CANADA
DEPARTMENT OF MINES
HON. W. A. GORDON, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY
W. H. COLLINS, DIRECTOR

ECONOMIC GEOLOGY SERIES
No. 10

Gold Occurrences of Canada

Summary Account

BY
H. C. Cooke and W. A. Johnston

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1932

Price, 20 cents

No. 2309

CANADA
DEPARTMENT OF MINES
HON. W. A. GORDON, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

GEOLOGICAL SURVEY
W. H. COLLINS, DIRECTOR

ECONOMIC GEOLOGY SERIES
No. 10

Gold Occurrences of Canada

Summary Account

BY
H. C. Cooke and W. A. Johnston

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1932

No. 2309

CONTENTS

PREFACE

A detailed report on gold in Canada was commenced several years ago, but cannot be completed and published for several years to come, owing to the great extent and complexity of the subject. However, the upset of general business conditions in 1929, discouraging to almost all other industries, has so stimulated prospecting and mining for gold that an immediate demand has arisen for whatever information is obtainable. To meet this demand the large report has been summarized in the present volume.

This summary is designed, so far as its size and rapid preparation admit, to serve two main purposes: to afford prospectors whatever guidance geology can give in the intelligent search for new supplies of gold; and to afford those interested in gold production knowledge of the history, present situation, and opportunities of the industry in this country.

W. H. COLLINS,

Director.

March 18, 1932

PART I

Canadian Lode Gold Areas

By H. C. Cooke

INTRODUCTION

Gold is an important part of the national wealth of Canada. In value it holds second place among our mineral products, being exceeded only by coal. As a world producer Canada ranked third in 1929: South Africa was first with a production of 10,412,326 fine ounces, and United States second with 2,056,629 fine ounces. The Canadian output rose from 1,928,592 fine ounces in 1929 to 2,107,073 fine ounces in 1930.

The gold production for 1930 was worth $43,557,063, of which $35,903,978 came from Ontario, and $3,379,638 from British Columbia. Quebec produced $2,930,088, chiefly from the Noranda ores; Manitoba $582,884; and the Yukon placers $734,181. Nova Scotia production decreased to $26,295. The British Columbia output was almost entirely from lode sources; the value of the placer gold was only $153,964.

Ontario production came mainly from the Porcupine and Kirkland Lake fields. In 1930 Porcupine produced gold to the value of $17,758,738, and Kirkland Lake $17,188,692. In 1928 Porcupine produced more than $20,000,000, and Kirkland Lake but slightly over $12,000,000. It seems probable, therefore, that the Kirkland Lake field will soon become the premier producing field of the Dominion. It is interesting to note that in 1930 gold to the value of $956,548 was produced in Ontario from sources other than these two fields, whereas in 1929 the corresponding figure was only $207,359. Such a large increase possibly indicates the commencement of development of new sources of supply.

The total gold production, by provinces, up to the end of 1930, is as follows:

Nova Scotia, 1862-1930	$ 19,105,156
Quebec	6,915,600
Ontario, 1867-1930	350,527,302
Manitoba	1,668,299
Alberta	314,710
British Columbia, 1858-1930	218,845,516
Yukon Territory, 1886-1930	184,598,213

The figures above are probably somewhat too low in the case of Quebec and British Columbia. The placers of Chaudière river in Quebec were estimated by observers to have produced between $2,000,000 and $3,000,000 worth of gold, but no government records appear to have been kept, and no such amounts are included above. Similarly, exact records for the placer gold recovered in British Columbia are very hard to obtain, because placer fields are mostly remote and except in a few instances are operated by small numbers of men with no fixed abode. It is, therefore, reasonably certain that the actual recoveries of placer gold are somewhat higher than the known figures.

GEOLOGICAL TERMS AND PHRASES

Geological studies have proved that the rocks of the earth's surface are divided into two main classes, *igneous* and *sedimentary*.

Igneous rocks are those that have solidified from a molten condition. They originated in the hot, inner parts of the earth's body, and rose to their present positions through openings of some sort. Those that reached the earth's surface are called *volcanic* rocks, and those that did not reach the surface but solidified at some distance below it are termed *plutonic*. The volcanic rocks are named according to the percentage of silica they contain. Those with the highest amounts of silica are the rhyolites; then with decreasing proportions of silica we have dacite, trachyte, andesite, and basalt. In some volcanoes explosions took place which hurled into the air great quantities of lava in the form of boulders, pebbles, and dust. When such fragmental material settled it formed beds of volcanic ash or tuff. Coarse, bouldery tuffs are often termed agglomerates.

The plutonic rocks are also classified according to their composition. Those highest in silica are termed granite; then in order of decreasing silica content we have granodiorite, syenite, diorite, gabbro or diabase, and peridotite. The granites contain 60 to 70 per cent of silica, the peridotites about 40 per cent. Plutonic rocks are also classified according to the size and shape of the masses. Huge, irregular bodies are called batholiths and smaller bodies with at least rudely circular outlines are stocks or plugs. Long, narrow bodies, filling more or less vertical cracks in the earth's crust, are dykes; similarly shaped bodies that lie almost flat, particularly if they parallel the bedding of surrounding sediments, are sills.

The sedimentary rocks are consolidated gravels, sands, and muds. These materials were laid down mainly on lake- and sea-bottoms in rather thin, flat beds. As other beds formed on top of them, the loose materials were compressed, and the separate grains became cemented together by the silica or carbonate of lime contained in the water that bathed them. Thus they became rock, and formed conglomerate, sandstone, shale, or limestone according as the original material was gravel, sand, clay, or limy mud mixed with shells.

After the rocks, either igneous or sedimentary, were formed many things might happen to them. Movements of the earth's body lifted new-formed sediments above sea-level, and often, after a longer or shorter time, sank them again. Most of the surfaces of all our continents have been at one time or another below sea-level, and some parts very frequently. In these movements the rocks were cracked, forming joints. More extreme stresses frequently broke the rocks, and forced one part of the earth's crust to move past the adjoining part, perhaps only a few inches or feet, but in some cases for miles. Such fractures are termed faults. Intense pressures from the sides caused the rocks, though hard and brittle, to bend like rubber, forming folds. That part of a fold in which the beds are convex upward is an anticline; that part where the beds are concave upward is a syncline. Where pressure, or pressure and heat, were extreme, the original minerals of the rock were recrystallized to other minerals to form a metamorphic rock, such as a schist, slate, or gneiss. In many instances recrystallization of this sort occurred locally along the plane of a strong fault and the band of schist thus formed is called a shear zone.

In any quarry or cutting in sedimentary rocks beds may be observed lying one above the other; and as these beds are merely consolidated sands, muds, and so on, it is obvious that any given bed must have been laid down later than one that lies below it. Only a comparatively few beds can be seen in any one cutting or outcrop; but by carefully tracing recognizable beds through other neighbouring outcrops, beds that do not appear in the first cutting can be found, and proved to lie either above or below the beds in that cutting. This is called determining the succession of the sedimentary beds, i.e., the order in which they succeed one another; and the task of determining the correct succession of the beds over the earth's surface is one that has occupied the attention of geologists for about one hundred and forty years. Before that time geologists had no means of making certain that the bed of sandstone or shale studied in one cutting was the same as that studied in the next, half a mile away. About 1794, however, William Smith, a famous British geologist, made the suggestion, since fully borne out by study, that the fossil remains of plants and animals found in sedimentary beds were characteristic of these beds; i.e., that one bed would everywhere contain a certain fossil assemblage, but that an earlier or later bed would contain a different fossil assemblage. This discovery gave geologists a means of following any given bed or series of beds from outcrop to outcrop, and the determination of the sedimentary succession has since gone rapidly forward.

This work has proved that the sediments on the earth are divisible into many thousands of beds, although only a limited number occur in any one locality. It has also proved that the deposition of beds was not a continuous process, but that after a number were laid down, deposition would be interrupted by some movement of the earth's body, as already mentioned. This movement might raise a given area above the sea, so that no sediments could be formed on it for a longer or shorter period; or it might fault or fold the rocks previously formed. It was further discovered that the larger movements extended over wide areas, over a great part of a continent, and in some instances over two or more continents.

We may think of the sedimentary rocks, with their fossil records of life, as a great volume from which the earth's story can be read. The smallest subdivision of a volume is the individual line; that of the sedimentary rocks is the individual bed. A larger or smaller group of lines forms a paragraph, which is separated by a brief interval from the next. Similarly, a larger or smaller number of beds group themselves naturally into what is termed a formation which exhibits some natural separation from formations above and below. Paragraphs are gathered into chapters, separated from one another in a more pronounced manner than the paragraphs; in the same way, formations fall naturally into larger units, the systems; and the systems are commonly separated, one from the other, by moderately long and large movements of the earth's body. Chapters are grouped into books, between which there is commonly a considerable gap in continuity; and in exactly the same way the systems form assemblages separated by intervals of great disturbance such as mountain building. These greater subdivisions of earth history are known as geologic eras.

Geologic time is divided into five such eras, and each of these again into several periods, which is the name applied to the time necessary for deposition of a system of rocks. The various eras and periods are shown in the following table in order of succession, the oldest at the bottom. Specialists in the subject carry subdivision much farther, but this is unnecessary here.

GEOLOGIC TIME TABLE

Era	Period or System	
Quaternary or Recent		
Tertiary	Pliocene	
	Miocene	
	Oligocene	
	Eocene	
Mesozoic	Cretaceous	
	Jurassic	
	Triassic	
Palæozoic	Permian	
	Pennsylvanian	Carboniferous
	Mississippian	
	Devonian	
	Silurian	
	Ordovician	
	Cambrian	
Precambrian		

Because fossils are lacking in the Precambrian, it is difficult to determine the succession of strata when dealing with large districts, and, therefore, no wholly satisfactory method of subdividing Precambrian time has yet been devised. However, one general subdivision is almost universally recognized between groups of Late Precambrian age, and other groups of Early Precambrian age. In Ontario and western Quebec the Early Precambrian strata consist very largely of volcanic rocks, and it has been customary to refer to these collectively as the Keewatin series. Groups of Early Precambrian sediments which in various districts overlie the Keewatin with some unconformity are often spoken of as the Timiskaming series. The Keewatin rocks and the overlying Timiskaming beds are highly folded in all known localities, and invaded by granites and other plutonic rocks, the whole forming a complex much older than the Late Precambrian. The latter consist of a number of groups which in Ontario pass under the names of Huronian, Animikie, and Keweenawan. The Huronian strata are the oldest of these groups and the Keweenawan the youngest.

To some readers it may seem an economic waste, a useless expenditure of energy and money, to absorb the lifetime labour of hundreds of men merely to establish the succession of the sedimentary rocks. This, however, is not the case. Isolated individuals of private means might have taken up this study for no other reason than to satisfy a scientific curiosity; but few geologists have been thus economically independent. A compelling economic reason must, therefore, lie behind the expenditure of thousands and hundreds of thousands of dollars for geological work, by governments, universities, private companies, and individuals; and this reason is found in the intimate connexion that exists between the rocks and the mineral deposits in them. The more we learn of mineral deposits, the clearer it becomes that they have definite and restricted age relationships, are limited or localized by structural features such as faults or folds, and in very many cases are so closely related to some given rock that it is useless to search for them very far from that rock. Relatively insignificant expenditures on geological work, therefore, save immense sums that would otherwise be wasted in unprofitable mining or prospecting operations, and for this reason governments and individuals gladly pay for geological work.

All Canadian lode gold deposits are found in rocks of two eras, the Precambrian and the Mesozoic, and all the Precambrian deposits, except some half dozen of minor importance, occur in rocks of the Early Precambrian era. A possibility exists that some may yet be found with certain Devonian rocks of eastern Quebec and New Brunswick. This knowledge enables the prospector to remove vast areas from the field of examination and concentrate on areas where discovery is possible.

Lode gold deposits are of two general types, fissure veins and replacement deposits. A fissure vein, as the name implies, is any fissure in the rock that had been filled with vein materials. Closely allied to the fissure veins are the shear-zone deposits, which consist of numerous rather narrow veins in the schist of a shear zone, so that the deposit as a whole consists of veins alternating with thin layers of schist.

It is obvious that solid materials filling narrow cracks must have been introduced either as liquids or gases; and there are many facts indicating that most of them entered as liquids, or solutions, of which water was a large constituent. These are commonly spoken of as the vein-forming solutions and their sources have been the subject of much study and speculation. The commonly accepted view is that they originally were constituents of molten igneous rocks; and when these cooled, and the rock minerals crystallized from them, the more liquid constituents were set free and escaped. One of the more striking proofs of this conception is found in the vast clouds of steam that rise from active volcanoes, and the deposits of sulphur, iron, and minerals of various kinds formed in volcanic craters by the escaping gases.

In replacement deposits the vein-forming solutions have not merely filled a fissure with vein matter, but have penetrated the surrounding country rock and replaced the original rock minerals with new minerals, partly by recrystallization, but mainly by addition of the new materials carried by the solutions. The reasons that some solutions merely fill fissures whereas others penetrate the pores of the rock and react with the rock minerals are not yet thoroughly understood; possibly the first type of solution is more glutinous, the second more aqueous, with a greater power of penetration. Probably, also, the second type of solution contained chemically active constituents which were absent from the first type. There seems to have been little difference between the temperatures of the two types.

Whatever the cause, the result has been to convert large bodies of rock into masses of vein materials mixed with more or less of unaltered rock material. Where the rock was greatly sheared or broken in the beginning, very large bodies of ore may have been formed. Nearly all the large gold mines of Canada and most of the large mines of other metals were formed in this way.

Most Canadian lode gold deposits have been formed at moderately high temperatures, between 300 and 500 degrees centigrade or 600 and 900 degrees Fahrenheit. The temperature of formation of mineral deposits is determined, roughly, by the character of the minerals present in them. By the study of large numbers of mineral deposits, of the deposits of hot springs, and of the emanations from volcanoes in cases where temperatures can be directly determined, by determining the minerals formed in smelter slags, and by numerous laboratory experiments, a great deal of information has accumulated concerning the conditions of heat, pressure, and moisture required for the formation of most minerals. Certain of them form only within rather narrow limits, and these are particularly valuable evidence of the conditions prevailing when they crystallized. Such minerals are known as high-temperature minerals, low-temperature minerals, contact-metamorphic minerals, and so on.

GEOLOGICAL PROVINCES

The great part of the gold of Canada comes from the Canadian Shield, an immense area of Precambrian rocks extending from the Labrador coast westward almost to the mouth of Mackenzie river. The area of the Shield is roughly 1,825,000 square miles, almost half of all Canada. It includes almost all of the province of Quebec north of St. Lawrence river, two-thirds or more of the province of Ontario, the greater part of Manitoba, parts of northern Saskatchewan and Alberta, and most of the Northwest Territories. From the Shield has come all the gold produced in Ontario and Manitoba, and most of that produced in Quebec. About 45 per cent of the total Canadian output of gold has been derived from the Shield, and about 90 per cent of the present annual production is from that source. These figures merely emphasize what has been recognized for many years, that the Precambrian Shield is not only our present greatest reservoir of the precious metal, but in all probability the most fruitful region for discovery of new deposits.

The deposits of the Shield are of two main types, namely, quartz veins, from which most of the gold up to the present has been won, and sulphide deposits, which produce a small but rapidly increasing proportion. The quartz veins may be further subdivided according to composition and origin, and the economic worth of the different types roughly estimated. This, however, will be considered on a later page.

The second great source of gold in Canada has been the western or Cordilleran section, comprising British Columbia and Yukon territory. The first gold to be mined in Canada was the placer of British Columbia, in the year 1858; and mining operations have been uninterrupted ever since. Altogether, up to the end of 1930, the Cordilleran region has produced more than $403,000,000 in gold, or approximately 51 per cent of Canada's total production. Of this amount, however, some $263,000,000 has been placer gold, and hence does not properly fall within the province of this paper. The production from the placers has greatly fallen off in recent years, until now it is less than $1,000,000 annually from the whole of British Columbia and the Yukon. The lode deposits, the first of which began production in 1893, have produced from $3,000,000 to

$5,500,000 annually since 1900. A few of them are simple quartz veins, but the majority are complex sulphide ores. Most of them are of Mesozoic age, and are genetically related to the great mass of granodiorite known as the Coast Range batholith.

The third principal area in which gold deposits occur is the Acadian region, which includes the mountainous district extending through the Eastern Townships of Quebec into Gaspe, New Brunswick, and Nova Scotia. It is a region of folded rocks, which was mountainous in Ordovician and Devonian times. Up to the present, gold has been found in only two parts of this region, in Nova Scotia and in the Eastern Townships, particularly in the basin of Chaudière river; but there seems no reason that other discoveries may not ultimately be made. In the Chaudière basin placer deposits were discovered and mined extensively between 1875 and 1885, and sporadically since. The source of the placers was undoubtedly the quartz veins of the district, none of which up to the present has been found large enough or rich enough for mining. In Nova Scotia mining commenced as early as 1862 and still continues, although production is now very small. The best years for the Nova Scotia mines were 1896 to 1902, when more than $500,000 worth of gold was the annual output. The gold occurs in quartz veins interbedded with Precambrian quartzites and slates; the veins are widest at the summits of anticlines, narrowing, and in many cases disappearing on the flanks. This peculiar shape has given them the name of saddle reefs. The slates and quartzites are intruded by granites of Devonian age, from which the quartz veins may have originated.

DEPOSITS OF THE CANADIAN SHIELD

SOUTHEASTERN ONTARIO

The first gold discovery in the Canadian Shield was made in southeastern Ontario in 1866, and further prospecting revealed veins throughout Peterborough, Hastings, Addington, and Frontenac counties, a distance of some 70 miles (*See* Figure 3). The rocks are ancient crystalline limestones, sedimentary gneisses, and some squeezed conglomerates, together with granites, diorites, and other igneous rocks of somewhat later age. Some ancient lavas also occur, supposed by some geologists to be equivalents of the Keewatin series farther north. The veins are found in any of these rocks, but seem to be more numerous near the contacts of diorite or granite, though later than both. They consist of quartz, accompanied in places by carbonates, and mineralized most commonly with visible gold and arsenopyrite, although in some deposits pyrite occurs instead. The Deloro deposit, in Hastings county, contained so much arsenopyrite that it was mined for arsenic as well as gold.

Most of the deposits were rather small and of low to medium grade. From the information available, it seems that they also became rapidly leaner with depth. A considerable amount of gold was taken from them, chiefly during the nineties and the first three or four years of the present century, when the costs of extraction were $1.50 to $2 a ton lower than at present. None of the deposits has been worked for many years, and it seems unlikely that any now known will be of great future value unless changes in the technique of mining once more reduce costs.

One or two descriptions of properties in this district may illuminate the preceding generalizations. The deposit at the Cordova mine in lot 20, concession I, Belmont township, was found in 1897. This mine produced gold to the value of $334,781. The rock is a rather coarse-grained gabbro or diorite characterized by gneissic flow textures and rather great changes of composition from place to place. Shear zones cut the gabbro in a general east–west direction, dipping steeply south. Vein material was injected into these zones, forming in some places veins several feet wide, in other places aggregates of stringers separated by schistose country rock. The vein material is quartz associated with a brown-weathering carbonate, probably ankerite. In the wider veins the ankerite is intergrown with the quartz, but the narrower consist almost wholly of ankerite. Pyrite is the chief metallic mineral.

The Deloro mine, in lot 9, concession VIII, Marmora township, operated from 1899 to 1903, and in that time recovered $181,907 in gold and $128,975 in arsenic. The country rock is a dark grey diorite, possibly a basic lava, cut by dykes of hornblende granite. Sheared zones cut through this complex almost due north and south, dipping steeply west. As at the Cordova mine, the veins were found in these sheared zones, and were rarely more than 3 or 4 feet wide. Vein material consisted of quartz associated with an iron-bearing carbonate, mineralized with arsenopyrite and small grains of free gold. The veins have been supposed to be closely related to pegmatite dykes emanating from the cooling granite of the neighbourhood.

WESTERN ONTARIO AND MANITOBA

The next important series of discoveries in the Canadian Shield followed closely the completion of the Canadian Pacific railway in 1886. The deposits were found throughout western Ontario between Port Arthur and the Manitoba boundary, but were most numerous near Lake of the Woods (*See* Figure 1). Intense excitement prevailed and development was carried rapidly forward, though much of it, as in all such cases, was unjustified. The field produced more than $2,000,000 in gold, mainly between 1897 and 1903, although several of the properties have been operated intermittently since that time. None of the mines was carried below a depth of 600 feet.

The veins for the most part occur in the altered lavas—greenstones and schists—of the Keewatin series, in the neighbourhood of granite contacts. Some of them run into, or lie wholly in, the granite. The more productive veins were rarely more than 5 feet wide. Larger veins are apt to be of the lode type, composed of a multitude of quartz stringers separated by bands of country rock. The width of the individual veins varies a great deal, so that an ordinary 5-foot vein will narrow in places to 1 or 2 feet, and swell in others to 7 or 8 feet.

