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

BUREAU OF ECONOMIC GEOLOGY
GEOLOGICAL SURVEY

ECONOMIC GEOLOGY SERIES
No. 7

Prospecting in Canada

(Second Edition)

BY

Officers of the Geological Survey, Ottawa

OTTAWA
J. O. PATENAUDE
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1935

Price, 75 cents

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CHAPTER I

ELEMENTS OF GEOLOGY AND MINERALOGY

(G. A. Young)

MINERALS

The kinds of valuable mineral deposits that occur in any region and their size, shape, and distribution are related to the ways in which the rocks of the region formed and were subsequently affected by natural agencies. The aim of geology is to determine how the rocks of a region originated and to ascertain what afterwards happened to them. Rocks (and ores) are of many kinds, but all are composed of minerals or, in some cases, mineral glass.

Minerals are of many kinds, about a thousand distinct species are known. Each has its own definite composition and tends to form individuals having crystal outlines. Minerals may be defined as the naturally occurring inorganic substances that form the greater part of the soils and solid rocks. The only parts of the soils and solid rocks that are not minerals are any animal or vegetable matter that may be present. Coal is not a mineral, for it is merely a fossil form of vegetable matter. Graphite, on the other hand, though in some cases it has formed from coal, is always considered to be a mineral.

All minerals, except mercury and water, are solids. Every piece of any mineral species has, within certain limits, the same chemical composition as any other piece of the same species. The chemical composition determines, directly or indirectly, various other properties possessed by a mineral such as its specific gravity, crystal form, hardness, and optical constants. These, as well as other characters, remain constant even though the pieces of a mineral species may range in size from such as are several feet long to others so small as not to be clearly distinguishable even with the aid of a microscope. Minerals vary much in appearance. Some are easily scratched with the finger-nail; others are harder than steel. Many are opaque, black, grey, or variously coloured, and have a sheen like polished metal. Others are opaque, dull, and earthy. Most are transparent, or at least permit the passage of light; they may be white or of various shades and tints of colour, and a single species may in different specimens or even in the same specimen exhibit different colours. A single species may form nearly the whole of a vein or large body of rock. In other cases two or more species may occur together, each in distinct individuals, or penetrating, or included within, one another. The individual grains may be irregular, rounded, or may exhibit crystal forms.

Chemical investigations have proved that minerals, like all other forms of matter, are composed of one or more substances known as chemical elements or, more simply, elements. Some eighty-three or eighty-four elements have been recognized. Chemistry indicates that for each element there is a certain mass which is the smallest that can take a part in chemical reactions. These limiting masses are known as *atoms*. The weight of the atom of each element is, for all practicable purposes, always the same, and differs from the weight of an atom of any other element. The relative weights of the atoms of each of the elements are known. The composition of most minerals may be represented by simple chemical formulæ which express the proportional numbers of the atoms of each chemical element that may be present. Thus pyrite is represented by the formula FeS_2 in which Fe is the symbol for the element iron and S that for sulphur. The meaning of the formula is that pyrite is composed of iron and sulphur combined in the proportion of one atom of iron to every two atoms of sulphur. Since the relative weights of the atoms of iron and sulphur are known (they are as 55·84 is to 32·06), the composition of pyrite may be calculated to be, very nearly, iron 46·5 per cent, sulphur 53·5 per cent.

The compositions of mineral species as determined by chemical analyses do not always agree with the theoretical compositions deduced from the chemical formulæ of the minerals. The variations between the actual and theoretic compositions are due in some cases to intimate intergrowths of two or more minerals or to particles of one mineral included in another, thus preventing the securing of pure materials for analysis. In other cases, two or more closely related elements may be capable of playing the same part in the chemical structure of the mineral species and, therefore, may occur in varying proportions. In nearly all cases, chemical analysis of a mineral reveals the presence of various substances that are not essential parts of the mineral, but which, nevertheless, are uniformly distributed throughout the body of the mineral, as if dissolved in it. In some cases these foreign elements are present in exceedingly minute quantities, but may be responsible for the colour of the mineral; in other cases the amount present may be considerable and may materially alter various properties of the mineral.

Most minerals form from, or in the presence of, gases, vapours, or liquid solutions. In some cases minerals wholly form from substances present in vapours or solutions; in other cases they are due to interactions between minerals, and gases, vapours, or solutions. Minerals form in obedience to chemical and physical laws. Pressure, temperature, the presence of certain substances not all of which enter into the composition of the minerals, and the degree of concentration and the relative amounts of substances in solutions, are some of the factors that govern the birth and growth of minerals.

No mineral is stable under all the natural conditions that may affect it. Those minerals, for instance, which form at considerable depths and, because of erosion or other causes, come to lie at or near the surface of the earth, are subjected there to agencies that tend to destroy them. Likewise minerals that form on or near the earth's surface and afterwards are buried deeply, tend to change to other minerals. Indeed, it seems possible that under certain conditions minerals and aggregates of minerals may change to new forms in the absence of any appreciable amounts of gases, vapours, or solutions.

Most minerals are the products of igneous activity or have been derived from minerals so formed. Igneous activity is directly manifested by volcanoes. These emit gases, vapours, solutions, and molten rock which, however, is only a particular kind of solution. In the past, bodies of molten igneous rocks have penetrated upwards into the outer shell of the earth and cooled and solidified there without reaching the surface. In many places the rocks that overlay these igneous bodies have been removed by erosion and the once deeply buried igneous rocks have been laid bare. These igneous bodies were also accompanied by gases, vapours, and solutions. The igneous rocks when molten were solutions of minerals. If the molten material cooled rapidly, it solidified partly or wholly as a glass, but if the molten matter cooled slowly, it solidified as an aggregate of minerals whose kinds and order of formation depended on the composition of the molten material and the conditions under which it solidified. The gases, vapours, and aqueous solutions that accompanied the deep-seated intrusions and, to a certain extent, those that accompanied volcanic action passed into the rocks of the outer crust of the earth. They might escape along fissures or zones of weakness, or might permeate the rocks. In the course of their migrations and as they were subjected to varying conditions, the vapours and solutions were partly or wholly precipitated as minerals that filled cavities and fissures, or the vapours and solutions reacted with minerals of the rocks traversed by them and thus produced new minerals. In some cases the mineral composition of the rocks invaded by the vapours and solutions was entirely changed; new material was added, old material carried away, and the changes so accomplished that at no time did cavities form.

