uplift or some other agency may cause the stream to deepen its valley, and the old paystreak, depending on its location, may then descend into the new valley or remain in its original position to form a bench or old channel placer. Barren ground may occur, therefore, in the bottom of the present stream valley in the stretches that are bordered by one or more rock benches, and exceptionally rich ground may occur in the places where the stream has cut down beneath the old channel.

Pot-holes and other depressions in the bedrock in the bed of a stream rarely contain gold. They are formed by erosion and any gold carried into them by the stream is likely to be ground fine by the action of current-transported sand and gravel and to be washed out. Gold does not occur in payable quantities in the submerged parts of deltas. Some gold may occur in alluvial fans that frequently form the upper parts of deltas, but only fine gold can occur in fans and there is little opportunity for its concentration into paystreaks because of frequent shifting of the stream channels.

Flood (bar or very fine) gold is sufficiently fine or flaky to be transported in muddy water. The particles range in size from a few to several thousand 'colours' to the cent. In regions where fine gold is supplied to the streams by erosion of their banks or beds, paystreaks may occur in the bars and banks of the streams. The paystreaks as a rule are only a few inches to 1 foot or 2 feet thick and lie at or near the surface between extreme low-water and high-water marks, in places (as on the upstream side of bars) where conditions are favourable for alternate deposition and erosion of material transported by the stream. They may occur in bench deposits at various elevations above the streams. As erosion and deposition go on from year to year the bars shift downstream; old paystreaks are destroyed and new ones are formed, but at a very slow rate. The rich flood gold deposits mined in the early days on the Fraser and on other streams in Canada represented the concentration of gold by these streams in post-Glacial time. The placer deposits of the Saskatchewan and Athabasca Rivers, in Alberta, as well as most of those along the Fraser, Stikine, and Columbia Rivers in British Columbia, are of this type. Many of the richer bars on these streams have been worked over several times. The first harvest, of course, was the richest and the work in recent years has rarely paid. Very little gold occurs below extreme low water in stream valleys containing flood gold deposits with no coarse or moderately coarse gold, and the flood gold paystreaks are thin and discontinuous. Many attempts at placer mining on a large scale by dredging and by other methods on such streams (for example, the Fraser) failed owing to failure to recognize the character of the paystreak or to inadequate testing of the ground.

Gravel plain placers are formed in broad valleys or alluvial plains containing gravels that have been repeatedly re-worked by meandering streams or by streams of fairly high gradients that tend to shift their channels. The gold is derived by erosion of the banks and the land at the headwaters of the streams and is likely to be moderately fine and fairly evenly distributed through the gravels. Such placers are best developed in unglaciated areas, but occur on a small scale in glaciated regions, for example, at a few places in Cariboo district, British Columbia. They can be profitably mined as a rule by dredging only.

Glacial gravels may contain gold, but have little economic value unless they have been re-concentrated by stream action or have been derived in part by erosion of pre-existing placers. Glacial erosion is more likely to disperse earlier placers than to form concentrations of heavy minerals. Moraines, kames, eskers, and glacial outwash plains do not contain gold in paying quantities. Scattered pieces of gold and isolated masses of gold-bearing gravels may occur in boulder clay. Stratified glacial silt and clay contain no gold. Interglacial paystreaks formed by normal stream erosion may occur in glaciated regions, being formed during a long interval between periods of glacial advance, in a place sheltered by topography from the scouring of later glaciation. Much of the gold found in glacial gravels is moderately coarse and is fairly uniform in size, as if sorted by powerful streams. The re-sorted glacial gravel placers of the old placer mining regions of British Columbia and of Beauceville district, Quebec, have been mined chiefly by hydraulicking and rarely can be profitably mined in any other way.

Buried placers are paystreaks that are covered with later deposits of glacia drift, lavas, and tuffs, or barren alluvium. Gold-bearing gravels, buried beneath great or small thicknesses of glacial drift, may occur in the bottoms of valleys or on rock benches and in old stream channels bordering valleys that were not severely glaciated. Such valleys are V-shaped. Rounded, U-shaped valleys are not likely to contain buried paystreaks, because of the effects of glacial erosion. Glacial gravels in the bottoms of such valleys may contain some gold, but usually the pay is so scattered that it cannot be mined profitably. Most of the rich paystreaks mined in the early days in Cariboo and in other districts in British Columbia were buried beneath glacial drift and were mined chiefly by drifting Lava-buried placers have been found in only a few places in Canada, as at Ruby Creek in Atlin district, but other occurrences may be found in British Columbia and Yukon Territory. The rising of the base-level of erosion, or overloading of streams, may cause deposition of barren alluvium above the pay gravels in a valley bottom. In arctic and sub-arctic regions, as in the Klondike, the ground is permanently frozen and thick deposits of 'muck' commonly overlie the gravels. Muck consists of slightly decomposed organic matter mixed or interbedded with fine sand, silt, and clay. It is formed partly by growth of vegetation in place and by soil creep and partly by deposition from overflowing streams. It contains in places much ground ice. As it is a good insulator it prevents thawing of the ground during the summer. Ground from which the muck has been removed by hydraulicking or by some other method becomes naturally thawed to depths of 10 to 30 feet in three or four years.

Beach placers are formed by wave erosion and concentration of the materials in sea cliffs. Rich beach placers occur as a rule only in places where stream or residual placers are eroded by waves. No important gold-bearing beach placers are known along the coasts of Canada, and do not seem likely to occur, except possibly very locally, as much of the material eroded by wave action is glacial drift. Beach sands containing magnetite have been found in places along the Pacific coast and the north shore of the Gulf of St. Lawrence.

Placers in the glaciated parts of Canada differ from those in the unglaciated parts of Yukon in several ways that affect their mining possibilities. The presence of large boulders in some placers in the glaciated areas renders the deposits workable only by the heaviest types of mechanical equipment. The bedrock in glaciated areas is likely to be hard and unweathered and this may make more difficult the recovery of all the gold by dredging, although modern dredges used in the Klondike successfully overcome this where the rock is jointed. Large boulders are absent and there is no overburden of glacial drift in the placers of the unglaciated parts of Yukon. There are thick deposits of muck, however, and thawing of the ground is necessary in mining operations.

The most favourable areas in Canada for prospecting for placers probably are the unexplored parts of Yukon and northern British Columbia. Unglaciated areas in which occur igneous or metamorphic rocks that are mineral-bearing, at least to some extent, are the most favourable. In glaciated areas narrow, V-shaped valleys, preferably those bordered by rock benches, should be sought, and rounded, severely glaciated valleys avoided. Valleys that were only slightly glaciated usually lie transverse to the general direction of glacial ice movement and do not head in glacial cirques.

In estimating the value of placer ground for mining it is important to determine the type of deposit to which the deposit belongs, for certain kinds of deposits, as outlined above, require much more testing than others to determine their value. Each type of deposit can be profitably mined as a rule by one or two methods only. It may be that certain kinds (for example, bar deposits) can be profitably mined only by hand methods. Preliminary testing of the ground may be done by panning (estimating 150 pans to the cubic yard), or by sinking test pits or shafts. Channel samples from the faces of the pits or shafts or, preferably, all the material excavated, are then tested by panning or 'rocking', as explained below. The material excavated swells in volume, usually increasing by about 50 per cent.

The most efficient means of testing placer ground is by drilling. As the Keystone drill cuts a somewhat larger hole than the outside diameter of the casing it is necessary to allow for this in estimating the volume of materials removed in drilling. One method of doing this is to consider that the value of gravel per cubic yard is the value of the gold obtained, multiplied by 100, and divided by the depth of the hole in feet. This is on the assumption that 100 linear feet of 6-inch hole (the size of casing ordinarily used being 6 inches) has a volume of 1 cubic yard. Thus the formula is:

$$\text{value of gravel per cu. yd.} = \frac{\text{value of gold obtained x 100}}{\text{depth of hole in feet}}$$

When drilling has been carefully done, 75 per cent or more of the estimated yield can be recovered by dredging. This includes all losses, not only those in the tailings, but unrecoverable 'islands' and corners left behind in the course of operation. The recovery of the gold in hydraulicking may be greater or less than 75 per cent, depending on whether the bedrock can be reached and how thoroughly it can be cleaned.

Historical Notes

In most countries, placer mining takes place at an early date because the more obvious placers are relatively easy to find and to mine. Fairly inexperienced persons can learn to find them by searching the beds and banks of streams, and the richer and less deeply buried ones can be mined with a few simple tools and contrivances.*

The first important placer discovery in Canada was in the basin of the Chaudière River southeast of Quebec city. Extensive mining did not begin there until 1875, although the first minor discovery was made in 1823. Gold to the value of about $2 million was obtained between 1875 and 1885, when about 500 miners were at work; after 1885 the yield declined. There may still be buried deposits in this and in similar regions, but the possibility of finding and exploiting them is not promising because of the amount of overburden, the number of large boulders, and the low gradients of the streams, which make it difficult to sluice the gravels. The operations in this part of Quebec were the only significant placer mining in Eastern Canada. A few low-grade occurrences of gold and other minerals have been found in other parts of Eastern Canada, but they have not been successfully exploited. The widespread and intense glaciation to which most of Canada was subjected seems to have destroyed most of any rich placers that may have existed in Tertiary times. The possibility of finding workable placers in Eastern Canada should not be overlooked, but the chances seem to lie mainly in the possibility of working, at some future date, certain sands and gravels for valuable residual minerals other than gold, if the demand for them should make this worthwhile, and if cheap methods can be evolved.

Canada's great placer fields were in the Cordilleran region. They were found as a result of prospectors spreading northward after the rich discoveries of placer gold in California which began in 1849. Some placer gold had been found earlier in what is now British Columbia, the first significant discovery having been in 1857, at Nicoamen on the Thompson River, a tributary of the Fraser. News of this caused a great influx of miners from California and elsewhere, and discovery after discovery was made along the Fraser and its tributaries. By 1860 the vanguard had reached the Cariboo region, where much richer deposits were found, thus initiating the great Cariboo gold rush that brought miners and adventurers from many countries. The total production from the Cariboo placers is estimated to exceed $50 million; production was at its peak from 1860 to 1863, after which it gradually declined, although important placer mining is still carried on in the region.

* The Greek legend of Jason and the Golden Fleece is based on the early practice of using sheepskins for catching fine particles of gold.

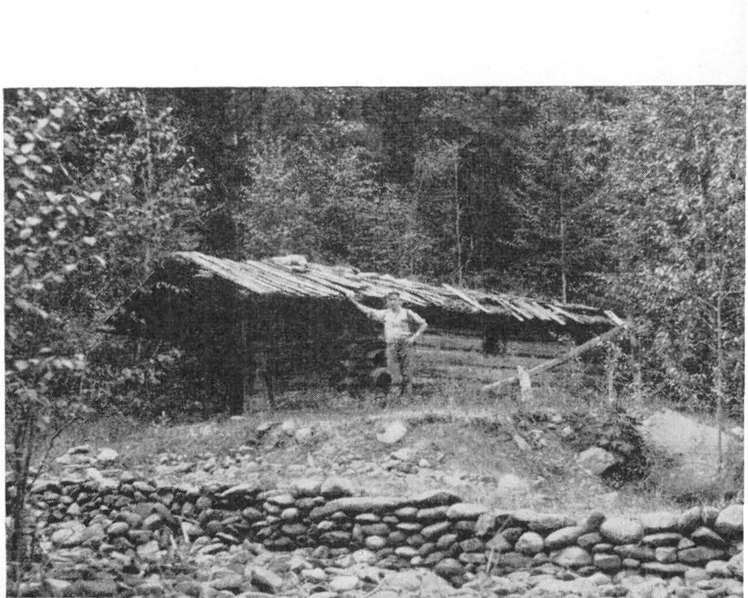
From the Cariboo, prospectors pressed northward and found important placers in the Omineca, Cassiar, and Atlin regions, where some placer mining still goes on. Then they penetrated Yukon Territory, where the discovery of gold on Bonanza Creek, a tributary of the Klondike River, in 1896 heralded the greatest gold rush of all. Production here reached its peak in 1900, when the output was valued at $22 million for the year. Value of total production from the Klondike to the time of writing is more than $200 million. Several minor placer fields were found in the Yukon outside the Klondike area. As in the Cariboo and other regions, the early work was done by individuals and small partnerships, mining along the banks of streams or probing ancient stream channels with shafts and tunnels driven in the gravels and supported by timbering. The Klondike region is one of the few parts of Canada that were not glaciated, and was thus favourable for the occurrence of rich placers. It is significant to note that the relatively small unglaciated area in Yukon Territory has yielded nearly three times as much placer gold as has the remainder of Canada, which was glaciated.

The gravels of the Klondike were permanently frozen and had to be thawed by lighting fires, but this was an advantage to the early miners because shafts could be sunk to bedrock without pumping, and it is still an advantage in Keystone drilling. In later years mining was done mainly by large companies using dredging and hydraulic methods and extensive special thawing equipment, but some small-scale placer mining continues.

The Peace and North Saskatchewan Rivers in British Columbia and Alberta are the only other places in Western Canada where placer mining has been done to any extent. A relatively small amount of fine-grained gold has been and still is being obtained along these rivers. The Peace River gold may have worked its way down from tributaries in the interior of British Columbia where lodes are known to occur, or it may have been reconcentrated from glacier gravels that included particles of gold weathered from deposits in the Canadian Shield. The gold of the North Saskatchewan apparently came from the erosion of sedimentary rocks that contain slight amounts of gold.

Plate LXVII

Site of early small-scale placer operation, British Columbia. Note boulders moved and piled by hand to permit reaching gold, probably for recovery by a rocker or by shovelling into a sluice-box.



After the heyday of the Klondike, placer production declined. Impetus was given to placer mining in Western Canada during the depression that began in 1930, because gold was in great demand, because its price was raised, and because unemployed men could make a dollar or two a day by gleaning along many streams that would not warrant commercial placer operations. This ended with the beginning of World War II, and since then interest in placers has been at a low ebb, because most of the known higher-grade workable deposits have been exhausted, and rising costs have made lower-grade deposits less attractive. However, since about 1950 the improvement of machinery has allowed greater yardages to be handled by fewer men, so reducing the cost, and there has been a noticeable revival in some camps in northern British Columbia and the Yukon.

Great as was the production of gold from placers in the Cordilleran region, this was not as important as the indirect effects. Before the discovery of gold in what later became British Columbia the region was in the hands of a few fur traders. The gold discoveries brought it world-wide attention and a great influx of people. Many of those who came seeking placer wealth turned soon to lode prospecting, to agriculture, and to business of various kinds. Roads and railways were built, and towns and cities were established. The story of the gold rushes is the epic of Western Canada.

The only significant production of metals other than gold from Canadian placers was about 10,000 ounces of platinum that accompanied gold in placers on the Tulameen River in southern British Columbia, and tungsten recovered from Canadian Creek and Dublin Gulch during both World Wars. Considerable tin is said to have been discarded during early operations in the Klondike. Increasing attention probably will be paid to the possibility of recovering minerals other than gold from Canadian placers as time goes on.

Methods of Prospecting for Placers

The principal placer region of Canada, particularly for gold, is the interior belt that extends through central British Columbia, flanked on the east by the Rocky Mountains and on the west by the Coast Mountains, and continues into the central part of Yukon Territory and on into Alaska. This large area, composed of plateaux and fairly ancient mountains, not only contains many lodes whose weathering provided the gold and other minerals that became concentrated in placers, but the topography was suitable for placers to accumulate and, largely, to withstand the effects of glaciation. Some placers formed in Tertiary time were preserved as old channels covered by glacial debris; others were scoured out by the glaciers, their gold being incorporated in glacial drift, only to be re-worked and re-concentrated by interglacial or modern streams. These parts of British Columbia and the Yukon are therefore the most favourable places in which to seek placers, but it must be emphasized that they have already been searched intensely. Other regions offer some possibilities.

The usual method of prospecting for placers is to follow up creeks and rivers, panning material from bars, patches of sand and gravel in stream beds, and gravel banks, particularly the lower gravels near bedrock. Most creeks have been tested in this way already but there are chances of finding places that were missed, or places that were worked by primitive methods and that would warrant hydraulicking or dredging, or others that were too lean to be worked formerly, or that could not be worked until the advent of modern machinery such as bulldozers, boulder hoists, and electric pumps. Even if only a few colours of gold are found in this way, they may lead to more, so the prospector keeps panning, and if he can no longer obtain traces, he back-tracks and tries another tributary or bank in the hope of finding a workable deposit. In prospecting streams containing moss-covered boulders, the moss should be scraped off and panned, because particles of heavy minerals may lodge in it.

Buried channels may be postulated from a theory of where a former course of a stream flowed, or from a study of the topography as shown on a map or air photograph. It is, however, difficult for an ordinary prospector to check such a theory if overburden is deep. Companies may do so by drilling or by geophysical surveys based on the frequent association of magnetite with placer minerals, or by geophysical methods that outline the profile of the bedrock. Speculations regarding buried channels have to be considered with caution, because testing them is expensive. In the old placer areas there are frequent rumours about the presence of old channels, and attempts are sometimes made to induce persons to finance work to trace them. Some of these efforts are well founded, but all such ventures should be guided by the opinion of a reliable placer engineer or geologist.

Panning

The gold pan, whose use dates from ancient times, is an indispensable aid in prospecting for placers, testing placer ground, and sometimes for the final 'cleaning up' of gold recovered from placer mining. Like almost all methods of recovering the valuable minerals in placers, panning is based on the fact that the material to be recovered is considerably heavier than the worthless grains of sand and other material that are to be discarded. Many think that the pan is the means of actually mining placers, but its use is too slow for that purpose except in the case of exceptionally rich placers. The pan is also very useful in connection with prospecting for lodes and testing crushed samples from lodes. Almost all prospectors will benefit from learning the art of panning, which can be mastered with a little practice.