The vein materials consist chiefly of quartz with some carbonate, but include tourmaline in many cases. The principal constituent of value is free gold, which in many instances is so coarse as to give rise to extraordinarily spectacular hand specimens and ore shoots. This condition

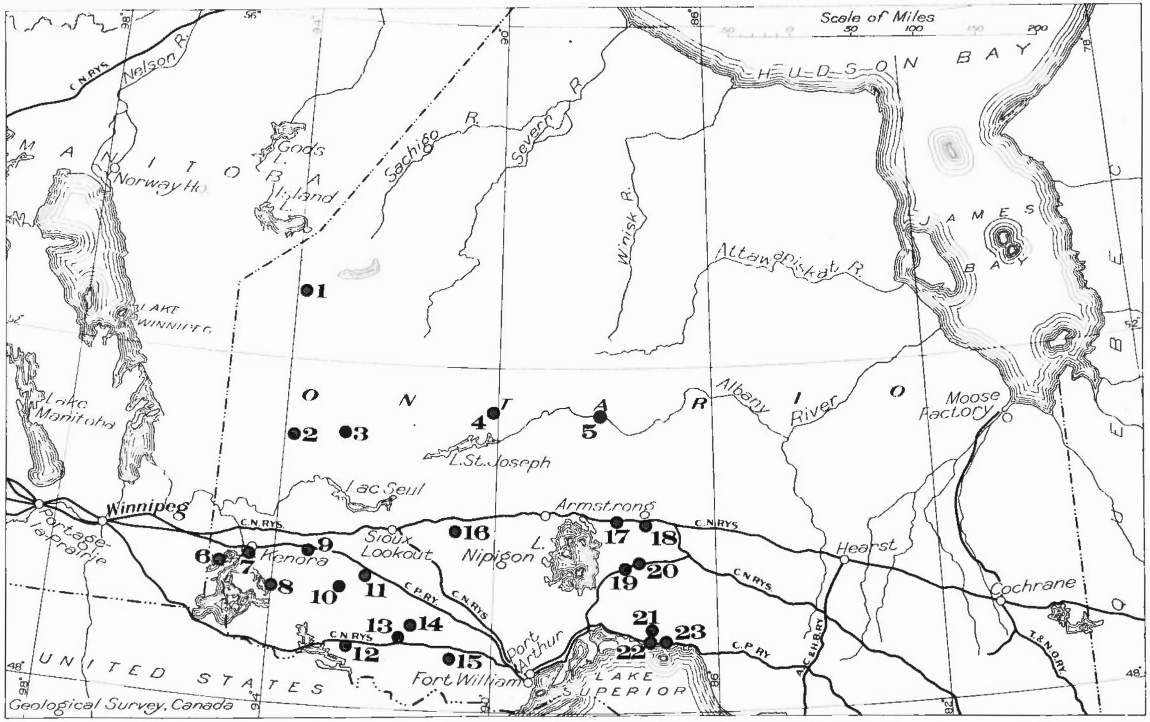


Figure 1. Index map of western Ontario showing location of principal known occurrences of gold. 1, Favourable lake; 2, Red lake; 3, Woman lake; 4, Pickle lake; 5, Fort Hope; 6, Mikado; 7, Sultana; 8, Regina; 9, Eagle lake; 10, Manitou lake; 11, Sakoose; 12, Mine Centre; 13, Harold lake; 14, Hammond Reef; 15, Moss mines; 16, Sturgeon lake (St. Anthony); 17, Tashota; 18, Kowkash; 19, Jellicoe; 20, Kinghorn; 21, Duck lake; 22, Schreiber; 23, Empress.

rendered the mines unusually liable to theft, and large quantities of gold were lost in this way. Tellurides of gold were found in some of the more important mines. The principal sulphide of the veins is pyrite, but arsenopyrite, chalcopyrite, bismuthinite, and molybdenite also occur.

The most important mines of the district were the Mikado, Regina, and Sultana, the first two of which produced about $500,000 each, the last nearly $1,000,000. Attempts have been made from time to time to reopen these and other properties, but the operations lasted for short periods only. Brief descriptions of these properties will perhaps help to define the conditions prevailing throughout the region.

The Sultana mine is on Sultana island, Lake of the Woods, about 7 miles from Kenora (*See* Figure 1). It was opened in 1891 and was worked almost continuously until 1906, attaining a depth of 600 feet. The rocks are Keewatin basalts, schistose in places, and intrusive grey granitoid gneiss. The veins occur in both rocks. For the most part the veins are lode-like, composed of bands and stringers of quartz separated by layers of schist, though in places, over short lengths, they are pure quartz. All were well mineralized, principally with iron pyrites, but also with other sulphides such as pyrrhotite, galena, zinc blende, and molybdenite. The largest vein varied from 20 to 30 feet in width, though in one place in the mine it swelled to 60 feet. Mining operations proved that the pay ore in the main vein formed a sort of irregular chimney extending downward from the second level, with a maximum cross-section of about 60 by 120 feet. It has been stated that all the higher-value sections of the different veins occurred close to the contacts of the granite and Keewatin rocks, so it seems likely that this chimney followed the contact downward. The ore shoot pinched out at about the 7th level and was originally supposed to have been cut off by a flat fault; but more recent work indicates that in all probability no such fault exists, and that further exploration should have been directed toward finding another ore-body below the known one.

The Mikado mine was discovered in 1893 and operated until 1903 and again in 1910-11 and 1924. It lies about 25 miles southwest of the town of Kenora (*See* Figure 1). The rocks are Keewatin basalts intruded by a mass of pinkish granite. With the granite are associated dykes of reddish pegmatite. The principal vein strikes north 30 degrees west, and dips 85 degrees northeast. It varied from 16 inches to 5 feet in width, and where it cut greenstone, it was a series of quartz-calcite stringers separated by bands of rock. Where it entered granite or pegmatite, it widened to a mass of clean quartz with a well-defined foot-wall. The vein material seems to have been rather heavily mineralized with sulphides, including pyrite, chalcopyrite, bismuthinite, molybdenite, and others, accompanied by native gold. Some of the ore shoots yielded highly spectacular specimens of coarse gold. According to the reports, the veins at depth ran out of the granite into greenstone, and the values fell off so greatly that mining became unprofitable.

The geological conditions prevailing at the Regina mine are much like those at the Mikado. The rocks are greenstones intruded by a mass of grey to pink granite. The veins strike about north 70 degrees west, with steep dips. The main vein varies from 2 to 5 feet in width at the surface, but widens in depth to 7 or 8 feet. Vein material was mainly quartz, with some iron-bearing carbonate and pyrite.

These descriptions serve to bring out the intimate connexion existing in Lake of the Woods area between the gold-bearing quartz veins and the granites. The quartz veins are closely related to the pegmatites. It is usually considered that pegmatites are deposited from the aqueous, siliceous residues of a cooling granite magma. After these solutions deposited quartz and feldspar as pegmatite, they still contained silica, carbonate, and metallic constituents, which were on further cooling deposited as veins. Such veins may form either in the granite itself or in the surrounding country rocks, but always near the boundary of the granite. As the granite is a brittle rock, the fissures within it are commonly clean-cut; but on passing out of it they may break up into a series of stringers. Such veins usually carry free gold as their principal constituents of value, though auriferous sulphides may also be present; and the best values commonly follow the granite contact pretty closely, so that the ore-bodies are apt to be chimneys in shape. Veins may show local enrichments where they cross dykes of granite or pegmatite.

Throughout the whole of eastern Manitoba and the adjacent part of Ontario the gold deposits have the same genetic relations as in Lake of the Woods district. In eastern Manitoba the rocks consist of lavas and interbedded sediments, the latter mainly of tuffaceous origin, intruded, successively, by an earlier granite, by various basic and acid dykes and sills, and by a later granite. The gold deposits are quartz veins closely associated with the later granite. Where they lie in the later granite they may contain some, in places much, albite, a large proportion of sulphides, and rather high values in gold. Just outside the later granite they consist wholly of quartz, with a moderate proportion of sulphides and fair gold values. As their distance from the granite increases iron carbonate begins to appear, and gradually displaces quartz entirely, the proportion of sulphides diminishes, and the gold values fall off.

The veins in masses of the later granite are apt to be rather narrow, lenticular, and to occur near and parallel to the edge. Presumably the fissures were formed by shrinkage during cooling, or by slight movements just subsequent to cooling, or by a combination of the two. The veins outside the granite masses may fill fissures of similar shapes and dimensions, formed presumably by the strains set up during injection of the granite, or may fill any other pre-existing fissures. Frequently large shear zones that existed in the older rocks prior to the intrusion of the granite, are filled with the vein materials for distances of a mile or two from the granite contact.

Up to the present time only one property, the Central Manitoba (*See* Figure 2), has yielded any notable amount of gold. It came into production in 1927 and up to 1930 has produced somewhat more than $1,700,000. A mill has recently been completed on a second property, the San Antonio (*See* Figure 2) and production is expected to commence early in 1932.

The same general conditions controlling gold deposition prevail throughout the district to the eastward, extending into Ontario through Red Lake and Woman Lake districts (*See* Figure 1). The rocks of the latter district consist of basic Keewatin lavas intruded by diorites, the whole overlain unconformably by sediments supposedly of Timiskaming age. These rocks were intruded by dykes and masses of quartz porphyry

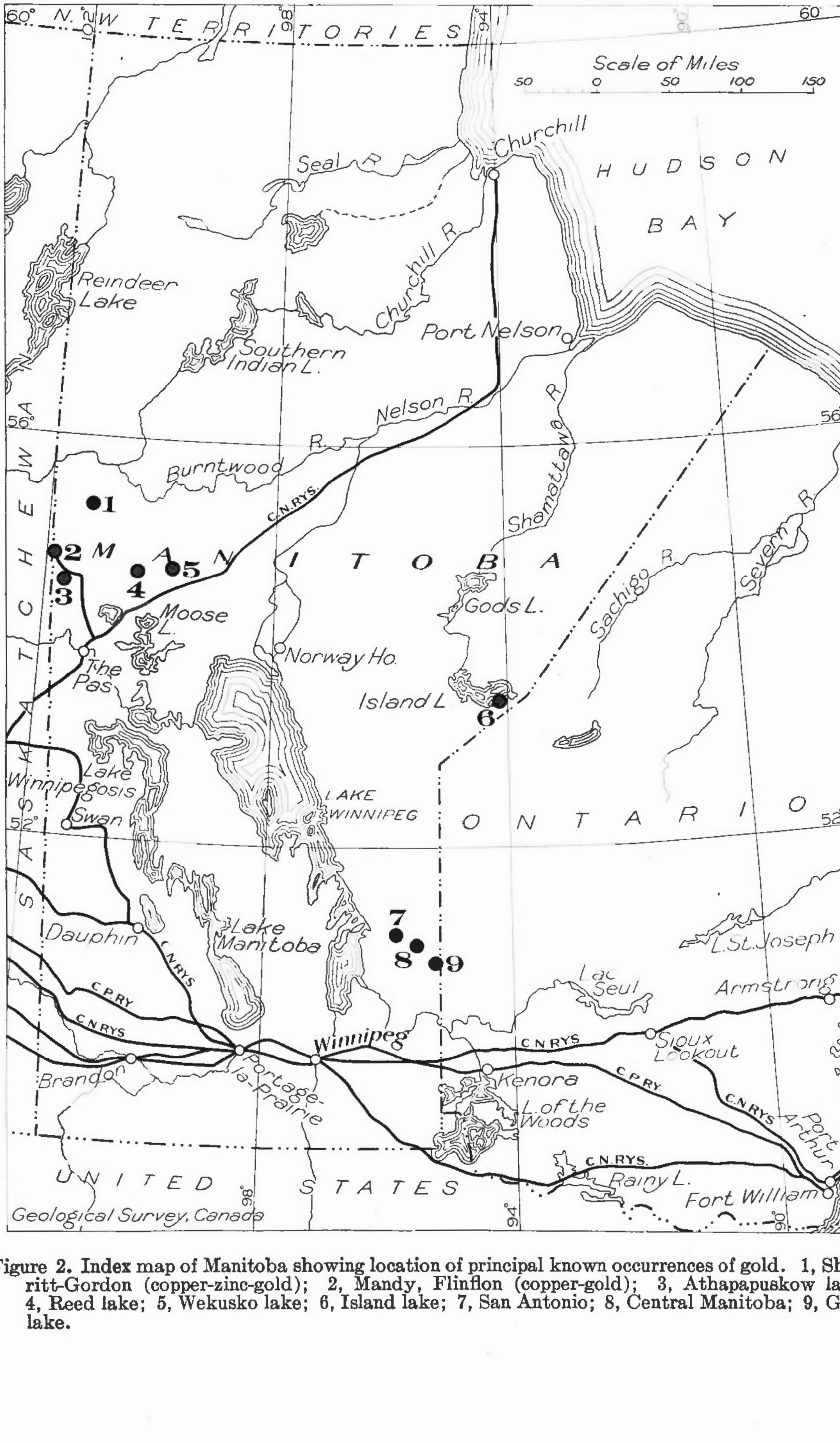


Figure 2. Index map of Manitoba showing location of principal known occurrences of gold. 1, Sherritt-Gordon (copper-zinc-gold); 2, Mandy, Flinflon (copper-gold); 3, Athapapuskow lake; 4, Reed lake; 5, Wekusko lake; 6, Island lake; 7, San Antonio; 8, Central Manitoba; 9, Gem lake.

and by other acidic prophyries, and then by bosses of granite. The veins occur in the vicinity of the granite bosses, in any of the older rocks. At Red lake, particularly, the quartz porphyry has proved an unusually favourable host for ore, because, being brittle, it fractured readily and in many places. The Howie discoveries, among the most promising in the area, consist of a dyke of quartz porphyry 30 to 100 feet wide, which has been so severely fractured as to convert large sections of the dyke into ore. The fissures are lenticular, and rarely more than a foot wide. The vein material filling them was deposited in two stages; during the first, high-temperature quartz with some pyrite was deposited; in the second, a fracturing of this quartz was followed by deposition, in the fractures, of native gold with small quantities of galena, sphalerite, and gold telluride.

The Howie is the only property as yet brought into production in this area. The ore-body is rather low in average grade, but so large that it is possible to treat a big daily tonnage at a profit. Other properties, particularly some of those around Woman lake, contain very spectacular lenses of free gold in quartz, but no attempt to mine them has yet been made.

In addition to the deposits described, a number of others may be briefly mentioned. The St. Anthony mine on Sturgeon lake (*See* Figure 1) has been worked intermittently from 1903 to the present, and has produced an appreciable quantity of gold. The Moss mine (*See* Figure 1), also known as the Huronian, where gold was first discovered in western Ontario, in 1871, has likewise been intermittently operated since 1883. East of lake Nipigon a considerable number of small discoveries have been made in an area extending from Schreiber, Jackfish, and Rossport on the Canadian Pacific railway to Kowkash and Tashota on the Canadian National railway, a distance of about 100 miles. The use of airplanes for prospecting has resulted during the last five or six years in various discoveries throughout Patricia district (*See* Figure 1), at Pickle lake, Fort Hope, Favourable lake, and at Island lake, just within the boundary of Manitoba. To the northwest of this general field lies the northern Manitoba field, northwest of lake Winnipeg, extending from Amisk lake to Wekusko lake (*See* Figure 2).

Throughout this region, more than 300 miles in diameter, similar conditions prevail. The gold deposits lie in the neighbourhood of granite bodies. The greater part of the gold is free; accompanying sulphides, in most of the known properties, carry a minor percentage of the values. Practically all the gold occurs in the quartz; mineralized schist of the vein walls carries little or none. Very rich and spectacular ore shoots occur, but are mostly too small to justify the expense of a mining and milling plant. Many attempts to mine the deposits have been made, but the recorded production figures make it evident that profits, if any, must have been small.

In general, conditions are most favourable for deposition where there are hard, brittle rocks which fracture readily to form open channels through which solutions can easily pass. Softer rocks, that shear to relatively impermeable schists, have not commonly proved favourable to deposition. The favourable brittle rocks have been found to include rhyolites, cherts, iron formation, quartz porphyry, and various basic dykes. In each case, the occurrence of fracturing instead of shearing under stress can be ascribed to the fact that the rocks are composed of fresh minerals. Rocks made up of secondary minerals such as kaolin, sericite, chlorite, and carbonates commonly crush under stress to relatively impermeable schists.

The conditions required for the formation of a large ore deposit in this region, therefore, appear to be: (1) the existence of a fairly large body of brittle rock; (2) shearing movements sufficiently great to shatter this rock over a wide belt; and (3) the proximity of a body of granite from which can come solutions sufficient in quantity to fill the fissures with auriferous quartz. Up to the present only one property, the Howie, has been found, on which all these conditions prevail.

The gold-bearing veins of this region commonly exhibit a characteristic mineral association. Almost everywhere pyrite, chalcopyrite, galena, sphalerite, molybdenite, and iron carbonate accompany the quartz; pyrrhotite, calcite, and magnetite are not uncommon, and tourmaline and bismuthinite are occasionally found. Oxidation of the iron minerals gives rise to rusty zones which are useful as indicators to prospectors, and in places the presence of silicified zones also serves to suggest the neighbourhood of auriferous veins.

Some years ago, in Rice Lake district, eastern Manitoba, the writer studied one of the small, rich ore shoots characteristic of the region, which was being mined in a small way. The equipment consisted of a couple of boilers, a three-drill compressor, and a little mill with three small stamps and an amalgamation plate. The operator who had leased the property stated his returns as about $5,000 a month; his operating expenses could hardly have been more than $1,500. There would seem to be no reason why a similar method of operating should not be applied to many of the small rich veins and ore shoots now known to exist throughout western Ontario and eastern Manitoba. A considerable quantity of gold might thereby be won at a reasonable profit to both owners and operators.

NORTHEASTERN ONTARIO

A belt more than 200 miles wide, within which no deposits of importance have yet been found, separates the northwestern from the northeastern gold field of Ontario. The latter includes the important Porcupine and Kirkland Lake fields and the minor ones of Lightning River, Larder Lake, Boston Creek, Matachewan, West Shiningtree, and Matheson. All these fields occur within an area about 100 miles in diameter (*See* Figure 3).

Porcupine

The Porcupine gold field, discovered in 1909, lies largely in the township of Tisdale. The three principal mines are the Hollinger, McIntyre, and Dome (*See* Figure 4), though a number of others in the district have produced some gold. The rocks include basic altered lavas of Keewatin age, unconformably overlain by conglomerates, greywackes, and slates of the Timiskaming series, all folded into steeply inclined attitudes and intruded by bodies of a grey quartz-feldspar porphyry. The veins of the Hollinger, McIntyre, and nearly all the other producing properties lie in the Keewatin greenstones; those of the Dome mine have been found both in the Keewatin and in a small, tightly infolded syncline of the Timiskaming series.

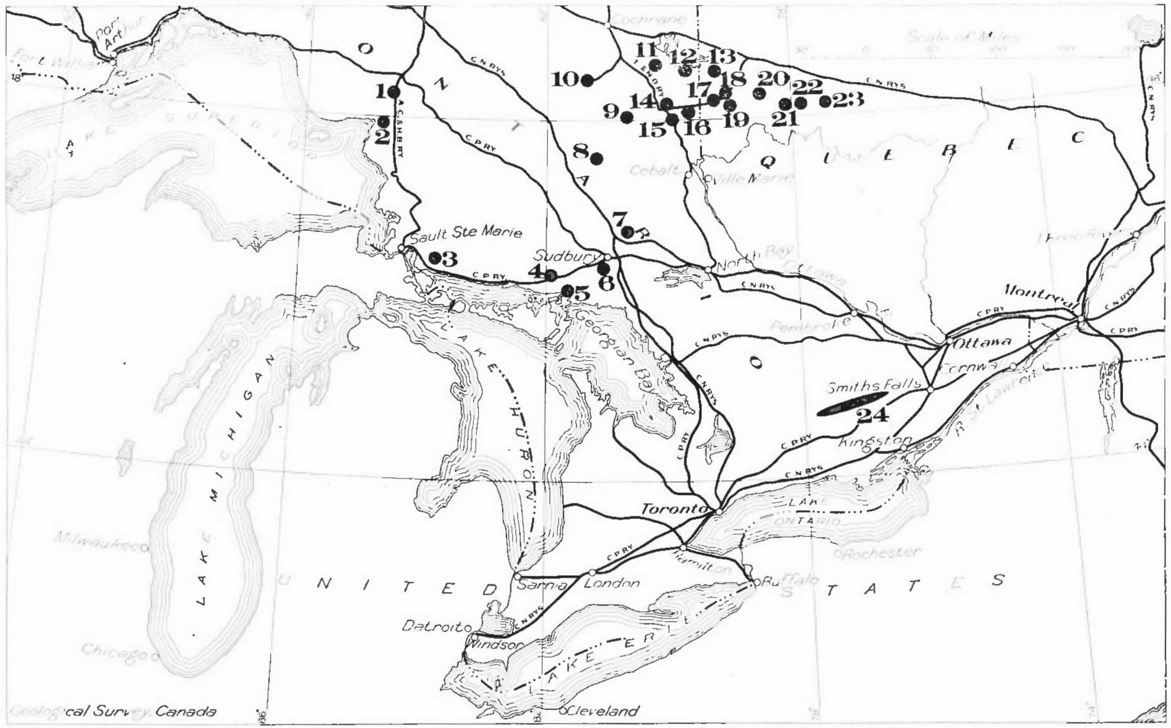


Figure 3. Index map of eastern Ontario and western Quebec showing location of principal known occurrences of gold. 1, Goudreau; 2, Norwalk; 3, Havilah; 4, Shakespeare; 5, Howry creek; 6, Long lake; 7, Crystal; 8, West Shiningtree; 9, Matachewan; 10, Porcupine; 11, Munro; 12, Lightning river; 13, Beattie; 14, Kirkland lake; 15, Boston creek; 16, Larder lake; 17, Arntfield; 18, Rouyn (copper-gold); 19, Granada; 20, O'Brien; 21, Malartic; 22, Siscoe; 23, Pascalis; 24, Southern Ontario.