Various agents act on minerals at and close to the earth's surface. All minerals are soluble in water, though usually very slightly, and solubility is increased by substances acquired by surface waters. The oxygen and carbonic acid of the air attack minerals. In various ways and in varying degrees, the minerals composing igneous rocks or which formed in association with igneous rocks, are dissolved or altered to other minerals. The materials going into solution may be carried away by surface waters to be deposited elsewhere, or, if the waters sink into the rocks, may be deposited there as new minerals. The changes that thus take place in the minerals forming igneous rocks tend to disintegrate these rocks. The disintegrated materials, with the other products of erosion, are the matter out of which the non-igneous rocks are composed and thus it is apparent that almost all minerals either form in or with igneous rocks, or are derived from such materials.

Minerals are classified according to their chemical composition, for it is their composition that determines all their other properties. The various main classes of minerals are briefly mentioned in the following pages.

NATIVE ELEMENTS

This class includes those minerals that are each composed of a single element. Examples: diamond and graphite, each composed of carbon; platinum; gold; silver; and copper.

SULPHIDES, SELENIDES, TELLURIDES, ARSENIDES, AND ANTIMONIDES

Minerals of this class are combinations of elements known as metals and semi-metals, with the elements, sulphur, selenium, tellurium, arsenic, or antimony. Examples are: molybdenite (molybdenum and sulphur); galena (lead and sulphur); chalcocite (copper and sulphur); chalcopyrite and bornite (copper, iron, and sulphur); sphalerite or zinc blende (zinc and sulphur); pyrite and pyrrhotite (iron and sulphur); arsenopyrite or mispickel (iron, arsenic, and sulphur).

SULPHO-SALTS

Minerals of this class are combinations of sulphur with the metals; they are separated from the sulphides for theoretic reasons. Chalcopyrite and bornite may be considered as sulpho-salts; tetrahedrite or grey copper (copper, antimony, and sulphur) is a sulpho-salt.

HALOIDS

The haloids are compounds in which chlorine, bromine, iodine, or fluorine are important constituents. Examples are: halite or rock salt (sodium and chlorine); fluorite (calcium and fluorine).

OXIDES

The oxides are combinations of one or more elements and oxygen. Examples are: quartz (silicon and oxygen); corundum (aluminium and oxygen); hematite and magnetite (iron and oxygen); limonite (iron, oxygen, and water).

CARBONATES

The carbonates are combinations of oxides and carbonic acid (carbon and oxygen). Examples are: calcite (calcium carbonate); magnesite (magnesium carbonate); siderite (iron carbonate); cerussite (lead carbonate).

SILICATES

About a fourth of the known mineral species are silicates. They are combinations of silicon and oxygen with one or more elements and, in some cases, water. Examples are: the feldspars, of which there are many varieties all of which are silicates with aluminium and various amounts of sodium, potassium, and calcium; the pyroxene and the hornblende families whose members are silicates with, for the most part, calcium, magnesium, and iron, with or without aluminium; the garnet family; olivine; epidote; the micas; chlorite; and talc.

OTHER CLASSES

Various other classes, amongst which may be mentioned the following: the phosphates to which belong the apatites (composed of phosphorous, lime, fluorine, chlorine, and oxygen); the sulphates exemplified by barite (barium, sulphur, and oxygen) and gypsum (calcium, sulphur, oxygen, and water); the tungstates which include scheelite (calcium, tungsten, and oxygen) and the hydrocarbons which strictly speaking are not minerals, examples are coal and petroleum.

The chemical composition of a mineral determines its optical and most, if not all, of its physical characters. This is so because minerals being definite chemical substances therefore solidify with crystalline structure and it is this crystalline structure that gives rise to the various optical and physical characters of a mineral. The crystalline structure varies from mineral to mineral because it depends on the number and structure of the chemical units that join to form the crystalline unit, and these chemical units express the chemical composition of the mineral. Thus each mineral species has, in addition to its chemical composition, various properties that distinguish it from all other minerals. In some cases it is by such properties alone that mineral species may be identified, for in a few instances the same chemical compound solidifies with different crystalline form (that is, forms two or more mineral species) according to the temperature and other conditions existing at the time of crystallization.

A few mineral species lack or seem to lack crystalline character; all others possess it. The crystalline character may or may not express itself in the outward form of individuals of a mineral; if it does the mineral is said to be *crystalline,* if it does not the mineral is described as *massive.* Though some minerals rarely occur except in a massive state, the crystalline or massive habit is mainly a result of the conditions under which the mineral individuals form and grow. For instance, solidification of an aqueous or igneous solution may take place in such a way that the growing crystals interfere with one another and are compelled to assume outward irregular shapes that have no relation to the crystal structure of the mineral. If a mineral is free to assume a crystalline habit as it forms, the resulting individuals are bounded by smooth, plane surfaces called faces. These faces are disposed symmetrically with respect to one another. The number of these faces is limited and in the case of any one mineral species, the angles between the same pair of faces is the same in every crystal that bears these faces. The faces of any crystal are referred to three, in some cases, four, axes, one of which is called the vertical axis and the other two or three lie in a plane at right angles or inclined to the vertical axis. The number of these axes, their relative lengths, and the angles they make with one another are constant features for each mineral species. For all of one group of mineral species, the crystallographic axes are of the same length and make the same angles with one another, therefore, like pairs of crystal faces make the same angle with one another on each and every mineral species of this group. But in the case of all other mineral species, the relative lengths of the crystallographic axes and the angles they make with one another, though always the same for any one mineral species, differ for different mineral species and, therefore, the angles between similar pairs of faces differ on different mineral species.