Gold pans are of different sizes, the most common being 16 inches in diameter at the top, the sides sloping at about 40 degrees, and the depth being about $2\frac{1}{2}$ inches. They are generally made of sheet iron. If they are too highly polished, or if they become greasy, they will not retain fine-grained gold; new ones may have been greased to prevent rusting.

The pan is filled with sand or gravel and immersed in a slack part of a stream, or in a lake or pond, or even in a tub of water, and the gravel is stirred with the hands. Any soil is thus washed away, after which any larger pebbles are tossed out by hand. The pan is then alternately shaken, and rotated under water, then raised to the surface at an angle so that the upper material is spilled and washed away. This process is repeated until only the heavier grains, if any, remain. These generally comprise magnetite, pyrite, hematite, and other heavy minerals, and any gold that may be present. If a little water is added and the pan is rotated with a deft movement, the gold, being heavier, is separated to form a 'tail' behind the other heavy minerals. The gold may include nuggets, or pieces about the size of grains of wheat, but it is usually in the form of small flakes or grains called 'colours'. Beginners often become excited if they see a few colours as a result of their panning, but these colours are so small that their value is slight. To save the gold in the pan, the heavy fraction is dried, magnetite is removed with a magnet, and other foreign grains are blown out, picked out, or allowed to remain. Very fine gold may have to be saved by panning with a copper pan and placing a little mercury in it to form an amalgam, which is heated in a retort to drive off the mercury and condense it for further use. Care must be taken not to breathe the poisonous mercury fumes.

Like many arts, panning cannot be learned merely by reading about it. It is best to obtain instruction from an experienced person, but if this is not possible the learner should practise along the shore of a stream or lake, or even in a tub of water. The gravel used for practice does not need to contain placer minerals; a small specimen of a heavy mineral can be crushed and added to the gravel, or if nothing else is available iron filings could be used. Practice should be continued until the exact amount of heavy grains added can be separated and retained in the pan.

Testing Placer Ground

No major placer operation should be undertaken until careful testing of the deposit, under the supervision of a qualified and reliable man, has shown sufficient material and content to exist under minable conditions. Many large projects undertaken several years ago failed because inadequate testing of the ground led to a too-optimistic opinion of the gold content.

For deposits that are not too deeply buried, the usual method of testing is to dig pits at regular distances, to measure in cubic yards the amount of gravel removed, and to treat this removed material, or the part that constitutes the paystreak, by panning or with a rocker. The gold or other mineral recovered is weighed. The average is calculated from the recovery from each pit, and the value of the deposit is expressed as a certain number of cubic yards averaging so many pennyweights or ounces of gold to the yard. It is commonly considered that a particle or 'colour' of gold large enough to make a sound that can be heard when dropped onto an empty gold pan, is worth about 1 cent; and that gold to the value of 1 cent in a panful of gravel (standard size pan) is the equivalent of about $1.30 per cubic yard of gravel.

For deeper deposits, it is customary to drill holes at regular intervals by means of Keystone Empire drills, as described in the section dealing with the exploration of lodes. The sand or gravel pumped out of the drill-hole is panned or rocked to permit weighing the amount of gold in it, and the value per yard

Plate LXVIII

Placer mining with a power-shovel and bulldozer. Movable sluice-box at left.

is estimated from this weight and the cubic content of the drill-hole in the pay-streak.

Small-Scale Mining Methods

In former years many placers were worked by individuals or partnerships of miners because elaborate equipment was not needed. Picks, shovels, axes, whipsaws, and perhaps wheels for making wheelbarrows were about all the tools required. There are still some opportunities for this kind of mining, apparently almost exclusively in British Columbia and the Yukon.

In the simplest operations gravel is shovelled from the bed of a stream or from a bank and placed directly in the gold-saving device, large boulders being rolled aside or stacked. Such piles of boulders can be seen in many places along western streams, marking the sites of early placer mining (*see* Plate II).

Another simple method, practical in some cases, is to sluice overburden or gold-bearing gravel by diverting a stream or part of it. If the amount of water is small, it is sometimes impounded and released periodically in the method called 'booming' (*see* Plate LIX), as explained in connection with the exploration of lodes.

One of the most common methods, called 'hydraulicking', consists of forcing water under pressure to cut away banks of gravel (*see* Plate LXIX). This is mainly a large-scale operation, but is sometimes practical for small operations, either by using pumps, hose, and nozzles, or by diverting water from a stream

Plate LXIX

A large hydraulic mine in British Columbia. Note two ground sluices in background, cutting into the bank to hasten its disintegration. Water from monitor at left is cutting the base of the bank, and that from monitor at right is breaking up large chunks of gravel that have fallen into the pit. The 'pay gravel' is on bedrock at the base of the pit. The water from the monitors drains the gravel into sluice-boxes that are not visible.

into a ditch sufficiently high above the placer to form a 'head'. The ditch discharges into a pipeline, at the end of which is a large nozzle called a 'monitor' or 'giant'; in small operations the diameter of the end of the monitor would be 1 inch to 4 inches. Pressures should not be more than 60 to 100 pounds per square inch, depending on the equipment, as higher pressures are less satisfactory and may be dangerous. When overburden is removed it may simply be allowed to flow away with the water discharged by the nozzle or monitor, but gold-bearing gravel or overburden that cannot be separated from it is sluiced into the gold-saving equipment, which is generally a line of 'sluice boxes' (*see* Plates LXX A and B). To accomplish this, water may simply be allowed to flow through the pit as a ground sluice, or the nozzle or monitor may be turned in the required direction from time to time, or a separate monitor may be required. It is often necessary to go over the bedrock exposed by sluicing or by hydraulicking, to pick up by hand or with tweezers gold lodged in crevices.

Buried channels that cannot be exposed by hydraulicking or other methods are mined by 'drifting' if rich enough to warrant it. This is done by tunnelling in the gravel, and supporting the opening by poles or boards called 'lagging', held in place by timber posts and cross-pieces. This is a dangerous procedure unless done skillfully. The opening may be begun either by driving directly into a bank or by sinking a shaft in overburden or sometimes in the rock rim of a valley. The drift is run on a slight incline to permit drainage, and gravel is usually removed with a wheelbarrow or a small mine-car on a track. Large boulders are often rolled aside into underground openings to avoid having to bring them to the surface. Much of the early mining in the Klondike was done by drifting. Because most of the ground remained frozen even in summer, the mining was done after thawing, by use of fire, or more often steam points, and the gravel was stockpiled until summer, when it could be treated in sluice boxes.

Nowadays, operations of moderate size may be worked by a few men with fairly expensive equipment, by using power shovels, draglines, or bulldozers to remove overburden and to mine gravel in places where hydraulicking or other methods are not practical. The gold-saving equipment is moved from place to place as required, and is commonly on a barge that floats in a water-filled pit, after the fashion of a dredge.

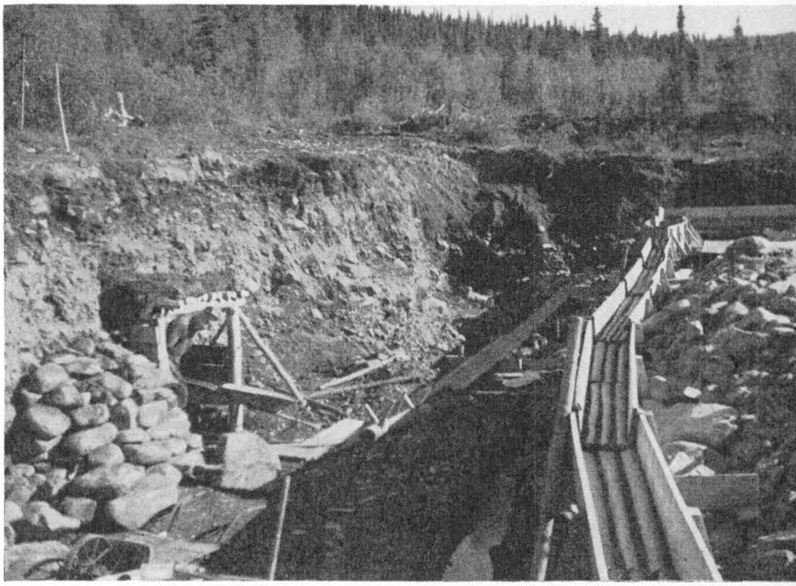
A discussion of the cost of mining placer deposits is not practical here because the figures vary so much with different deposits, methods of mining, and costs of labour and supplies. Considerable information about costs may be obtained in some of the references listed, particularly the paper by A. Nordale.

Large-Scale Methods

Large placer deposits are operated by companies, using large hydraulic or dredging equipment or underground mining methods. Large hydraulic and dredging operations are still continued in British Columbia and the Yukon. These are beyond the scope of a book on prospecting, except in so far as prospectors might be able to interest companies in acquiring a large placer discovery.

A. Sluice-box with transverse riffles.

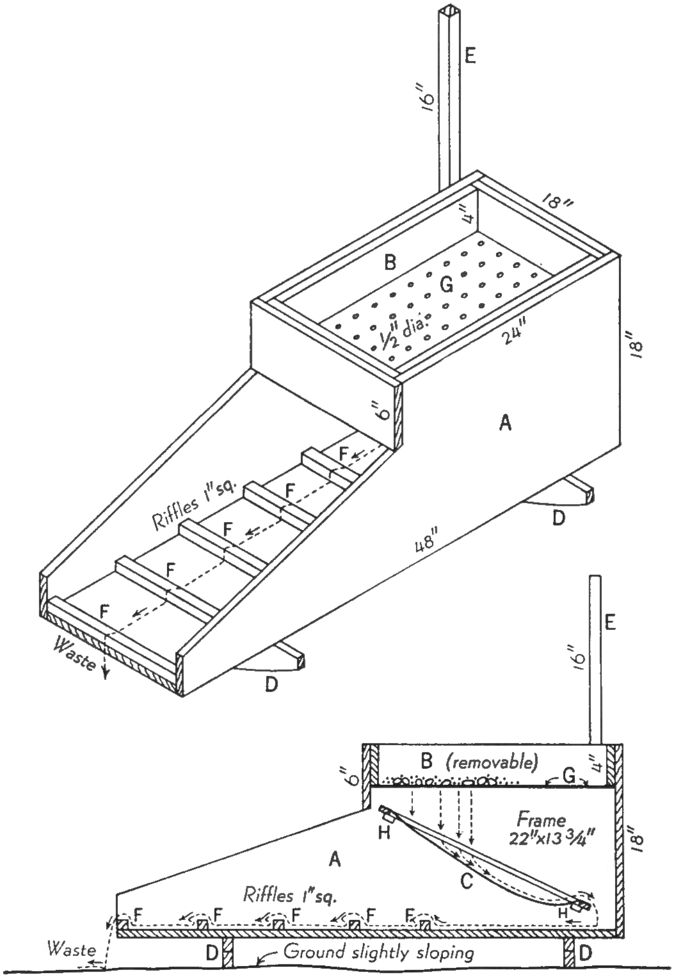
Plate LXX | *Sluice-boxes in Yukon Territory.*



B. Sluice-box with longitudinal riffles.

Equipment for Recovering Placer Minerals

A common device for separating the gold obtained in small operations, called a rocker, is somewhat the size and shape of a cradle. One can be made from a few pieces of board, a piece of coarse screen or sheet iron with holes drilled or punched in it, and a piece of canvas, burlap, blanket, or some other cloth having a nap, which is necessary to catch fine gold. Rockers are of slightly different designs and sizes, the larger ones being used when most of the gold is fine grained, because the longer box is then more efficient. A medium-sized one is illustrated in Figure 23.



A. Box, 48"x18"x18". B. Tray with iron bottom containing ½" holes. C. Apron of burlap mounted in frame. D. Rockers. E. Handle for rocking. F. Riffles, for catching gold. G. ½" holes in iron bottom of tray. H. Cleats holding frame in place. ---→ Course of material through rocker.

Dirt and water are put into B and apparatus is rocked by handle. Water and sand and gold pass through holes onto apron C where most black sand and gold is caught, then over riffles by which more gold is caught, thence to waste. Material remaining in B is thrown out and apron is removed and washed.

G.S.C.

FIGURE 23. Diagram illustrating construction and mode of operation of a rocker. (after J. D. Galloway.)

To operate a rocker, gravel is shovelled onto the screen. Water is then poured over it from a dipper and at the same time the rocker is given a quick jerk with a sudden stop. This is repeated, with the addition of just enough water to wash the sand through without flushing out any fine gold. The coarse material that does not pass through the screen is thrown out, after removing any nuggets that might be present. A rocker is most efficient when used by two men, one of whom shovels in the gravel while the other operates the rocker and the dipper. Water can be saved and used over again if necessary, but clean fresh water is best. Two men can wash 3 to 5 cubic yards of gravel a day in this way, which is ten to twenty times as much as they could do by panning.

The commonest method of saving gold is by one or more sluice boxes, which are wooden flumes or troughs through which water is made to flow (*see* Plates LXX A and B). The gravel may be shovelled in, or dumped mechanically or from a wheelbarrow at the top of the box or line of boxes, or it may be washed in by ground sluicing or hydraulicking. The boxes are usually 8 feet long and 12 inches in width and depth, but smaller ones are sometimes seen. They are

Plate LXXI *'Cleanup' of placer gold in a sluice-box (riffles removed).*

placed on the ground or on trestles or boulders, commonly with a slope of 1 to 10 or 1 to 12, depending on the amount of water and the coarseness of the gold; there should be enough water to half fill the boxes. To catch the gold, the bottoms of the boxes have movable riffles placed crosswise or longitudinally, or are lined with blocks of wood or cobblestones or expanded metal. Canvas, burlap, blankets, or matting may be placed on the bottom of the last box to catch fine gold; the cloth is sometimes covered with a piece of expanded metal.

After a sluice has been operated for several days or weeks, depending on the richness of the placer, supply of water, size and number of boxes, etc., the boxes are 'cleaned up'. The water is turned off, the riffles or blocks, etc. are removed, and a little water is allowed to flow down the boxes to wash the gold and other heavy minerals down towards the end of the box. As a rule, there is a section consisting mainly of nuggets or grains of gold, which is brushed into a small scoop and then panned to get rid of unwanted material, and also a concentrate composed mainly of magnetite, other heavy minerals, and some sand and gravel. This is shovelled out and the gold or other valuable minerals are separated by panning or rocking. Very fine gold may have to be recovered by amalgamation with mercury, and if there is much fine gold, mercury may be placed behind the riffles during sluicing, in which case the resulting amalgam is removed during the clean-up. Where mercury has been used in sluice boxes or to separate gold from heavy sands, the amalgam is softened by adding more mercury, and the material is then stirred so as to cause base material to rise to the surface, where it can be skimmed off. The amalgam is then placed in a bag of chamois skin or closely woven cotton cloth, and the excess mercury is removed by squeezing it through the bag. The mercury is then driven off by heat, leaving the gold, the operation being preferably performed in a retort, which makes it possible to recover the mercury by condensing it in water, or by simply heating on a shovel. In any event, as mercury is very poisonous, the heating should be done in the open or in a well-ventilated place, and the hands should be brought into contact with the metal as little as possible, and should be well washed as soon as the operation is completed.

Other methods used for saving gold under particular conditions in small operations, such as 'long toms', 'undercurrents', and mechanical and magnetic separators, are described in more detailed publications.

In large hydraulic operations, the method of recovery is usually a long line of large sluice boxes, which are often bottomed with round wooden blocks sawn from logs. If the concentrates require the use of much mercury, the amalgamation may be done in a rotating metal drum called an amalgamation barrel.

The gold washing plants used in connection with dragline operations, dredges, etc. may consist merely of sluice boxes arranged in a zig-zag manner to save space, or they may contain mechanical equipment such as revolving screens, shaking screens, or vibrating tables. An efficient device for some kinds of placer operations consists of a battery of metal troughs in spiral shape. As water carrying mineral grains descends the spiral, centrifugal force separates the heavier grains.

The Possibilities in Prospecting for Placers

Interest in placers has been declining for many years, and the outlook is certainly in favour of lode rather than placer prospecting. There are, however, possibilities of finding workable placers, particularly for gold, and mainly in Western Canada, and if gold should ever increase in value some deposits too poor to be worked at present might become workable. In any future placer operations for gold, it would be well to consider also the possibility of recovering other valuable minerals. Tin, in particular, and perhaps platinum and tungsten, were discarded in some old placer operations either because they were not recognized or were not thought worth saving. Other concentrations of rare heavy minerals may yet be found and worked, particularly in the unglaciated part of Yukon Territory and certain lightly glaciated parts of British Columbia and the Yukon.

New demands or increased prices for certain minerals, or improved methods of extracting certain elements from minerals may at some future time make their recovery from sands and gravels economically feasible and thus initiate types of placer mining that are not practical today. It should be noted, however, that small and unimportant amounts of many minerals can be found in sands and other forms of overburden. The prospector's hopes are often aroused because analyses of such samples show a little of some valuable element, but, as in the case of lode prospecting, the problem is not simply to find occurrences but to find deposits of sufficient size and content to be worked economically.

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Lode Mining

The actual mining of lode deposits is almost always beyond the scope of the prospector. However, a general knowledge of the mining and treating of ores will help the prospector to decide whether or not a discovery has possibilities. Also, occasionally, it is advantageous to work a lode single-handed or with a small partnership. Therefore a short discussion on lode mining in general is included here, and is followed by a short account of small-scale mining methods.

General Principles

Mining on the commercial scale, which generally ranges from one hundred to several thousand tons of ore a day, is a highly organized industry. It employs skilled miners and other tradesmen, professional engineers, geologists, and other scientists, and many forms of machinery and specialized equipment. By these means it is often possible to mine successfully on narrow margins of profit. As in other industries, production costs are often lower in the larger operations, because many fixed expenditures can be spread over a larger volume of output. Hence, it is commonly possible to mine ores of low value if they occur in sufficient quantity to permit an operation in the class of thousands of tons a day, whereas the mining of smaller deposits of similar grade would be uneconomic.