A most striking feature of the area is the presence of long and wide belts of shear which may be traced for miles in a general east-west direction. They have very steep, almost vertical dips, some northward, others southward, and they cut indiscriminately through lavas, sediments, and porphyries. The rocks in these sheared zones are commonly quite schistose, the amount of schistosity depending on the hardness and massiveness of the original rock. Thus the relatively soft sediments are rendered highly schistose over wide belts, whereas more massive lavas are less schistose and the schistose belts in them are narrower. Where the lavas are particularly hard and massive the sheared zone may become very narrow or may grade into a fracture zone very difficult to recognize or trace. These features make it evident that the sheared zones are the result of differential stress acting on the rocks at some period after the folding and the intrusion of the porphyry masses. The economic importance of the sheared zones is that they contain practically all the ore-bodies of the district, so that the shearing was evidently one pre-requisite of ore formation. Two of the three large mines, the Hollinger and McIntyre, are located on a wide zone of shear formed by the coalescence of several narrower belts.

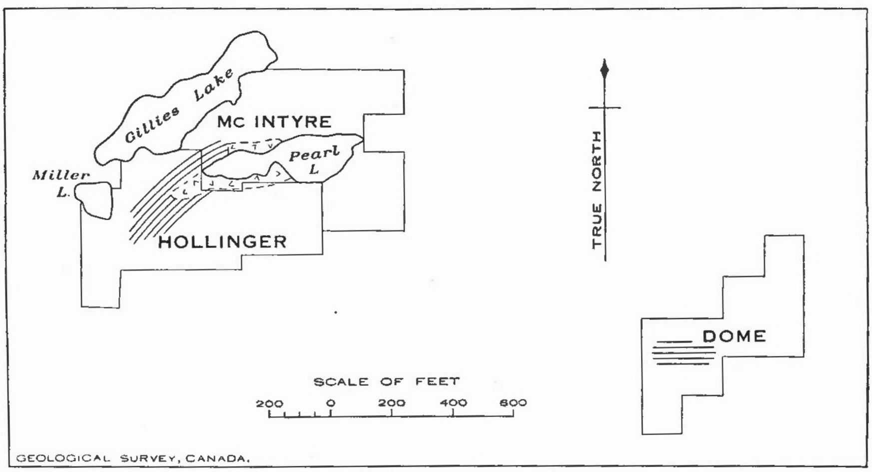


Figure 4. Location of Hollinger, McIntyre, and Dome mines, Tisdale township, Porcupine district, Ontario. Vein zones shown by pattern of ruling; porphyry mass by angles.

The Hollinger and McIntyre mines are adjacent properties developed on the same series of vein systems, the Hollinger lying to the southwest, the McIntyre to the northeast. The veins, with one or two exceptions, lie within a sheared zone approximately 1,800 feet wide at the boundary between the properties. The veins do not parallel the shearing, however, but cut across it at a small angle. On the Hollinger property the shearing strikes north 60 degrees to 70 degrees east, with an almost vertical dip, but the veins have an average strike of about north 50 degrees east, some of the systems dipping steeply north, others steeply south. Where the veins run out of the sheared zone they feather and die out.

A number of porphyry masses intrude the lavas on the Hollinger and McIntyre properties, and like them are sheared where they fall within the schistose belt. The porphyry is a light grey rock carrying small phenocrysts of quartz and acid plagioclase. The principal mass lies in the centre of the zone of shearing and vein formation, its west end on the Hollinger property about 1,400 feet from the McIntyre boundary. The outcrop is elliptical, and underground work has shown that the western end of the ellipse rakes north 85 degrees east with a 40 to 45 degree dip. In depth, therefore, the porphyry is found farther and farther east, and likewise progressively farther to the south of the vein zones which, as mentioned, strike about north 50 degrees east. This structure has been of the highest importance in directing the development of the McIntyre mine.

The veins are almost wholly within the greenstone areas. They enter the schistose porphyries, and in some cases run long distances through them, but for the most part gold values in the porphyry sections are too low for mining. There appears to be a relationship between the values found in a vein in the greenstone, and the distances within the porphyry to which commercial values will be found. Thus a vein that carries $8 to the ton in the greenstones will at once sink below commercial grade when it enters the porphyry, but a vein that runs $50 a ton in the greenstones may retain commercial values for 50 to 100 feet within the porphyry. It would seem that the chloritic greenstones acted as a precipitant of the gold, and that the sericitic schistose porphyry did not.

On the Hollinger property most of the veins are in the zone lying west-southwest of the porphyry nose, and they run into it. Only one vein, the No. 5 vein of the McIntyre property, passes north of the porphyry mass. Owing, however, to the eastward recession of the porphyry with depth, other members of the Hollinger vein system begin below the 1,200-foot level to appear *beneath* the porphyry body, on the McIntyre property; so that the McIntyre mine is becoming progressively more valuable with depth.

The ore in the Hollinger and McIntyre mines consists of quartz and mineralized schist. The schist near the veins is much altered by addition of silica, carbonate, potash which appears as sericite, and auriferous pyrite. Altogether the amount of auriferous schist mined in the Hollinger is greater than the amount of quartz. The distribution of the quartz is most irregular. In places it forms lens-like masses the full width of a vein; in others it occurs as a multitude of narrow stringers varying widely in dip and strike. A large mass of quartz may carry irregular blocks and strips of schist, the strips in places being so numerous as to give the vein a rough banding. From the larger masses of quartz a multitude of veinlets run off into the surrounding schist, some parallel to the schistosity, others cutting it at various angles. It is common to find a "vein", the general strike of which cuts the schistosity at a small angle, composed of a succession of quartz lenses separated by schist, each lens lying parallel to the schistosity and the next lens offset to the left *en échelon.*

It is clear that the veins were formed at high temperatures and pressures. They never exhibit the crustified or banded structure characteristic of low-temperature fissure fillings. Under the microscope the quartz is seen to be coarsely crystalline and to contain numerous gas and liquid inclusions. Some of the veins carry primary albite, and others such high-temperature minerals as tourmaline, pyrrhotite, and scheelite.

Gold is the principal constituent of value, in places free, but more commonly combined with pyrite or other sulphides. Some of the ore is highly spectacular, with gold in coarse plates and cords traversing the quartz and binding it together. As a rule the gold contains a little silver, and averages about 850 fine. Gold tellurides have been found, but are rare. Small quantities of pyrrhotite, chalcopyrite, galena, and zinc blende are fairly generally distributed, and arsenopyrite occurs in some veins. Scheelite has been found in many places, but never abundantly enough to be of economic importance.

The ore deposits of the Dome mine are of a somewhat different character from those of the Hollinger and McIntyre mines, although the mineral associations are of the same type. The Dome property lies near the extreme south edge of the basin of Timiskaming sediments, which has a general synclinal structure plunging east-northeast. A deep, narrow synclinal trough of the sediments has been infolded in the Keewatin greenstones at the south edge of the main syncline, and it is within this syncline and along the crest of the intervening anticline that the principal ore-bodies of the Dome have been found. The subordinate syncline, like the large one, plunges east-northeast. Its north side is almost vertical, and the sediments within it are carried to a depth of about 2,500 feet. Toward its western end the syncline is simple, but some hundreds of feet farther east an anticlinal wrinkle appears at the bottom, so that the syncline thus becomes compound and broader. The sediments of the syncline are beds of conglomerate with more or less greywacke, interspersed with beds of slate. All the rocks in and near this minor syncline are strongly sheared and form part of a belt of schistose rock some miles in length.

The ore-bodies were of extremely irregular shape, utterly unlike the more or less regular veins and lodes of the Hollinger and McIntyre mines. They might be termed irregular lenses. They varied in length up to 600 feet, and in width from 30 to 150 feet. The depth of some was found to be as much as 800 feet, that of others less than 100 feet. More than thirty such bodies were found. They were commonly developed in the conglomerate-greywacke parts of the Timiskaming series but not in the slate, which appears to have been impermeable to the ore-bearing solutions. Many were, therefore, overlain or underlain by slate bands; at the sides and ends, however, they faded imperceptibly into barren conglomerate. As the syncline plunges east-northeast, the ore-bodies also naturally plunged or raked in the same direction. It was found, however, that they strike somewhat more easterly than the sediments, so that their angle of plunge was somewhat less than that of the syncline. Consequently, the ore-bodies tended to pass across the syncline, from the north to the south side.

Toward the middle of the south side of the syncline an intrusive body of porphyry broke across the steeply-dipping sedimentary beds. Beneath the overhanging porphyry roof, and extending upward a short distance into the porphyry itself were some of the richest ore-bodies of the mine. This occurrence, together with those of ore formed beneath impervious slates, suggests that one factor of ore formation may have been the damming of moving solutions by slate or porphyry.

In the eastern part of the mine, where the syncline is broken intc two by the anticlinal wrinkle already mentioned, it was found that ore-bodies were most numerous along the synclinal axes, and were practically absent along the anticlinal axis.

The ores consisted, as at the Hollinger, of quartz and mineralized schist, but the proportion of schist was much larger, amounting nearly to 85 per cent. Some of the ore was simply a dark grey schist spotted with pyrite and cut by vague veinlets of quartz. Most of the gold occurred in combination with pyrite, which sulphide formed nearly 5 per cent of the ore. The proportion of quartz in the different ore-bodies varied greatly, from moderately large in some to insignificant in others. The other minerals present were, for the most part, those found in the Hollinger.

The ore-bodies described are now largely or completely worked out, and the management has pushed exploration into the Keewatin schists lying north of the syncline, where considerable new ore has been found. Some of this ore has afforded spectacular specimens of free gold.

The following table shows the amounts of gold produced by each of the three principal mines annually, and by Porcupine district as a whole. The value of the silver alloying the gold, which is small, is included:

Year	Hollinger	McIntyre	Dome	Total
	$	$	$	$
1910	31,194	....	4,355	35,549
1911	6,000	....	4,277	15,437
1912	909,181	77,657	737,499	1,740,596
1913	2,488,122	236,299	1,242,625	4,316,807
1914	2,719,355	549,166	1,059,238	5,231,989
1915	4,206,015	750,812	1,530,287	7,495,853
1916	5,073,401	1,218,073	2,153,820	9,442,417
1917	4,261,938	1,710,204	1,480,174	8,285,321
1918	5,752,371	1,578,444	82,127	7,833,966
1919	6,722,266	1,978,014	1,290,301	10,041,580
1920	6,219,665	2,223,083	2,020,568	10,690,561
1921	9,051,276	1,827,761	2,290,264	13,177,244
1922	12,274,114	2,021,811	4,178,936	18,479,325
1923	10,446,412	2,550,129	4,374,144	17,405,648
1924	13,433,063	3,604,874	4,307,624	22,266,894
1925	15,749,109	3,721,499	4,365,923	24,886,615
1926	14,829,655	3,862,074	3,940,053	23,810,700
1927	14,539,538	3,965,210	4,031,575	23,976,577
1928	10,706,325	4,201,808	3,915,051	20,352,099
1929	9,455,290	4,295,491	3,590,537	19,373,240
1930	10,260,950	4,696,579	774,943	17,822,365
Total	159,135,050	45,061,196	47,374,321	266,680,783

The previous descriptions make it clear that at Porcupine the type of ore deposit is different from any of those yet described. The latter are clean-cut fissure veins with rich but scattered ore shoots; the bulk of their values consists of native gold; their sulphides are not highly auriferous; and their wall-rocks contain low values or none, and are not altered beyond a few inches from the veins. At Porcupine the wall-rocks are altered over wide zones, throughout which the rock minerals are partly replaced by carbonates, silica, sericite, and other products; the pyrite is auriferous, and is distributed thickly enough throughout the altered zones to make great bodies of ore. Consequently, instead of small and irregular ore-bodies, we have at Porcupine large, comparatively regular masses of ore suitable for mining on a large scale.

It may also be noted that although the Porcupine ores were certainly deposited by hot solutions which presumably arose from some body of cooling igneous rock, it has not yet been possible to determine whether any rock now exposed was the source of the solutions.

Kirkland Lake

In Kirkland Lake area, second in importance to Porcupine but likely to surpass it in the near future, conditions are quite unlike those at Porcupine. The principal mines are the Teck-Hughes, Lake Shore, and Wright-Hargreaves; the Kirkland Lake and Tough-Oakes mines have also produced considerable amounts. The Tough-Oakes is now closed for lack of ore.

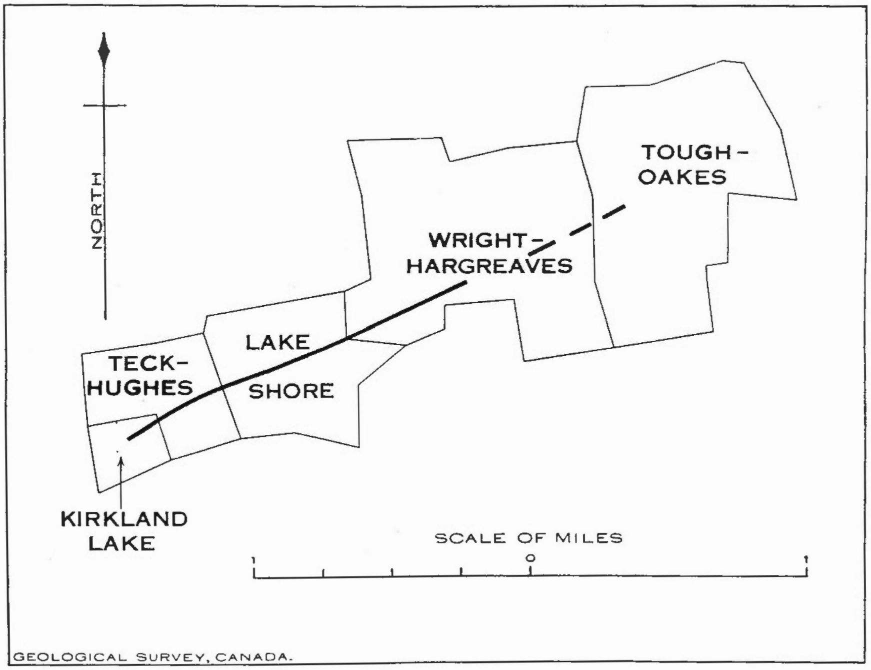


Figure 5. Location of principal mines, Kirkland Lake district, Ontario. Mineralized fault shown by solid black.

These properties are situated in the middle of a large mass of Timiskaming sediments. As at Porcupine the sediments are conglomerate and greywacke with some slate, closely folded and dipping at high angles. Where the ore-bodies occur the sediments are intruded by two igneous rocks, the older a sort of diorite, the younger a reddish syenite porphyry composed of albite and anorthoclase phenocrysts in a feldspathic groundmass. These rocks occupy the greater part of the producing area. The syenite porphyry forms a large mass on the Wright-Hargreaves property, extending almost to the Lake Shore boundary. On the west it throws off long dykes that cut the diorite and sediments on the Lake Shore and Teck-Hughes properties.

A large pre-mineral fault cuts all the rocks described, with a strike north 62 degrees east and a dip of 85 degrees south. The south side of the fault has been thrust upward about 2,000 feet. On the Kirkland Lake, Teck-Hughes, and western half of the Lake Shore properties, the greater part of the fault movement has been concentrated along one plane. To the east the fault is split into two faults 300 to 600 feet apart on the eastern part of the Lake Shore and on the Wright-Hargreaves properties. Still farther east, on the Tough-Oakes, the fault splits again into many small faults.

The ore has formed in the crushed and shattered zone of the fault. The width of this zone varies greatly. In places the walls of the fault zone are close together, and there the ore-body is lean and narrow, as the rock was very completely crushed to a clayey gouge not readily replaced. Where the zone was wider, the intervening rock was brecciated rather than powdered, thus affording not only a good channel for the passage of solutions, but also material that was readily replaced. For the most part these brecciated zones are 5 to 10 feet wide, and yield ore of good grade. In a number of places the fault splits into two branches that unite again farther on, enclosing a horse of country rock. Such a horse, in many instances, was sufficiently brecciated to permit the entry of ore-bearing solutions, with consequent formation of great widths of ore. Rich bodies 50 feet or even more in width have been thus formed.

The nature of the country rock has a profound influence on ore formation. The syenite porphyry, a hard, brittle rock, shattered readily in faulting, but did not form schist, and consequently the veins in the porphyry are of good width and grade. The complex of porphyry dykes and diorite on the Teck-Hughes and western part of the Lake Shore properties shattered even more readily and widely, and consequently in this section the veins are widest and richest. Where the fault passes into other rock types, such as diorite or sediments, shearing rather than shattering occurred. Such schistose fault gouge does not appear to have been favourable for passage of solutions or for replacement, because, although scattered nests of ore occur in it, they are not numerous or large enough to be profitably mined.

On the Tough-Oakes property to the east, where the fault breaks into a large number of smaller faults, many veins of rich ore up to 5 feet in width were found, and for a time were mined. These have now been exhausted and, no more having been found, the mine has been closed.

The ore consists mainly of mineralized porphyry with more or less quartz. In places quartz occurs as large masses nearly the full width of the vein, but more often it is found intersecting the porphyry in numerous thin strings and ribbons. Some calcite is present. The wall-rock is commonly greatly altered to a mass of sericite and carbonate, and analyses show pronounced additions of potash and carbonic acid, and a decrease in soda. Gold and gold tellurides are the principal constituents of value; 2 or 3 per cent of pyrite is commonly present, but does not appear to be highly auriferous. Tellurides are present in considerable variety and amount. Altaite (PbTe) is the most abundant; it is usually accompanied by free gold, and its presence in many cases indicates high-grade parts of the vein. Calaverite ($AuTe_2$) and petzite ($(AgAu)_2Te$) are not uncommon and hessite (Ag_2Te), coloradoite ($HgTe$), tetradymite ($Bi_2(TeS)_3$), and melonite ($NiTe_3$), have also been identified. Other minerals present in small quantity are chalcopyrite, galena, sphalerite, molybdenite, and graphite.

The annual production from the four principal mines and from the district as a whole is as follows:

Year	Lake Shore	Teck-Hughes	Wright-Hargreaves	Tough-Oakes	Total
	$	$	$	$	$
1913	....	....	1,127	66,632	67,759
1914	....	....	....	117,644	122,848
1915	....	....	....	555,539	555,539
1916	....	....	....	711,625	711,625
1917	....	66,722	....	342,831	409,553
1918	416,414	80,570	....	139,683	636,667
1919	263,354	169,590	....	....	491,838
1920	503,735	247,757	....	....	1,065,256
1921	495,276	322,919	468,751	....	1,529,875
1922	471,341	596,495	762,753	107,481	2,172,548
1923	547,600	1,117,963	754,979	12,174	2,728,331
1924	1,098,572	1,023,025	1,088,725	47,547	3,456,453
1925	1,958,720	996,943	1,913,402	263,064	5,403,290
1926	2,775,000	1,601,209	2,150,844	30,709	7,193,411
1927	3,375,053	2,781,962	2,151,916	153,215	9,703,843
1928	4,073,965	4,948,896	1,838,510	82,316	12,271,110
1929	6,090,189	5,048,420	1,734,728	....	14,089,233
1930	7,854,444	5,398,231	2,432,888	....	17,231,709
Totals	29,923,663	24,400,702	15,298,622	2,909,460	79,872,179

The previous descriptions make it clear that the Kirkland Lake ores are intermediate in type between the Porcupine ores and those of western Ontario and Manitoba. At Porcupine much of the gold occurs in auriferous pyrite, and large bodies of schist are so mineralized with the auriferous pyrite as to be commercial ore. In western Ontario there is little auriferous pyrite, and no mineralized schist of value, but the gold occurs free in quartz and commonly in rather coarse particles. At Kirkland Lake there is likewise little auriferous pyrite, and no schist ore of the Porcupine type, but the gold accompanies quartz, and is largely free. Unlike the ores of western Ontario, however, most of the gold is in very small particles, so that spectacular specimens are rare; and a good deal of it is present as telluride. As in western Ontario, however, the best ore-bodies are found where fault zones cut hard, brittle rocks. On the whole, the Kirkland Lake ores seem more analogous to the Howie ore-body than to the ores of Porcupine district; but, unlike the western Ontario deposits, they have no demonstrable connexion with any known body of granite or other igneous rock. The general impression gained from a study of these ores is that they represent a lower-temperature type of deposition than the usual deposit of western Ontario, but perhaps a higher-temperature type than that of Porcupine.

Other Areas

Gold deposits of sufficient merit to warrant development have been found in a number of other areas. The most important are those of Munro township, Lightning river, Larder lake, Matachewan, West Shiningtree, and Boston Creek (*See* Figure 3).