As already stated, all except perhaps a very few minerals are always crystalline, though the mineral individuals do not always exhibit crystal faces, but are said to be massive and occur in rounded or more irregular forms either singly or in aggregates. Each piece of a mineral species, whether a crystal or massive, has the same chemical constitution and, therefore, the same physical properties, since these are dependent on the chemical structure. Some of the physical properties are briefly referred to below.

CLEAVAGE AND FRACTURE

Mineral crystals and grains tend to part along planes with smooth surfaces parallel to one or more directions definitely related to the crystallographic form and internal structure of the mineral species. This property is termed cleavage. The number of cleavage planes, their degree of imperfection, and the varying ease or difficulty with which they may be obtained, vary from one mineral species to another. If cleavage is not too highly developed, mineral specimens may be caused to break along other directions than the cleavage planes. The surfaces of the fractures so produced are uneven, but in general have qualities each characteristic of certain groups of minerals. These fractures may be curved (conchoidal), hackly, fibrous, etc.

TENACITY

Minerals may be brittle (if by hammering or cutting they break into grains), sectile (if they may be cut by a knife without falling to pieces), malleable (if pieces may be flattened by hammering), flexible (if the mineral may be bent and remains bent), elastic (if the mineral be bent and will return to its original position); etc.

HARDNESS

By hardness is meant the ease or difficulty with which a mineral may be scratched. Some minerals are so soft that they may be scratched by the finger-nail, others may be scratched with a knife, and others are harder than steel.

SPECIFIC GRAVITY

The specific gravity of a mineral is the ratio of the weight of a unit volume of the mineral to the weight of an equal unit volume of water. If the specific gravity of a mineral is 2, the meaning is that the weight of the mineral will be two times that of an equal volume of water. The specific gravity is fairly constant for each mineral species. It ranges from less than 1 for ice to about 19 for gold and even higher for certain rare minerals.

OPTICAL PROPERTIES

Thin sections of most minerals transmit light and in so doing the velocity, direction, and vibrations of the light are modified. The nature and degree of these modifications are determinable and constitute the optical properties of minerals. They vary from mineral to mineral and in many cases offer a very precise method of distinguishing between mineral species.

TRANSPARENCY

A mineral is said to be transparent if the outlines of an object can be distinguished through it; translucent when light is transmitted but outlines of objects are no longer distinguishable through a specimen; and opaque if no light passes through even the thin edge of a splinter.

COLOUR, STREAK, AND LUSTRE

Many minerals when pure are white, or black, or possess a particular shade or tint of colour; other minerals, since two or three chemical elements may be present in relatively varying amounts, exhibit a certain range of colour; and most minerals because of the presence of impurities may vary widely in colour. Colour is also affected by the degree of transparency of a mineral species, the nature of the outward surface, etc. A more uniform property is the colour exhibited by the finely ground powder of a mineral; this is known as the streak. Lustre is the term applied to the quality of the light reflected by a mineral. A mineral is said to have a metallic lustre if the mineral is opaque and reflects light like polished metal. All other lustres are non-metallic, if like that afforded by surfaces of fractured glass, they are termed vitreous, or they may be resinous, pearly, etc.

OTHER PHYSICAL PROPERTIES

Some minerals (those highly soluble in water) have a taste; some on being rubbed or moistened give off an odour. Certain minerals are phosphorescent or fluorescent. A few minerals are magnetic—that is, are attracted by magnets—and several of these under certain conditions are magnets themselves.

All the above-mentioned characters are aids in distinguishing mineral species. After much practice most minerals can be recognized by careful inspection, but unless chemical and optical tests are also made there is always a danger that specimens may be incorrectly identified, for even the commonest minerals under certain conditions mimic, or are mimicked by, other mineral species. In most cases simple chemical tests made with apparatus and reagents costing but little and easily carried, will positively identify mineral specimens. The apparatus, reagents, and method of use are fully described in various text books, amongst which may be mentioned the "Manual of Determinative Mineralogy," by Brush and Penfield (John Wiley and Sons, New York, U.S.A). Convenient tables to aid the determining of minerals by their general characters without chemical tests are given in "Tables for the Determination of Minerals," by E. H. Kraus and W. F. Hunt (McGraw-Hill Book Co., New York, U.S.A.). Less complete tables are given in "Introduction to the Study of Minerals and Rocks," by A. F. Rogers (McGraw-Hill Book Co., New York, U.S.A.), which deals also with all aspects of mineralogy and contains descriptions of 175 of the commoner minerals. Descriptions of almost all known mineral species are given in "A Text-book of Mineralogy," by E. S. Dana, revised edition by W. E. Ford (John Wiley and Sons, New York, U.S.A.).

The study of minerals should be based on the study of specimens. Samples of some of the commoner minerals are contained in the "Prospector's Collection" obtainable from the Director of the Geological Survey, Ottawa. If any doubt exists as to the identity of a mineral specimen and if it is important that the specimen should be correctly identified, a fragment of the specimen accompanied by a statement giving the manner of occurrence and locality where found, may be sent to the Director of the Geological Survey, Ottawa, who will furnish the desired information. Similar aid may be obtained from the British Columbia Office of the Geological Survey, 510 Winch Building, Vancouver, B.C.; in the case of minerals found in British Columbia, from the Provincial Mineralogist, Victoria, B.C.; and in the case of minerals found in Ontario, from the Ontario Department of Mines, Toronto, Ontario.

ROCKS

Rocks are of many kinds. As already stated, all are composed of minerals (or, in some cases, mineral glass), some mainly of a single mineral, but most of two or more. The mineral grains in rocks may have perfect or imperfect crystal outlines or they may be rounded or irregular. They may be so small as to be indistinguishable or of any size up to such as are several inches long. They may penetrate or interlock with one another, or they may appear to be welded or cemented together as if at one time they had formed an incoherent assemblage. Unconsolidated materials such as gravel, sand, clay, and soil are rocks since they are aggregates of minerals, but the term rock is popularly applied only to the coherent mineral aggregates that underlie the soil, etc., and form the solid part of the earth. Not all aggregations of minerals are considered to be rocks. Veins and various accidental mineral aggregates are not rocks, for the term is limited to those bodies that are an essential part of the earth and, individually, exhibit a certain constancy of chemical and mineralogical composition.