Another important consideration is that many mines contain sections of different grades of ore. When costs can be reduced or when the price obtained for the product is high, or if more efficient methods of treatment are developed, some of the lower-grade material may become ore. It is usually necessary, therefore, to do a great deal of sampling of the underground exposures and of the ore and rock mined and to prepare careful and detailed sampling plans. This permits close control of mining and adjustment of the average grade of ore to meet the costs and prices pertaining at the time. For these reasons a mine may be operated at a larger tonnage during one period than another, or it may have to be closed entirely during unfavourable periods.

There are two principal methods of working lode deposits: open-pit mining (also called strip mining when large areas are removed), and underground mining.

Open-pit mining is suitable for deposits that are fairly broad and that reach the surface or require the removal of only a reasonable amount of overburden. After any overburden has been stripped away, a pit is opened and the ore or rock is usually blasted down in benches by drilling vertical holes. The material broken is usually loaded by power shovels onto trucks or hoisted in 'skips' on an aerial cable-way. When a flat-lying stratum is worked for building stone the pit is usually called a 'quarry', and when the operation is for ore or minerals to be crushed and treated the pit is usually called an open-cut or open-pit. The term 'glory hole' is generally applied to a large pit connected to underground working; in such operations the ore from the pit is recovered through the underground workings instead of being hoisted directly from the pit. Large open-pit methods are generally the cheapest ways of mining, and are particularly characteristic of iron mines.

Underground methods are necessary for mining deep orebodies and for narrow, steeply dipping ones at or near the surface. If the terrain is suitable, it is more efficient to begin operations from an adit, as explained in connection with the exploration of deposits, but many underground mines must be begun by sinking more costly shafts. Horizontal workings are then driven at appropriate levels, generally at intervals of between 100 and 200 feet. Ore is removed by blasting openings called 'stopes', of which there are different types to suit particular conditions. Workings that will not stand safely of their own accord are supported by timbers or by filling with waste rock, or sand or other material brought from the surface.

Mining operations usually include plants in which the ore is treated at the property, either to an almost finished product such as gold which requires only final refining, or which concentrate the ore to avoid the payment of freight on worthless material that can be separated fairly easily. The processes used generally consist of crushing, grinding, and one or more of many different methods of concentrating. Concentrates, and in some cases 'raw' high-grade ore, are then usually treated in a smelter, where the material is melted and separated by the draining off of worthless slag, or in a leaching plant in which the valuable constituents are extracted by solution. It is not usually possible to have ores from different mines treated in a common concentrator, because the process has to be closely adapted to a particular ore, but several mines more commonly supply one smelter, either in the district or far removed from the mines. Such a smelter may either buy the ore outright, or treat it on a fee basis. Concentrators and smelters that treat ores from different mines are often called 'custom' mills and 'custom' smelters.

Small-Scale Lode Mining

It cannot be emphasized too strongly that, in general, prospecting and mining are distinct phases of the mineral industry. The prospector usually has neither the finances nor the training and experience necessary to conduct the large technical operations involved in advanced exploration of most deposits, to say nothing of the still more involved problems of production. However some deposits are too small to interest large companies but are rich enough to make mining by one man or a few men practical, and others are so rich that the discov-

Plate LXXII

Chromite ore piled for shipping at a small mine in British Columbia.

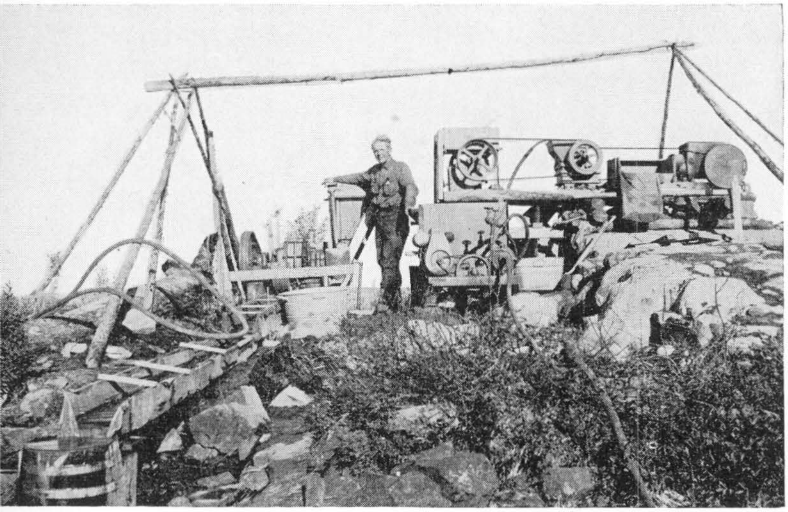
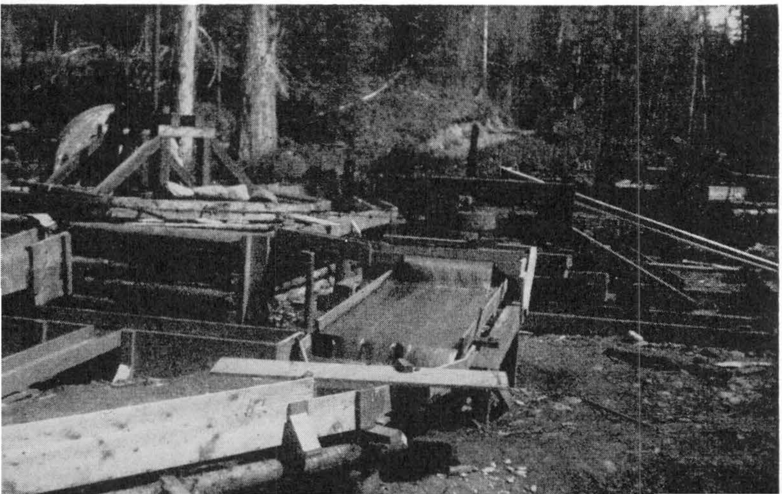


Plate LXXIII

A. A small mill in Northwest Territories.



B. An arrastra in British Columbia.

erers prefer to work them themselves. These, however, are the exceptions, and this kind of mining should only be attempted by experienced persons or those who have studied the matter carefully. Such mining is sometimes done by those who have staked a property, and sometimes by lessees who undertake to mine material on a property where sufficient ore to interest a large company was not found, or where patches were left after a larger operation was closed.

Mining of this kind has been done in British Columbia for many years on small high-grade metal deposits mined fairly readily from adits. Another factor here is the presence of custom smelters in and near the province. The crude ore is generally shipped to a smelter after cobbing, i.e., breaking off richer parts of lumps, and sorting by hand; also, in some cases small mills that concentrate a ton or more of ore a day have been successful. Small-scale mining for metals has not been a feature of mining in the Canadian Shield, partly because most deposits mined successfully there tend to be large ones of moderate grade that require extensive operations, and partly because most of them have to be operated from shafts. An exception is the Cobalt district, where small high-grade silver veins were worked by independent miners and lessees, as well as by companies. A number of relatively small pegmatite deposits have been worked on a small scale in the Shield for feldspar, mica, and other minerals typical of pegmatites, generally by open-pit methods.

Small-scale mining, when practical, is a useful phase of the mineral industry because it permits production from deposits that would otherwise probably not be worked, because it permits gainful occupation, and because work of this kind may show that a deposit is larger and more important than it appeared to be. The disadvantages and the points about which caution should be exercised are: (1) even experienced miners may not have the necessary knowledge to decide whether a deposit can be profitably worked, or to understand the marketing of the product, (2) mining by inexperienced persons may be hazardous, (3) the profit from the sale of ore might be less than could be obtained as wages in some other occupation, and (4) it is possible to ruin a large deposit by mining the higher-grade material only, as what is left may not be worth mining. Anyone contemplating work of this kind would be well advised to work for a mining company for a time to gain experience, to take a correspondence course in mining, or to study the literature on the subject, and to obtain advice from a provincial government engineer, if available, or a consulting engineer.

Mining Methods

The methods used in small-scale mining are about the same as those described in connection with the exploration of deposits. In open-pit work, blast holes may be drilled by hand steel, portable drills with built-in gasoline motors, or air drills used in connection with portable compressors. The methods are fairly similar to those used in blasting rock on construction projects. Underground mining is more complicated and requires more experience. The drilling may be done by hand steel, but this method is now rarely used underground except by those who cannot afford a portable compressor and air drill, or in places where it would be difficult to transport a compressor. Drills driven by attached gasoline engines are not used underground because of the fumes. Great care has to be used in storing and handling explosives, and in adhering to the elaborate regulations dealing with explosives and mine safety in general. Rock too weak to remain safely in place has to be supported by timbering—an art in itself. The rock broken by blasting is shovelled into a wheelbarrow or mine car, and pushed to the surface, or into a bucket and hoisted.

Treatment Methods

In most instances, the only local processing done on ore from small mining operations is to sort out the material that is worth shipping. Strictly speaking, when the valuable material is picked out, the process is called 'selection', and when the reverse is done, by picking out and discarding unprofitable material, the process is called 'sorting'. Selection or sorting may be done in the mine or pit or at some other place on the property. At some mines the ore is dumped in a bin, from which a hopper discharges on to a 'picking table' or 'picking belt'. Large chunks may be cobbed with a hammer to allow separation of valuable and valueless pieces.

Milling and concentrating ore from a small operation, in a small plant at the property, is seldom done except on high-grade 'free-milling' gold ores, because of the very complex and expensive equipment usually required. Gold ores that contain most of the gold in grains sufficiently large to be free-milling, that is, to break free when ground, are sometimes successfully treated in small stamp or rotary mills driven by gasoline engines. The gold may be amalgamated with mercury or washed in sluice boxes or saved in other ways. In the early days arrastras (*see* Plate LXXIII B) were sometimes used in British Columbia, particularly for grinding and amalgamating; an arrastra is an ancient Spanish and Mexican contrivance composed of a large tub-like enclosure in which the ore is ground by two large stones attached to a horizontal beam rotated by a mule or horse walking in a circle.

Transportation

Ores that can be shipped profitably are transported to railways or docks by the best method suited to local conditions. If roads are available the ores may be hauled in trucks, jeeps, or wagons. Failing that, they may be carried on pack horses, or on a stone-boat hauled by a horse or tractor, or on a sleigh over a winter road. A method called 'rawhiding' was used considerably in the Cordilleran region in the early days, and may still be applicable in places. It consists of using a sack made of a raw beef hide, with the hair left on the outside for additional serviceability. The sack of ore is skidded down a mountain trail by a horse harnessed to the sack. Rich ores have occasionally warranted being transported by air.

References

Metal Mining; Correspondence Course, B. C. Dept. of Education. Fee $10.

A correspondence course for those definitely interested in metal mining and in prospecting. It is suitable for adults and is open to students in other provinces. Students are required to take the course in Elementary Geology before taking this course. Inquiries should be addressed to: The Director of High School Correspondence Instruction, Weiler Bldg., Victoria, B.C.

Practical Mining; Textbooklet No. 3 on mining, Canadian Legion Educational Services, Ottawa (out of print).

This useful booklet, prepared for a correspondence course for veterans, may be found in libraries.

Stout, Koehler S.: Practical Guide for Prospectors and Small-mine Operators in Montana; Misc. Cont. No. 13, Montana Bureau of Mines and Geology, Montana School of Mines (1955).

Von Bernewitz, M. W.: Handbook for Prospectors and Operators of Small Mines; McGraw-Hill, 1943. Price $4.

Contains useful information on prospecting, exploration, and operating small mines and equipment for treating ores.

Plate LXXIV | *Staking in the Northwest Territories.*

CHAPTER XIV

MINING LAWS AND OTHER BUSINESS MATTERS

Laws Regarding Prospecting and Mining

The control of prospecting, mineral right, staking, mining and related matters is vested in the various provincial governments and the administration of the Northwest Territories and Yukon Territory. There is no uniform law respecting these matters for Canada as a whole, because some of the laws and regulations took root when certain provinces were separate colonies, and because each province was later free to make its own laws to suit its particular needs and wishes. Now that better facilities for travel are available, a prospector may need to know the regulations for more than one province and to take out a licence for more than one. In addition to the provincial and territorial laws, there are certain federal laws that affect prospecting and mining even in a province. Examples are laws relating to atomic energy, explosives, income tax, and staking of claims and mining in national parks and Indian reserves.

Although the laws and regulations for the different jurisdictions follow more or less the same pattern, they differ in far too many details to be discussed fully here. A publication called "The Mining Laws of Canada", now in its fourth edition, summarizes the main features and is a useful reference, but it cannot cover all details or include changes since publication, of which there have been many. Therefore a prospector must familiarize himself with the details for the province or territory in which he intends to prospect. Each province has a department of mines or equivalent; the Northwest Territories and Yukon Territory are administered by the federal department of Northern Affairs and National Resources. Most provinces and territories are divided into Mining Districts or Divisions, for each of which there is a Mining Recording Office, and some districts are divided further into subdivisions for which there are sub-offices. Information, copies of the full Acts and Regulations, and in some instances pamphlets explaining the principal regulations in non-legal language, can be obtained by calling at local recording offices, which are usually in county towns or equivalent towns where there is a Court House, or they may be obtained by writing to or calling at the headquarters of the department concerned. The names and addresses of these departments are listed on page 379. The Department of Mines and Technical Surveys supplies only the summarized "Mining Laws of Canada", which should be ordered from the Queen's Printer, Department Public Printing and Stationery, Ottawa; the price is 50 cents.

The following short discussions of the principal features of the laws regarding prospecting and mining are intended only to give a general idea of the subject, as an introduction for beginners in prospecting or newcomers to Canada. It is only a short account of the general pattern of the laws and regulations, and must be supplemented by obtaining and studying detailed, up-to-date information for the province or territory concerned.

Historical Background

Some of the principles regarding mineral rights date from early mining in other parts of the world. It is worthwhile to consider these briefly, for in addition to being of historical interest, they help in understanding some present regulations and terminologies.

In ancient times, in the Old World, there was no question about the ownership of mineral rights. All belonged to emperors, kings, or feudal lords, for whom mines were worked by slaves and captives, often under the most appalling conditions. The Romans 'farmed out' the right to mine, particularly in conquered countries, to the owners of land. From very early times it was recognized that the monarch or the state must have the exclusive right to make coins, therefore gold and silver mines were in particular the property of kings and emperors. The Romans either permitted mining for base metals, for which a tax was charged, and withheld the right to mine gold and silver, or they permitted mining for gold and silver on payment of a special amount to the ruler; thus began the principle of paying a 'royalty', which persists to the present day.

In Roman times the owner of the soil was considered the owner of any underlying mineral rights that were granted, because then mines could be worked only to shallow depths beneath the surface. The true nature of deep lodes was unsuspected. During the Middle Ages, however, deeper mining was done, and in some places it became recognized that the discoverer of a lode should have title to it regardless of the ownership of the soil, provided that the landlord was compensated for surface damage. Thus the principle of a claim was established. It is said that in some parts of Europe the size of a claim was the distance the discoverer could throw his axe along the strike of the lode in both directions from the discovery. As serfdom was gradually abolished, miners became free men, and it is interesting to note that even today, in British Columbia, a prospecting permit is called a 'free miner's certificate'.

Thus basic principles that are common to all mining laws today are rooted in antiquity and have stood the test of time. These are: the right of the ruler or the state to dispose of mineral deposits; the right of the person or organization to whom mineral property is granted to maintain uninterrupted possession so long as the requirements are fulfilled; and the right of the ruler or the state to collect a share of the product. These principles were brought to North America by the early colonists and have persisted, along with the conflicting theories of whether mineral rights belong to the landlord or are separate from land titles, and with the age-old concept that gold and silver rights should be treated separately from rights to other metals and minerals. In Canada it is now recognized that all mineral rights not already granted or withheld may be acquired by staking, regardless of the ownership of the surface rights, but old grants made under different terms are protected.

Another perplexing problem in mining rights, now happily a thing of the past in Canada, was the question of whether the owner of an inclined lode could follow it indefinitely, or only to a point vertically below the boundary of his claim or claims. The principle of unlimited ownership, so long as it could be proved that the lode, vein, fracture, etc. was continuous, called the principle of extralateral rights, was adopted in the early days of mining in the United States, and may have had its origin in somewhat similar rights claimed in parts of Europe long before. It was adopted in British Columbia as a result of an early influx of prospectors from the western states, but it caused so much confusion and litigation because of the difficulty of proving whether many lodes were in fact continuous or not that the law was repealed. In Canada all claim boundaries are now considered to extend vertically downward. It is important, therefore, for the staker of an inclined lode to consider whether it is necessary to stake an additional claim, or more, in order to cover the downward extension of the lode. This is called 'protecting the dip'.

Kinds of Mineral Rights

In general, there are separate laws and regulations governing the rights to lode deposits, placer deposits, coal, petroleum and natural gas, stone, gravel, sand, etc. The following topics deal with lode deposits, because they are of principal concern to prospectors.

Licences

The name of the licence to permit prospecting and staking of claims varies from province to province. It may be called a prospecting licence, miner's licence, miner's certificate, miner's permit, or free miner's certificate. The fee for an individual is usually $5 or $10, and the licence must be renewed annually at a similar charge. The licences are not transferable, but in some provinces the holder of a licence may stake a limited number of additional claims for another licence holder. A licence for one province or territory is not valid elsewhere.

Lands Open for Prospecting and Staking

Any person 18 years old or more who has obtained the necessary licence may prospect and stake on Crown lands, or on occupied lands if the mineral rights have been reserved to the Crown, except in special instances where lands have been withdrawn from staking. Citizens of other countries have the same rights as Canadians in this regard. In some provinces, incorporated companies may obtain licences, but the fee is usually much greater than for an individual; in other provinces, companies may obtain claims only by transfer from individual stakers.

In most parts of Canada, particularly in the less-settled regions, mineral rights are quite separate from surface rights. In such areas, unless staking is banned for a special reason, the prospector is only concerned with whether or not a particular piece of ground is already staked and whether such staking is in good standing. He can learn this by looking for claim lines and posts, or by consulting the local mining recorder. In many of the older parts of Canada, however, land titles may carry all the mineral rights, or all but the rights to gold and silver. A prospector is not usually permitted to enter upon or stake on land which carries the mineral rights, unless by agreement with the owner. To verify whether a particular property carries mineral rights as well, it is necessary to consult the mining recorder or the land titles office.