Munro township is chiefly famous for the Croesus mine, a small deposit of what was probably the richest ore ever mined in Ontario; 765 pounds of ore taken from one place in the shaft yielded $47,000 worth of gold. The deposit was a quartz vein rich in free gold, with a little pyrite and arsenopyrite. The vein was about 200 feet long, and from a few inches wide on the north to a few feet on the south, where it was cut off by a series of east and west faults. Gold to the value of somewhat more than $250,000 was taken from this vein. Other properties in the neighbourhood display rather small quartz veins carrying some visible gold, more or less pyrite, and some galena in places. None of them has proved to be of commercial value.

The Lightning River deposits occur in Harker and Holloway townships, south of Abitibi lake. Although none of the properties has yet become a producer, the deposits are of interest because they resemble closely the Porcupine type. They are zones of shattering or shearing which have been invaded by auriferous solutions and mineralized with quartz, carbonate, auriferous pyrite, and a little free gold.

At Larder Lake the country rocks are altered along great shear zones to masses of ferruginous carbonate shot through with small quartz veins. These carbonate bodies contain scattered flakes of free gold, and in parts are rich in the precious metal. Exploratory operations were carried on for many years without, however, discovering any ore-body of economic value. In 1920 ore-bodies of a different type were found to the north of those previously known. These were lavas and tuff beds highly altered by thermal solutions to mixtures of calcite, quartz, and some albite or oligoclase, the whole coloured bright red with fine-grained hematite and thickly sprinkled with auriferous pyrite and arsenopyrite. The ore was rather low in grade, but it undoubtedly could have been mined at a profit. Unfortunately the body was cut off below the 500-foot level by a large fault, and its continuation has not been found.

At the Argonaut mine, about 6 miles northwest of Larder lake, mining operations were carried on for many years on a vein largely of massive chalcopyrite with some quartz and calcite. The chalcopyrite carried high gold values, in places $200 a ton. The ore appears to have been deposited from waters heated by a large dyke of quartz diorite. Near the dyke the vein changed in composition, and became a mass of high-temperature minerals such as magnetite, hornblende, and epidote, with some tourmaline and axinite. Because with increasing depth the dyke approached closer and closer to the vein, these changes eventually caused the mine to be abandoned. It produced, between 1914 and 1929, gold to the value of $787,202.

At Matachewan two types of ores are known. In one, a body of syenite porphyry is sliced by numerous joints, and the joints are filled by narrow quartz veins carrying free gold. A large body of rock is thus converted into a low-grade ore of gold, with, it has been stated, a tenor of about $3 a ton. In the other type, pegmatite dykes have altered beds of tuff to mixtures of calcite, sericite, and albite, and have mineralized the altered parts with auriferous pyrite. Steeply-dipping pipes of ore lenticular in outcrop have thereby been formed. Although at least one of these proved large enough to mine, the total amount of ore available was hardly enough to warrant erection of a plant.

At Boston Creek, about 12 miles southeast of Kirkland Lake, there has been considerable development work done on various properties since 1915, but no great amount of gold has been produced, except from the Barry-Hollinger, formerly the Patricia, mine, the output of which has been $810,408 to the end of 1930. The main vein strikes north 57 degrees east and dips 70 degrees southeast, with an average width of 6 to 14 feet. It is developed along a fault plane. The ore is quartz, interlaminated in places with schist, and carrying a little pyrite, chalcopyrite, and visible gold. Values are higher in the quartz than in the schist, and seem to accompany chalcopyrite rather than pyrite.

Gold tellurides are present in some of the other properties of this area, and in general the main values seem to occur as native gold and gold telluride rather than as auriferous sulphides.

A. G. Burrows and P. E. Hopkins[1] state, "The gold generally occurs near these acid rocks (i.e. granite, syenite, and feldspar porphyry). The presence of a number of gold-bearing veins along the contact of the intrusive porphyry and older rocks at Boston Creek, as in many other parts of central Canada, and the frequent occurrence of auriferous quartz veinlets in the porphyry and granite, suggest the relationship between the intrusives and the veins. The relationship is more clearly shown in this area by the occurrence of gold in a pegmatitic vein in the granite on the Charest claim, McElroy township."

West Shiningtree district, about 60 miles almost due south of Porcupine district, has been prospected intermittently since the first discovery of gold in 1911, but no producing mine has yet been developed. The veins, some of which have been traced over great lengths, are of quartz. The quartz contains a little albite and tourmaline in places, and chalcopyrite, molybdenite, sphalerite, and galena sparingly. Pyrite, the principal sulphide, is not abundant in the quartz, though more so in the wall-rock. Native gold is the principal constituent of value and spectacular specimens have been found from time to time. The deposits of West Shiningtree district thus more nearly resemble those of western Ontario than those of Porcupine and Kirkland Lake districts.

Summary and Generalizations

The lode gold deposits of northeastern Ontario fall into at least two main types. The first includes the simple fissures and lodes, like those of western Ontario. These consist of high-temperature quartz with free gold, and small amounts of sulphides which carry little or no gold. The wall-rocks are slightly altered, if at all. Such veins may afford spectacular sections and samples, but rarely have been mined at a profit. The short-lived Croesus mine is the best known example of this type. It is noticeable that most of the deposits of this kind have been found around the outskirts of the northeastern Ontario area, as at West Shiningtree and Boston Creek.

[1] Ont. Dept. Mines Rept., vol 30, pt. 6, p. 9 (1921).

The second type, found toward the centre of the northeastern Ontario area, is profoundly different from the first. The gold-bearing solutions appear to have been of much more complex composition, rich in carbonic acid, and probably carrying potash, lime, magnesia, and iron, as well as gold and sulphur. They vigorously attacked the country rocks over wide zones, altering them to aggregations of lime, iron, and magnesium carbonates; they converted the feldspars into sericite, leached out silica, and deposited gold, auriferous pyrite, and in places tellurides. These conditions obtain at Porcupine, Lightning River, Matachewan, Kirkland Lake, and Larder Lake.

The extensiveness of the action of the solutions was controlled, however, by the structure. The wide shear zones at Porcupine and the great fault zone at Kirkland Lake allowed the gold-bearing solutions to percolate readily through wide belts of country rock, and to exercise their alterative effects. In these places, therefore, great ore-bodies were formed. At Matachewan and Larder Lake structural conditions were far less favourable, and as a result the ore-bodies, though of fairly good grade, are small.

A further curious structural relationship is evident in this region, one which, so far as the writer is aware, has never previously been pointed out, although Knight approached it closely.[1] This is the manner in which the gold deposits follow the synclines. Thus the deposits of Porcupine, Munro township, and Lightning river all lie in one syncline in the older rocks; and, it may be added, the Beattie property in Quebec, 30 miles farther east, lies in what appears to be the continuation of this syncline. The deposits of Matachewan, Kirkland Lake, and Larder Lake all lie in a second syncline, which extends eastward to include the Granada, Graham-Bousquet, Thompson-Cadillac, and O'Brien mines in Quebec. The deposits of Boston Creek fall into the next syncline to the south, and other veins have been found farther east along the synclinal axis. In western Ontario less is known about the structure, but it is known that the Red Lake deposits lie within a syncline. It is to be hoped that further data tending to prove or disprove this generalization will be accumulated.

Little is definitely known as to the origin of the gold-bearing solutions. The mineral associations of all the deposits indicate that they crystallized from heated waters of high mineral content, and such waters may reasonably be presumed to have originated from some body of cooling igneous rocks. At Matachewan it has been fairly well proved that the gold-bearing solutions originated from bodies of syenite porphyry; at Boston Creek, that they emanated from syenite porphyry or granite; at the Argonaut mine, that they were heated by a body of quartz diorite; but for the more important veins, those of Porcupine and Kirkland Lake, no connexion with any known body of igneous rocks has ever yet been proved. The presence of high-temperature quartz containing liquid and gas inclusions, and the presence of such minerals as albite and tourmaline imply that such a connexion must exist; but if so the intrusive supplying the solutions must lie deep beneath the surface, either not reaching the surface at all or reaching it so far away that its relationship to the deposits is unrecognizable.

---

[1] Ont. Dept. of Mines, Ann. Rept., vol. XXXIII, pt. 3, p. 44 (1924).

QUEBEC

The most important gold producer in Quebec at present is Noranda Mines, Rouyn township, which in 1931 obtained about $5,000,000 of gold as a by-product of its copper ores. This deposit will be mentioned in another part of this report, where complex sulphide ores are discussed. Attention is here confined to those deposits in which gold is the principal constituent of value.

In Quebec, lode gold in payable amount has been found, up to now, only in the Rouyn-Harricanaw region, the eastward extension of the Porcupine and Kirkland Lake districts of Ontario. Throughout this region, which extends from the Interprovincial Boundary about 100 miles east to Bell river, many small discoveries have been made, but few, up to now, have proved worth mining. The Siscoe mine, in Dubuisson township, produced in 1929 somewhat more than $300,000 in gold; some high-grade ore has been recovered from the O'Brien mine, in Cadillac township; and development of the Granada mine, in Rouyn township, has been actively proceeding. To the north the Beattie deposit in Duparquet township, a large body of low-grade ore, is at present under development.

The deposits are of two general types, quartz veins and replacements. The quartz veins are mostly of the high-temperature type, characterized by such minerals as albite and tourmaline. High-temperature veins are very numerous in the Timiskaming sediments for some miles from the edge of a great granite batholith on the south, and most of them are barren except for an occasional splash of metallic gold. The only deposit of this type as yet proved to be of value is the Siscoe vein, in Dubuisson township. Others that have proved to be of promise are mixtures of white and dark quartz with free gold and small amounts of such minerals as pyrite, arsenopyrite, pyrrhotite, galena, and sphalerite. They therefore are of a fairly high temperature type, but not so high as the tourmaline-dark quartz type. It is interesting to note that all the known veins of the latter class occur about 6 to 8 miles north of the boundary of the great granite batholith already mentioned. Still lower temperature types are known—ordinary quartz-pyrite veins—but none of economic value.

Replacement deposits are of two types. In one the original minerals of the country rock are replaced mainly by carbonates, in the other by silica. The Arntfield deposit, in Beauchastel township, is the best example of the carbonate replacement type; the Malartic mine, in Fournière township, of the silica replacement type. In both the ore-bodies are of good size, but their tenor is rather low for profitable mining.

The Beattie property in Duparquet township, on which attention is centred at present, is also of the replacement type. A wide band of rhyolites and rhyolite tuffs along the north side of a large mass of red feldspar porphyry is thoroughly altered and uniformly mineralized with very fine-grained auriferous pyrite. The mineralized mass is bounded on the north by a wide, east-west fault, through which the mineralizing solutions may have entered. The mineralized mass at the surface is about 1,200 feet long and 110 feet wide, with an average tenor, according to mine officials, of $3.22 a ton. Drilling, according to the same authorities, has shown the mass at a depth of 500 feet to be 84 feet wide and about as long as at the surface, with an average grade of $3.25 a ton. It is calculated that above the 550-foot level there are more than 5,000,000 tons of ore carrying $3.07 or better in gold and that of this amount 3,000,000 tons average $3.89 a ton. The rock alterations accompanying mineralization consist chiefly of the addition of carbonates, formation of large amounts of sericite, and disappearance of most of the original minerals of the rock except part of the quartz.

A second area that is attracting much attention at present is the extreme eastern end of the district, at the corner of Pascalis, Louvicourt, Senneville, and Bourlamaque townships. The discoveries lie in the eastern end of a large body of granodiorite which intruded Keewatin lavas. The granodiorite has been broken by strong shear zones, striking approximately east–west, some of them more than 100 feet wide. Vein material has entered both the shear zones and individual fissures to form fissure veins and shear zone deposits, the latter predominating. Vein material is mainly white quartz with more or less tourmaline, mineralized with pyrite and native gold. Some of the pyrite is said to be auriferous, but most of the gold seems to be native. Some quite spectacular specimens of native gold have been found.

The Quebec deposits again illustrate the controlling influence of structure in localizing deposition. The Beattie deposit, above described, is localized adjacent to a wide zone of shear. The Lake Fortune mine, the first discovery of the district, is a partial replacement in a strong sheared zone. The O'Brien, Thompson-Cadillac, and Graham-Bousquet deposits, all of which have attracted a good deal of attention in the last few years, are developed on or close to the wide shear zone of a large fault. The Noranda and the Malartic mines are each developed in the twisted and shattered strata of a sharp drag-fold. The Siscoe vein lies in a fault plane and the Pascalis deposits are located along zones of shear.

OTHER TYPES OF DEPOSIT OF THE PRECAMBRIAN SHIELD

In addition to the deposits already described, there are a few of distinctly later age near the north shore of lake Huron. None of them has proved of much economic value as yet. It is altogether likely that some of the known deposits in districts already mentioned may be of the same age and origin as those about to be described, but if so, the lack of Huronian and younger rocks in those districts makes it impossible to determine their age. Along the north shore of lake Huron, however, a comparatively complete Precambrian succession is developed, and, therefore, the age of any deposit can be fairly accurately determined. The following deposits, together with some of less importance, seem to have originated either from the Nipissing diabase or from the Killarney granite. Both intrusives are of late Precambrian age, younger than the Cobalt series and very much younger than the deposits previously described.

Deposits Originating from the Nipissing Diabase

(*See* Figure 3)

The Crystal mine was discovered in 1888 on the east side of Wanapitei lake, in Rathbun township, and was operated for some years with a small production. The deposit lies along the contact of a sill of Nipissing diabase with arkose and greywacke of the Cobalt series. In places the contact is marked by a crush breccia composed of diabase and sediments and the sediments have steeper dips here than elsewhere. Both diabase and sediments are cut by numerous veins, most of them less than a foot wide. They consist of quartz and breunnerite, a pink or pale brown carbonate of magnesium and iron; the breunnerite weathers to a characteristic deep bronze colour. This gangue is mineralized with pyrite containing a little copper, and with visible gold, in many places quite coarse. The sediments near the veins, over widths of about 6 inches, are bleached and mineralized with pyrite and breunnerite. As the veins cut the diabase, they are evidently younger than it; and their proximity to the diabase, and the lack of any other igneous rock from which they might be derived, strongly suggest that they were derived from it.

The Havilah mine, in lot 12, concession III, Galbraith township, was discovered in 1899 and has been worked at intervals. A high bluff of Nipissing diabase trends north-northwest, and the contact of the diabase with quartzites of the Bruce series (Lower Huronian) to the west lies at the foot of the bluff. The principal vein is in the diabase near the contact. It strikes north 75 degrees east, dips 80 degrees south, and has been traced about 1,300 feet. It is said to finger out where it enters the quartzite. The width varies from 18 inches to 7 feet. Three smaller veins more or less parallel to each other branch off from the north side of the main vein and swing around in an arc to rejoin the main vein some 450 feet farther on. This part of the mine is termed the ore chimney. The vein materials are quartz and a grey carbonate, probably breunnerite as it has the characteristic bronze weathering, together with a little chalcopyrite, pyrite, and visible gold. They enclose greenish streaks and bands of the schistose country rock. The average tenor of the ore appears to have been between $5 and $6 a ton, although parts of it ran much higher.

A number of smaller deposits of similar type have been found, such as: the Payton vein, on Whiskey lake, a quartz vein mineralized with pyrite in the Bruce series; the McKenzie mine, about 5 miles east of Wanapitei lake, located on quartz veins cutting greywacke of the Cobalt series near a mass of Nipissing diabase; and the Mount Aetna mine, in Davis township, which has quartz veins mineralized with pyrite, chalcopyrite, barite, and gold, cutting Cobalt conglomerate close to a mass of diabase.

The reasons for associating these ores with the diabase are as follows. The diabase magmas certainly contained some gold, because it occurs in the copper-nickel ores of Sudbury, which settled out from the molten diabase, and in Gowganda district in some of the cobalt-silver veins, now known to have been formed as differentiation products from the diabase magma. Secondly, the age of the gold veins is such as to indicate that they could have been derived from the diabase. They either cut the diabase or occur in late Precambrian sediments close to it. Finally, they are closely related in composition to other veins that carry little or no gold but have a fairly definite relation to the diabase. These are quartz veins mineralized more or less heavily with chalcopyrite, and containing usually some pyrite, siderite, or other carbonate, and barite. Occasionally, as stated, they carry some gold, but copper is the main constituent of value. Bruce Mines is the largest and best known of these deposits. The descriptions make it evident that except in the matter of gold values they are very similar to the gold veins; and as they are generally admitted to be derived from the diabases, it seems reasonable to conclude that the gold veins of this type were also derived from the diabase.

Veins Derived from the Killarney Granite

In the region immediately north of lake Huron there are masses of granite much younger than most of the known granites of the Canadian Shield. They cut the Nipissing diabase, to which reference has just been made, and hence are among the youngest of the known Precambrian rocks. They are termed the Killarney granites, because first recognized near the village of that name on the north shore of Georgian bay; and certain gold deposits appear to have been derived from them.

The Long Lake gold mine is about a mile south of Long lake, or about 14 miles southwest of Sudbury (*See* Figure 3). It was worked from 1909 to 1916, and in that time produced more than $800,000 in gold. The known ore-body ended against a fault, beyond which it could not be found. The geological relations are rather complex. A large body of Killarney granite almost surrounds a long tongue, about 2,000 feet wide, of the quartzite of the Bruce series. An irregular, linear body of diorite older than the granite likewise intrudes the quartzite tongue, and encloses or almost encloses a mass of quartzite, in which the ore-body occurred. The ore-body was merely a part of the quartzite impregnated with fine-grained pyrite and arsenopyrite carrying gold. It had no definite walls, but passed into country rock by gradual decrease in the amount of mineralization. Mining operations proved that it was a chimney-shaped mass, about 250 feet long and 150 feet wide, pitching steeply southwest. At a depth of 340 feet it was cut off by a fault, as already mentioned.

Near Howry creek (*See* Figure 3) gold was found in 1911-13, within an area about 6 miles long and 1 mile wide. The ore-bodies occur in sediments of the Cobalt series which have been much metamorphosed, supposedly by the heat of underlying masses of Killarney granite. Most of the deposits are veins up to 6 feet in width. They consist of quartz and the iron-magnesium-lime carbonate ankerite, with varying amounts of arsenopyrite, pyrite, and gold. Some of the veins are nearly half arsenopyrite. Gold values are said to range from nil to $10 a ton. None of the deposits has been mined. A second type of deposit found only in one place in Howry Creek district, is a broad, sheared zone in conglomerate, impregnated with pyrite and ankerite, and thickly netted with veinlets like the larger veins in composition. The mineralized zone is 40 feet or more in width, and is said to be at least half a mile long; but values are lower than in the veins because of dilution by the interlaminated country rock.

The Shakespeare mine in lot 5, concession I, Shakespeare township, was opened in 1903 and worked for four years. Somewhat more than $38,000 in gold was recovered. There appears to be a lode 40 feet wide with an ore zone on each side made up of quartz veins interlaminated with chlorite schist, and mineralized with native gold, pyrite, and some thin films of native copper. The body lies about half a mile from the Killarney granite.

All these deposits are supposed to have been derived from the Killarney granites for the following reasons. The age of the deposits is fairly close to that of the granites; in all cases they lie in rocks of fairly late Precambrian age, and one of the Howry Creek veins cuts a dyke of Nipissing diabase. They are all fairly close to bodies of granite. They lack the chalcopyrite that commonly occurs in the veins derived from diabase, but instead, contain arsenopyrite. As the diabases are the only other late Precambrian intrusive from which ore-bodies might arise, it is concluded that these ores must have been derived from the Killarney granite.

GENERAL SUMMARY OF CONDITIONS ON THE CANADIAN SHIELD

Preceding descriptions make it evident that there were at least two periods during which gold was deposited in the Canadian Shield. The first, so far as known, and infinitely the most important, was that great interval of folding, mountain building, and granite intrusion that separated earlier from later Precambrian time. During this interval, apparently, all the known gold deposits were formed except a dozen or so. Late in Precambrian time there was a second period of folding and mountain building accompanied by intrusion of granites and diabases, which disturbed the rocks of a localized belt along the north shore of lake Huron; from these intrusives some deposits were derived, from which a little gold has been recovered, but on the whole their economic importance is small. It is quite possible, however, that either in the Lake Huron area or elsewhere larger deposits of this origin may exist.

The rocks in which the gold deposits are found consist, as the descriptions show, of ancient lavas and sediments mainly. In a few instances deposits have been found within small bodies of intrusive granite, syenite, or porphyry, and other instances are known of veins in larger granite masses; but the latter always occur close to the edges of the granites.

The Canadian Shield has a total area of about 1,825,000 square miles, the greater part of which is underlain by rocks of early Precambrian age, hence it evidently still has large possibilities for the prospector, as only the southern end, where access is easy, has been prospected in any degree of detail. At the same time it cannot be assumed, as has been done by some writers, that the unknown northerly parts of the Shield are likely to be as productive as the southerly parts have proved. The more northerly parts have as yet been explored only by widely scattered traverses along the principal rivers, so that much remains to be learned of them. The preliminary traverses have shown, however, that immense areas are underlain by granites, which, past experience indicates, are almost certainly barren of mineral deposits. It is probably true that not more than 10 per cent of the northern part of the Shield is underlain by rocks in which mineral deposits are likely to occur.