Rocks may be classed as sedimentary or igneous according to their mode of origin. Both these classes are in many cases altered and if they have been considerably changed, they are named metamorphic rocks.

SEDIMENTARY ROCKS; MODE OF ORIGIN

Sedimentary rocks, or sediments as they are frequently named, are largely the products of weathering and erosion of the bedrock of the continents.

Many of the minerals composing rocks are attacked by substances present in water or in the atmosphere. In some cases the minerals are partly or wholly dissolved in the water, in other cases they are changed to different minerals. The rocks are said to weather, and weathering tends to cause them to crumble. Rocks are also destroyed in mechanical ways as, for instance, by the scouring action of rock particles carried along by streams, winds, and glaciers. Thus, by weathering and in various mechanical ways, rocks break down into fragments from which are produced the clays, sands, and coarser materials that in most districts largely conceal the solid bedrock.

Winds, glaciers, and streams, particularly swiftly flowing streams, not only wear away rocks, but also carry off the materials so produced, and these materials are worn finer and finer. This general process is termed erosion. Its effects are most pronounced in mountainous regions, where the peaks and valleys have been carved by erosion out of what would have been elevated, but otherwise perhaps nearly featureless, districts. Long-continued erosion tends to reduce every region to the condition of a gently sloping plain and there is abundant evidence that in the past whole mountain systems have been thus destroyed.

The products of erosion are transported by streams, and in other ways, from higher to lower levels. Where the current of a stream slackens, the load of "detritus" or rock debris is partly or wholly deposited. The burden carried may be largely laid down in lakes, or along valleys, or on plains, and in this way thick accumulations of mud, sand, gravel, and boulders may be built up within the borders of the continents. Thus, the sand and mud that are being carried into the Great Lakes settle there and the water of the St. Lawrence where it leaves lake Ontario is clear. But with changing conditions such deposits may again be subjected to erosion and, in the long run, the tendency is for the products of erosion to be carried to the sea, where they accumulate about the margins of the continents there to mingle with the detritus produced by the waves and the currents acting on the rocks and soils of the seashore.

If the land areas were stable they would, as a result of long-continued erosion, be low-lying regions rising imperceptibly from the sea to broad, scarcely distinguishable divides in the interior. The rocks that had formed the uplands and mountains would have been eroded away and the resulting muds and sands would have accumulated in the bordering seas to form very thick, widespread deposits. But the land areas are not stable. It is certain that at long intervals, extensive regions have been uplifted hundreds or thousands of feet and other regions have been subjected to great stresses and mountainous areas thereby produced. The opposing forces of erosion and uplift seem, in the past, to have balanced one another, for periods of erosion have alternated with periods of uplift and mountain building, and continental masses, though their outlines and surface features have been constantly changing, have existed since a very remote period. The continued existence of the continents has been due in part to the fact that the wastage from the land has been largely deposited on only temporarily submerged parts of the continents.

The flooded mouths of river valleys, submerged forests, and other features along seacoasts indicate that parts of the continental margins have sunk relatively to sea-level. Elevated shorelines along stretches of the seacoasts are evidence that these parts have risen relatively to sea-level. Far inland in the St. Lawrence valley of eastern Canada, the remains of marine life occur in unconsolidated clays and sands, and indicate that in comparatively recent times, the sea reached nearly to lake Ontario. In more remote times, seas must have extended over large parts of the continent, for in almost every region occur hardened muds, sands, and other rocks which hold fossil remains of marine animals and, therefore, must have accumulated along the shores and on the bottoms of seas. The materials composing these marine rocks in some cases are the products of erosion of ancient land areas, in other cases the rocks are limestones largely composed of the debris of marine organisms.

The seas which once occupied large parts of the continents and whose extent is indicated by the marine rocks now underlying parts of the land areas, must have been comparatively shallow bodies of water. The clays and sands could not have been carried far out to sea and the remains of animals occurring in them and in the limestones are of types that inhabited comparatively shoal waters. In many places the characters of the surface on which the marine rocks lie and which must have been the bed of the ancient sea, may be inspected or inferred. Almost invariably this surface is, in the main, gently undulatory or plane-like and without doubt was produced by the long-continued erosion of an earlier land surface. In some cases the rocks forming this earlier land surface are also marine rocks. It is plain, therefore, that the seas alternately advanced upon and retreated from the land areas. The successive seas have been temporary in character. All have been comparatively shallow, but in some of them, limestones and detritus from the bordering lands accumulated in thicknesses of many thousands of feet. The seas, however, were not correspondingly deep. Instead, the waters remained shallow and the beds of the seas gradually sank as the sands, muds, and limestones were deposited.

The advances and subsequent retreats of the ancient seas in some cases may have been partly or wholly due to changes in the levels of the oceans, but in other cases movements of the land masses were the causes. Such movements have affected parts of Canada at comparatively recent dates, for in various places may be traced the beaches of former great lakes which, instead of being horizontal as they must have been when first formed, are tilted and warped, thus showing that parts of the country have been uplifted relative to other parts. Such tilting and warping movements affecting great stretches of the continents and in some cases accompanying more pronounced movements, such as are later referred to, would explain the alternate advance and retreat of the ancient seas.

The land areas now are partly underlain by marine rocks and with them in many places are associated other rocks of somewhat similar characters but which formed on the land areas and, therefore, are known as continental rocks. The marine and the continental rocks are somewhat loosely termed *sediments*, because most of them may be conceived of as having settled from bodies of running or standing water. The sedimentary rocks in many places are accompanied by rocks of quite different general character and are called *igneous rocks* because they are known or inferred to have been molten. The igneous rocks compose two great classes: the *volcanic* or *extrusive* rocks, which rose from considerable depths and solidified on or near the surface of the earth; and the *plutonic* or *intrusive* rocks, which cooled and solidified at considerable depths. There is, however, no sharp distinction between the volcanic and plutonic rocks, for they are of related origin.