If the surface and mining rights are separate, the owner of the land must be compensated for any damage done by the holder of mining rights. The latter is entitled to obtain such land as is needed for access and for working the deposit; if agreement with the owner cannot be reached, the matter may be settled by arbitration.

In the case of lands such as national and provincial parks, Indian reserves, townsites, lands occupied by buildings or required for highways or water-power projects, and certain summer resorts and railroad grants, staking may be either prohibited or permitted under special regulations. In such cases, the existing regulations should be studied.

Number of Claims Allowed

The number of claims that a licence holder may stake in any one year varies greatly in different jurisdictions.

Sizes of Claims

Lode claims are usually about 40 acres (1,320 feet to a side) or 51·65 acres (1,500 feet to a side). In areas that have been subdivided into townships and lots, claims must usually correspond to the appropriate lots. In unsurveyed territory the staker is supposed to arrange his claim lines as nearly as possible in north-south and east-west directions, and to make the sides approximately the correct length. There may be a penalty for oversize claims, or the authorities may reduce the size. If the manner of staking leaves gaps, which are called 'fractions' or 'fractional claims', these may be open for staking or there may be special provisions for their disposal.

Staking

Prospectors should study the local staking regulations carefully and endeavour to follow them in detail, because the haphazard staking often done not only causes much confusion and wasted time for others, but may cause the staker to lose title to his claims. In most provinces and territories, staking is done by placing a post at each corner of a claim, and by blazing and clearing brush from the side lines of the claims if they are in wooded country. Usually, posts must stand not less than 4 feet above ground level, at least the upper foot being squared, with sides at least 4 inches wide (*see* Plate LXXIV). Posts may be set in place, or a tree stump properly squared will sometimes suffice. In regions where trees are lacking, a cairn of rocks may be used instead of a post, and pickets or mounds of earth or rocks may be used instead of blazes to mark the lines.

The northeast corner is usually the No. 1 post, the other corners being called No. 2, No. 3, and No. 4 in clockwise order, the numbers being marked on the posts. On the No. 1 post is usually placed the name of the licence holder, the serial number of the licence, the date and hour of staking, and, if in surveyed territory, the numbers of the lot and concession or other legal description of the land covered by the claim. The name of the licensee, and other information in some provinces, is placed on posts 2, 3, and 4.

If claims are staked so as to adjoin one another, separate posts must usually be placed. Thus, if four claims adjoin, there would be four posts at their common corner, and these would be the No. 1 post of one claim, the No. 2 of another, the No. 3 of another, and the No. 4 of the other claim. If a corner of a claim is under water, 'witness posts' are placed where the claim lines intersect the shore; these are marked 'WP' together with a statement indicating the approximate direction and distance to the corner concerned. Claims that are entirely under water are staked by placing witness posts on the shore, in line with the claim boundaries. In some provinces, a post erected for one claim may also serve for an adjoining claim.

In several provinces, metal tags bearing claim numbers are supplied by the recorder. In some instances these are provided after recording and must be placed on the posts within a specified time. Another system is to supply tags for the number of claims a person is entitled to stake when the licence is issued; the staker then affixes the tags at the time of staking.

In Western Canada claims are usually named as well as numbered. The usual practice now is to use short names consisting of two to four letters and, since there are not many of these, to use the same name for the claims comprising a group and to distinguish them by numbers, thus: Sol 1, Sol 2, Sol 3, etc. In earlier times, when men were not too hurried to write or carve long names on posts, the naming of claims often provided an outlet for romantic or witty tendencies.

A different system of staking is used in British Columbia and Yukon Territory, where important placer mining began in colonial times, earlier than in other parts of what is now Canada. The early placer regulations were based on Australian, American, and Mexican rules because the influx of miners came mainly from gold rushes in Australia and California that had taken place a few years earlier. When attention was turned to the possibilities of lodes, the method of staking was developed from the system for staking placer claims. The latter was to place two posts along the course of the stream, to mark the extent of the claim in that direction, and to allow a certain amount of ground on each side of the stream, without the necessity of placing posts at the corners. Lode claims were therefore staked by placing a 'discovery post' at the discovery and by placing No. 1 and No. 2 posts at appropriate distances from the discovery and along the strike of the lode. On these posts was placed a statement that the claim extended a certain distance on each side of the line joining the No. 1 and No. 2 posts. This system has an advantage in mountainous country, where it would be difficult for anyone but a surveyor to determine the corners of a square with sufficient accuracy for 'four-post staking', so the system has been continued in British Columbia and Yukon Territory, except that the requirement of a discovery post has been dropped. Claims may be laid out in any direction by placing No. 1 and No. 2 posts approximately 1,500 feet apart. The claim may lie 1,500 feet entirely to the right or left of the 'location' line joining the posts, or any part of 1,500 feet may lie to the right and the remainder to the left. If a claim so staked includes part of a claim previously staked and in good standing, only the unstaked portion is valid. Although the location line may be in any direction, when possible it should be north and south and the claim should be as nearly square as possible, as this lessens the likelihood of confusion, overlapping, and fractional claims. The Yukon Quartz Mining Act is at present under revision.

Recording

Claims must be recorded within a specified time after staking. This is usually 15 days for districts near a recording office, with an allowance for extra time for distance from the office. There may be a period after recording during which interested parties may appeal staking that they wish to dispute. In some places, if the recorder believes that there may be confliction as a result of several persons having staked at about the same time, or if searching of titles will require time, he may record a claim subject to verification. A recording fee is charged in most provinces.

Assessment Work, etc.

To retain title to a claim, a certain amount of work must be done each year on the claim or group of claims, unless there is provision for making a payment instead of doing work. Work of this kind is called 'assessment work' or 'representation'. The amount of work or payment varies considerably with different provinces or territories.

Obtaining Title

After the required work has been done, or payment has been made in lieu of work, and after the claim boundaries have been surveyed by an authorized surveyor if the claim is in an unsurveyed region, the claim may be patented or leased. Thereafter, the claim may usually be retained without further work, but a tax or rental based on acreage must be paid annually.

Taxes and Royalties

Apart from this small yearly acreage tax, governments collect revenues on production or profits from operating mines. The federal government collects revenue through income taxes. The provincial governments charge taxes or royalties on production or profits. The provincial levies vary from province to province and with the scale of profits, and may be less for the first few years of production from a new mine. New mines are presently exempt from income tax for the first three years.

Concessions

In certain regions and in special circumstances, concessions giving the exclusive right to prospect in a certain area (that may vary from a few to several hundred square miles) are granted. They are usually confined to regions so remote that individual prospectors are unlikely to be active, and where the expenses involved in exploring the area would be great. Concessions may be disposed of by auction or on the payment of a substantial fee. The terms usually limit the rights to a specific term of years, during which specified amounts of work must be done. At the expiration of the term, the holder may retain certain portions as mineral claims, the remainder being thrown open for general staking.

Parks

In parks under the jurisdiction of the federal government, no provision is made for the disposal of mining rights. In some provincial parks claims may be held under certain conditions.

Indian Reserves

In general, mining rights on Indian reserves are held for the benefit of the band. In a few cases, the band has surrendered the mineral rights to the Crown: in such cases, the holder of a provincial prospecting permit may obtain a special permit from the Director, Indian Affairs Branch, Department of Citizenship and Immigration, Ottawa.

Atomic Energy Regulations

The Atomic Energy Control Act gives the federal government certain control over prospecting and mining for uranium and thorium. The regulations made by virtue of the Act are designed to give all possible encouragement to prospecting and mining for uranium by the public, to exercise the necessary control over the destination of shipments and the publication of figures on production and ore reserves of producing mines, and to provide for the reporting of information on radioactive occurrences so that an inventory can be maintained and generalized information useful to prospectors and mine operators can be made available.

No special permit is required to prospect for uranium or thorium. A person simply obtains the appropriate provincial or territorial licence and stakes in the same way as for any other metal. The Atomic Energy Regulations are additional to the usual provincial and territorial regulations, and those affecting prospecting and mining provide as follows:

1. Anyone who finds or has reason to believe he has found an occurrence containing 0·05 per cent or more of uranium or thorium must promptly notify the Geological Survey of Canada, which acts as official agent of the Atomic Energy Control Board in matters related to the resources of radioactive materials. The notification should include all information available on the occurrence, and the location should be described accurately enough to permit the occurrence being found without a guide. The Geological Survey does not, however, undertake to examine discoveries at the request of the discoverers or owners. Notifications should be addressed to: The Director, Geological Survey of Canada; attention: Mineral Deposits Division. All information received is treated confidentially unless released by the sender or published elsewhere.

2. No further formalities in connection with preliminary exploration are required, but an exploration permit must be obtained from the *Secretary, Atomic Energy Control Board, P.O. Box 1046, Ottawa*, before undertaking advanced exploration, such as surface trenching to the extent of more than 300 man-days, any detailed geophysical or geological surveys such as would be accepted for assessment work, any diamond drilling or underground exploration, and any removal of *bulk* samples. Applications for permits should include:

(a) The full name and address of the applicant and, if the applicant is a corporation, the nature of its incorporation and the names and addresses of all its directors and officers;

(b) The name and address of the person who will be in charge of the work on the ground;

(c) A complete and accurate description by claim number, district, and province, or by lot and concession number, township, county or district, and province of all property intended to be covered by the order;

(d) A general description of the work contemplated;

(e) A consent by the holder of any existing exploration permit covering the property or any part thereof to the revocation of the existing permit.

An exploration permit stipulates that a detailed report on the results of exploration be sent every three months to the Director, Geological Survey of Canada; attention: Mineral Deposits Division. The report must include adequate plans, diamond-drill records, and assay data. Special reports do not usually need to be prepared, as most companies require that full reports be prepared for their own use, and if these are prepared for some other period than three months, arrangements can be made to have them accepted instead of quarterly reports. All information is treated confidentially.

An individual is permitted to publish any information he obtains on a discovery or property under exploration so long as the Geological Survey of Canada is also kept informed.

When the stage of production is approached, application must be made for a mining permit to replace the exploration permit. These permits are issued free of charge. If a property is abandoned or an option is dropped, the Atomic Energy Control Board should be asked to cancel or amend any permit that may have been issued.

Methods of Financing Prospecting

The typical old-time prospector was a rugged individualist who was willing to live and travel frugally for the sake of pursuing the kind of life he enjoyed and the chance of 'striking it rich'. He did not need great financial resources, and he generally obtained what he needed either by working for wages or trapping until he had saved enough, or by having someone provide a 'grubstake'. The latter implies the provision of groceries or the money to purchase them, usually on the understanding that the supplier will have a half interest in anything found; the use of 'stake' probably arises from the practice of staking one claim for the discoverer and one for the backer. Prospectors are still sometimes backed by a single grubstaker, but the expense of travel and equipment tends to make this prohibitive. The principal ways by which prospecting is now carried on are as follows:

Prospecting as an Avocation

An increasing number of persons take up prospecting as a hobby or minor occupation on week-ends and vacations. This can be an interesting and worthwhile pursuit for those who live away from the more settled parts of the country or who can spend vacations in favourable areas, provided they study the subject as thoroughly as do those who follow any other avocation eagerly and intelligently.

Part-Time Prospectors

There are still many prospectors who trap or work for wages, as miners or in other trades, during the winter and spend the summer prospecting on their own account.

Full-Time Prospectors

A number of men make prospecting their full-time occupation. They usually spend a good part of the winter in the study of geological reports, maps, and air photographs with a view to planning work in the coming season. They may work independently or with a partner, and some make a good living by selling prospects; a few have made fortunes from exceptional discoveries.

Syndicates

Because of the cost of prospecting today, the old grubstaking system is now largely replaced by syndicates, several backers joining to pay the expenses of one prospector or more. An inexperienced prospector can seldom, if ever, obtain this sort of backing, but one of demonstrated ability and integrity can often interest a group of business or professional men; alternatively, such groups may take the initiative and be on the lookout for experienced men.

In an ordinary syndicate, the amount of money required for the venture is estimated and divided into 'units' of, say, $100 each; the members of the syndicate may then subscribe for an equal or unequal number of units and the prospector is apportioned the share agreed upon. If a worthwhile discovery is made, the claims might be sold and the proceeds apportioned on the basis of the number of units held by each participant, or a company might be formed, in which case each unit would be exchanged for a certain number of shares in the company. The prospector may be given a free hand, or a syndicate manager may be selected to handle business matters and to exercise some control over the prospector.

Ordinary syndicates have the disadvantage that the members may have to assume heavy responsibilities for debts, lawsuits, or defalcations. To rectify some of these problems, certain provinces have made provision for special partnerships or for the incorporation of small limited-liability companies to finance prospecting and early exploration of prospects.

Employment by Mining Companies

Many companies that own large producing mines employ experienced prospectors in the hope that they will discover new deposits to increase the holdings or to take the place of the parent mines when they become exhausted. Experienced prospectors need, and usually receive, little supervision. They are usually paid a monthly salary and supplied with all necessary equipment, groceries, and funds for travelling. In addition to salary, the company usually pays a specified bonus for a discovery that meets certain specifications, or gives the prospector a certain share in the profits from a discovery that eventually proves productive. Often neither party favours the latter arrangement, although it seems reasonable in some ways. The drawbacks are that the prospector would probably have to wait for several years before the property became productive, if it ever did so, and the company would have to continue paying a share of the profits to the prospector or his heirs throughout the life of the mine.

Prospecting Programs

Organized prospecting schemes financed by companies are increasingly common. They may be conducted in what is believed to be a favourable area, without acquiring ground beforehand, or on concessions or groups of claims. A geologist experienced in work of this kind is usually placed in charge, and he may have other geologists or engineers to assist him. The actual prospecting may be done by teams each composed of two experienced prospectors or of one experienced man and one trainee; if the ground is being covered in great detail, a number of woodsmen or of university students without particular skill in prospecting may be employed to work under supervision. Payment may be entirely by salary, but there is usually some form of incentive bonus in one of the forms mentioned above. The actual prospecting may be done by having the supervisor select a small area in which a team of prospectors will work for a time, after which the supervisor visits them and either instructs them in how to continue in that area or moves them to another. Usually, however, ordinary prospecting is combined with geological mapping, geophysical surveys, or some of the other special methods of prospecting.

Government Grubstaking

Under certain circumstances, the governments of British Columbia and Saskatchewan assist residents of those provinces by providing funds or equipment for prospecting. Information is contained in literature supplied by the provincial department concerned.

Seeking Backing or Employment

Government departments receive numerous inquiries from prospectors regarding employment, but with the exception mentioned below government officials cannot assist in such matters. Companies in need of prospectors do, however, occasionally list their requirements with branch offices of the National Employment Service.

The best way for a prospector to obtain backing or employment if he does not know of suitable contacts, is probably to advertise in a mining paper or magazine or in a newspaper published in a mining district. He may also, by reading the mining press and consulting mining handbooks, ascertain what companies are actively engaged in prospecting and exploration.

Agreements

All agreements between prospecting partners, or between prospectors and grubstakers, syndicates, or companies should be in writing and should also be witnessed, with a view to avoiding disputes, disappointments, or misunderstandings. Agreements should preferably be drawn up by a lawyer, but if this is not possible the inexperienced prospector should consult a more experienced prospector or a business man in whom he has confidence.

When granting an option it is advisable for the owner of the claim to try to have provision made for the party taking the option to supply him with full plans and other details in the event of the option being discontinued.

The following brief notes on prospecting agreements, based on instruction included in the prospecting courses given at Yellowknife, touch on some of the main features.

The area in which the prospecting or staking is to be done should be defined as nearly as possible, and the parties should agree on who is to do the actual staking. The handling and sharing of expenses should be specified. In regions where staking by proxy is permitted, it should be made clear whether the claims are to be left in the names of the persons in whose names they are recorded or are to be transferred. Some agreement should be made as to the manner in which claims shall be sold or optioned; in some cases this may be left to the discretion of one party, while in others a majority of the associates must agree. In option agreements the claims involved, price, and terms of payment should be stated carefully. When shares in a company are part of the consideration for the sale of a claim or property, the structure of the proposed company and the prospectors' share should be specified fully.

Disposing of Discoveries

Neither prospectors nor members of syndicates have, as a rule, the training, experience, or financial resources to undertake more than the preliminary exploration of a prospect. The mineral industry is very technical and highly specialized; in general, therefore, it is most practical and efficient for prospecting and preliminary exploration to be done by prospectors, and advanced exploration and mining by mining companies. There are also nowadays companies that specialize in acquiring promising prospects, exploring them and, if the results are successful, selling them to mining companies.

Most companies are anxious to acquire promising prospects. Many prospectors, however, find it difficult to dispose of their claims or prospects, usually because their ideas of the value of the discovery differ widely from those of the company approached. Some prospectors pin their hopes on a showing that no company would consider, or they may attach too high a value to a prospect that a company would be willing to explore on different terms. These are matters for which there are no simple answers or remedies. It is true that some very successful mines have yielded little to the discoverer, but it is also true that sometimes prospectors have refused to come to terms and have died in poverty when they could have had a substantial payment or share in a discovery that was obviously important, but few discoveries are obviously important. In almost all cases exploration has to be done by a slow process of elimination, as explained elsewhere, in which most prospects do not reach the producing stage. Those who finance such exploration risk their funds and the discoverer must usually be content with a settlement commensurate with the risk, or be prepared to wait until exploration has been completed. He will then receive nothing if it is a failure or may receive a large settlement if the results of exploration are successful.

Because of the risks involved, companies seldom buy a prospect outright. The usual procedure is to take an option by a legal agreement drawn up and signed by both parties in the presence of a witness, specifying that in consideration of a certain cash payment, generally small, having been made, the company undertakes to carry on exploration for a certain period of time, after which it may either abandon the property or buy it for a specified sum in cash or a specified number of shares, or both.