Even this amount is still a very large area, however, and affords plenty of space for future prospecting. Some of the suitable areas of older rocks have been mapped in part by the preliminary explorations mentioned; others can readily be detected by airplane reconnaissance. In prospecting such areas the relations described in the preceding pages should be kept in mind. Preliminary evidences of mineralization may be rusty areas or zones, silicified zones or sericitized zones; scattered boulders of ore or vein material; or quartz veins. Since the best and largest deposits occur in the shattered zones of brittle rocks, any strong shear zone in which evidences of mineralization occur should be followed to determine whether it cuts a brittle rock such as porphyry, rhyolite, and so on. The neighbourhood of contacts between granite masses and older rocks should be carefully examined, especially if the granite masses are small. If veins are found running from the granite masses into older rocks, they are likely to be richest close to the contact. Replacement deposits carrying auriferous sulphides are to be sought for in preference to quartz veins containing visible gold, as they are more apt to form large bodies and to be more uniform in tenor.

DEPOSITS OF SOUTHEASTERN QUEBEC AND NEW BRUNSWICK

Throughout the Eastern Townships of Quebec, and particularly on Chaudière river and its tributaries, between Valley Junction and Beauceville, placer gold was mined throughout the latter half of last century, especially between 1875 and 1885; and sporadic attempts to continue operations were made until a few years ago. Many of the nuggets obtained were rough and angular and others still clung to bits of the quartz matrix from which they were derived, thus suggesting that they had not travelled far from their point of origin. Evidently, therefore, the placers were derived from quartz veins in the vicinity. The heavy cover of glacial drift makes prospecting difficult, yet many veins throughout the Eastern Townships were sampled and assayed, with discouraging results. Apparently some or many of the veins contain free gold,[1] in some cases fairly coarse; but no vein so far discovered is large enough or rich enough to mine. The veins are of two general types. Those of the first type consist of barren quartz and are extremely numerous, particularly throughout Notre Dame hills. Those of the second type consist of quartz accompanied by some or all of the sulphides, pyrite, marcasite, arsenopyrite, chalcopyrite, galena, and sphalerite. Assays made in past years indicate that the clear quartz veins contain no gold, but that the quartz-sulphide veins generally show at least traces.

No gold deposits have yet been found in New Brunswick, but the presence in the western part of several large bodies of granite as well as some smaller ones suggests that deposits may occur in their vicinity. The heavy cover of glacial drift over the great part of the province is, however, a great hindrance to prospecting.

DEPOSITS OF NOVA SCOTIA

The Gold-bearing series of Nova Scotia is a monotonous succession of quartzites and slates, folded into long east-west anticlines and synclines. It is considered to be Precambrian by some geologists, Cambrian by others. The first school base their opinion on the resemblance of the series to a definitely Precambrian series in Newfoundland; the second school point to the fact that the Gold-bearing series grades without any visible break into fossiliferous Palæozoic rocks. The Gold-bearing series is invaded by numerous large and small masses of granite, of Devonian age. Granites of two ages may be present, but this is not yet definitely established.

The Gold-bearing series is more than 30,000 feet thick, occupies that half of the province lying along the Atlantic coast, and extends the full length of Nova Scotia peninsula. The beds commonly dip at high angles, and the anticlines are more or less regularly spaced about 3 miles apart. Many of them are of great length; some have been traced for 100 miles. The anticlines plunge east and west at low angles, so as to form a series of domes, the crests of which may be 10 to 25 miles apart on any one anticline. Towards the west end of the province the folds become broader and less tightly compressed than in the eastern part, a change that has seriously affected gold deposition.

[1] Geol. Surv., Canada, Ann. Rept., vol. X, pt. J (1899).

Fairly important amounts of gold have been produced from more than a score of fields, and of these all but four or five occur in the eastern part of the province, east of the great granite mass which comes down to the Atlantic coast at Halifax. The others are fairly closely grouped, in the northeastern part of Queens and the adjoining part of Lunenburg counties. No deposits of importance have been found in the western fifth of the province.

The gold occurs in quartz veins, most of which lie in thin slate beds between bands of quartzite. The veins are found near the crests of plunging anticlines, and in many instances pass completely across a crest from one limb to the other. Because of their habit of thus straddling the anticlines, they are termed saddle veins. In some anticlines a whole series of parallel saddles is developed, many of which, mining operations have shown, do not come to the surface. Many veins appear to have been formed before the folding processes were completed, because the vein matter is wrinkled and thickened at the noses of the anticlines, as if dragged between the quartzite walls. The corrugations in many cases are quite large and are then known as barrels.

As a general rule the veins are limited to those parts of an anticline or dome in which the strata have a pronounced curvature. Thus little or no vein material is found on the flanks, where the beds maintain a uniform dip in depth, or at the summits of anticlines that have broad, flat tops. This is the reason that veins are few and poor in the western part of the province, where folds are broad and open. The best veins are found at the crests of fairly sharp folds, in which the two limbs enclose an angle of 45 degrees or less. In such anticlines the veins form saddles, curving around the crests and extending down the limbs until the strata cease to bend. In short domes, veins may run completely round the dome. In broad anticlines, there may be no quartz at the crest, but some may be developed at a distance from the axis, where the bends bend from their nearly horizontal position on the axis to the normal steep dip of the limbs. In some districts vein formation is closely connected with subordinate flexures on the limbs of a fold. In others the anticlinal axis itself is curved or bent, and where this occurs veins are more numerous on the convex side.

All these facts indicate an intimate connexion between folding and vein formation. The accepted theory is that the slipping of one bed over another during folding produced openings along the bedding planes, which were widest where curvature was sharpest. As the slipping was concentrated in the beds of easily deformed slate, the openings were formed in the slate. Into these openings the vein matter was introduced by solutions.

The principal gangue mineral is quartz, but calcite and sulphides occur locally, usually in subordinate amount. Pyrite and arsenopyrite are the principal sulphides, but galena, sphalerite, pyrrhotite, and chalcopyrite are also found. Auriferous stibnite is mined at West Gore, chiefly for the antimony. In some instances the sulphides are distributed more or less evenly throughout the quartz, but more generally they are concentrated along the walls and in the wall-rock for a few inches from the vein. Films and fragments of the slate walls form a minor part of the vein matter. The chief constituent of economic value is native gold, much of which is very coarse; but some gold is intimately combined with the sulphides, from which it cannot be separated by amalgamation.

For the most part the veins rarely exceed 2 feet in width, and many that have been worked are less than 1 foot. In places, however, especially where a vein has been thickened by corrugation near the apex of a fold, the width greatly exceeds this figure. The quartz in many of the narrow veins was very rich, carrying $50 to $60 in gold a ton. The common method of mining has been to stope just the width of the vein as far as economically possible, then to blow down the wall to a working width, leaving the waste in the stope.

Some of the wider beds of slate carry several quartz veins, which may be so small that they cannot profitably be separated from the slate. Such "belts", as they are locally termed, attain widths of 10 to 20 feet. Some of them are sufficiently rich to be worked as a whole and furnish large bodies of low-grade ore.

The veins of Nova Scotia are far from being exhausted. In the early days of mining prospectors were granted only claims of very small size, commonly lengths of 150 feet along the vein, but in one instance as little as 20 feet. This resulted in multiplication of the number of owners, most of them without funds sufficient to carry on extensive operations. The usual practice was, therefore, to sink an inclined shaft for a short distance, following the vein, and stope out the ore most readily won, after which the workings were allowed to slump and fill. Large numbers of these shafts now dot the mining areas and practically all the ore near the surface has been removed. It seems likely, however, that efficient operation by modern methods might win a good deal of gold from deeper levels of known veins, and that all veins of value have not yet been discovered. The disadvantage of the deposits is the prevailing narrowness of the veins and the lack of extension to depth; but to offset this there is the high grade of many of them, their length, and, above all, their perfect regularity and the certainty with which their position from level to level can be forecast.

DEPOSITS OF BRITISH COLUMBIA

In British Columbia practically all the known lode gold deposits are in Mesozoic rocks, and are considered to be genetically related to the great intrusion of granodiorite known as the Coast Range batholith, or to batholiths approximately contemporaneous with it.

Deposits mined wholly or largely for their gold content are comparatively few. The mines of Bridge River and Sheep Creek districts, the Hedley deposits, the Surf Inlet mine, and the Engineer mine are those in which gold is or was almost the only constituent of value. In the Rossland deposits and the Premier mine, gold was the principal constituent, but there are others of great value. Some gold is recovered from sulphide bodies of more or less complex composition, which are mined mainly to recover other metals.

The Bridge River deposits occur in the Bridge River section of Lillooet mining division. The principal producing property at present is the Pioneer mine, which yielded gold to the value of nearly $286,000 in 1930, from ore of an average tenor of $14 to $15 a ton. The ores of the district are quartz veins developed within but close to the edges of elongated, stock-like masses of augite diorite striking in a general north–northwest direction. Most of the veins parallel the longer axes of the stocks, but on

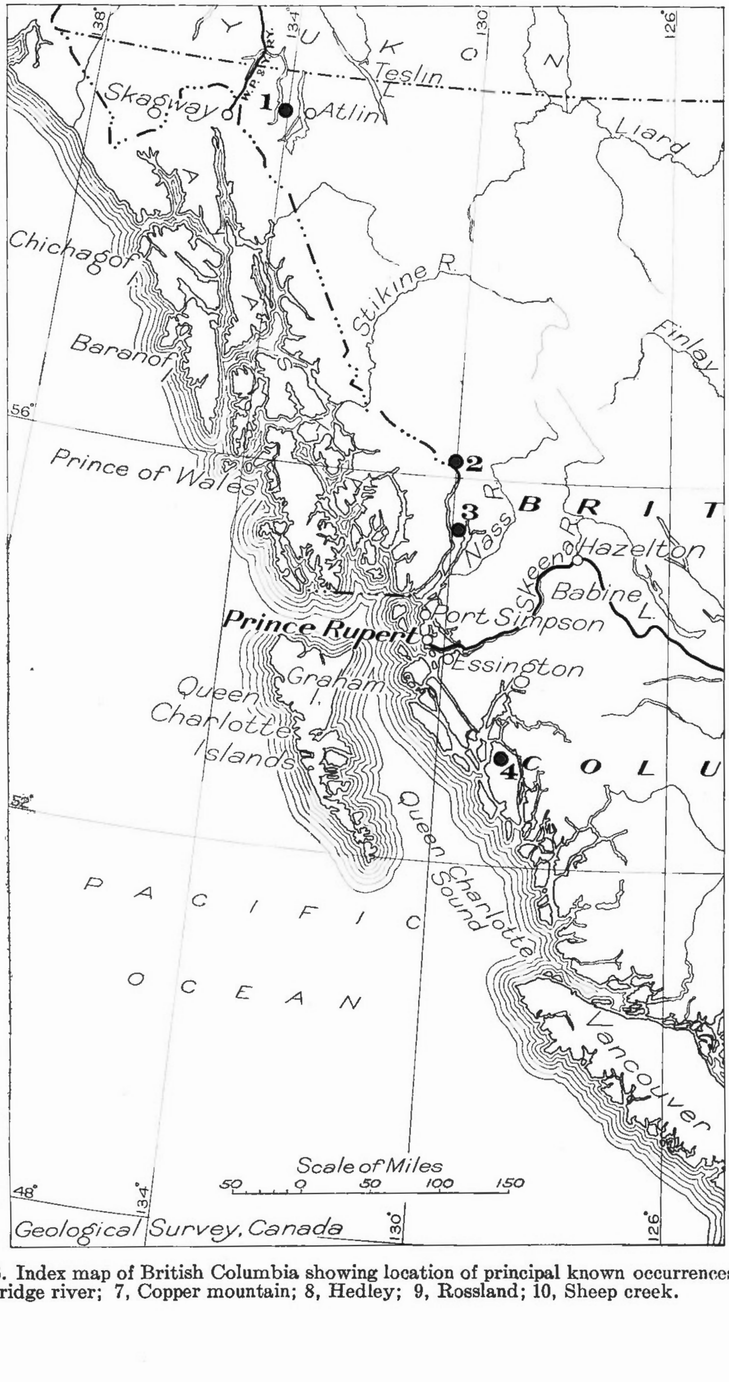
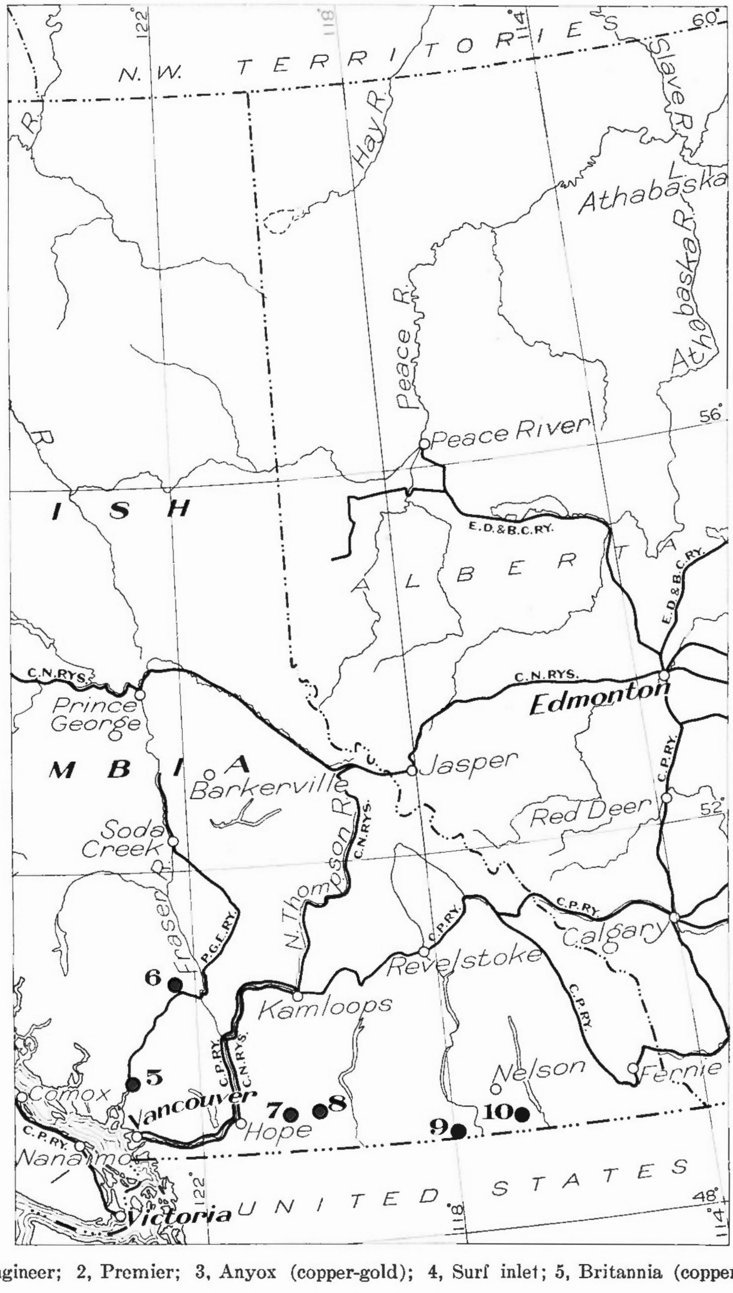


Figure 6. Index map of British Columbia showing location of principal known occurrences of gold. 6, Bridge river; 7, Copper mountain; 8, Hedley; 9, Rossland; 10, Sheep creek.



1, Engineer; 2, Premier; 3, Anyox (copper-gold); 4, Surf inlet; 5, Britannia (copper-gold);

at least one property at the end of one of the stock-like bodies, strike easterly parallel with the northern boundary of the stock. The quartz of the veins has been crushed and sheared in most cases by fault movements. The high values are found in the sheared or "ribboned" quartz, as it is locally termed, whereas the tenor of unsheared quartz is low.

The metalliferous constituents are native gold, the gold telluride sylvanite, and a sprinkling of pyrite and arsenopyrite. Other sulphides occur sparingly here and there. Some of the gold is intimately combined with the sulphides, though the greater part is free. The wall-rocks for distances ranging from a few inches to 10 feet from the veins are altered to a yellowish or whitish product with a greasy feel, a mixture of sericite, carbonates, and residual quartz. These altered zones carry crystals of pyrite and arsenopyrite, but no gold.

The Sheep Creek deposits are in Nelson mining district, in the southwestern part of the province close to the International Boundary. They were discovered in 1899, and since that time have produced about $3,000,000 in gold. The rocks of the district are sediments folded along north and south axes, and most of the gold deposits occur along one of these anticlines. This appears to be because the anticlinal structure brings to the surface a series of hard quartzite beds in which open fractures could be formed, for it is found that where the fractures pass into schists and other soft rocks they close up and contain little vein matter.

The north-striking folds are cut by a series of small faults striking east to east-northeast. Movement along the faults has varied from a few feet to 200 feet. The fissures thus produced were afterwards filled with vein matter, more or less mixed with the crushed country rock. The veins so formed are on the whole rather narrow, although some are as much as 20 feet wide.

Vein materials consist of quartz rather sparingly mineralized with auriferous pyrite and a little galena and sphalerite. In most of the mines this primary ore has proved too lean to be profitably worked, and operations have accordingly been confined to the upper parts of the veins, where oxidation has destroyed the pyrite and enriched the gold content. These oxidized zones vary in depth from a few feet to 500 feet. In one property, however, the Reno, which was brought into production in 1929, primary ore of good grade has been discovered, and has caused a revival of interest in the district. This mine during its period of production from 1929 to 1931 has produced about $375,000 in gold.

The Hedley deposits are found, in the main, on Nickel Plate mountain, in Osoyoos mining district, southern British Columbia. The largest and best developed property is the Nickel Plate mine. The rocks are interbedded quartzites, chert, and limestones of varying purity, striking approximately north and dipping 23 degrees west. They are slightly flexed to form an anticlinal cross fold plunging slightly north of west; and exhibit numerous small cross folds, the axes of which do not plunge straight down the dip, i.e., west, but rather plunge northwest. This structure is of importance as it apparently controlled and localized ore deposition. Numerous sills of gabbro-diorite have been injected into the sediments parallel to the bedding. It seems probable that injection took place either during or after the folding; at any rate the sills parallel closely the bedding of the sediments.

The ore-bearing solutions entered the base of one of the minor synclines, from the northwest, and followed the bedding planes upward, at the same time working somewhat south into the axis of the next adjoining anticline. They altered the country rock to various silicates and introduced auriferous sulphides. The gabbro-diorite sills formed barriers causing the solutions to spread out along their contacts. In this way a series of flat, plate-like masses of ore were formed, with gabbro-diorite along the foot-wall, the hanging-wall, or both. The other walls of the ore-bodies are vague and ill-defined, the ore fading gradually into unmineralized country rock.

In the Nickel Plate mine the ore-bodies occur throughout a zone some 2,000 feet long, 350 feet wide, and 215 feet thick. In this zone there are five of the irregular sheets described, overlapping *en échelon*. The maximum thickness of any single ore-body is about 65 feet, and its length 500 feet.

The ore-bearing solutions were very hot and converted the siliceous limestones into contact-metamorphic minerals such as garnet, epidote, diopside, tremolite, and axinite. They added large quantities of auriferous arsenopyrite, and small amounts of pyrrhotite, chalcopyrite, pyrite, and zinc blende. The arsenopyrite is massive in places, but more commonly forms 10 to 50 per cent of the volume of the rock.

The tenor of the ore is extremely variable, but its average value, as shown by annual mill returns, was $10 to $15 a ton in the earlier days of the mine. With exhaustion of the richer ores the average tenor has sunk to about $5.50 a ton.

Mining began at Hedley in 1903. Up to 1918 the mines produced from $500,000 to $750,000 in gold annually, with a peak production in 1915 of more than $900,000. Figures for production prior to 1907 have not been obtained, but total production from that year to the end of 1930 has been nearly $11,000,000.

The Surf Inlet mine is on Princess Royal island. The mine began producing on a large scale in 1917 and was closed in June, 1926, for lack of ore. In that period it yielded 322,297 ounces of gold, 176,734 ounces of silver, and 5,224,772 pounds of copper, with a total value of nearly $8,000,000. At the surface the deposit consisted of two veins of pyritized quartz 100 to 160 feet apart, one on each side of a large sheared zone striking north 3 degrees east. The veins dipped 40 to 60 degrees west and came together at a depth of about 550 feet to form one large vein. The maximum length was about 1,000 feet. The country rock is mainly quartz diorite of the Coast Range batholith, but the sheared zone cut through a large mass of chlorite schist included in the batholith. The veins were somewhat richer in the schist than outside of it. The gangue minerals were mainly quartz, a good deal of ankerite, and small amounts of other minerals. Auriferous pyrite composed up to 25 per cent of the vein material, and native silver, chalcopyrite, and minute amounts of other copper minerals were also present.

The Engineer mine is in Atlin district, at the extreme northwest corner of British Columbia, on the east side of the Coast range. The rocks are shales and greywackes of Jura-Cretaceous age, some of them tuffaceous in origin. They strike north 60 degrees west, and dip about 35 degrees northeast. The sediments are cut by a swarm of acidic dykes. Both sediments and dykes are broken by numerous small faults, with displacements ranging from a few inches to 10 feet. The fault fissures are filled with quartz and other vein minerals.

Some of the veins are very large, and composed mainly of quartz with intercalated layers and fragments of country rock. Several are as much as 50 feet wide. In addition there are two areas, described as being the "hubs" of the vein systems, 200 and 270 or more feet in width, respectively, and 300 or 400 feet long, of quartz and brecciated country rock. Other vein minerals include calcite, pyrite, and a little antimony. Gold occurs native and as telluride, along with the vanadium-bearing mica, roscoelite, in very rich pockets in the narrower veins where intersected by cross fissures. On account of the pockety nature of the occurrences, the mine has never been an important producer.