METAMORPHIC ROCKS

Igneous and sedimentary rocks, locally and over great areas, have been variously altered. If they have been considerably changed, they are named *metamorphic* rocks. In some instances the rocks have been so greatly altered that their original characters are much obscured and it may be difficult or impossible to determine whether the rocks originally were sedimentary or igneous. The alteration, that is the metamorphism, may be caused in various ways, as by great pressure, by shearing, by increase of temperature, or by permeating vapours and solutions. In general, metamorphism tends to change the habit of the individual mineral grains composing the rocks and to cause the formation of species of minerals that were absent from or relatively unimportant in the rocks in their original states; this general process is termed recrystallization.

IGNEOUS ROCKS

Volcanic rocks are being formed even at the present day. Conical, volcanic mountains occur in various regions. Through a central conduit extending downwards to unknown depths rise gases and vapours, and, at times, molten rock or lava which, escaping from the crater, flows down the outer slope of the mountain and eventually cools and solidifies. These lavas may be of great volume and extend for miles. The vapours and gases that rise in the volcanoes sometimes escape with explosive violence so as to partly destroy the volcanic pile or to carry with them particles of rock, molten or solid. The finer materials so produced may, on falling, accumulate in thick layers known as tuff or volcanic ash. Rocks similar in all respects to the lavas and tuffs produced by modern volcanoes, occur in many places, occupy large districts, and may be thousands of feet thick. Some of these rock assemblages were produced by ancient volcanoes, but others resulted from eruptions through long, deep fissures. Some of the volcanic piles formed on the land, but others accumulated on the beds of seas. They occur in many regions interlayered with marine and continental sediments and thus indicate that volcanic activity took place at different times in different areas during the long history of the earth.

The other class of igneous rocks, the plutonic, is mainly found in mountainous areas or in regions that presumably once were mountainous but have been eroded to a more nearly plain-like condition. The plutonic rocks in places occur in bodies of small area and pipe-like form, as though they might be filling conduits which lead to higher levels since eroded away. More commonly they occupy irregular areas of hundreds or thousands of square miles. At their edges they cut across the structures of the surrounding rocks, embay them, send tongue-like bodies into them, enclose small and large fragments of them, and behave in all respects as if they once had been molten. In some much eroded but still mountainous regions, bodies of plutonic rocks may be observed through vertical distances of thousands of feet; they presumably continue downwards through distances many times greater than the thicknesses of their exposed parts.

The areal extent of the plutonic bodies is usually so great as to indicate that the main molten masses scarcely could have reached the surface. Comparatively small off-shoots may have done so, but the main bodies appear to have cooled and solidified beneath a cover of the rocks invaded by them. That this was the case is shown in various ways. Not infrequently the larger bodies of plutonic rocks are bordered by smaller masses which presumably extend downwards to join a part of the parent body still covered in those places by a remnant of the roof that once extended over the whole mass. In many places immense blocks of the country rock occur within the plutonic body in such attitudes as to show that they are not gigantic, engulfed fragments, but that they are downward extensions of a roof that has been largely removed by erosion. The plutonic rocks have risen in a molten state. In some regions the surrounding and partly overlying rocks have structures suggesting that they were displaced by the plutonic body, but it is probable that in most cases the molten mass reached upwards by gradually absorbing the overlying rocks. The plutonic rocks, as already stated, usually occur in mountainous regions or in regions that once were mountainous. It thus appears that the building of mountains and the ascent of plutonic rocks are in some way connected in origin.

The igneous and the sedimentary rocks embrace all known rock types. The two classes are radically different in origin and, as a rule, in general characters. The sedimentary rocks, whether they were laid down in the sea or on the land, have been formed of materials derived from the destruction of previously existing rocks, either sedimentary or igneous. In some cases the materials are fragments of rocks or of grains of minerals; rocks composed of such materials are termed clastics. Other sediments are chemical deposits formed by the evaporation of solutions such as sea water, or produced by the intermingling of different solutions with the resultant formation of chemical precipitates. Other sediments are due to living organisms which in the sea and on the land have given rise to organic rocks such as limestone. Sedimentary rocks may form on the beds of seas, in estuaries, along stream courses, in lake basins, on plains temporarily flooded by shifting streams, and as talus accumulations at the base of slopes. They may form local or widespread mantles of glacially produced materials, or of very fine materials transported by winds (aeolian deposits). They may be fine or coarse materials due to volcanic explosions and which may or may not have been transported by streams and partly intermingled with other detrital matter.

The sedimentary rocks, because of the ways in which they form, occur for the most part in distinct layers or beds. Where sediments accumulate on the land or in fresh or salt water basins, the first layers naturally tend to fill the hollows in the pre-existing rock surface. As the deposits grow in thickness, the upper surface tends to become more and more plane-like and, therefore, successive layers of the sediments more and more closely mimic horizontal sheets or beds which may extend for very considerable distances or may be lens-like and occupy areas varying from a few inches to many yards in diameter. The deposits grow very slowly and during their period of accumulation changes affecting the source of the materials and their manner of transportation and deposition take place, so that successive groups of beds, or alternate beds, or the upper and lower parts of single beds may differ in character or composition. Variations in the nature of the materials and the rate at which they were supplied in some cases were so rapid that the alternate layers are no thicker than sheets of paper; all gradations may exist from such paper-thin layers to others tens of feet thick.