Several companies interested in acquiring prospects employ scouts who tour mining camps and prospecting fields, keeping in touch with prospectors and discoveries. Other companies wait for prospectors to approach them, and may have contacts with certain prospectors with whom they have established mutual respect and trust through previous dealings. Failing these methods of approach, a prospector may advertise claims or prospects in the mining press, or he can consult mining papers and periodicals for the names and addresses of companies that are active in exploration for a particular metal or mineral. The surest way to obtain a favourable hearing is by submitting samples that are representative of the deposit, rather than the selected ones that are generally obvious to an experienced mining man, and by being able to show a reasonably accurate sketch of the showings and sampling places. If the prospector is in doubt about the value of a discovery or the terms of an agreement, he should get advice from a consulting engineer or geologist, or a lawyer, or at least from a business man or other prospector in whom he has confidence. Government departments receive requests for advice in such matters but can seldom be of assistance because they are usually strictly business or legal questions, or are such as lie within the sphere of consulting engineers or geologists.

Services of Government Departments

Departments of the federal and of most provincial governments have different responsibilities connected with prospecting and mining, and provide various services of great importance to prospectors. The responsibilities of the different organizations are kept as distinct as possible, so that the work can be done with maximum efficiency, and minimum overlapping, but more than one organization may undertake certain services such as geological mapping, because of the great amount of work needed. The activities of different departments are outlined here to assist prospectors to learn the appropriate ones to contact for publications or regulations.

The federal government has two departments of particular concern to prospectors, one being the Department of Mines and Technical Surveys. The Geological Survey of Canada, a branch of this Department, is most closely connected with prospecting, so its activities are outlined in more detail later. The Mines Branch is mainly concerned with research on methods of treating ores, fuels, etc. and on new or improved uses for metals, alloys, minerals and mineral products; therefore its activities are chiefly connected with phases of the mineral industry that follow the preliminary work of prospecting. The Branch also publishes information on resources, markets, prices, and uses of minerals produced in Canada, and tests specimens of industrial minerals, for which specifications rather than analyses are generally of great importance. It will perform chemical analyses of samples for a fee under certain circumstances, such as when analyses for a particular element are difficult to obtain elsewhere. The Surveys and Mapping Branch publishes topographical maps and administers the National Air Photographic Library.

The Northern Administration and Lands Branch of the Department of Northern Affairs and National Resources administers mining laws and regulations for the Yukon and Northwest Territories. The Lands Division of this Branch is responsible for information on staking and for the recording of claims, assessment work, and mine safety in this region. Its main office is at Ottawa, and it has offices at Whitehorse and Yellowknife.

When writing for maps or reports, sending samples, etc. it is important to keep in mind that various government agencies are distinct from one another and are often in widely separated quarters. Delays and, possibly, loss of letters or samples may be caused by improper addressing and by requesting the publications or services of different agencies in a single letter. The functions of the different agencies, as outlined here and the addresses listed in an appendix should be carefully noted.

Geological Survey of Canada

The Geological Survey of Canada was formed in 1842 and is the oldest scientific organization in the country. Its primary purpose is to map and study the geology of the country and to provide maps and reports that help prospectors and companies in the selection of their fields of operation and that help to guide their work. In this way the Geological Survey has contributed indirectly to the discovery and development of most Canadian mines. In addition to geological mapping divisions, it has special units devoted to the study of mineral deposits, petroleum and coal, mineralogy, geophysics, Pleistocene geology, engineering geology (including water supply from wells), and the study of fossils.

In a little more than a century, the Geological Survey has grown from a staff of two or three men to an organization that now places from 70 to 90 parties in the field each year and also has specialized laboratory and other staffs. It has published roughly five thousand different maps and reports, yet there are many parts of Canada that have not been investigated in even reconnaissance fashion; vast areas are in need of more detailed work; many areas that were covered in considerable detail now require revision in the light of new knowledge, new exposures, and new needs; and many problems await special investigation.

The Geological Survey is not itself a prospecting organization, although its geologists have made important discoveries from time to time while mapping, and it has undertaken special prospecting programs in times of emergency.

Catalogues of publications are available and individuals or companies may also be placed on a notice list for cards announcing new publications. A charge to help cover the cost of printing is made for most publications and requests by mail should be accompanied by a money order payable to the Receiver General of Canada. If the charge is not known, an excess can be sent with the order and the balance will be returned. Publications should be ordered from the Queen's Printer, Ottawa, or publications covering their respective regions may be obtained from branch offices of the Geological Survey of Canada at Whitehorse, Yellowknife, Vancouver, and Calgary. Publications, including many out of print, can be studied at the head and branch offices of the Geological Survey of Canada, and libraries can arrange to borrow out-of-print publications of the Geological Survey from its library.

Letters sent to the head office of the Geological Survey should usually be addressed to the Director rather than to individual officers, because the latter may no longer be on the staff or may be in the field.

The Geological Survey also sells small specimens of several rocks and minerals, as well as sets, to assist students and prospectors. A price list is available and it and the specimens should be ordered from the Director.

As a service to prospectors, samples of minerals and rocks are identified free of charge, so far as this can be done without complicated laboratory procedure. Assays or analyses are not made, except that special services are available in connection with radioactive samples, as explained in a pamphlet available on request. Samples should be sent to the Director and the outside of the parcel should bear a note stating either "for ordinary examination" or "for radioactivity tests", because these services are performed by different divisions of the Geological Survey. The sender is required to specify the exact locality from which the sample was obtained, and this information is treated in strictest confidence if desired.

Officers of the Geological Survey are pleased to assist prospectors individually when possible, but there are limitations on what can be done, because they do not attempt to duplicate the services of consulting geologists and engineers. Giving information in advance of publication is restricted to that which would not confer an unfair advantage and which pertains only to the mining property owned by the applicant. In the case of a property owned by a company it is possible to discuss it only with an official of the company. The Geological Survey does not examine a discovery at the request of the discoverer or owner, although it examines many discoveries and properties in the course of its work, and at such times is pleased to give what advice it can. Its officers can devote only a fraction of their time to inquiries by callers and by correspondence because such inquiries delay the preparation of maps and reports. Those seeking information should first obtain the publications available on the matter in question as they usually contain all the information the Geological Survey possesses or is able to impart.

Services of Provincial Governments

Most provinces have a department of mines or a mines branch in a department of some other name. These departments are responsible for all matters connected with staking, assessment work, mine safety, etc., and many of them also provide services that assist prospectors greatly. These services vary from one province to another and from time to time and are more extensive in those provinces where mining is a major industry. In several instances they consist of pamphlets giving general advice on prospecting in the province, annual reports describing mining properties, geological maps and reports on certain areas, and free identifications, spectrographic analyses, or assays on a limited number of samples. In some provinces a certain number of coupons are issued with a prospecting permit, entitling the prospector to one assay per coupon. Mining engineers or geologists may also examine discoveries and advise prospectors, but no department attempts to meet all requests for such examinations. For particulars, mining recorders or other officials of the department concerned may be consulted, or a letter may be sent to the head office of the department. The names of the provincial departments and the addresses of their head offices are listed in Appendix V.

APPENDIXES

1. *Table of Elements*

2. *Aids for Identifying Minerals*

3. *Mineral Table*

4. *Classification of Rocks*

5. *Addresses*

6. *Tracing Float in Glacial Drift*

APPENDIX I

TABLE OF THE ELEMENTS

The elements, as mentioned in Chapter III, are the basic substances of which matter is composed. Under normal conditions, most elements are solid. Eleven are gases, and two, bromine and mercury, are liquids. The elements are sometimes roughly classified under the heads of metals, semi-metals (or metalloids), non-metals, and gases. However, this classification is merely a matter of convenience, and not a scientific definition. For the purpose of this table, substances having what is known as 'metallic lustre' are classified as metals, and those without as non-metals. Those elements which are gaseous at normal temperature and pressure are classified as gases, e.g. oxygen, nitrogen; two such elements, however, chlorine and fluorine, are rarely, if ever, found as gases, but occur in combination with other elements.

Elements marked with an asterisk belong to the rare earth groups, to which scandium and yttrium are closely related.

Table of Elements

Name	Symbol	Nature	Atomic Weight
Actinium	Ac	metal (?)	227
Aluminum	Al	metal	27·0
Americium	Am	metal (?)	243
Antimony	Sb	semi-metal	121·8
Argon	A	gas	39·9
Arsenic	As	semi-metal	74·9
Astatine	At	non-metal	210
Barium	Ba	metal	137·4
Berkelium	Bk	metal	245
Beryllium	Be	metal	9·0
Bismuth	Bi	metal	209
Boron	B	non-metal	10·8
Bromine	Br	non-metal	79·9
Cadmium	Cd	metal	112·4
Caesium	Cs	metal	132·9
Calcium	Ca	metal	40·1
Californium	Cf	metal	248
Carbon	C	non-metal	12·0
Cerium*	Ce	metal	140·1
Chlorine	Cl	gas	35·5
Chromium	Cr	metal	52·0
Cobalt	Co	metal	58·9
Columbium (*see* Niobium)			
Copper	Cu	metal	63·5
Curium	Cm	metal (?)	245
Dysprosium*	Dy	metal	162·5
Erbium*	Er	metal	167·2
Europium*	Eu	metal	152
Fluorine	F	gas	19
Francium	Fr	metal	223
Gadolinium*	Gd	metal	156·9
Gallium	Ga	metal	69·7
Germanium	Ge	metal	72·6
Gold	Au	metal	197·0
Hafnium	Hf	metal	178·6
Helium	He	gas	4·0
Holmium*	Ho	metal	164·9
Hydrogen	H	gas	1·0
Indium	In	metal	114·8
Iodine	I	non-metal	126·9
Iridium	Ir	metal	192·2
Iron	Fe	metal	55·9
Krypton	Kr	gas	83·8
Lanthanum*	La	metal	138·9
Lead	Pb	metal	207·2
Lithium	Li	metal	6·9
Lutetium*	Lu	metal	175·0
Magnesium	Mg	metal	24·3
Manganese	Mn	metal	54·9
Mercury	Hg	metal (liquid)	200·6
Molybdenum	Mo	metal	96·0
Neodymium*	Nd	metal	144·3
Neon	Ne	gas	20·2
Neptunium	Np	metal	237
Nickel	Ni	metal	58·7
Niobium (formerly columbium)	Nb	metal	92·9
Nitrogen	N	gas	14·0
Osmium	Os	metal	190·2
Oxygen	O	gas	16
Palladium	Pd	metal	106·7
Phosphorus	P	non-metal	31·0
Platinum	Pt	metal	195·2
Plutonium	Pu	metal	242
Polonium	Po	metal	210
Potassium	K	metal	39·1
Praseodymium*	Pr	metal	140·9
Promethium*	Pm	metal	145
Protoactinium	Pa	metal (?)	231
Radium	Ra	metal	226·1
Radon	Rn	gas	222
Rhenium	Re	metal	186·3
Rhodium	Rh	metal	102·9
Rubidium	Rb	metal	85·5
Ruthenium	Ru	metal	101·1
Samarium*	Sm	metal	150·4
Scandium	Sc	metal	45·0
Selenium	Se	non-metal	79·0
Silicon	Si	non-metal	28·1
Silver	Ag	metal	107·9
Sodium	Na	metal	23·0
Strontium	Sr	metal	87·6
Sulphur	S	non-metal	32·1
Tantalum	Ta	metal	181·0
Technetium	Tc	metal	99
Tellurium	Te	non-metal	127·6
Terbium*	Tb	metal	158·9
Thallium	Tl	metal	204·4
Thorium	Th	metal	232·1
Thulium*	Tm	(rare-earth metal ?)	168·9
Tin	Sn	metal	118·7
Titanium	Ti	metal	47·9
Tungsten	W	metal	183·9
Uranium	U	metal	238·1
Vanadium	V	metal	51·0
Wolfram (*see* Tungsten)			
Xenon	Xe	gas	131·3
Ytterbium*	Yb	metal	173·0
Yttrium	Y	metal	88·9
Zinc	Zn	metal	65·4
Zirconium	Zr	metal	91·2

APPENDIX II

LIST OF USEFUL AIDS FOR IDENTIFYING MINERALS

Minerals are identified by their chemical or physical properties. The properties of the commoner minerals can usually be determined by simple tests that require only a few inexpensive pieces of apparatus and a small supply of chemicals. The following list contains the basic essentials for making such tests and is recommended to the prospector who does not attend a course and who does not buy a complete readymade kit. The entire lot may be packed into a small portable kit. The chemicals listed can be obtained at drug stores, and both chemicals and apparatus can be bought from dealers in laboratory supplies.[1] Some of the chemicals are poisonous and adequate precautions should be taken when handling them. For instructions in using the equipment, the reader is referred to one of the books on mineralogy listed at the end of Chapter III, since the subject is beyond the scope of this book. However, some of the simpler tests for particular minerals are mentioned in the tables in Appendix III.

Apparatus

Magnet This is used to distinguish the magnetic minerals, such as magnetite, ilmenite, pyrrhotite, etc. Magnets are available in a variety of sizes and shapes, but probably the most suitable is a horseshoe-shaped magnet about 1½ inches in width. Many persons prefer one made of a special alloy called alnico, but an ordinary steel magnet will serve equally well. When separating magnetite from black sand, the magnet should be wrapped in paper as particles are difficult to clean from the magnet itself.

Pocket-knife A pocket-knife is indispensable to a prospector for many reasons. It is included here because it is useful for determining the hardness of minerals. The blade has a hardness value of between 5 and 6. (*see* also Appendix III, footnote 2). Rather than carry a magnet, some prospectors find it convenient to magnetize one blade of their pocket knife. This may be done by stroking the blade of the knife slowly and in one direction with a hand magnet.

Streak Plate This is a piece of white unglazed porcelain that is used to determine the streak of the mineral. The streak is the colour of the finely powdered mineral and it may be quickly produced by rubbing the mineral across a streak plate.

File A small triangular file may also be used to determine the streak and hardness of minerals. The streak is determined by filing an edge of the mineral and collecting the powder. The hardness value of the file is between 6 and 7.

Hand Lens A hand lens is necessary for examining small mineral grains, and for studying closely such properties as cleavage and twinning. A simple magnifying lens, 1½ inches in diameter and with a magnifiying power of 3½, is adequate. The lens should be protected by a chamois bag.

Lamp The lamp is an essential piece of apparatus for many tests. If gas is available, the Bunsen burner is the most convenient type of lamp to use, as it provides a hot flame, and may be regulated. When gas is not available, an alcohol lamp with a wick is probably the most satisfactory. Lamps which burn solid fuel are also available. Candles may be used for some tests.

Blowpipe This is a curved, slender metal tube about seven inches in length that is used to concentrate the lamp flame at a point. The tube is drawn to a fine tip at one end, and is fitted with a mouthpiece at the larger end. To use the blowpipe, the tip is inserted into the lamp flame and a constant jet of air is directed across the flame and slightly downwards towards the specimen under test. The blowpipe is required for testing the fusibility of minerals, for making bead tests, for studying the reactions of minerals on charcoal tablets, and for other purposes where an intense source of heat is required.

Tweezers A pair of tweezers is essential for holding mineral fragments when testing their fusibility and when noting flame colorations. Tweezers equipped with platinum tips are preferred, but ordinary steel tweezers will give adequate service, although for a shorter length of time. The tweezers will become quite hot during the heating of the mineral fragments, and for this reason a small piece of asbestos will be found useful in handling them.

Hammer A small hammer or improvised mortar weighing two or three ounces is useful for crushing mineral fragments to be tested. A small, square metal block on which to crush the fragments is also useful. When crushing friable minerals, the hand should be cupped around the block to prevent loss of fragments.

Pliers A pair of cutting pliers is useful for breaking off mineral fragments for tests.

Platinum Wire A length of platinum wire is necessary for making bead tests, in which the mineral is dissolved in a bead of flux in the blowpipe flame. The tests are useful because certain elements impart characteristic colours to the beads. The commonest fluxes used are borax, sodium carbonate and, for detecting uranium, sodium fluoride. The wire may be fused into a piece of glass tubing to form a handle.

Glass Tubes These should be 4 to 5 inches in length and about $\frac{3}{16}$ inch in diameter. They are useful for determining the presence of water and volatile constituents such as sulphur, arsenic, and antimony. This is done by heating a little of the powdered mineral in the tube in the blowpipe flame. The tubes may be open at both ends, or closed at one end. The closed tube is especially useful for determining the presence of water.

Charcoal Blocks Small rectangular blocks of charcoal are useful for studying the reactions of minerals under the blowpipe flame. Such reactions may yield characteristic odours, sublimates, or magnetic residues or metallic globules. Charcoal made from basswood or pine is recommended, but any kind of charcoal that will not splinter on heating is suitable.

Chemicals

Dry chemicals

Borax — for bead tests
Hydrogen sodium ammonium phosphate — for bead tests; sometimes called salt of phosphorus or microcosmic salt
Sodium carbonate — for bead tests and for decomposing minerals by fusion
Potassium bisulphate — for decomposing minerals by fusion
Sodium fluoride — for testing for uranium
Ammonium molybdate — for testing for phosphorus
Dimethylglyoxime — for testing for nickel
Potassium iodide — for testing for bismuth and lead
Granulated zinc — to produce special chemical reactions
Granulated tin — to produce special chemical reactions.

Wet chemicals These should be kept in glass stoppered bottles. Acids are usually sold in concentrated form and should be diluted with 2 to 5 equal volumes of water. When diluting sulphuric acid, *the acid should always be added to the water, little by little.*

Water — for diluting acids, washing apparatus, etc.
Hydrochloric acid — useful for testing carbonates and dissolving minerals
Nitric acid — useful for dissolving minerals
Sulphuric acid — used in some special tests
Ammonium hydroxide — strong alkali; should be diluted with 2 parts water before using.