The Rossland camp, now dead, is in the Trail Creek mining division of West Kootenay district, about 6 miles west of Columbia river and 5 miles north of the International Boundary. The deposits were mined principally for gold, although they also yielded large amounts of silver and copper. Production began in 1894, and continued on a large scale from 1897 to 1916, during which time the annual output of gold was about 130,000 ounces. From 1917 to 1921, gold production averaged some 40,000 ounces annually, then fell off rapidly, until in 1927 only 6,625 ounces were obtained. Of late years the principal mines have been shut down, but until 1930 a little production was maintained from some small, high-grade veins. The total production of the camp, from 1894 to 1930 inclusive, was 2,868,227 ounces of gold, 3,616,465 ounces of silver, and 118,037,675 pounds of copper.

The Rossland ore-bodies were replacement veins. Ore-bearing solutions, forced into fissures and sheeted zones, replaced the country rock so as to form tabular masses of rich sulphide ore ranging from a few inches to 130 feet in width, and up to 4,000 feet or more in length. The typical ore consisted of pyrrhotite and chalcopyrite associated with a gangue of altered country rock, some quartz, and calcite. All gradations could be obtained from country rock and gangue sprinkled with sulphides to massive sulphide ore, but in average ore there was from 50 to 70 per cent of sulphides.

The rocks of the area include a series of highly silicified slates and tuffs known as the Mount Roberts formation, sills of augite porphyrite intrusive into the sediments, stock-like masses of granodiorite, a closely related, irregular body of monzonite, and a basic border and dyke facies of the granodiorite known as diorite porphyrite. All these rocks are older than the ore-bodies, and each influenced deposition in its own manner. In the intrusives fissures were strong and persistent, so that the ore-bearing solutions were restricted within zones of moderate width and moved freely in those zones; and good ore-bodies were formed as a result. The sediments, on the other hand, were completely shattered by the great dynamic stresses, so that the mineralizing solutions diffused over wide areas instead of being confined to particular channels. Thus no deposits of importance were formed in the sediments. Again, where fissures cut deeply into the granodiorite or monzonite it was found that, although they might remain wide and strong, the ore shoots became small, low-grade, and sporadic in occurrence; and that instead of depositing ore the solutions had silicified the granodiorite and formed such minerals as biotite, epidote, and pyrite.

Apparently, therefore, temperatures within these intrusives were too high for ore deposition. The best ore-bodies were found in the augite and diorite porphyrites and along contacts between the augite porphyrite and the monzonite, granodiorite, or diorite porphyrite. Veins were wider and richer in the diorite porphyrite than in the augite porphyrite, suggesting that the diorite porphyrite was the more easily replaced. Where veins traversed diorite porphyrite they tended to be richer in gold, and where they traversed augite porphyrite, to be richer in copper.

The Premier mine, in Salmon River section of Portland Canal mining division, is a deposit of entirely different type. It may be considered representative of the gold-silver ores of British Columbia, as well as their most outstanding example. Development on this famous bonanza began in a small way in 1918; and it has yielded, up to the end of 1930, 1,097,621 ounces of gold and 26,969,570 ounces of silver, together with some lead and copper. As this yield was obtained from only 1,870,411 tons of ore, the high average value of the ore is evident.[1]

The veins occupy fracture zones that cut a complex of andesitic tuffs and agglomerates intruded by dykes, sills, and irregular masses of granodiorite porphyry. The veins are wider and of higher grade in the brittle porphyries than in the easily sheared and relatively impermeable tuffs. The main fracture system strikes north 50 degrees east, dipping 50 to 75 degrees northwest, but at the southwest end it swings to a course nearly due northwest. In the part around the bend mineralization has been particularly wide, and the northeast arm of the fracture system, together with the part at the bend, is the section from which practically all the ore has come. This ore-bearing section, on Premier ground, is about 1,600 feet long.

The ores appear to have been formed by the secondary enrichment of a lean primary ore, through the agency of downward-percolating waters. They exhibit the variation characteristic of such deposits. The uppermost 300 feet, or, locally 600 feet, of the ore-body was a dark-coloured mixture of heavy sulphides, accompanied in places by a good deal of silica, though more commonly by little. The main part of this mixture was pyrite, the normal colour of which was masked by admixture of galena, sphalerite, ruby silvers, tetrahedrite, polybasite, and other silver compounds; native silver and electrum were also locally present in considerable amount. Below this secondarily enriched zone the ore was a heavy, granular pyrite, carrying small amounts of other minerals, particularly sphalerite, and a little silica. Certain shoots of limited extent carried large quantities of galena. Gold values in this material were relatively high in the upper parts, but gradually decreased with depth, although there was no visible change in the appearance of the ore, until, at a depth of about 1,200 feet, the tenor became too low for mining. According to the annual reports of the company, the deposit now appears to be nearly exhausted.

SUMMARY AND GENERALIZATIONS

A study of the mineral deposits of British Columbia indicates quite clearly that most, if not all, were deposited by waters emanating from the numerous cooling masses of igneous rock so widely scattered throughout

[1] These figures are taken from the 1930 Annual Report of the Minister of Mines for British Columbia. They differ considerably from the figures given in the Annual Report of the Premier Gold Mining Company for 1930, which are 1,119,096 ounces of gold and 29,296,769 ounces of silver, from a slightly smaller tonnage of ore.

the province. For the most part these rocks vary in composition between granite and diorite. The greatest continuous body of them underlies the Coast range, the western quarter or fifth of the province. Other very large bodies occur across the southern part of the province, nearly as far as the western boundary of the Rocky mountains, and also in the northern part. Still other masses of varying size are scattered throughout the interior. Only the Rocky mountains, the eastern range of the Cordillera, contain no batholithic intrusives, so far as known, except one small mass south of Field.

In the Canadian Shield the solutions forming gold deposits seem to have been of fairly simple composition. They contained silica, gold, varying amounts of iron and sulphur which later combined to form pyrite, and small amounts of other constituents. In British Columbia, on the contrary, the solutions appear to have been much more complex, and to have contained less silica but immensely greater amounts of sulphur; the metals present were not only gold, but also copper, silver, lead, and zinc in important amounts. Two striking results followed.

First, the cooling of the complex solutions produced a graded series of deposits. The first metal to separate as cooling began was gold, followed by copper, then by silver, lead, and zinc. As a consequence, a rough arrangement of the deposits relative to the source is found. Nearest the igneous rocks, which were the source, are found the gold deposits. Somewhat farther away occur the copper-gold and the copper deposits and still farther away are found the silver-lead-zinc deposits.

This arrangement obviously affords suggestions as to prospecting possibilities. Thus, if in the south end of a given district silver-lead deposits are known, and farther to the north copper-bearing veins are found, then it is evident that in going northward from the silver to the copper ores the source of both is being approached. Should this source be an intrusive mass that outcrops at the surface, the ground north of the copper deposits should be favourable for the occurrence of gold deposits. If on the other hand the source should be some mass of intrusive that does not reach the surface, gold deposits might not be found, but the copper and silver zones might be crossed again, after the summit of the source was passed. Again, if ore-bodies of the silver-lead type are found close to some igneous mass that appears to have been their source, then it would evidently be useless to look for gold deposits in connexion with that mass, as the ore-bearing solutions were evidently cooled past the gold-depositing stage when they escaped.

The second result of the complexity in composition of the ore-forming solutions is a corresponding complexity in the ores. Although quartz veins carrying free gold are common in British Columbia as in the Canadian Shield, they are for the most part of no economic value. Most of the real ore-bodies are complex ores. In other words, even in those ore-bodies where gold is the chief constituent of value, it is usual to find important amounts of copper or silver; and it is equally common to recover important amounts of gold from ores mined primarily for their copper, silver, or lead.

Another point worth mentioning in connexion with prospecting is that the examination of the intrusive bodies themselves should not be neglected. In the Canadian Shield, as a rule, bodies of granite and similar rocks are unfavourable prospecting ground, but this is not so much the case in British Columbia. The descriptions of individual properties show that many of the deposits occur within bodies of igneous rocks, particularly small ones. In some cases the igneous rocks are more favourable ground than the rocks around them because, being brittle, they broke to form clean, open fractures, whereas the softer rocks around them sheared to a multitude of little fissures, unfavourable for the formation of good ore-bodies.

Another curious difference between the ore-bodies of British Columbia and those of the Canadian Shield appears to be the depth to which they extend, and the changes that occur in them with depth.[1] It is noticeable that most of the large ore-bodies of British Columbia become worthless at comparatively shallow depths, and also that more or less pronounced changes take place with depth in the character of their mineralization. Thus, in the Nickel Plate mine the ore-bodies have a vertical depth of 1,150 feet, the Surf Inlet mine attained a depth of 1,250 feet, the Rossland deposits extended to a maximum depth of 1,800 or 1,900 feet, and the Premier to about 1,200 feet. In all of these deposits, and in others, changes in the character of the ore take place so that the ore becomes too lean for mining, even though, as in certain instances, mineralization may continue downwards. The bodies thus contrast sharply with those of similar size in the Canadian Shield, several of which are being mined below 4,000 feet, and throughout that depth no noticeable change in the character or tenor of the ores takes place. This behaviour is in line with that of Precambrian ore deposits throughout the world, for most of the very deep mines occur in Precambrian rocks. The cause of the difference in behaviour is not known, but may be a function of the depth beneath the original surface at which the ore-bodies were formed. Precambrian ore-bodies are known to have been formed at great depths, probably of the order of 5 or 6 miles, below the then existing surfaces, and, consequently, within the vertical extent of about a mile throughout which the veins have been explored there was not likely to have been sufficient change in temperatures, pressures, or other conditions to produce much change in composition. In the British Columbia deposits, however, the original surface appears to have been not more than 1 or 2 miles above the present surface, and zoning, due to changes in temperature and pressure as solutions rose, would be much more pronounced.

SULPHIDE ORE-BODIES

There are many ore deposits throughout Canada which are mined primarily for some metal or metals other than gold, but which contain also appreciable amounts of gold. Although it is outside the scope of this paper to discuss such deposits at length, the following brief descriptions are introduced to give some idea of the nature of these bodies and the importance of their contributions to the national gold output.

In the Canadian Shield a number of such deposits have been opened in recent years. These include the Noranda and some smaller mines in western Quebec, and the Mandy, Flin Flon, and Sherritt-Gordon properties in northwestern Manitoba. The great copper-nickel ore-bodies of Sudbury also carry a little gold.

[1] The writer is indebted to Mr. George Hanson for this most interesting generalization.

All these deposits, except those at Sudbury, are of the same type. They are irregular, lens-like masses of sulphides formed by replacement of very ancient Precambrian rocks. At the Sherritt-Gordon mine these rocks are very old, highly metamorphosed sediments; in the other mines they are the Keewatin lavas and tuffs. Certain of the ore-bodies consist only of country rock thickly spattered with sulphides, but in most of the commercially important bodies replacement has been complete enough to produce masses of solid sulphides with a few unimportant inclusions of rock. In all of them the first-formed sulphide was pyrite, pyrrhotite, or a mixture of the two, and this initial deposit was then replaced by chalcopyrite or a mixture of chalcopyrite and sphalerite.

In Manitoba the Sherritt-Gordon ore-bodies are estimated to contain more than 4,000,000 tons of copper-zinc ore carrying 40 cents to $1 a ton in gold. The Flin Flon ore-bodies are estimated at 16,600,000 tons above the 900-foot level, and the average gold content at 40 cents to $2 a ton. Much of the richer ore at the Mandy mine has been already removed, and the remainder is estimated at 180,000 tons in the main lens, with a gold content of perhaps $2 a ton. These bodies will, therefore, yield important amounts of gold as mining proceeds.

In Ontario the principal sulphide bodies are the copper-nickel ores of Sudbury, which average about 20 cents a ton in gold. Gold recoveries in 1930, from the smelting of 2,357,154 tons of ore, amounted to $472,703.

In Quebec the largest sulphide bodies as well as those richest in gold occur at Noranda Mines. These are replacements of acid lavas and tuffs shattered by intense drag-folding and faulting. Gold values occur, not only in the sulphide masses but also in the silicified lava and tuff used as flux. In 1930 the average gold value of the ore and flux smelted was $3.30 a ton, and a total of $2,423,332 in gold was produced. In 1931, according to returns of the Quebec Department of Mines as reported in the press, Noranda will produce nearly $5,000,000 in gold.

The other sulphide deposits of Rouyn district, Quebec, namely, Amulet, Waite-Ackerman-Montgomery, and Aldermac, carry only low gold values. The Aldermac mine is known to contain more than 2,000,000 tons of ore with an average gold content of 40 to 50 cents a ton. Amulet ore-bodies contain some 600,000 tons of ore with an average gold content of about $1 a ton. These figures, though only rough approximations, will serve to give some idea of the probable gold recoveries from the mining of these bodies.

In British Columbia the principal mines of this type are the Hidden Creek mine at Anyox, the Britannia mines about 20 miles north of Vancouver, and Copper Mountain mine, near Princeton. All of these are sulphide bodies mined principally for their copper. The ores are mainly iron sulphides, with more or less chalcopyrite and subordinate amounts of galena, zinc blende, and arsenopyrite. They have been formed by replacement of basic schists. The amount of gold in the ores is very low, between 10 and 20 cents a ton, or much the same as that of Sudbury ores; but with the large tonnages milled, the total gold recoveries are of importance. Thus Britannia Mines in recent years has recovered from 13,000 to 14,000 ounces of gold annually; Hidden Creek between 4,000 and 5,000 ounces; and Copper Mountain about the same.

PART II

Placer Gold in Canada; Modes of Occurrence and Hand Methods of Mining

By W. A. Johnston

INTRODUCTION

Interest in the possibilities of placer or alluvial gold mining in Canada has been revived owing to the premium on gold as compared with other metals and to unemployment. During the past two summers much prospecting for placer gold and mining by hand methods has been carried on at a number of places along North Saskatchewan river and at many places in British Columbia and Yukon. Consequently, there has been considerable demand for information as to mining possibilities and methods of prospecting and mining. In British Columbia this demand has been met by the publication of a series of bulletins compiled by John D. Galloway, Provincial Mineralogist. These include summaries of placer mining in the several fields of the province and reports of recent investigations of placer gold occurrences. In the other provinces little published information is available. The present report is intended to furnish information regarding the modes of occurrence of placer gold in the several fields in Canada and to describe some of the simple methods by which the gold is recovered. Placer mining has been carried on for many years in these old fields and the yield has gradually declined from $24,000,000 in 1900 to about $1,000,000 in 1931, so that it is not to be expected that any very rich ground remains to be worked. Nevertheless, there are probably many places where at least small returns may be had by hand methods of mining; and prospecting may result in new finds which will yield better returns.

MODE OF FORMATION AND KINDS OF PLACERS

Placers are deposits of sand and gravel or other such materials containing gold and other valuable minerals in paying quantities. The phrase "in paying quantities" is a necessary qualification, for many gravel deposits contain some gold which cannot be recovered profitably by any method. On the other hand, certain gravels may be mined profitably under some conditions, such as the cost of living at one time, and not under other conditions, so that the term is a relative one. At the present time, for example, where there is a premium on gold and a great demand for work that will at least pay a living wage, many deposits may be considered as placers which otherwise would be regarded simply as gravels.

The gold found in placers originally existed in the bedrock as deposits of various kinds and usually in areas where intrusive rocks occur. In some cases the gold was in finely disseminated particles of free gold; in other cases it was combined with other elements. The gold in some cases may have been in the free form only in the upper, weathered parts of the deposits and combined with sulphides or other elements in the lower parts.

In some cases, also, placer gold has been rederived from the wearing away of hard rocks containing ancient placers. In whatever way the gold originally occurred, it has been freed as the result of disintegration and weathering of the rock, and streams, along with other forces such as wave action, have concentrated it to form the workable deposits known as placers or alluvials. Concentration of the gold takes place in many different ways. Running water tends to carry away the light materials and leave the heavy gold behind; gold transported along with gravel tends to sink down through the gravel to the bottom of the stream bed and to remain in crevices or other irregular openings in the bedrock or on an impervious layer of clay or other material. Flood or flour gold, however, which is transported in suspension in muddy water and occurs in the form of bar placers, does not sink through the gravels to be concentrated on the bedrock, but forms thin paystreaks in the gravels at about low water-level. Moreover, the paystreaks are more unevenly distributed than is the coarse gold; they occur locally on the upstream side of bars and at other places where alternate deposition and erosion of material has taken place.

Placers may be moved or re-sorted several times. Bars may be carried away by floods and re-formed at other places. Uplifting of the land or the normal tendency of streams to cut down their valleys may cause placers to be left in the form of benches or old channels and the cutting away of these by meandering or shifting of streams flowing at lower levels may cause a reconcentration of gold. In the Klondike placer field it was frequently noted that the richest deposits occurred where the present streams had cut away old stream deposits. In other places the rather abrupt termination of a paystreak in the valley bottom was found to be due to the fact that above this point the only paystreak was on a bench or in an old high-level channel. Even in the present valley bottom the paystreak may be quite irregular and may not necessarily lie below the present stream meandering from side to side; the gravel in the valley bottom probably has been worked over many times, for the bends of the stream migrate downstream and the valley flat is constantly being widened. Coarse gold passes down through porous gravels and remains on or in crevices in the bedrock and erosion of this bedrock by stream action may result in little downstream transportation of the gold. In many cases the vertical distance to which gold has been transported from its original source is greater than the horizontal distance. This has been proved in Klondike district by the relationship of the occurrences of gold in the present creek bottoms to those in old channels at high levels. On the other hand coarse gold cannot sink through clayey gravels or other impervious material such as talus containing clay, and because of clay adhering to the gold may be transported downstream by floods to be again deposited at places where the current slackens. Concentration of the gold then takes place by stream erosion of the material deposited. Thus there is a tendency, as in the case of bar gold, for the richest deposits to be found at places where there has been alternate erosion and deposition and, therefore, irregularity in the bottoms of the stream valleys. In unglaciated areas such as the Klondike where the streams have worked over only the local gravels, unmixed with glacial drift, the gold is more evenly distributed through the bedrock gravels than in glaciated areas where the glacial drift is thick and much of it barren of gold. Probably, also, stream action in the existing valleys has continued very much longer in the unglaciated areas; the time since the disappearance of the glaciers of the ice age is only a few thousand years, so that the streams in the glaciated areas, which include nearly all of Canada except parts of Yukon, are quite youthful, whereas in the Klondike they may be fairly old.

For placers to have formed, gold must have been present in the bedrock, it must have been freed from the rock by weathering, and have been concentrated by stream action or in some other way. Residual placers are formed by weathering and erosion of mineral deposits without transporting the gold from its source. Most rich placers are concentrations from enormous volumes of rock and occur in regions that have been worn down for several thousand feet to plains of low relief, which later were uplifted and dissected by streams.

Creek placers occupy the bottoms of small stream valleys and are the commonest and most productive placers. In them the gold is in the lower few feet of the gravels or on and in the bedrock in joints and cracks. If the gravels are porous, nearly all the gold is likely to be on or in the bedrock, which may be a false bedrock of clay or the solid rock. As the paystreaks are irregular the whole width of the valley flat should be tested. Similar placers do not occur as a rule in the beds of rivers or of streams large enough and of sufficient grade to transport gravels along their beds and to erode their beds; for the gold transported with the gravel is ground fine enough to be carried in suspension in muddy water. It is deposited on bars to form river-bar placers. In these most of the gold is fine and the deposits are usually very low grade as compared with creek placers, but on some streams the gold is much coarser than on others.

Bench placers are ancient placers, occurring on benches or terraces above the present stream level. They are remnants of old stream channels formed when the streams flowed at a higher level than at present. In places the entire channels partly filled with gravels may be preserved. These are frequently referred to as ancient or high-level channels. A common feature in glaciated regions is the presence of buried or drift-filled channels alongside rock canyons on the streams. The channels are the old beds of the streams. In places, also, old channels have been buried beneath lava flows and may contain gold-bearing gravels.

Gravel plain placers are formed in broad, flat-bottomed valleys and contain gravels that have been repeatedly worked over by streams. The gold is likely to be moderately fine and fairly evenly distributed through the gravels. The placers are best developed in unglaciated regions where stream action has continued for a long period of time.