The sediments as they formed were, for the most part, friable deposits no more compacted or hardened than the muds, sands, etc., which now partly mantle the land areas. In some instances the ancient deposits are still essentially in such a state, but most of them have been changed to hardened, no longer friable, bodies of rock. This change has been brought about in various ways. The pressure exerted by overlying materials tends to consolidate the underlying beds and perhaps even to weld them into relatively hard, solid rocks. The rocks may be cemented into firm masses through the action of circulating waters which introduce matter, or by solution and redeposition cause new mineral combinations or redistribute the materials of the rock. The components of the sediments, perhaps aided by pressure, also may in part unite to form new mineral combinations. More profound changes take place where the sediments have been subjected to great stresses such as are sometimes set up in the earth's crust. In such cases mineral grains may be crushed and what were once pebbles and boulders may be flattened into elongated, plate-like bodies. Under more extreme conditions, as where the rocks have been buried or depressed to great depths and subjected to great stresses and to comparatively high temperatures, many of the mineral grains may recrystallize with new outlines or may react on one another to form new minerals. In extreme cases the materials of the rocks are transferred along some general direction either by mechanical movements or by processes of solution and redeposition, the rocks flow, and not seldom the mineral composition is entirely altered and the rock is said to have recrystallized. In the neighbourhood of large bodies of plutonic rocks, sediments may not only be subjected to high pressures and temperatures but they may be permeated by solutions and gases given off by the igneous bodies, new materials may be added, and some of the old components subtracted; the process of recrystallization may be carried to such an extreme stage that the sediments become coarsely crystalline masses, in some cases closely resembling igneous rocks. Thus in various ways sediments are altered or metamorphosed and the tendency is to convert them into schists and gneisses. Typical schists are rocks that part readily along planes that are paralleled by abundantly developed platy or micaceous minerals, or others with elongated or fibrous forms. The gneisses are banded crystalline rocks in which alternate bands differ in mineral composition. The schists and gneisses produced from sediments in some cases closely resemble schists and gneisses due to the metamorphism of igneous rocks.

The main types of the sediments are not many, but the number of varieties is very large. Sediments partly or largely composed of pebbles and boulders are termed conglomerates if the pebbles and boulders are rounded, and breccias if they are decidedly angular. The pebbles and boulders may form practically the whole of the rock, but in more cases they lie in a matrix of what was once mud, sand, or gravel. In some cases the matrix is of the nature of limestone or some other substance. Various gradations exist, from the coarse conglomerates to deposits of sand or mud. The sandy rocks are known as sandstones if largely composed of quartz grains and as arkoses if feldspar as well as quartz is abundant. The name greywacke is in many cases applied to sandy rocks which have been considerably altered, are usually dark, and hold much feldspar lying as a matrix of various minerals. Some greywackes may be partly or largely composed of tufaceous materials produced by volcanoes or they may have been largely formed of disintegrated volcanic rocks. Quartzites are sandstones composed largely of quartz grains firmly cemented in a matrix of quartz. All gradations exist from sandstones to mudstones. If the mudstones are not excessively hardened or changed in mineral composition, they are termed shales. More compacted forms which cleave across the bedding planes are known as slates.

The chemical sediments, classed according to origin, are of two main types: those caused by evaporation and those due to mingling of solutions. They form in standing bodies of water, fresh or salt. The most widespread are those due to the evaporation of sea water and are represented by beds of salt, gypsum, etc. These rocks are conceived of as having formed in temporarily enclosed lagoon-like basins where evaporation exceeded any inflow of water and the brines became more and more concentrated until they no longer could hold the salts in solution. These salts were contributed to the seas, mainly if not wholly, by the waters that drained the land areas and had dissolved these materials from the rocks.

The organic sediments are those directly formed through the agency of living matter. The most important examples are the limestones. These may have formed in fresh water, but, so far as known, all the thicker, more important deposits were produced in the seas. They are in the main composed of fragments of the calcareous skeletons of sea animals cemented in finely comminuted material. The limestones in places accumulated in thicknesses of many hundreds of feet, or in layers of various thicknesses alternating with layers of other sediments. The beds in some cases are almost pure, but all gradations exist between limestones and other sediments. In most cases mechanical and chemical processes have largely destroyed the fragments of shell, etc., and converted the material into an even-grained aggregate of grains of calcite (calcium carbonate). Rocks mainly composed of calcium carbonate are limestones; if magnesium carbonate is an important constituent, the rocks are classed as dolomites. Both limestones and dolomites may be converted into a crystalline state and are then known as crystalline limestones or marbles. Other organic sediments are the layers of coal formed from vegetable remains.

In general, sedimentary rocks that have formed in standing water are distinguished by being fine grained and evenly, in many cases, thinly, laminated. Amongst the marine strata, limestones and shales are the characteristic rocks, sandstones are less abundant, and the conglomerates are usually thin. If the sediments formed in fresh water, marine fossils are absent and limestone is not an important element. If deposited along streams and over the land, the sediments are usually coarse, sandstones and conglomerates are common phases, the different rock types tend to alternate with one another, the individual layers are less regular than in marine strata, and limestone is almost altogether absent. In short, the various assemblages of sediments not uncommonly display features indicating the manner in which the rocks formed.

Igneous rocks are classified by their composition, by whether they are intrusives or extrusives, and, to a certain extent, by the form of the igneous bodies. While in a molten state they may be conceived of as solutions of the substances which give rise to the various minerals that crystallize as the melt cools. The solutions also hold vapours and gases which are largely expelled as the rock solidifies. If the molten material cools comparatively quickly, it produces a glass, as in the case of some lavas and at the edges of some intrusive bodies. But more commonly cooling proceeds very slowly and as the temperature lowers and, in some cases, the pressure varies, the molten fluid in obedience to physical and chemical laws is no longer able to hold certain components in solution. These, therefore, commence to form crystals of minerals. These minerals continue to form so long as the remaining fluid rock continues to be saturated with the chemical substance of which the minerals are composed. But with changing conditions other compounds no longer can be held in solution and they, too, commence to form crystals of other kinds of minerals. As crystallization proceeds, the earlier formed kinds of minerals may cease growing and in some cases they may be partly or wholly dissolved or replaced by other minerals, because the first-formed minerals are no longer stable in the remaining fluid part of the rock under the conditions then obtaining. As a net result of the operation of various chemical and physical laws, the igneous rocks finally solidify as glass, or as a mixture of glass and mineral crystals, or as an interlocking mass of crystals and irregular grains of different minerals. The kinds of minerals that form naturally depend on the composition of the molten rock in which they grew and on the conditions that obtained during the period of crystallization.