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[1] The names and addresses of some such dealers are:

Canadian Laboratory Supplies Limited,
403 St. Paul St. West, Montreal, Que.
3701 Dundas St. West, Toronto, Ont.
288 William Ave., Winnipeg, Man.
10182 - 103 St., Edmonton, Alta.

Case and Company Limited,
567 Hornby St., Vancouver, B.C.

Central Scientific Company of Canada Limited,
129 Adelaide St. West, Toronto, Ont.
107 Clarke Building, Edmonton, Alta.

Fisher Scientific Company Limited,
904 St. James St., Montreal, Que.
245 Carlaw Ave., Toronto 8, Ont.
7-10923-124 St., Edmonton, Alta.

23-828—24

APPENDIX III

INTRODUCTORY MINERAL TABLE[1]

(Compiled by H. R. Steacy)

Note: Separate copies of this table are available for field use from the Queen's Printer at 10 cents each.

A. Minerals with Metallic or Sub-metallic Lustre

Name and Composition	Hardness[2]	Characteristics	Remarks
1. Colour is white to light grey — streak[3] is white.			
Silver Ag	2·5–3	Wiry forms, leaves, scales, and plates. Malleable. Very heavy. Colour and streak silver-white, but tarnishes grey to black.	Often alloyed with gold. Almost always tarnished except on a very fresh surface.
2. Colour is white to light grey — streak is greyish black to black.			
Cobaltite CoAsS	5·5	Commonly as small crystals with striated faces; sometimes massive. Colour, silver-white, often with reddish tinge. Streak, greyish black.	A source of cobalt; alters to pink erythrite.
Arsenopyrite FeAsS	5·5–6	Massive; disseminated crystals, conspicuously striated. Colour, silver-white to steel-grey. Streak, greyish black. Garlic odour on breaking.	Source of white arsenic. Often contains cobalt, and silver; sometimes gold.
Skutterudite (CoNi) As_3	6	Usually massive. Colour between tin-white and silver-grey; sometimes tarnished grey. Streak, greyish black.	Skutterudite is the name given to a series of cobalt-nickel arsenides of similar crystal structure. The minerals smaltite and chloanthite are included in the series. Colour resembles aluminum paint.

[1] The minerals listed are those recommended for first study. Because of variable characteristics, a mineral may appear in more than one place in the table.

[2] Hardness is one of the most useful properties in identifying minerals. The numbers listed in this column indicate the relative hardness of the minerals, as determined by comparison with a standard scale. This is known as Mohs' Scale of Hardness and consists of the following ten minerals of relative increasing hardness: 1 – Talc; 2 – Gypsum; 3 – Calcite; 4 – Fluorite; 5 – Apatite; 6 – Feldspar; 7 – Quartz; 8 — Topaz; 9 – Corundum; 10 – Diamond. The hardness is best determined by scratching the mineral on a smooth surface. The finger nail has a hardness value of about 2·5. The blade of an ordinary pocket-knife has a value of 5·5 to 6.

[3] The streak is the colour of the finely powdered mineral. It may be determined by powdering a fragment of the mineral, by filing it, or by rubbing it across a piece of unglazed white porcelain. The streak is especially helpful in identifying minerals of metallic or sub-metallic lustre. These minerals have therefore been sub-classified according to their streak.

Introductory Mineral Table (*continued*)

A. Minerals with Metallic or Sub-metallic Lustre (*continued*)

Name and Composition	Hardness	Characteristics	Remarks
3. Colour is lead-grey to black — streak is white, grey, light brown, or red.			
Molybdenite MoS_2	1–1·5	Commonly in flakes or foliated masses[4]. Greasy feel. Sectile. Laminae flexible. Colour, lead-grey. Streak, greenish grey on porcelain, bluish grey on paper. Yields sulphurous fumes on heating.	Important source of molybdenum. Found in pegmatites; in veins, associated with scheelite, wolframite, and fluorite; and as an accessory mineral in granites. Differs from graphite in colour and streak, and in effect on heating.
Silver Ag	2·5–3	Wiry forms, leaves, scales, and plates. Malleable. Very heavy. Colour and streak silver-white, but tarnishes grey to black.	Often alloyed with gold. Almost always tarnished except on a very fresh surface.
Sphalerite ZnS	3·5–4	Massive. Perfect dodecahedral cleavage. Brilliant to resinous lustre. Colour, black, brown, or yellow. Streak, brownish to light yellow and white.	Most important source of zinc. Usually closely associated with galena.
Hematite Fe_2O_3	5–6	Compact, granular, botryoidal, and earthy masses. Colour, steel-grey to reddish brown. Streak, red to reddish brown.	Most important ore of iron. Streak is quite distinctive. *Specularite*[5] has a micaceous structure with a splendent lustre.
Cassiterite SnO_2	6–7	Massive and as crystals (ordinary); botryoidal, with fibrous structure (wood tin); rolled grains (stream tin). Heavy. Colour usually black or brown. Streak, greyish to brownish.	Most important source of tin. Commonly occurs in veins closely associated with granitic rocks or pegmatites. Often in placer deposits.
4. Colour is lead-grey to black — streak is dark brown or black.			
Graphite C	1–2	Commonly in flakes or foliated masses. Greasy feel. Sectile. Laminae flexible. Colour, steel-grey to iron-black. Streak, shining black.	Found mainly in metamorphic rocks; common in crystalline limestone. Colour and streak aid in distinguishing it from molybdenite.
Stibnite Sb_2S_3	2	Columnar and bladed masses; aggregates of needle-like crystals, often striated and bent. Perfect cleavage. Colour and streak, lead-grey. Thin edge fuses in candle flame.	Most important source of antimony. Harder than graphite. Lighter than galena.
Pyrolusite MnO_2	2–2·5	Usually as fibrous, granular, or powdery masses; also as coatings. Colour, steel-grey to iron-black. Streak, black to bluish black. Soils the fingers.	A source of manganese. Secondary in origin.
Galena PbS	2·5	Massive, with cubic cleavage; sometimes as crystals, usually cubic. Heavy. Colour and streak, pure lead-grey.	Most important source of lead. Frequently contains silver.

continued . . .

[4] Some minerals occur typically as well-formed crystals, but most occur in masses showing no external crystalline form. The structure of such masses may be cleavable, granular, lamellar, columnar, fibrous, bladed, foliated, scaly, botryoidal, or compact. Cleavable masses break along smooth, flat surfaces; granular masses are composed of individual grains, either coarse or fine; lamellar masses are made up of thin layers; columnar masses are made up of slender columns; fibrous masses are made up of fibres, which may be coarse or fine and which may or may not be separable; bladed masses are composed of thin blades; foliated masses are made up of thin plates, or leaves, which are easily separable; scaly masses consist of thin, easily separable scales; botryoidal masses have rounded surfaces, resembling a bunch of grapes; and compact masses are dense granular masses which are very resistant to fracturing or breaking.

[5] Names in italics are varieties of the species described, e.g., *specularite* is a variety of hematite.

Introductory Mineral Table (*continued*)

A. Minerals with Metallic or Sub-metallic Lustre (*continued*)

Name and Composition	Hardness	Characteristics	Remarks
4. Colour is lead-grey to black — streak is dark brown or black. — Cont'd			
Chalcocite Cu_2S	2·5–3	Massive; also as crystals, deeply striated and frequently twinned. Heavy. Rather sectile. Colour and streak, blackish lead-grey; often tarnished blue or green.	Important source of copper. Usually associated with other copper minerals.
Tetrahedrite $(CuFe)_{12}Sb_4S_{13}$	3–4	Massive; also as tetrahedral crystals. Brilliant lustre. Colour, flint-grey to iron-black. Streak, brown to black.	A source of copper. Often contains silver.
Wolframite $(FeMn)WO_4$	5–5·5	Granular or lamellar masses; also as crystals, usually striated, and as rolled grains. Perfect cleavage. Heavy. Sometimes weakly magnetic. Colour, dark grey to brownish black. Streak, dark brownish to black. Fuses easily.	A source of tungsten. Occurs in quartz veins, pegmatites, and granites. Commonly associated with cassiterite and scheelite. Often found in placer deposits.
Chromite $FeCr_2O_4$	5·5	Granular to compact masses. Sometimes feebly magnetic. Colour, iron-black to brownish black. Streak, brown.	A source of chromium. Occurs commonly in serpentinized basic rocks; also found in placers. Distinguished from magnetite by streak and feeble magnetic property.
Ilmenite $FeTiO_3$	5–6	Granular and compact masses. Slightly magnetic. Colour, iron-black. Streak, brownish to black.	A source of titanium. Often intergrown with magnetite. Commonly present in black sands.
Uraninite UO_2	5–6	Typically as well-developed cubic and octahedral crystals. Heavy. Strongly radioactive. Colour, steel-black to black. Streak, black.	Occurs mainly in granite and syenite pegmatites. Usually contains several per cent thorium and rare earths.
Uraninite, variety *pitchblende* UO_2	5–6	Massive, sometimes in rounded or botryoidal forms; also finely disseminated. Heavy. Pitchy lustre. Colour, dark steely to pitch-black. Streak, black.	Occurs in vein-type deposits. Often associated with hematite. Practically free of thorium and rare earths.
Magnetite Fe_3O_4	5·5–6·5	Usually as granular masses; sometimes as octahedral crystals. Octahedral parting. Strongly magnetic. Colour and streak, black.	Important source of iron. Alters to limonite and hematite. Widespread occurrence. Very common in black sands.
Columbite-tantalite $(FeMn)(NbTa)_2O_6$	6	Platy or rectangular crystals, often in radial or parallel aggregates; disseminated grains. Quite heavy. Colour and streak, brownish black to iron-black. Frequently iridescent.	A source of columbium and tantalum. Commonly occurs in pegmatites.

Introductory Mineral Table (*continued*)

A. Minerals with Metallic or Sub-metallic Lustre (*continued*)

Name and Composition	Hardness	Characteristics	Remarks
5. Colour is yellow, brass, or bronze — streak is yellow or black.			
Gold Au	2·5–3	Commonly in flakes, scales, and wires. Hackly fracture. Malleable. Very heavy. Colour and streak, golden yellow.	Generally alloyed with silver. Frequently found in quartz veins; also in placer deposits as flakes or nuggets, when it may be easily panned.
Bornite Cu_5FeS_4	3	Massive. Colour, bronze-red on fresh surface; tarnishes readily to purple. Streak, greyish black.	A source of copper. Sometimes called 'peacock ore' or 'purple copper ore'.
Chalcopyrite $CuFeS_2$	3·5–4	Massive. Colour, brass-yellow; often tarnished and iridescent. Streak, greenish black.	Most important source of copper. Sometimes contains gold and silver.
Pyrrhotite Fe_7S_8	3·5–4	Massive, usually granular. Weakly magnetic. Colour, bronze-yellow to copper-red; tarnishes quickly. Streak, greyish black.	May contain nickel, owing to the presence of pentlandite. Magnetic property distinguishes it from chalcopyrite and pyrite.
Pentlandite $(FeNi)S$	3·5–4	Massive and disseminated. Colour, light bronze-yellow. Streak, light bronze-brown.	A source of nickel. Almost always found associated with pyrrhotite.
Pyrite FeS_2	6–6·5	Massive, frequently fine granular; cubic crystals common, often striated. Colour, pale brass-yellow. Streak, greenish black or brownish black.	Most common sulphide mineral. Alters to limonite. May contain gold. Hardness distinguishes it from chalcopyrite, pyrrhotite, and gold.
6. Colour is red or brown — streak is red or brown.			
Copper Cu	2·5–3	Masses; scales; distorted crystals. Hackly fracture. Malleable. Heavy. Colour and streak, copper-red.	Often stained with green and blue secondary copper minerals.
Cinnabar HgS	2–2·5	Earthy coatings; crystalline crusts; and massive. Heavy. Colour, bright red. Streak, scarlet. On being heated, it produces sulphurous fumes and minute globules of mercury.	Principal source of mercury. Resembles some varieties of hematite, but distinguished by heating test.
Sphalerite ZnS	3·5–4	Massive. Perfect dodecahedral cleavage. Brilliant to resinous lustre. Colour, brown, yellow, or black. Streak, brownish to light yellow and white.	Most important source of zinc. Usually closely associated with galena.
Hematite Fe_2O_3	5·5–6·5	Compact, granular, botryoidal, and earthy masses. Colour, reddish brown to steel-grey. Streak, red to reddish brown.	Most important ore of iron. Streak is quite distinctive. *Specularite* has a micaceous structure with a splendent lustre.
Cassiterite SnO_2	6–7	Massive and as crystals (ordinary); botryoidal, with fibrous structure (wood tin); rolled grains (stream tin). Heavy. Colour usually brown to black. Streak, greyish to brownish.	Most important source of tin. Commonly occurs in veins closely associated with granitic rocks or pegmatites. Often in placer deposits.

Introductory Mineral Table (*continued*)

A. Minerals with Metallic or Sub-metallic Lustre (*continued*)

Name and Composition	Hardness	Characteristics	Remarks
7. Colour is red or brown — streak is greyish or brownish black.			
Bornite Cu_5FeS_4	3	Massive. Colour, bronze-red on fresh surface; tarnishes readily to purple. Streak, greyish black.	A source of copper. Sometimes called 'peacock ore' or 'purple copper ore'.
Pyrrhotite Fe_7S_8	3·5–4	Massive, usually granular. Weakly magnetic. Colour between copper-red and bronze-yellow; tarnishes quickly. Streak, greyish black.	May contain nickel, owing to the presence of pentlandite. Magnetic property distinguishes it from chalcopyrite and pyrite.
Wolframite $(FeMn)WO_4$	5–5·5	Granular or lamellar masses; also as crystals, usually striated, and as rolled grains. Perfect cleavage. Heavy. Sometimes weakly magnetic. Colour, reddish-brown to black. Streak, dark brownish to black. Fuses easily.	A source of tungsten. Occurs in quartz veins, pegmatites, and granites. Commonly associated with cassiterite and scheelite. Often found in placer deposits.
Niccolite NiAs	5–5·5	Usually massive; rounded or columnar forms common. Heavy. Colour, copper-red, tarnishing quickly to brown. Streak, brownish black.	A source of nickel. Commonly associated with cobalt-nickel arsenides and annabergite (green nickel bloom).

B. Minerals with Non-metallic Lustre[1]

Name and Composition	Hardness	Characteristics	Remarks
1. Colour is white or grey, or the mineral is colourless.			
Talc $H_2Mg_3(SiO_3)_4$	1–1·5	Usually foliated or massive. Perfect basal cleavage. Laminae flexible, but not elastic. Greasy feel. Colour commonly white or light green; also grey, dark green or brown. May be easily marked with the finger nail.	Secondary origin. Occurs frequently as talcose schists; often associated with serpentine. Mined at Madoc, Ont. *Soapstone* is a massive variety, sometimes forming extensive beds.
Gypsum $CaSO_4.2H_2O$	2	Granular and foliated masses; platy crystals, often as 'swallow-tail' twins. Perfect cleavage. Glassy to pearly lustre. Colourless or white, often tinted grey, red, or yellow.	In mineral veins and in sedimentary deposits. *Selenite* – colourless, transparent crystals and broad foliæ. *Satin spar* – fine-fibrous with silky lustre.
Kaolin $H_4Al_2Si_2O_9$	2–2·5	Massive, usually clay-like or earthy. Pearly to dull lustre. Colour, white, often stained with iron oxides.	Occurs prominently as decomposition product of feldspars in granites and pegmatites. Also in sedimentary beds.

continued . . .

[1] Minerals of non-metallic lustre have not been sub-classified according to their streak because the majority have either a colourless or light greyish streak, or a streak faintly tinted the colour of the mineral. However, there are a few exceptions, and where the streak is a distinguishing characteristic it is noted in the table. The most notable exceptions are cinnabar, hematite, and limonite.

Introductory Mineral Table (*continued*)

B. Minerals with Non-metallic Lustre (*continued*)

Name and Composition	Hardness	Characteristics	Remarks
1. Colour is white or grey, or the mineral is colourless. — Cont'd			
Muscovite (white mica). Silicate of Al and K.	2–2·5	Flakes and scaly or foliated masses. Perfect basal cleavage. Thin flakes flexible and elastic. Usually colourless, pale amber, or light green.	An abundant rock-forming mineral. Commonly found in granites, pegmatites, and schists. Valuable because of its high dialectric constant. May be split easily into thin, transparent flakes.
Brucite $Mg(OH)_2$	2·5	Foliated and fibrous masses; embedded grains; and broad, platy crystals. Foliæ flexible. Sectile. Pearly, waxy, or glassy lustre. Transparent to translucent. Colour, white, often tinted grey, blue, or green.	Found in metamorphic limestones and with serpentine and chlorite minerals. Harder than talc.
Halite NaCl	2·5	Massive, with cubic cleavage. Salty taste. Colourless or white; various colours when impure. Soluble in water.	Occurs in sedimentary rocks. Often associated with gypsum.
Calcite $CaCO_3$	3	Cleavable, granular, and compact masses; also as crystals. Perfect rhombohedral cleavage. Colourless or white; also pink or grey; sometimes blue or yellow. Effervesces in cold, dilute, hydrochloric acid.	Widely distributed mineral. Common in metalliferous veins as a gangue mineral. Occurs in sedimentary deposits as limestone, marble, and chalk. Much softer than feldspar.
Barite $BaSO_4$	3–3·5	Columnar, laminated, compact, and earthy masses; platy crystals. Perfect cleavage. Quite heavy. Colour, white; also yellow, brown, red, or grey.	Occurs in sedimentary rocks and in metalliferous veins. Frequently associated with ores of lead and zinc. Heavier than calcite or gypsum. Softer than feldspar.
Celestite $SrSO_4$	3–3·5	Fibrous and granular masses; platy crystals. Perfect cleavage. Quite heavy. Glassy to pearly lustre. Colour, white, sometimes bluish or reddish. Colours blowpipe flame red.	Occurs mainly in sedimentary rocks; sometimes in veins, associated with galena and sphalerite.
Siderite $FeCO_3$	3·5–4	Cleavable, compact, and botryoidal masses. Perfect rhombohedral cleavage. Colour, greyish or brownish; dark brownish on weathered surface. Effervesces in hot hydrochloric acid.	Occurs in sedimentary and replacement-type deposits, and in metalliferous veins. Heavier than calcite or dolomite.
Dolomite $CaMg(CO_3)_2$	3·5–4	Cleavable, granular, and compact masses; rhombohedral crystals, often curved. Perfect rhombohedral cleavage. Colour, white, grey, or pink. Powder effervesces in warm, dilute, hydrochloric acid.	Occurs in sedimentary rocks and in metalliferous veins. Resembles calcite, but does not effervesce in cold acid.
Scheelite $CaWO_4$	4·5–5	Massive. Quite heavy. Fluoresces. Brilliant lustre. Transparent to translucent. Colour, usually white, yellowish, or brownish.	A source of tungsten. Occurs in pegmatites and ore veins associated with granitic rocks; also in contact metamorphic deposits.

continued . . .