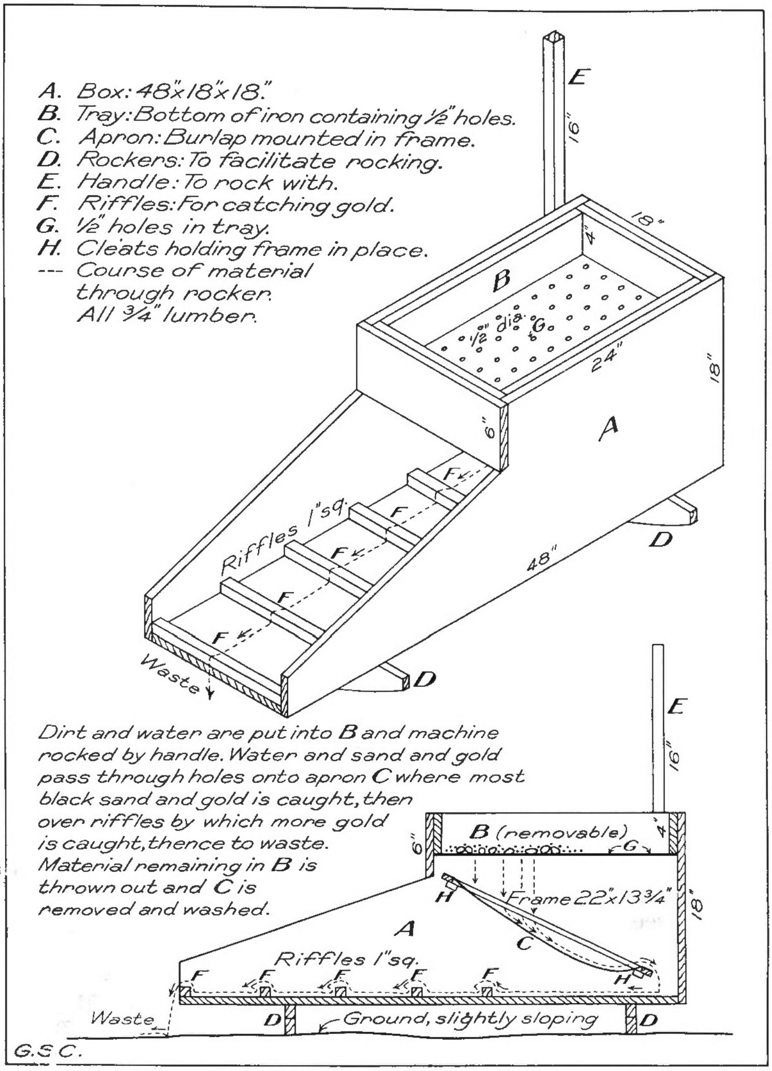
Beach placers are formed by wave erosion and concentration of the materials in sea-cliffs. As a rule they are of value only in places where there has also been some concentration of the gold by stream action. The beach placers on the northeast coast of Graham island, Queen Charlotte islands, are derived from the erosion of glacial drift. The gold is fine and occurs with black sand which renders its recovery difficult. Some investigators hold that although the deposits cannot be worked profitably on a large scale, fair returns may be had by hand methods in favourable places, for example where stream and wave-action have combined to concentrate the gold.

DESCRIPTION OF HAND MINING METHODS

A gold pan is used for testing the value of placer ground and for recovery of gold from concentrates. It is not ordinarily used alone for mining, as there are other methods that can be used to better advantage, but it is a necessary part of the equipment of a prospector unless the ordinary 10-inch frying pan with the handle removed is used. A gold pan with a copper bottom is of advantage for the recovery of very fine gold like that on North Saskatchewan river. By rubbing mercury on the copper bottom, fine gold is retained through amalgamation.

Recovery of gold by panning is based on the principle that the gold when brought into suspension along with sand and gravel in water tends to settle through these materials and to collect in the bottom of the pan. This principle should be kept in mind in operating a pan. After placing the pan under water the gold is freed from any clayey material by breaking up any lumps and thoroughly mixing the materials. When the material has been thoroughly broken up and the large stones removed, the pan is given a slight, oscillating, circular motion that keeps the lighter material in suspension and washes it out of the pan. The operation is continued until only the gold and other heavy concentrates are left. If only coarse gold is present there is no difficulty in saving it, and panning may be done rapidly and the gold picked out from the concentrates by hand. In the case of fine gold much black sand is likely to be present and the operation is not so simple. By circulating a small amount of water over the concentrates the gold may be separated from the black sand in the pan sufficiently to permit of counting the colours; the gold being heavier than the sand remains behind in the form of a tail. Separation of the gold from the black sand and other concentrates and saving it is done by drying the mixture and blowing the lighter materials away or, in the case of finely divided gold, by amalgamating it with mercury.

Estimation of the value of ground from the results of panning can be made accurately only by determining the amount of gravel washed and weighing the gold recovered; but some idea of the value may be obtained by counting the colours or small particles of gold obtained in panning, observing their character and comparing them with gold the value of which is known. Much of the gold found on river bars is so fine that it is known as flour gold. It ranges from 100 or 200 to over 1,000 colours to 1 cent and all of it will pass a 40-mesh screen unless the particles are in the form of thin, flattened scales. Individual colours as small as 500 to 1 cent can be readily seen in a pan even without the aid of a lens, so that one should not be misled by the large number of small colours that may be obtained by panning in many places, into believing that the ground is of exceptional value. For example, 100 colours to the pan may mean that the value of the ground is approximately 30 cents a cubic yard assuming 150 pans equal a cubic yard and that the gold averages 500 colours to 1 cent. Flour, or flood, gold as it is sometimes called, is fine enough to be carried in suspension in flood waters of streams. Gold which passes a 10-mesh, and remains on a 40-mesh, screen has an average value of 3 or 4 to 1 cent unless the gold is much flattened or scaly. Alluvial gold is always alloyed with silver and ranges in value from about $12 to nearly $20 an ounce, the value of pure gold being $20.67 an ounce. There is no difficulty in saving, by means of a rocker or in sluice boxes, gold that is coarse enough to be held on a 40-mesh screen, but flour gold can be recovered economically only by amalgamation with mercury. It is important, therefore, before attempting to mine to determine the character of the gold and the approximate value a cubic yard of the ground.



F ure 7. Diagram illustrating construction and mode of operation of a rocker (after J. D. Galloway).

Rockers (*See* Figure 7) are of many forms and sizes depending ıpon the size of gold to be recovered and on other factors. The rocker handles about 3 to 5 cubic yards of material per 10 hours, its capacity depen^ding upon ^the size of the gold and the amount of clay present. The gold ı ı ı ıt be washed free of clay. Coarse gold is easily saved, whereas very fine gold may be carried in suspension in dirty water and pass through the rocker; the grade or slope at which the rocker is placed must be small if there is much clay and the gold is fine. For the recovery of flour gold it is necessary to use instead of canvas for the apron a piece of blanket or some material that has a nap on it that will retain the gold; the lower part may consist of a copper amalgamation plate on which mercury is rubbed to catch and retain the gold. Copper plates as a rule are silver plated to render them more efficient. If both coarse and very fine gold are present the former can be caught in folds in the canvas apron; the canvas is not stretched tight, but allowed to sag so as to form one or more open folds. Even the best equipped rocker is not as efficient as the gold pan but probably is more efficient than any large-scale operation. In operating a rocker it is important to bear in mind that recovery of a maximum amount of gold in a given time is what is desired, not necessarily recovery of all the gold; speeding up of the operation, for example by increasing the grade of the rocker, may cause loss of some of the finest of the gold but cause a larger total recovery. It is true, of course, that some operators are much more successful than others and that for successful operation a certain amount of experience and care is necessary.

For the operation of a rocker sufficient water is required to thoroughly wash the gravel. If necessary it can be used over and over, but clean water is preferable. The gravel is placed in the screen or grizzly and water poured over it. At the same time the rocker is shaken; the motion is a quick jerk with a sudden stop. Judgment must be exercised in the use of water. If too much is used the fine gold is washed over the riffles, yet sufficient must be used to wash the gravel clean and remove the clay. The concentrates must not be permitted to build up so as to overtop the riffles, but should be removed from time to time and the canvas or apron rinsed off in a tub.

Sluice boxes into which a stream of water is led and which are equipped with riffles for saving the gold are by far the commonest and most efficient means of mining alluvial gold by hand methods, because lumber for the boxes can be hewn out with the whipsaw even in the most remote districts and much larger amounts of ground can be handled by their use than by any other simple method. As a rule the boxes are 12 feet long, 12 inches wide, and 12 inches deep, but the sizes depend partly on the lumber available. One end of each box may be narrower than the other, thus permitting telescoping of the boxes, but this is not necessary if joints can be made water tight. The boxes may rest on the ground, but as a rule are elevated on trestles or on boulders to provide for disposal of tailings or waste, and to maintain a grade of about 6 inches for each 12 feet of sluice. The grade may be somewhat less if the gold is fine and there is a large supply of water. Sufficient water, preferably enough to fill the boxes about half full, should be available, otherwise it is useless to construct the sluice. In order to lead the water into the upper end of the boxes it may be necessary to dam the stream or to bring water some little distance by means of a ditch or flume. In order to mine the bed of a creek it may be necessary to divert the creek; the extent of such operations depends upon the value of the ground, which if possible should be determined beforehand. Very extensive operations may be carried on by hand methods, in fact the great bulk of the gold in the Klondike was recovered by simple hand methods.

Riffles for the sluice boxes can be constructed of many different things; wooden blocks, expanded metal, angle iron, poles run lengthwise of the box, crossbars of wood or metal, and even stones and boulders. They should not be fastened permanently in the box, as it is necessary to remove them for the clean up. They may be held in place by nails that are not driven all the way in from the sides or by wedges. They may be placed in one or more boxes depending upon the amount of material to be handled and the size of the gold. Fine gold requires more time to settle.

In operating the sluice the gravel is shovelled into the boxes and the coarse material removed with a fork or the gravel is shovelled into a grizzly at the head box and the water run over it, the oversize being raked or shovelled to one side. When fine gold is present mercury may be placed back of the riffles in the boxes near the discharge end of the sluice, or the fine materials may be screened off at the discharge end and made to pass over an amalgamating plate or over burlap tables. If the gold is coated with a film of clay or some other material such as iron oxide it will not amalgamate. It may sometimes be cleaned by lye made by leaching wood ashes.

The clean up of the sluice or recovery of the gold is done by removing the riffles and allowing a stream of water, just large enough to wash the heavy sands, to flow down the sluice. The clean, coarse gold is picked up or scooped up and the finer concentrates washed into a tub or a gold pan. If mercury has been used in the boxes or is used to separate the gold from the heavy sands, the amalgam is softened with an excess of mercury and the mixture stirred so as to cause the base material to rise to the surface where it can be skimmed off. The excess mercury is removed from the cleaned amalgam by squeezing through a chamois skin or strong, cotton cloth. Retorting of the amalgam removes the mercury. The prospector usually heats the amalgam on a shovel over the fire to drive off the mercury. This should be done out of doors, as the fumes of mercury are very poisonous. Platinum does not amalgamate with gold; it may be separated, if present, from the other concentrates by careful panning.

DESCRIPTION OF PLACER FIELDS IN CANADA

GENERAL STATEMENT

No new placer gold field has been found in Canada since the discovery of the Klondike and Atlin gold fields over thirty years ago, but many finds, a few of them of considerable importance, for example Cedar creek in Cariboo district, British Columbia, have been made in the old placer mining areas. Other discoveries of importance probably will be made in these fields even if new fields are not found. It may be of value, in the search for new finds, to consider the various ways in which placer gold occurs in the old fields, for the modes of occurrence furnish clues as to how to prospect for other deposits. Moreover, the best known and richest placer fields probably offer the best opportunity for mining by hand methods, though the returns in many cases may be exceedingly small owing to the fact that mining in all the areas has been carried on for many years. Although the production of placer gold is only a small fraction of what it formerly was, it has been markedly increased during the past two years, both in British Columbia and in Yukon, owing to greater activities in these old fields and not to any new discoveries of importance. In connexion with any proposed attempts at mining, however, it should be borne in mind that placer ground of value in any of the mining fields is likely to be held by individuals or companies under some form of title, and that it is by no means easy to find places where even a living wage can be made by hand methods, even if the ground is open for staking, unless one is fortunate enough to discover a gold-bearing creek that has not previously been mined.

The placer fields of British Columbia lie along a broad belt between the Coast mountains on the west and the Rocky mountains on the east and northeast. They include Tulameen area and isolated creeks such as Rock, Boundary, and Wild Horse in the southern part of the province, the important Cariboo district in the central part, Omineca and Peace River areas in the northeast, and Cassiar and Atlin districts in the far north and northwest. In Yukon, also, the main placer field, the Klondike, lies in the interior plateau region bordered on the north, east, and south by mountain ranges. A notable feature, which should be taken into consideration in the search for other fields, is that nearly all the important occurrences are in the plateau regions that have been deeply dissected by streams and not in rugged mountain areas. Some of the placer fields, for example, the well-known Barkerville district in the Cariboo, are so deeply trenched by streams that they appear to be mountainous. Nevertheless there are numerous, flat, upland remnants and the general appearance of this area is quite different from that of the rugged Cariboo mountains to the east, in which no placer gold has been found. The reason why placer gold is found in the plateau areas and not, at least so abundantly, in the mountain areas, appears to be because the uplands or plateau remnants are old surfaces that have been produced by streams eroding away great thicknesses of once overlying rocks and, therefore, on these surfaces there was concentration of heavy minerals from the erosion of possibly several hundreds or even thousands of feet of bedrock; when uplift occurred or for some other reason the present streams eroded their valleys in the old erosion surface, new concentrations took place in the bottoms of the valleys. On the other hand, in the mountain regions there were no old concentrates and the gradients of the streams are much steeper, so that any concentrates produced may be ground up and transported out of the region and the concentration remaining may be only of the mineral in the limited amount of rock eroded by the streams. Of course the rock must have been mineralized to some extent else there could be no concentration, and it is conceivable that placers may occur in mountain regions where the rock is heavily mineralized. Fine gold may be transported by rivers for long distances and important bar deposits may occur in mountainous areas, for example on the lower Fraser near Hope, so that the above theoretical considerations apply only to the occurrence of fairly coarse gold.

A study of the geological map of western Canada furnishes other evidence why the placer fields are discontinuous and why certain areas are much more favourable than others. For example, in the Rocky mountains the bedrock consists largely of limestones which are not mineralized to any great extent. On the west the great Coast Range batholith itself is largely barren of minerals, though it and many other intrusives probably caused mineralization in the rocks surrounding them. The great lava plateaux northeast of Cariboo district are unfavourable as they are areas of deposition of barren rock rather than areas of erosion. On the other hand, Cariboo and other districts are favourable because they are in parts underlain by ancient slates and schists mineralized by intrusions of igneous rocks.

A feature of importance which distinguishes the placers of the Klondike field in Yukon from those in British Columbia is that the former are in an unglaciated area, whereas the latter were greatly and adversely affected by glaciation during the Pleistocene or last ice age. The effect of glaciation in general was to erode the pre-Glacial placers in the valley bottoms and to scatter the gold and mix it with the glacial drift. A few were preserved in narrow valleys which happened not to be severely glaciated or which lay across the general direction of glacial ice movement so that the bottoms of the valleys were not eroded. These old placers, however, as a rule were deeply buried beneath glacial drift. Placers in the unglaciated Klondike region, therefore, were much more favourably situated than those in British Columbia, and were the richer. The action of the ice-sheets in scattering of the placer gold was far more pronounced in areas of low relief, such as the Canadian Shield, than in mountain areas, so that, as a rule, in these areas no ancient gold-bearing gravels are found. In a few places, however, for example in Beauceville area in Quebec, ancient gold-bearing gravels were preserved in spite of glaciation, probably because they lay in valleys transverse to the direction of movement of the ice-sheet.

YUKON

Prospecting for placer gold in Yukon territory was carried on for at least fifteen years prior to the discovery of the Klondike in 1896. From this field the main production of placer gold in Canada has come. Production reached a maximum in 1900, when it exceeded $22,000,000. Discovery of this remarkably rich field was delayed because attention had been directed to the larger streams such as the Yukon, Stewart, and Big Salmon, where only bar gold was found, rather than to the small streams, from which the bulk of the gold in the Klondike has come. Bonanza creek, for example, one of the most important creeks of Klondike district, is a comparatively small stream even near its mouth, where it measures about 15 feet in width and 3 or 4 inches in depth. It flows through a valley flat 300 to 600 feet wide, bounded by steep slopes. Creek gravels 4 to 8 feet thick, extended across the valley bottom and were overlain by a few feet of frozen muck. The valley proved productive for about 13 miles and yielded in the part about mid-length over $1,000 a running foot of valley. The fact that the creeks have proved of much greater value than the river valleys may be of significance in the search for new fields, even though it is scarcely to be expected that any such rich creeks as Bonanza remain to be discovered.

Placer gold has been produced from the Fortymile, Sixtymile, Mayo, Big Salmon, and Kluane areas (Figure 8) in addition to the Klondike and a number of isolated creeks. Klondike area is east of Yukon river in

Figure 8. Index map of Yukon showing unglaciated areas (pattern of ruling) and location of principal placer gold areas. 1, Klondike; 2, Fortymile; 3, Sixtymile; 4, Mayo; 5, Big Salmon; 6, Kluane.

latitude 60 degrees north and is bounded in a general way by Yukon river on the west, by Klondike river on the north, by Flat creek, a tributary of the Klondike, and Dominion creek, a tributary of Indian river, on the east, and by Indian river on the south. The area includes about 800 square miles.

Klondike district[1] is an upland or plateau thoroughly dissected by stream valleys. Viewed from a distance, the district has a hilly or even mountainous aspect, but in reality consists of a series of long, branching ridges separated by deep valleys. Most of the ridges originate at or near the Dome, the topographic centre of the district, and the highest point in it. The Dome is 19 miles southeast of Dawson and about midway between Indian and Klondike rivers. It has a height of about 4,250 feet above the sea, 3,050 feet above Yukon river at Dawson, and about 500 feet above the ridges at its base. It is the principal drainage centre of the district; from it several of the gold-bearing creeks radiate. Subordinate drainage centres occur at other places.

The area is underlain by rocks ranging in age through the greater part of the geological scale, and presenting extreme variety in structure and composition. The rocks consist dominantly, however, of various schistose members that are believed to be Precambrian in age. These have been repeatedly pierced, at widely separated periods, by igneous intrusions. The older rocks are in places overlain by Tertiary sediments and volcanics and by superficial accumulations. The oldest and most important formations consist of schists, partly of clastic and partly of igneous origin. The principal producing creeks of the district traverse the area occupied by these schists.

Klondike district was not glaciated; the gold-bearing gravels are not covered with glacial drift as is generally the case in glaciated areas, and were not disturbed or eroded by over-riding of the ice-sheet. The Pleistocene glaciers in the surrounding regions extended down Lewes river only as far as Rink rapids and left the Klondike and a surrounding area free from glaciation (Figure 8). A thick covering of decomposed rock, usually intermingled with slide rock or talus, mantles the valley slopes nearly everywhere in the unglaciated area. Muck or frozen bog which has a maximum thickness of about 100 feet is a characteristic feature of the district. It is being formed at the present time, owing chiefly to the fact that the mean annual temperature is a few degrees below the freezing point and the ground, therefore, is permanently frozen, except in favourable places, and this prevents destruction by oxidation of the rather abundant marsh vegetation. The thickness of the frozen stratum including the frozen muck varies from a few feet to over 200 feet, and is less on the ridges than in the valleys, and on southern than on northern exposures. Running water is always struck below frost-line in the valley bottoms and this may cause difficulty in testing the deep ground by sinking shafts. The summer heat has little effect on the frozen layer except in the few places where the surface is unprotected by moss. Gravel beds exposed to the sun thaw out to a depth of from 6 to 10 feet, and gravels over which or through which water flows are not likely to be frozen. The depth of

[1] The general description here given of the Klondike gold fields is based on R. G. McConnell's reports on the district.

the frozen ground in Mayo district (in the glaciated region) is at least 400 feet in places. Frozen ground probably occurs at least locally to some extent throughout nearly the whole of Yukon territory both in the glaciated and unglaciated areas.

A cross-section of any of the gold-bearing stream valleys in the Klondike usually shows a comparatively narrow inner valley, bordered on one or both sides by wide benches beyond which the surface rises gradually to the crests of the inter-valley ridges. The benches are fragments of old valley bottoms partly destroyed by the excavation of the present valleys. Narrow terraces occur in places between the level of these old channels and the level of the present stream. Auriferous gravels occur on the present valley bottoms, on the rock benches cut into the valley sides, and on the preserved parts of the old high-level benches of channels. These deposits may be classified as follows:

Low-level gravels........................	Gulch gravels Creek gravels River gravels
Gravels at intermediate levels.............	Terrace gravels
High-level gravels........................	River gravels White Channel gravels

The creek gravels are the most important and floor the bottoms of the valleys to depths of 4 to 10 feet. They rest on bedrock and the gold in many places extends down cracks and joints in the bedrock to depths of 2 to 3 feet or even more, so that in mining a few feet of bedrock must be removed. The gulch gravels occupy smaller tributary valleys and the upper parts of the main creek valleys and as a rule are overlain by a considerable thickness of muck. River gravels containing gold in paying quantities occur on the wide flats bordering the lower part of Klondike river below the mouth of Humber creek. These gravels have been enriched by deposition of fine gold transported by rich tributary streams and by deposition of coarse gold derived from former extensions of the high-level, White Channel gravels, which were eroded away as a result of the deepening of Klondike River valley.

Terrace gravels occur on rock benches cut into the steep slopes of the present valleys at various levels. The benches are irregular in distribution and are remnants of valley bottoms formed when the streams flowed at higher levels than the present. The gravels are very similar to the creek gravels, but show more wear. As a rule they are overlain with muck.

High-level river gravels, usually at an elevation of from 200 to 300 feet above the valley flats, occur at various points along Klondike river. They have a thickness of 150 to 175 feet and consist of well-w... pebbles derived in large part from the western slopes of Ogilvie range. T... avels as a rule carry only slight values, but below th... mouth of Bona... creek they hav... een enriched and in places contain gold in commercial q... tities.