Large and small igneous bodies in many cases display considerable diversity of mineral composition. Such variations, whether exhibited by a single body or by groups of related bodies, are commonly referred to as being due to processes of differentiation. The causes of differentiation are not definitely known and may be few or many. A general conception, widely held but not susceptible of proof, is that the molten rocks rose from deep-seated reservoirs in which the molten matter or magma was originally of fairly uniform composition. The magma, so it may be supposed, either in the deep-seated reservoirs or as it gradually rose to higher levels, or after it was in its final resting place, underwent differentiation. In some cases differentiation may have been due to events connected with the gradual crystallization of the fluid materials. As crystals of earlier forming minerals grew, it is conceivable that they might sink in the molten mass. The part from which the crystals were abstracted would have changed its composition and the part in which the sinking crystals had been concentrated would also have changed in composition. By such simple or more intricate processes of crystallization combined, possibly, with movements of the whole magma or with the transference of parts of it to higher levels, many of the results of differentiation may be explained. Another cause of differentiation is attributed to the absorption of the rocks penetrated by the igneous bodies. Whatever the causes of differentiation may be, the results are clearly manifested. Almost every large igneous body exhibits variations in mineral composition. The bodies of plutonic rocks in many instances are formed of radically different rock types, each occupying considerable areas to the exclusion of the other types. In some cases these different rock types merge into one another; in other cases one variety may cut another and the connecting, intermediate varieties may be wanting. In the case of the volcanic rocks, the more pronounced results of differentiation are usually indicated by differences in the successive lava flows. In such cases differentiation took place before the eruption of the lavas.

Chemical analyses of all kinds of igneous rock show that they essentially consist of the following nine chemical elements: silicon, aluminium, iron, calcium, magnesium, sodium, potassium, hydrogen, and oxygen. Many of the remaining chemical elements are also present and some, such as titanium and barium, in some cases occur in notable amounts. But, on the whole, the igneous rocks may be considered as being essentially composed of various amounts of the nine elements specified, which are usually regarded, if present in combination with oxygen, as respectively, silica (SiO_2), alumina (Al_2O_3), iron oxides (FeO and Fe_2O_3), lime (CaO), magnesia (MgO), soda (Na_2O), potash (K_2O), and water (H_2O). Though the different oxides occur in various proportions in different igneous rocks, yet it has been found that the chemical compositions of the igneous rocks as a whole vary only between certain comparatively narrow limits. Within these limits all gradations occur, but on the whole the rocks tend to belong to one or other of a limited number of families each having a characteristic though variable chemical composition.

Silica, when it crystallizes alone forms quartz, and is one of the chief constituents of igneous rocks, since much the greater part of every igneous rock is formed of minerals in which silica is an important constituent; these minerals are termed silicates. Their number is not large and the important species or families are: quartz which consists of silica; the feldspars which are combinations of silica, alumina, and, in varying proportions, lime, soda, and potash; the feldspathoids (e.g. nepheline) which are in the main combinations of silica, alumina, soda, and potash; the micas which are characterized by the presence of silica, alumina, iron, potash, and water; the pyroxenes and amphiboles (hornblendes) characterized by the presence of silica, iron, oxides, lime, and magnesia; and the olivines characterized by their content of silica, iron oxide, and magnesia. The feldspars form several groups, two of which are particularly important. One group includes orthoclase, a potash-bearing variety; the other group is the plagioclase feldspars which form a long series ranging from a soda-rich variety through others with soda and lime in varying proportions, to a lime-rich variety.

Quartz, and the feldspars, are relatively high in silica and, therefore, are the chief mineral components of rocks with comparatively high silica contents, the so-called acid (or salic) igneous rocks. The micas, amphiboles, pyroxenes, and olivines are comparatively low in silica and, therefore, tend to predominate in the rocks with relatively low silica contents, the basic (or femic) rocks. The silica, and the soda and potash (i.e. the alkalis) content of the feldspars decrease as the lime content rises and, therefore, the alkali feldspars (orthoclase, soda-rich plagioclase, etc.) characterize the more acid igneous rocks, whereas the lime-rich plagioclase feldspars are more characteristic of the basic rocks.

The more abundant mineral components of the igneous rocks definitely express the chemical composition of the rocks as a whole. For classification purposes, quartz and the feldspars are perhaps the most important mineral constituents. They are light coloured and as they are the most important constituents of the acid igneous rocks, these are generally light coloured also. As the light-coloured constituents decrease in amount, the dark-coloured constituents, the micas, amphiboles, pyroxenes, and olivines increase and, therefore, the basic igneous rocks tend to be dark coloured. On the basis of their mineral composition, the igneous rocks have been divided into a number of groups. Each group includes representatives of the plutonics that cooled slowly at depth and, therefore, are comparatively coarsely crystalline, and of the volcanics that solidified at the surface and, therefore, on the whole rapidly, and which as a result tend to be finely crystalline or glassy.

The most acid plutonics form the granite family, the members of which are essentially composed of important amounts of quartz, several varieties of feldspars, and one or more members of the mica, amphiboles, and pyroxene families. Quartz and feldspar predominate. In the so-called normal granites, orthoclase or a related feldspar and plagioclase feldspar are about equal in amount, and the plagioclase feldspars are acid varieties comparatively low in lime. Granites in which orthoclase or soda-rich feldspars greatly predominate over the lime-bearing varieties are known as alkali granites; if the lime-bearing plagioclase feldspars are in excess the rock is a granodiorite.

The granites by a lowering of the silica content grade into syenites. These rocks contain little or no quartz, are rich in alkali feldspars, comparatively poor in plagioclase feldspars, and carry one or more varieties of mica, amphibole, and pyroxene. Some varieties hold feldspathoids (nepheline, leucite, etc.).

The granites, by a lowering of the silica content so that quartz is absent or present in only small amounts, and by an increase in the amount of the lime-bearing plagioclase feldspars, grade into monzonites and diorites. The syenites by changes in the proportions of the feldspars also grade into these rocks.

The monzonites hold little or no quartz, and consist of alkali and plagioclase feldspars and one or more varieties of mica, amphibole, and pyroxene. The feldspars predominate and the plagioclase varieties approximately equal or exceed the alkali feldspars.