Introductory Mineral Table (*continued*)

B. Minerals with Non-metallic Lustre (*continued*)

Name and Composition	Hardness	Characteristics	Remarks
1. Colour is white or grey, or the mineral is colourless. — Cont'd			
Feldspar Group Silicates of Al, K, Na, and Ca.	6–6·5	Massive, usually cleavable or granular, sometimes lamellar or compact. Two cleavages at, or nearly at, right angles; also less perfect prismatic cleavage. Brittle. Glassy to pearly lustre. Variously coloured but generally white, greyish, or reddish. *Amazonstone* – green.	Abundant rock-forming minerals. Especially common in granites, syenites, gneisses, and pegmatites; also as crystals in porphyries and as a constituent of sands. *Microcline* – commonly reddish; widespread; used in ceramic industry. *Plagioclase* group – usually show fine striations on cleavage surfaces; also play of colours.
Spodumene $LiAl(SiO_3)_2$	6·5–7	Cleavable and columnar masses; prismatic crystals, often vertically striated. Perfect prismatic cleavage. Splintery fracture. Glassy to pearly lustre. Colour, white, greyish, or greenish. Fuses easily, colouring flame purple-red.	A source of lithium. Occurs in granite pegmatites, sometimes as very large crystals.
Quartz SiO_2	7	Massive, often as formless glassy grains; hexagonal crystals. Conchoidal fracture. Glassy lustre. Transparent to opaque. Colourless or variously coloured. *Milky* – milky-white; *rose* – pink; *amethyst* – violet; *smoky* – brown to black.	Most common mineral. Especially abundant in granites, gneisses, quartzites, sandstones, and sands. Also very common as a vein mineral. Cryptocrystalline varieties include *flint, chert, chalcedony, agate* (banded), and *jasper* (red).
Zircon $ZrSiO_4$	7·5	Usually as small, square, elongated crystals with pyramidal ends. Brilliant lustre. Colourless, yellowish, greyish, or brownish.	Common accessory constituent of igneous rocks, especially granites. Also in pegmatites and sands. *Cyrtolite* contains rare earths.
Corundum Al_2O_3	9	Barrel-shaped crystals common; also massive, with rectangular parting. Frequently striated. Colour, grey, brown, blue, red, or yellow.	Important amounts found in syenite and nepheline syenite. Gem varieties include *sapphire* (blue), and *ruby* (red).

The following minerals may also occur in this group, but occur more commonly in other groups and are described elsewhere in the table: **apatite, amphibole, pyroxene, kyanite, olivine,** *and* **beryl.**

Name and Composition	Hardness	Characteristics	Remarks
2. Colour is blue, green, or violet.			
Talc $H_2Mg_3(SiO_3)_4$	1–1·5	Usually foliated or massive. Perfect basal cleavage. Laminae flexible, but not elastic. Greasy feel. Colour commonly light green or white; also grey, dark green or brown. May be easily marked with the finger nail.	Secondary in origin. Occurs frequently as talcose schists; often associated with serpentine. Mined at Madoc, Ont. *Soapstone* is the massive variety, sometimes forming extensive masses.

continued . . .

Introductory Mineral Table (*continued*)

B. Minerals with Non-metallic Lustre (*continued*)

Name and Composition	Hardness	Characteristics	Remarks
2. Colour is blue, green or violet. — Cont'd			
Chlorite Hydrous silicate of Al, Fe, and Mg.	2–2·5	Commonly in scaly, dense, or earthy masses. Perfect cleavage. Thin flakes flexible but not elastic. Colour usually greenish.	Usually occurs as a secondary mineral. Often associated with amphibole, pyroxene, biotite, and serpentine. Common as chlorite schists. Distinguished from micas by greenish colour and inelasticity of flakes.
Annabergite (nickel bloom) $Ni_3As_2O_8.8H_2O$	2·5–3	Usually as stains or earthy crusts. Colour, apple-green. Streak, light green.	Secondary in origin. Indication of nickel-bearing minerals, from which it is formed.
Serpentine $H_4Mg_3Si_2O_9$	2·5–4	Usually massive; sometimes foliated. Smooth to greasy feel. Waxy to greasy lustre. Colour, pale to dark green, yellowish, or brownish. Powder yields water when ignited in closed tube. *Chrysotile* (asbestos) – delicately fibrous. Fibres flexible and easily separable. Silky lustre. Colour usually greenish white.	Secondary mineral. Commonly associated with olivine, pyroxene, and amphibole. Also forms large masses by alteration of basic rocks. *Chrysotile* usually occurs in veinlets in massive serpentine.
Azurite $2CuCO_3.Cu(OH)_2$	3·5–4	Stains and fibrous crusts; also as botryoidal masses and as crystals. Colour, light blue to dark blue. Streak, light blue. Effervesces in hydrochloric acid.	Secondary mineral. Almost always associated with malachite. Indication of primary copper-bearing minerals.
Malachite $CuCO_3.Cu(OH)_2$	3·5–4	Stains and fibrous crusts; banded, botryoidal masses; and earthy. Colour usually bright green. Streak, light green. Effervesces in hydrochloric acid.	Secondary mineral. Indication of primary copper-bearing minerals.
Fluorite CaF_2	4	Granular and compact masses; cubic crystals. Octahedral cleavage. Fluoresces. Colour commonly greenish, bluish, yellowish, or violet.	Occurs in sedimentary and igneous rocks; in pegmatites; and as a vein mineral, often associated with ores of lead, silver, and zinc.
Apatite $Ca_5(PO_4)_3(F,Cl,OH)$	4·5–5	Hexagonal crystals; also granular, compact, and nodular masses. Brittle. Glassy to resinous lustre. Colour usually greenish; sometimes brown, red, blue, or grey.	Found in most types of rocks. Common in contact metamorphic limestones and in pegmatites. Also occurs as extensive sedimentary deposits. Softer than beryl.
Amphibole Group Silicates of, chiefly, Ca, Mg, and Fe.	5–6	Granular, columnar, and fibrous masses; prismatic crystals, stubby or bladed. Two cleavages, meeting at angles of 56° and 124°. Colour, greyish green through green to black; also white or grey.	Abundant rock-forming minerals. *Tremolite* and *actinolite* usually grey to green; common in metamorphic limestones, schists, and gneisses. *Hornblende* usually dark green to black; common constituent of igneous rocks. Cleavage distinguishes amphibole from pyroxene.

continued . . .

Introductory Mineral Table (*continued*)

B. Minerals with Non-metallic Lustre (*continued*)

Name and Composition	Hardness	Characteristics	Remarks
2. Colour is blue, green or violet. — Cont'd			
Pyroxene Group Silicates of, chiefly, Ca, Mg, and Fe.	5–6	Granular and lamellar masses; prismatic crystals, square or eight-sided. Two cleavages, almost at right angles. Colour usually light to dark green to black; also white or grey.	Very common rock-forming minerals. *Diopside* – light green; found in contact metamorphic limestones and dolomites. *Augite* – dark green to black; common in dark-coloured igneous rocks. Cleavage distinguishes pyroxene from amphibole.
Kyanite Al_2SiO_5	5–7	Coarsely bladed or columnar masses; long-bladed crystals. Perfect cleavage. Glassy lustre. Colour usually bluish; also white, greyish, or greenish.	Occurs mainly in schists and gneisses. Often associated with garnet.
Epidote $HCa_2(AlFe)_3Si_3O_{13}$	6–7	Granular, fibrous, and compact masses; elongated prismatic crystals, deeply striated. Perfect cleavage. Glassy lustre. Colour, pistachio green to greenish black. Fuses easily.	Metamorphic mineral. Common alteration product of feldspars.
Olivine $(MgFe)_2SiO_4$	6·5–7	Usually as disseminated grains or granular, sugar-like masses. Good cleavage. Glassy lustre. Colour usually olive-green; sometimes yellowish, greyish, or brownish.	Occurs in basic igneous rocks such as peridotite, diabase, and gabbro, where often associated with chromite, magnetite, and spinel; also found in metamorphosed limestones and dolomites.
Spodumene $LiAl(SiO_3)_2$	6·5–7	Cleavable and columnar masses; prismatic crystals, often vertically striated. Perfect prismatic cleavage. Splintery fracture. Glassy to pearly lustre. Colour, greenish white or greyish white. Fuses easily, colouring flame purple-red.	A source of lithium. Occurs in granite pegmatites, sometimes as very large crystals.
Beryl $Be_3Al_2(SiO_3)_6$	7·5–8	Usually as prismatic crystals with hexagonal cross-section; occasionally massive. Glassy lustre. Colour generally pale greenish; also bluish, greyish, or white.	Principal source of beryllium. Commonly found in pegmatites. Some transparent varieties valuable as gem stones; these include *emerald* (green), and *aquamarine* (bluish green).

The following minerals may also occur in this group, but occur more commonly in other groups and are described elsewhere in the table: **muscovite, brucite, halite, calcite, celestite, feldspar** (*var. amazonstone*), **garnet, quartz** (*var. amethyst*), **tourmaline, spinel,** *and* **corundum.**

Introductory Mineral Table (*continued*)

B. Minerals with Non-metallic Lustre (*continued*)

Name and Composition	Hardness	Characteristics	Remarks
3. Colour is pink, red, or reddish brown.			
Erythrite (cobalt bloom) $Co_3As_2O_8.8H_2O$	1·5–2·5	Usually as stains or earthy crusts; sometimes botryoidal. Colour, peach-red to crimson red. Streak, pale red. In closed tube yields water and turns bluish at low heat.	Secondary mineral. Indication of cobalt-bearing minerals, from which it is formed.
Cinnabar HgS	2–2·5	Earthy coatings; crystalline crusts; and massive. Heavy. Colour, bright red. Streak, scarlet. On being heated in open tube, it produces sulphurous fumes and minute globules of mercury.	Principal source of mercury. Resembles some varieties of hematite, but distinguished by heating test.
Monazite Phosphate of the cerium group of rare earths, chiefly, and thorium.	5–5·5	Usually as wedge-shaped crystals or rounded, embedded grains; also as rolled grains in placers. Good cleavage. Brittle. Radioactive. Resinous lustre. Colour commonly clove-brown, reddish or yellowish brown.	A source of rare earths and thorium oxide. Occurs chiefly in pegmatites and placer deposits.
Titanite $CaTiSiO_5$	5–5·5	Commonly as flattened, wedge-shaped crystals; sometimes massive or disseminated. Glassy lustre. Colour generally reddish brown to black.	Common accessory constituent of igneous and metamorphic rocks. Frequently found in metamorphic limestones.
Hematite Fe_2O_3	5·5–6·5	Compact, granular, botryoidal, and earthy masses. Colour, reddish brown to steel-grey. Streak, red to reddish brown.	Most important ore of iron. Streak is quite distinctive. *Specularite* has a micaceous structure with a splendent lustre.
Feldspar Group Silicates of Al,K,Na, and Ca.	6–6·5	Massive, usually cleavable or granular, sometimes lamellar or compact. Two cleavages at, or nearly at, right angles; also less perfect prismatic cleavage. Brittle. Glassy to pearly lustre. Variously coloured but generally reddish, greyish, or white. *Amazonstone* – green.	Abundant rock-forming minerals. Especially common in granites, syenites, gneisses, and pegmatites; also as crystals in porphyries and as a constituent of sands. *Microcline* – commonly reddish; widespread; used in ceramic industry. *Plagioclase* group – usually show fine striations on cleavage surfaces; also play of colours.
Garnet Group Complex silicates of, chiefly, Al, Ca, Mg, Fe, and Mn.	6·5–7·5	Commonly as dodecahedral crystals; also as granular or lamellar masses. Conchoidal fracture. Glassy lustre. Transparent to translucent. Colour commonly red, brown, or black.	Widely distributed minerals. Common as isolated crystals in schists. Also occurs as an accessory constituent in granitic and contact metamorphic rocks. Used as an abrasive.

The following minerals may also occur in this group, but occur more commonly in other groups and are described elsewhere in the table: **gypsum, halite, calcite, dolomite, phlogopite, celestite, apatite, quartz** (*var. rose*), **zircon, spinel,** *and* **corundum.**

Introductory Mineral Table (*continued*)

B. Minerals with Non-metallic Lustre (*continued*)

Name and Composition	Hardness	Characteristics	Remarks
4. Colour is yellow, yellowish brown, or brown.			
Ferrimolybdite (molybdenum stain) $Fe_2(MoO_4).8H_2O$	1·5	Usually as stains or earthy crusts. Colour, canary yellow. Streak, pale yellow.	Secondary mineral, formed by the alteration of molybdenite. Frequently associated with limonite. May be confused with uranium stain (which follows).
Uranium stain Hydrous silico-uranates of Ca, Pb, etc.	to 3	Commonly as stains or dense coatings. Radioactive. Fluoresces. Lustre greasy to dull. Colour usually yellow to orange.	Uranium stain is a general term used to describe the brightly coloured secondary uranium minerals occurring at or near uranium deposits.
Limonite $2Fe_2O_3.3H_2O$	to 5·5	Massive, usually in botryoidal and stalactitic forms with fibrous structure; sometimes earthy. Colour, yellowish to dark brown. Streak, yellowish brown.	Secondary mineral. Common as rust-like stains on weathered rocks. Distinguished from hematite by its streak. *Bog iron ore* occurs in marshy places; porous texture.
Phlogopite (amber mica) Silicate of Al, K and Mg.	2·5–3	Commonly in disseminated flakes; also as crystals, usually hexagonal in outline. Perfect basal cleavage. Thin flakes flexible and elastic. Colour, pale amber to brownish-red.	Found mainly in crystalline limestones and dolomites, and in schists. This association serves to distinguish it from muscovite. May be split easily into thin, transparent flakes.
Siderite $FeCO_3$	3·5–4	Cleavable, compact, and botryoidal masses. Perfect rhombohedral cleavage. Colour, brownish or greyish, dark brownish on weathered surface. Effervesces in hot hydrochloric acid.	Occurs in sedimentary and replacement-type deposits, and in metallic veins. Heavier than calcite or dolomite.
Sphalerite ZnS	3·5–4	Massive. Perfect dodecahedral cleavage. Brilliant to resinous lustre. Colour, yellow, brown, or black. Streak, brownish to light yellow and white.	Most important source of zinc. Usually closely associated with galena.
Scheelite $CaWO_4$	4·5–5	Massive. Quite heavy. Fluoresces. Brilliant lustre. Transparent to translucent. Colour usually yellowish, brownish, or white.	A source of tungsten. Occurs in pegmatites and ore veins associated with granitic rocks; also in contact metamorphic deposits.
Thorite $ThSiO_4$	4·5–5	Usually as small crystals, resembling zircon in form; also as rounded grains. Radioactive. Resinous lustre. Colour, yellowish, orange, brown or black.	Commonly found in pegmatites and associated rocks.
Monazite Phosphate of the cerium group of rare earths, chiefly, and thorium.	5–5·5	Usually as wedge-shaped crystals or rounded, embedded grains; also as rolled grains in placers. Good cleavage. Brittle. Radioactive. Resinous lustre. Colour commonly clove-brown, reddish or yellowish brown.	A source of rare earths and thorium oxide. Occurs chiefly in pegmatites and placer deposits.

continued . . .

Introductory Mineral Table *(continued)*

B. Minerals with Non-metallic Lustre *(continued)*

Name and Composition	Hardness	Characteristics	Remarks
4. Colour is yellow, yellowish brown, or brown. — Cont'd			
Pyrochlore-microlite Group, Niobates and tantalates of Ca, Na,U,Th, and rare earths.	5–5·5	Commonly in rounded grains and octahedral crystals. Radioactive. Glassy, resinous, or waxy lustre. Colour, yellow to brown to black. Streak, yellowish brown.	Found in pegmatites and in contact metamorphic deposits.
Titanite $CaTiSiO_5$	5–5·5	Commonly as flattened, wedge-shaped crystals; sometimes massive or disseminated. Glassy lustre. Colour generally brown to black.	Common accessory constituent of igneous and metamorphic rocks. Frequently found in metamorphic limestones.
Zircon $ZrSiO_4$	7·5	Usually as small, square, elongated crystals with pyramidal ends. Brilliant lustre. Colour, yellowish, greyish, or brownish; sometimes colourless.	Common accessory constituent of igneous rocks, especially granites. Also in pegmatites and sands. *Cyrtolite* contains rare earths.