The ...hite Channel bench or hill gravels are the oldest in the ...strict. They occur on benches and in old channels bor...ring the present ...lleys at elevations of 150 to 300 feet. Their distribu...n is irregular, as large portions were destroyed during the deepening of t... alleys. The deposits range in width from 100 feet to more than half a mile, and in thickness from a few feet to nearly 400 feet. They are very compact, the bedding planes as a rule are inconspicuous, and there has been no sorting of the constituents into beds. The gravels consist chiefly of rounded pebbles and rounded and subangular boulders of vein quartz in a matrix of little worn quartz and sericite. Unlike the creek and gulch gravels they appear to be destitute of vegetable and animal remains. Loosely-bedded, yellow gravels, containing a smaller proportion of quartz than the ordinary white variety, in places overlie or are interbedded with the white gravels. They are seldom productive. The White Channel gravels are evidence of a long period of erosion during which the main concentration of placer gold into definite paystreaks took place. Practically all the gold in the present low-level valley flats was derived by reconcentration from the high-level gravels.

The age of the White Channel gravels has not been determined, but they probably date back to the Pliocene at least. They were certainly deposited before the advent of the present severe climatic conditions, as the whole coloration is largely due to the leaching of the greater part of the iron by circulating waters, and this must have taken place before they were permanently frozen. The fossil remains of mammals in the low-level creek and gulch gravels indicate that these gravels are Quaternary (Pleistocene and Recent) in age. There is no very definite evidence as to the age of the intermediate terrace gravel and the high-level river gravels, but judging by the unweathered character of the high-level river gravels and their derivation from Ogilvie mountains—which was probably a result of mountain glaciation—it seems probable that these gravels, as well as the intermediate terrace gravels, are of Quaternary age.

In the Klondike three main conditions account for the extreme richness of the placer deposits. (1) the bedrock is mineralized; it contains numerous quartz veins carrying small amounts of gold. (2) the area is a deeply eroded plateau remnant; probably several thousand feet of rock have been removed by stream action and the gold it contained was concentrated in the gravels formed from the more resistant rocks such as vein quartz. (3) the area has not been glaciated; consequently whatever gold became concentrated in the stream gravels remained there and was not swept away or scattered by glacial ice, nor buried under boulder clay or other glacial accumulations.

Conditions in Big Salmon and Mayo areas, the chief districts outside of the Klondike to which attention has been directed during the past few years, are different from those in the Klondike because these areas have been glaciated. Many of the old stream channels are buried beneath glacial drift and the present stream gravels are difficult to mine because of the p sence of boulders and abundance of glacial drift. Owing partly to th difficulties production from the glaciated areas has been small.

ing the past few years mining operations have been largely restr d to the Klondike, and most of the gold has been won dredging on th Klondike River flats and on Dominion creek and by h draulicking of th high-level White Channel gravels along the lower par of Bonanza creek and in the channel extending through to Klondike River valley, and at other places. Since the discovery in 1919 that the cost of thawing the frozen ground with cold water is about half that of steam thawing there has been a great saving in the cost of dredging; some has been done for as low as 6½ cents a cubic yard, so that large quantities of low-grade gravels, which were formerly thought to be unworkable, have been mined at a small profit. The problem of profitably working large quantities of low-grade gravels in benches too high above the water-levels to admit of operation by floating dredges, and not sufficiently elevated for hydraulicking, has not yet been solved, although electrically operated traction shovels introduced in 1925 appeared to be successful for a time.

If muck is not interbedded with sand and gravel it can be excavated with a pick without being thawed. Otherwise thawing is necessary and may be done with heated rocks covered with moss or some other material so as to retain the heat, by means of wood fires or with hot or cold water using "points" or pipes that are driven to bedrock and the water or steam forced into the ground. Ground sluicing consists of diverting the stream and using it to erode the overburden and concentrate the heavy minerals in the gravels. This work is best done in the spring by taking advantage of the freshets. Muck and ground ice are easily thawed by the flood waters; the upper gravels are sluiced off and the pay gravels shovelled into boxes and sluiced in the ordinary way. The pay dirt, which may be mined during the winter and piled at the surface, is shovelled into boxes and washed, after it is thawed in the spring, the boxes being placed high enough to provide for disposal of the tailings. The self-dumping carrier specially designed for the Yukon may be used to hoist the dirt from the bottom of the shaft to the dump or sluice box. The frozen ground is of advantage in mining as there is no trouble from the inflow of water and timbering as a rule is not necessary. On the other hand, and especially in the glaciated areas where the pay gravels may lie at a considerable depth below the frost-line, there is generally a strong flow of water which may prevent mining or adequate testing of the ground.

BRITISH COLUMBIA

The placer fields of British Columbia (Figure 9) are only briefly described here, as all of them are referred to in Bulletin No. 1, 1931, published by the Department of Mines, B.C., and in other available publications.

Atlin

This district, which lies in the extreme northwest corner of British Columbia, became known as a productive placer gold camp in 1898 at the time of the Klondike rush. The gold output in 1899 amounted to $800,000. From 1900 to 1924 the annual production was from $150,000 to $530,000; since 1924 it has been about $50,000, but was somewhat greater in 1930 and 1931.

The area is a deeply eroded and glaciated plateau region bordered on the west by the rugged mountains of the Coast range. The general elevation of the valley bottoms is about 2,200 feet; that of the mountain tops or plateau is 5,000 to 6,000 feet.

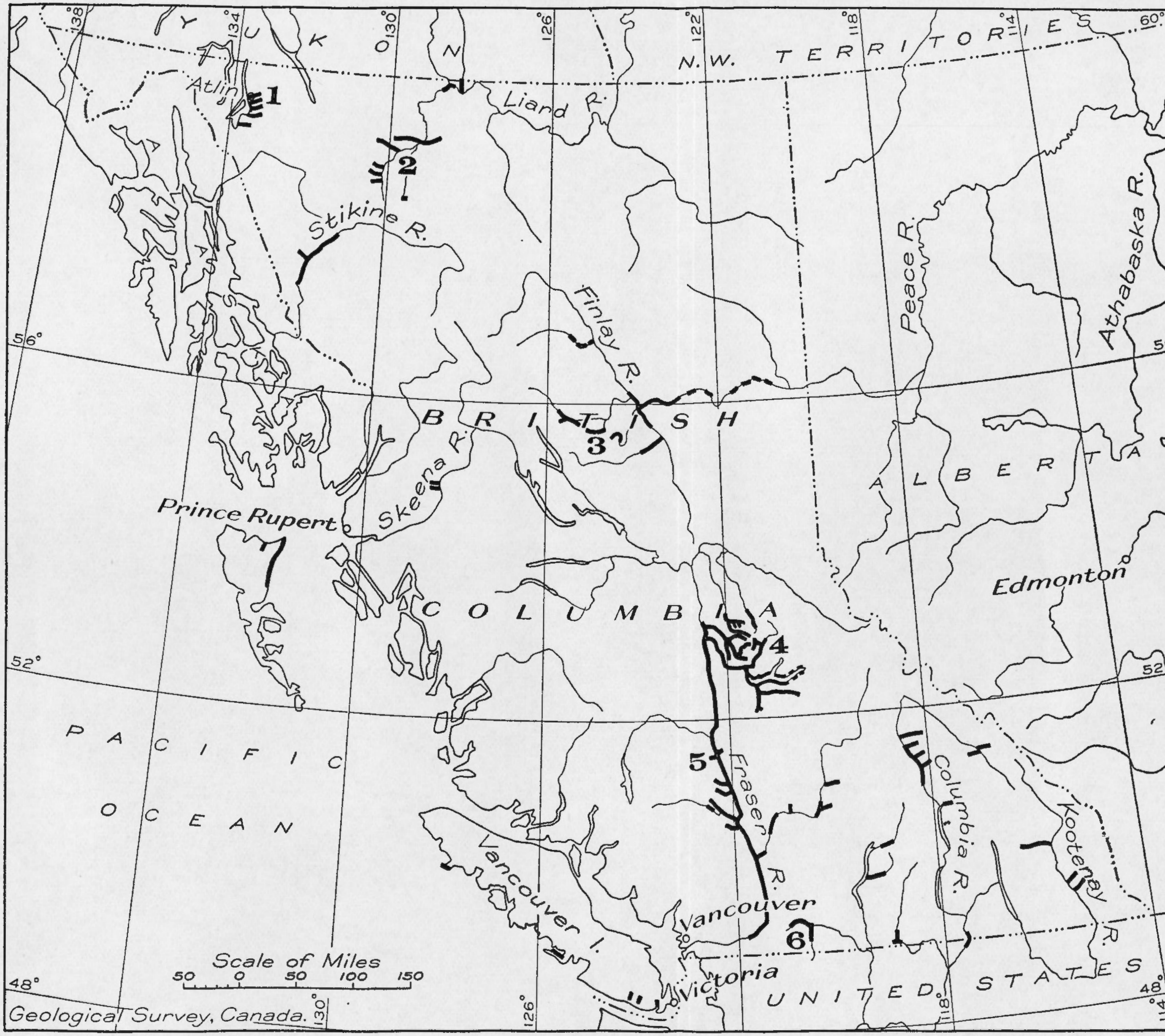


Figure 9. Index map of British Columbia showing location of gold placers (shown by heavy black lines). 1, Atlin; 2, Cassiar; 3, Omineca; 4, Cariboo; 5, Fraser river; 6, Tulameen.

The bedrocks underlying the area present great variety in structure and composition, and range in age from Palæozoic to Pleistocene. The only streams in the district that have been found to be gold-bearing to any great extent traverse an area on the east side of Atlin lake that was not so heavily glaciated as other parts of the region, and that is underlain by greenstone, biotite, and actinolite-schists, peridotite, magnesite, and serpentine. These rocks contain quartz veins and zones mineralized with iron, lead, and copper sulphides, and carrying small amounts of gold. The placer gold probably was derived from the wearing away of large masses of the country rock and the included veins and mineralized zones.

The auriferous stream gravels are of two kinds: (1) yellow, much decomposed gravels, that are usually buried beneath glacial drift; and (2) gravels formed by stream erosion of the glacial drift and included masses of ancient gold-bearing gravels. These gravels in many cases rest on a false bedrock of boulder clay and there is no gold in the boulder clay or on the true bedrock beneath it. In a few places auriferous gravels are reported to occur beneath basalt and tuffs that probably are Pleistocene in age, but these gravels have not been proved to be of much importance. Profitable placer mining either by dredging or by hydraulicking is rendered uncertain by the occurrence in places of an overburden of barren glacial drift and the presence of numerous boulders and boulder clay, so that careful testing of the ground is necessary before any large-scale operations are undertaken. It is generally held that there are still some possibilities for successful hydraulicking in the area and but little chance for mining by hand methods.

Cassiar

The main gold-producing part of Cassiar district in northern British Columbia is Dease Lake area, which lies just north of the Arctic divide and drains north by Dease river into the Liard. The area is an old placer field that was discovered in 1872 and reached its maximum production two years later. The total gold production from Cassiar amounts to about $5,000,000, of which nearly four-fifths was produced in the seventies and about one-fifth since that time. Although placer mining has been carried on almost continuously since the discovery, the gold production has gradually declined and in 1923 and 1924 was practically nothing. The discovery in 1924 of Goldpan Creek, about 20 miles east of Dease lake, resulted in a further small production. In addition, hydraulicking on Dease creek will probably ensure a small output of gold for several years.

The main gold-producing creeks were Dease, Thibert, and McDame flowing into Dease lake and Dease river from the west. Rock benches and abandoned stream channels occur along these creeks at various heights above the present creeks, and carried gold-bearing gravels overlain in places by considerable thicknesses of glacial drift. The gold found in the present creek beds was derived from the old channels. The original source of the gold probably was quartz-sulphide veins. In places in the area east of Dease lake, and along Stikine river above Telegraph Creek, stream gravels underlie basaltic lavas which are Pleistocene in age. These gravels have not been proved to carry gold in commercial quantities.

Cariboo

The Cariboo gold fields lie east of Fraser river in central British Columbia. The main producing areas are in the vicinity of Barkerville and in the upper parts of Quesnel river. The first gold discoveries in Cariboo were made in 1859 and 1860. The total gold production is approximately $45,000,000. After 1863 the production gradually declined, but as late as 1915 it was $300,000. The possibilities of the district have not been exhausted and development work indicates a probable gold production of at least $100,000 a year for several years to come.

Cariboo district is a deeply dissected and glaciated upland region. The upland areas range in elevation from 6,500 feet down to 3,500 feet; the valley bottoms of the main streams from 2,000 feet to 4,000 feet.

The gold-bearing gravels of Cariboo may be classified as follows: (1) Ancient stream gravels resting on bedrock in the valley bottoms and on rock benches or old channels, and usually buried beneath great or small thicknesses of glacial drift. (2) Interglacial stream gravels, usually overlain and underlain by glacial drift. (3) Glacial outwash gravels filling stream valleys and derived in part from pre-existing auriferous gravels. (4) Post-glacial stream gravels, derived mainly from erosion of the glacial drift and older auriferous gravels.

The main gold-producing parts of the district are underlain by a series of rocks consisting of quartzite, slate, schist, and limestone, that probably are Precambrian in age. These rocks are cut in places by numerous, small quartz-sulphide veins which in many cases contain free gold in their upper oxidized parts. The placer gold was originally derived from the gradual wearing away of great thicknesses of these country rocks and included veins.

Fraser River

The placer gold found along Fraser river at intervals from about 20 miles above Quesnel to below Hope was derived, in large part at least, from erosion of the glacial drift overlying the bedrock. The river in places has cut down through 500 feet of these surface deposits, so that there has been concentration from a large amount of material and, as the river is still eroding these deposits, there is some renewal of the gold in the bars that were mined for many years. These bars yielded several millions of dollars in the two years following the discovery in 1857 of gold on, as held by some authorities, Thompson river near Nicoamen, or, as held by others, at Lytton near the junction of the Thompson and Fraser. The gold occurs in sand and gravel in the banks and bars exposed at low water and some occurrences differed from [illegible]thers in ch[illegible]racter and mode of origin. Hills bar near Yale, which has pr[illegible]ably affor[illegible]d more gold than any [illegible]er locality o[illegible]e Fraser, lies at th[illegible]ot of Fr[illegible]er canyon. Where the current slack[illegible] the material tran[illegible]ted [illegible]ugh the canyon is deposited and gold wa[illegible]deposited along wi[illegible] sand and gravel and was scattered through it. [illegible]omewhat similar [illegible]ons exist below other canyons on the river an[illegible] below or at the [illegible] of tributary streams such as the

Quesnel and Thompson. On other bars formed by alternate erosion and deposition by the stream the paystreak may be only a few inches to a few feet thick and in many cases most of the gold may be found in the upper few inches of the bar or bank. As a rule there is little gold below extreme low water. In places where coarse gold was found or where there are numerous boulders this may not apply. In places, for example, in the bed of the river at and for some distance below Quesnel where there is a small thickness of gravel overlying soft, easily eroded bedrock, there is likely to be little gold as the gravels shift downstream and any included gold is likely to be ground fine and carried away in freshets, to be deposited on bars or along the banks at bends. Coarse gold, however, appears to have been found in places in bouldery ground below water-level, for example at the site of the old Beatty dredge near North Bend. Dawson has pointed out[1] that

> "From a point on the river a few miles below Boston bar (or about 16 miles above Yale) to Sisco Flat, a short way below Lytton, a distance in all of about 25 miles, rich deposits of 'heavy' gold were worked. Farther up the river is a second run of 'heavy' gold, the limits of which cannot now be so well defined, but which appears to have extended from a point about half-way between Lytton and Foster bar, to some little distance above Fountain. Here nuggets of some size were occasionally unearthed, and there were some exceptionally rich diggings. On the Thompson, the vicinity of Nicoamen, where the original gold discovery occurred, has always been noted for its 'coarse' gold."

Some of the better known bars were Cameron, Emery, and Texas between Hope and Yale; Sailor, Nicaragua, and Boston between Yale and Lytton; Mormon, Foster, Great Falls, Lillooet, and Upper Mormon between Lytton and Fountain; Haskell, Big, and Island between Fountain and Alexandria; British or Cornish, Ferguson or Rich between Alexandria and Quesnel; Long, 7 miles above Quesnel, and Spanish 13 miles above Quesnel. It is probable that some gold can still be recovered by hand methods of mining at these and other bars along Fraser and Quesnel rivers, though only small returns are to be expected.

Tulameen

Placer mining on Tulameen and Similkameen rivers in south-central British Columbia has been carried on to some extent since 1885. There is still considered to be some possibilities for mining on a small scale at favourable places along these rivers and their tributaries. The area is a deeply eroded and heavily glaciated plateau, having a maximum relief of about 3,800 feet. The placer gold deposits, which also carry small amounts of platinum, are Pleistocene and Recent in age. The original source of the gold probably is quartz veins cutting a series of volcanic and sedimentary rocks of Triassic (?) age. Considerable testing of the ground in the valley bottoms and on the benches has been done in recent years to determine the value of the ground for dredging or hydraulicking, but there have been no very favourable results, as the paystreaks are discontinuous and the presence in places of boulders and boulder clay renders mining operations difficult. Some of the favourable places for hand mining are around and under boulders that have acted as natural riffles.

[1] Dawson, G. M.: "The Mineral Wealth of British Columbia"; Geol. Surv., Canada, Ann. Rept., vol. III, pt. II, pt. R, p. 28 (1889).

ALBERTA

Placer gold was discovered on North Saskatchewan river in 1859 or 1860, and mining has been carried on, chiefly by hand methods but partly by the use of dredges, at intervals down to the present time. Placer gold occurs on other streams in Alberta, but the main production has been from the North Saskatchewan. All the gold is fine and is found associated with coarse gravels on such bars as are uncovered at low water. There is no concentration of gold on bedrock. The pay-gravels are only a few inches to a few feet thick and occur only on bars where conditions are favourable for the concentration of gold by alternate deposition and erosion by stream action. In places the bars are overlain by a considerable thickness of barren alluvium. The gold is derived from sedimentary formations, of Upper Cretaceous or early Tertiary age, through which the valleys of the streams have been eroded; it has been reconcentrated from ancient low-grade placers. This discovery, made by J. B. Tyrrell many years ago, put an end to the useless search for a possible source of the gold in the mountains to the west. The gold extends up the river from Edmonton for about 50 miles or somewhat more, and downstream nearly to Battleford, but the most productive areas were in the stretch extending for 15 or 20 miles above and below Edmonton. Mining by hand methods on the bars can only be done in the spring and autumn when the water is low. High water, due to the melting of snow in the mountains, occurs as a rule in July. Mining with rockers was done at a number of places along the river in 1931, but the returns are said to have been very small.

QUEBEC

Placer gold mining was carried on in Chaudière River basin, 40 to 50 miles southeast of Quebec city, chiefly from 1870 to 1885. Hydraulic mining on Meule creek, a tributary of Mill river flowing into the Chaudière at Beauceville, was carried on in 1911 and 1912, but did not prove profitable. Since 1912 no mining operations of importance have been undertaken.

The placer gold deposits comprise post-Glacial and pre-Glacial deposits, the former occurring at or near the surface, the latter being concealed beneath glacial drift, and lying in most places a considerable distance beneath the present stream beds. The original source of the gold probably was auriferous quartz veins cutting a series of extrusive igneous and sedimentary rocks of Palæozoic age.

The possibilities of placer mining in the area are confined mainly to the buried placers, which, however, are difficult to mine because of the overburden of barren glacial drift, the presence of large boulders in the drift, of quicksand in places beneath the boulder clay, and of the low gradients of the present stream channels.

BIBLIOGRAPHY

Camsell, Charles: "Geology and Mineral Deposits of the Tulameen District, B.C."; Geol. Surv., Canada, Mem. 26 (1913).

Gwillim, J. G.: "Report on the Atlin Mining District, British Columbia"; Geol. Surv., Canada, Ann. Rept., vol. XII, pt. B (1902).

Johnston, W. A.: "Gold Placers of Dease Lake Area, Cassiar District, B.C."; Geol. Surv., Canada, Sum. Rept. 1925, pt. A, pp. 33-74.

Johnston, W. A.: "Placer Mining in Cedar Creek Area, B.C."; Geol. Surv., Canada, Sum. Rept. 1922, pt. A, pp. 68-81.

Johnston, W. A., and Uglow, W. L.: "Placer and Vein Gold Deposits of Barkerville, Cariboo District, British Columbia"; Geol. Surv., Canada, Mem. 149 (1926).

McConnell, R. G.: "Report on the Klondike Gold Fields"; Geol. Surv., Canada, Ann. Rept., vol. XIV, pt. B (1906).

McConnell, R. G.: "Report on the Gold Values in the Klondike High Level Gravels"; Geol. Surv., Canada, Pub. No. 979 (1907).

MacKay, B. R.: "Beauceville Map-area, Quebec"; Geol. Surv., Canada, Mem. 127 (1921).

"The Yukon Territory," 1926; Dept. of the Interior, Ottawa, Canada.

Tyrrell, J. B.: "Gold on the North Saskatchewan River"; Trans. Can. Min. Inst., vol. 18, pp. 160-173 (1915).