The following minerals may also occur in this group, but occur more commonly in other groups and are described elsewhere in the table: **talc, gypsum, kaolin, halite, serpentine, calcite, barite, fluorite, apatite, uranothorite, allanite, olivine, spinel,** *and* **corundum.**

5. Colour is greenish black, brownish black, or black.			
Biotite (black mica) Silicate of Al, K, Mg, and Fe.	2·5–3	Flakes and scaly masses. Perfect basal cleavage. Thin flakes flexible and elastic. Splendent lustre. Colour generally black.	Very common rock-forming mineral. Found in igneous and metamorphic rocks, such as granite, syenite, diorite, and gneisses, and in pegmatites. May be split easily into thin black flakes.
Sphalerite ZnS	3·5–4	Massive. Perfect dodecahedral cleavage. Brilliant to resinous lustre. Colour, black, brown, or yellow. Streak, brownish to light yellow and white.	Most important ore of zinc. Usually closely associated with galena.
Thorite $ThSiO_4$	4·5–5	Usually as small crystals, resembling zircon in form; also as rounded grains. Radioactive. Colour, black, brown, orange, or yellowish.	Commonly found in pegmatites and associated rocks.
Uranothorite Hydrous silicate of Th, chiefly, and U.	4·5–5	Elongated, square, prismatic crystals, sometimes very slender; also as rounded masses and grains. Radioactive. Pitchy lustre. Colour, generally black; also reddish or yellowish.	Commonly found in pegmatites and related rocks.
Pyrochlore-microlite Group, Niobates and tantalates of Ca, Na, U,Th, and rare earths.	5–5·5	Commonly in rounded grains and octahedral crystals. Radioactive. Glassy, resinous, or waxy lustre. Colour, black, brown or yellow. Streak yellowish brown.	Found in pegmatites and in contact metamorphic deposits.

continued . . .

Introductory Mineral Table *(continued)*

B. Minerals with Non-metallic Lustre *(continued)*

Name and Composition	Hardness	Characteristics	Remarks
5. Colour is greenish black, brownish black, or black. — Cont'd			
Titanite $CaTiSiO_5$	5–5·5	Commonly as flattened, wedge-shaped crystals; sometimes massive and disseminated. Glassy lustre. Colour generally reddish brown to black.	Common accessory constituent of igneous and metamorphic rocks. Frequently found in metamorphic limestones.
Amphibole Group Silicates of, chiefly, Ca, Mg, and Fe.	5–6	Granular, columnar, and fibrous masses; prismatic crystals, stubby or bladed. Two cleàvages, meeting at angles of 56° and 124°. Colour commonly greenish to black.	Abundant rock-forming minerals. *Hornblende* – usually dark green to black; common constituent of igneous rocks. Cleavage distinguishes amphibole from pyroxene.
Pyroxene Group Silicates of, chiefly, Ca, Mg, and Fe.	5–6	Granular and lamellar masses; prismatic crystals, square or eight-sided. Two cleavages, almost at right angles. Colour commonly greenish to black.	Very common rock-forming minerals. *Augite* – dark green to black; common in dark-coloured igneous rocks. Cleavage distinguishes pyroxene from amphibole.
Allanite Silicate of, chiefly, rare earths Ca, Fe, and Al.	5·5–6	Massive and as embedded grains; platy crystals. Brittle. Radioactive. Pitchy to glassy lustre. Colour, black, but alters readily to brown. Fuses easily to a black magnetic glass.	Found in granitic rocks and pegmatites; also in metamorphic rocks. Sometimes associated with magnetite. Radioactivity is caused chiefly by thorium.
Epidote $HCa_2(AlFe)_3Si_3O_{13}$	6–7	Granular, fibrous, and compact masses; elongated prismatic crystals, deeply striated. Perfect cleavage. Glassy lustre. Colour, pistachio green to greenish black. Fuses easily.	Metamorphic mineral. Common alteration product of feldspars.
Garnet Group Complex silicate of, chiefly, Al, Ca, Mg, Fe, and Mn.	6·5–7·5	Commonly as dodecahedral crystals; also as granular or lamellar masses. Conchoidal fracture. Glassy lustre. Transparent to translucent. Colour commonly brown, red, or black.	Widely distributed minerals. Common as isolated crystals in schists. Also occur as accessory constituents in granitic and contact metamorphic rocks. Used as an abrasive.
Quartz variety *smoky* SiO_2	7	Usually massive. Conchoidal fracture. Glassy lustre. Transparent to opaque. Colour, smoky-brown to brownish black.	Common in granites and pegmatites.
Tourmaline Complex silicate of B and Al with Mg, Fe, etc.	7–7·5	Commonly as prismatic crystals, vertically striated, with triangular cross-section; also massive. Brittle. Colour usually black, sometimes red, blue, or green. Some varieties fuse easily.	Common in pegmatites; also in granites and gneisses. Some varieties used as gem stones.
Spinel $MgAl_2O_4$	8	Octahedral crystals, often twinned; also as granular masses and as embedded grains. Brittle. Transparent to opaque. Glassy lustre. Colour, black, green, brown, or red.	Found mainly as an accessory constituent of basic igneous rocks, and as a metamorphic mineral in schists and crystalline limestones.

The following minerals may also occur in this group, but occur more commonly in other groups and are described elsewhere in the table: **chlorite, serpentine,** *and* **corundum.**

APPENDIX IV

FIELD CLASSIFICATIONS OF COMMON ROCKS

1. Igneous Rocks[1]

<table>
<tr><th rowspan="3">Amount of Quartz</th><th rowspan="3">Proportion of Potash Feldspar to total Feldspar</th><th colspan="4">More than 10% Feldspar</th><th rowspan="3">Less than 10% Feldspar</th><th rowspan="3">Monomineralic[2]
Commonly less than 10% extraneous minerals</th></tr>
<tr><th colspan="4">Composition of Plagioclase</th></tr>
<tr><th>Albite
An_0 — An_{10}</th><th>Oligoclase
An_{10} — An_{30}</th><th>Andesine
An_{30} — An_{50}</th><th>Labradorite, etc.
An_{50} — An_{100}</th></tr>
<tr><td rowspan="3">More than 10% Quartz</td><td>More than 2/3</td><td colspan="4">GRANITE
RHYOLITE</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>1/3-2/3</td><td></td><td colspan="3">QUARTZ MONZONITE
QUARTZ LATITE</td></tr>
<tr><td>Less than 1/3</td><td>ALBITE GRANITE
RHYOLITE</td><td>GRANODIORITE
QUARTZ LATITE</td><td>QUARTZ DIORITE
DACITE</td><td>QUARTZ GABBRO
QUARTZ BASALT</td></tr>
<tr><td rowspan="3">Less than 10% Quartz</td><td>More than 2/3</td><td colspan="4">SYENITE
TRACHYTE</td><td rowspan="3">PERKNITE
PERIDOTITE
(More than 5% Olivine)</td><td rowspan="3">PYROXENITE
HORNBLENDITE
DUNITE
ANORTHOSITE</td></tr>
<tr><td>1/3-2/3</td><td></td><td colspan="3">MONZONITE
LATITE</td></tr>
<tr><td>Less than 1/3</td><td>ALBITE SYENITE
TRACHYTE</td><td>SYENODIORITE
LATITE</td><td>DIORITE
ANDESITE</td><td>GABBRO
BASALT</td></tr>
</table>

COMMON CONTENT OF DARK MINERALS

0 — 10	10 — 40	40 — 70	70 — 100

GENERAL TERMS FOR FINE-GRAINED ROCKS

FELSITE (*light coloured on fresh surface*) TRAP (*dark coloured on fresh surface*)

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[1] Table from I. C. Brown and other officers of the Geological Survey of Canada.

[2] Rocks consisting almost entirely of a single mineral.

Note: Names of coarser-grained (plutonic) rocks are in heavier type, and those of finer-grained rocks (dyke and volcanic rocks) are in lighter type (slanting).

2. Sedimentary Rocks*

Origin	Unconsolidated	Consolidated	
Mechanical	Gravel	Conglomerates	Gravels consist of fragments of rocks and minerals of various kinds and sizes. They are more or less rounded. A conglomerate consists of such an assemblage cemented by deposition of minerals between fragments. Breccia has no rounded pebbles but angular fragments.
	Sand	Sandstone	Sands are incoherent masses made up of more or less well rounded grains of minerals or rocks. The grains are usually only a few millimetres in diameter. Ordinarily quartz is the most abundant mineral but the term sand has reference to the grain size, not to the kind of grain. A sandstone is a sand cemented by deposition of minerals around the grains. The cementing mineral may be quartz, calcite, iron oxide, or even bituminous material.
	Clay	Shale	Clay is made up of tiny flakes of kaolin and similar minerals. When it becomes consolidated the rock is a shale.
	Loess		Consists of wind-blown dust.
	Till		Unsorted glacial material.
Chemical		Salt; gypsum	Formed by evaporation of water of salt lakes.
		Chert, some limestones and dolomites	Formed by loss of carbon dioxide (CO_2) from solutions containing the bicarbonate. Chert is probably formed by coagulation of colloidal silica.
		Bog iron	Formed by coagulation of colloidal solutions of iron. Iron secreting bacteria may be instrumental.
Organic		Most limestones	Formed or composed of shells, or fragments of shells, chalk, marl, etc.

* Tables from Mining Textbooklet No. 1, Canadian Legion Educational Services.

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3. Metamorphic Rocks*

A. From Sediments

Original rocks	Affected by	Physical character	Metamorphic rock
Quartz sands and sandstones	heat or pressure and solutions;	cemented	quartzite
	differential pressures	schistose	quartz schist
Impure sands and sandstones	heat or pressure and solutions;	cemented	arkose
	differential stress	schistose or gneissic	paragneiss
Mud and shale	heat or pressure and solutions; differential stress	dense appearance and fine grained	staurolite, chloritoid, and andalusite rocks; slate, phyllite, and chlorite schist
Limestone	all agents	recrystallized	crystalline limestone

B. From Igneous Rocks

Granite, syenite, diorite, gabbro	differential stress	foliated	orthogneiss
Rhyolite and trachyte	differential stress	foliated	quartz-sericite schists, and sericite schists
Andesite and basalt	uniform pressure and solutions;	massive	greenstone
	differential stress	schistose	chlorite schist, talc schist, actinolite schist, hornblende schist

*Tables from Mining Textbooklet No. 1, Canadian Legion Educational Services.

APPENDIX V

ADDRESSES

Provincial Departments of Mines.

British Columbia: Department of Mines, Victoria, B.C.

Alberta: Department of Lands and Mines, Edmonton, Alta.

Saskatchewan: Department of Mineral Resources, Regina, Sask.

Manitoba: Mines Branch, Department of Mines and Natural Resources, Winnipeg, Man.

Ontario: Department of Mines, Toronto, Ont.

Quebec: Department of Mines, Quebec, Que.

New Brunswick: Department of Lands and Mines, Fredericton, N.B.

Nova Scotia: Department of Mines, Halifax, N.S.

Prince Edward Island: Deputy Provincial Secretary, Provincial Government Offices, Charlottetown, P.E.I.

Newfoundland: Department of Mines and Resources, St. John's, Nfld.

Northwest Territories and Yukon.

Lands Division, Northern Administration and Lands Branch, Department of Northern Affairs and National Resources, 238 Sparks Street, Ottawa.

Department of Mines and Technical Surveys.

Topographic maps: The Director, Surveys and Mapping Branch, Department of Mines and Technical Surveys, Ottawa.

Air Photographs: The Director, Surveys and Mapping Branch, Department of Mines and Technical Surveys, Ottawa: attention: National Air Photo Library.

Treatment tests: The Director, Mines Branch, Department of Mines and Technical Surveys, 568 Booth Street, Ottawa.

Geological publications, radiometric tests, etc.: The Director, Geological Survey of Canada, Department of Mines and Technical Surveys, Ottawa.

Branch Offices, Geological Survey of Canada:

739 West Hastings Street, Vancouver 1, B.C.
406 Customs Building, Calgary, Alta.
Whitehorse, Y.T.
Yellowknife, N.W.T.

Atomic Energy Control Board.

The Secretary, Atomic Energy Control Board, P.O. Box 1046, Ottawa, Ont.

Entry to Canada.

Immigration Branch, Department of Citizenship and Immigration, Ottawa, Ont.

Customs.

Customs and Excise Division, Department of National Revenue, Ottawa, Ont.

Travel.

Canadian Government Travel Bureau, Department of Northern Affairs and National Resources, Ottawa, Ont.

Addresses of Several Periodicals Cited in References

Bulletin, Canadian Institute of Mining and Metallurgy: 911 Drummond Building, Montreal, Que.

Canadian Mining Journal: Gardenvale, Que.

Economic Geology: Economic Geology Publishing Co., Urbana, Illinois.

Engineering and Mining Journal: 330 West 42nd Street, New York 36, N.Y.

Geophysics: 1138 East 37th Street, P.O. Box 7248, Tulsa 18, Oklahoma.

Mining Engineering: 29 West 39th Street, New York 18, N.Y.

Northern Miner: 122 Richmond Street, Toronto, Ont.

Precambrian: 365 Bannatyne Avenue, Winnipeg 2, Man.

Western Miner: 505 Metropolitan Building, Vancouver 1, B.C.

APPENDIX VI

TRACING FLOAT IN GLACIAL DRIFT

The methods and problems of tracing 'float' in glacial drift, although of importance in Canada, are in many respects distinct from other kinds of prospecting, therefore the subject is included as an appendix. The brief discussion that follows is intended to acquaint general prospectors with principles that they may be able to use if the need arises, and to remind geologists and those who sponsor prospecting enterprises of the possibilities for specialized work in this phase of prospecting. The subject is only touched upon here because it is largely a specialized field.

For generations, prospectors skilled in the search for minerals have followed the practice of tracing float found in slides and talus slopes, in the beds of streams, as fragments brought to the surface by frost action or soil creep from an underlying deposit, or lodged in the roots of an overturned tree. Float that has been transported longer distances by glaciers and has been incorporated later in glacial gravels or other forms of glacial drift poses more complicated problems. Some of these can be solved fairly readily by prospectors who have patience and keen observation, and some require a special knowledge of glacial geology to solve; others cannot be solved because the float is too widely dispersed. Several mineral deposits have been found in Canada as a result of tracing glacial float, including a deposit of iron ore in Lake Superior region, of fluorite near Madoc, Ont., of corundum near Bancroft, Ont., and gold-bearing quartz veins in Nova Scotia. This kind of prospecting is practised extensively in Finland and Sweden where conditions are comparable to those of the Canadian Shield and where refined techniques have resulted in the discovery of several important deposits. Tracing of float may lead directly to an outcropping deposit, but more frequently it would be expected to indicate only a general area in which detailed geological, geophysical, or geochemical work might be successful in guiding diamond drilling.

The manner in which vast glaciers and sheets of ice accumulated, advanced, and melted away over most parts of Canada, several times during the Pleistocene Period or "Ice Age", is outlined in Chapter II. Fragments of rock of various sizes, including occasional pieces of float from mineral deposits, were frozen into those glaciers and ice sheets, carried forward with the advancing ice, and finally deposited in moraines and other forms of drift when the ice melted. Most of the stones and boulders in glacial drift are of fairly local origin, and, particularly, many ore minerals are too soft or soluble to withstand travelling great distances. In Canada, float containing ore minerals, found within or near the boundaries of the Canadian Shield or other geological provinces favourable for the occurrence of mineral deposits, may repay attempts at tracing, particularly if the float is fairly abundant. On the other hand it would probably be difficult or impossible to trace boulders of Precambrian rock containing ore minerals, found on the

Plains far from the Canadian Shield. 'Stone counts' of the kinds of rocks and minerals found within sample areas of drift may indicate whether it is feasible to try to trace float containing a particular mineral or favourable rock.

The chances of tracing float to its origin are probably best in the higher parts of the Cordilleran region, where most glaciers moved down valleys. Some float may have been transported beyond its source valley by ice that overrode the valleys, but this is probably not so in most cases. In most other parts of Canada the movement of ice was less restricted and the tracing of float may be more difficult, particularly as it may have been moved in one direction by one stage of glaciation and in a different direction by a later stage.

Float may be widely scattered and offer little chance of being traced; it may be strung out in a fairly straight line to form a 'boulder train' that can be traced back to the vicinity of its origin; or it may occur as a 'fan' having its apex at the place of origin. Fans may be traced by plotting occurrences of float on a map and drawing lines through the outermost occurrences, whereupon the lines should intersect near the place of origin.

Evidence regarding the direction of ice movement in a particular locality can be had from published maps, particularly the Glacial Map of North America, listed below, or by observing in the field such phenomena as striations, flutings, and drumlins and other streamlined topographical features. Striations are scratches on outcrops caused by small sharp rock fragments frozen in the ice; flutings are larger parallel troughs gouged in the surface of outcrops; and drumlins are oval-shaped hills of glacial drift that are oriented in the direction of ice movement and that may be observed on air photographs. Striations, flutings, and drumlins usually indicate only one of two possible directions of ice movement and it would be difficult for most prospectors who are not well versed in the subject to determine which of the two it actually was. In most instances they would have to test both directions or obtain information from a published map. Those who make a special study can obtain evidence from such phenomena as stoss-and-lee, crag-and-tail, nail-head striations, friction cracks or crescentic gouges, end moraines, washboard moraines, and till-fabric analysis. Descriptions of these features are found in some of the publications listed below and in other works on glacial geology.

Suggestions for Additional Reading

Flint, R. F.: Glacial Geology and the Pleistocene Epoch; Wiley, 1947, (particularly pages 102-132).

Grip, E.: Tracing of Glacial Boulders as an Aid to Ore Prospecting in Sweden; *Econ. Geol.* vol. 48, No. 8, 1953, pp. 715-725.

Krumbein, W. C.: Preferred Orientation of Pebbles in Sedimentary Deposits; *J. Geol.* vol. 47, pp. 673-699, 1939.

Hyyppa, E.: Tracing the Source of the Pyrite Stones from Vihanti on the Basis of Glacial Geology; *Bull. Comm. Geol. Finlande,* No. 142, vol. 21, pp. 97-122, 1948. (In English.)

Dreimanis, A.: Studies of Friction Cracks Along the Shores of Cirrus Lake and Kosakokwoy Lake, Ontario; *Am. J. Sci.*, vol. 251, pp. 769-783, 1953.

Sauramo, M.: Tracing of Glacial Boulders and its Application in Prospecting; *Bull. Comm. Geol. Finlande,* No. 67, 1924. (In English.)

Glacial Map of North America; *Geol. Soc. Amer., Special Paper* 60, 1945. Price $2.

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