The diorites may hold some quartz or none at all. Plagioclase feldspars exceed the alkali feldspars and considerable mica, amphibole, or pyroxene are present. The diorites grade into gabbros. These are basic rocks consisting of rather basic plagioclase feldspar and abundant pyroxene or amphibole with or without olivine. What may be considered as special types of gabbros are basic rocks largely composed of basic plagioclase feldspars, but accompanied by considerable alkali feldspars and, in some cases, nepheline.

The gabbros grade into rocks composed almost wholly of plagioclase feldspars and known as anorthosites. They also grade into rocks largely composed of pyroxene and, therefore, named pyroxenites; and they may grade into varieties largely composed of olivine and pyroxene and known as peridotites.

The volcanic rocks form various families corresponding to those of the plutonics. The most acid varieties, those corresponding to the granites, are the rhyolites; the trachytes correspond to the syenites; the andesites to the diorites; and the basalts to the gabbros. The volcanics are largely fine-grained rocks whose mineral components in most cases cannot be determined except by special means. Many of the volcanic rocks consist of occasional, larger mineral crystals embedded in a fine-grained matrix and are said to be porphyritic. If such porphyritic volcanic rocks are believed to be acid they are called porphyries, if basic they are porphyrites. Different varieties are named according to the prevailing minerals that form the larger crystals or phenocrysts, as, quartz porphyry, feldspar porphyry, hornblende, porphyrite, etc. The plutonic rocks, like their volcanic counterparts, are porphyritic in some cases, but are not classed as porphyries, they are called porphyritic granite, porphyritic diorite, etc.

A third group of igneous rocks with special names are the dyke (or dike) rocks. These characteristically occur in long, narrow, sheet-like bodies which appear to have filled vertical or steeply inclined fissures. A common variety of the dyke rocks and one that in many cases accompanied the granites, is the pegmatites. These are composed largely of quartz, alkali feldspars, mica, and, not uncommonly, comparatively rare minerals such as tourmaline, etc. The pegmatites are usually very coarsely grained, some of the component minerals may even be several feet in length or diameter. Another group of dyke rocks is known as the lamprophyres. These are comparatively basic, usually dark rocks, and are of various kinds according to their mineral and chemical composition. Both the plutonic and the volcanic rocks may form dykes, but are not then classed as dyke rocks. They are merely dykes of granite, rhyolite, etc., as the case may be. Diabase is a widely occurring species having the composition of a gabbro or basalt, but with a particular texture. The diabases commonly occur as dykes or more nearly horizontal, sheet-like bodies.

The bodies of igneous rock either rose to and overflowed the earth's surface and, therefore, are known as extrusives, or they invaded other rocks and, therefore, are called intrusives. The extrusives are always volcanic rock varieties and because they cooled comparatively quickly are usually fine grained. Since they are flow rocks, they form sheet-like bodies which in places are superimposed in great thicknesses. The molten material that formed the flows in many instances was charged with vapours which on escaping produced small cavities in the rock. These holes later were, in many instances, filled with minerals and are known as amygdules, the rocks containing them are said to be amygdaloidal. Not seldom the upper and lower parts of flows are finer grained than the interior which cooled more slowly. Many flows exhibit structures due to the movement of the once viscous mass. The lava sheets or flows may be of any thickness from a few feet or less to scores of feet. Individual flows may overlie one another in layers each maintaining a fairly uniform thickness over large areas. Not uncommonly beds of tuff or of sediments are interlayered with the flows.

The intrusives are either of volcanic or plutonic rocks. The volcanic types where they occur as intrusives form, in most cases, dykes or sills.

Dykes, as already stated, are comparatively narrow, sheet-like, nearly vertical bodies that evidently were injected into fissures. Sills are also sheet-like, in some cases very thick, but are inclined at low angles and were intruded along planes of weakness. Sills, dykes, and more irregular bodies of intrusive volcanic rocks usually occur where lavas form thick assemblages, but they also occur in sediments and plutonic rocks. The volcanic rocks, in some places, form approximately circular masses representing eroded volcanic vents or pipes.

The bodies of plutonic rocks that occupy areas of hundreds of square miles are usually termed batholiths and are presumed to extend to great depths. They appear to be the upper parts of immense bodies of once molten rock which made their way upwards by engulfing the rocks replaced by them. About their edges they may project into the bounding strata. Relatively small bodies of plutonic rocks are referred to as stocks and bosses if it is assumed that they extend to considerable depths with approximately uniform cross-sections. In places, plutonic rocks form immense sill-like masses or they may form laccoliths which are intrusive masses enclosed by sediments and having a plane-like floor and an arched roof.

Nearly all igneous bodies exhibit jointing which in many cases is due to shrinkage following the cooling of the body. In some cases, as in dykes and sills, the intersecting joints divide the rock into columns extending from wall to wall of the dyke or from bottom to top of the sill. In large plutonic bodies, the jointing not uncommonly follows three planes, one approximately horizontal, the other two vertical and approximately at right angles to one another.

The fact that rocks are subjected to change or metamorphism, as it is called, has already been briefly referred to. All rocks are liable to change and many have been greatly altered. Rocks that have been radically changed are termed metamorphic rocks and in some cases the change is so great that it is difficult or impossible to determine whether the rock originally was a sediment or an igneous rock.

One great cause of changes in rocks is weathering due to the action of water, carbon dioxide, oxygen, and other substances present at the surface of the earth. Since sedimentary rocks are in large part the products of weathering, they remain comparatively unaffected and it is igneous rocks that in general show the most pronounced effects of weathering. On the other hand, a comparatively soluble rock like limestone, and which is a sediment, may be practically destroyed by weathering. Weathering is chiefly confined to the part of the rock crust lying above ground water level. In this zone the final results of the weathering of an igneous rock may be a clay; in the earlier stages of the process, the feldspars become clouded and, according to their composition, change in part to a pale-coloured scaly mineral, sericite, or to epidote or calcite. The pyroxenes, hornblendes, and micas change to chlorite, serpentine, magnetite, etc.

Weathering is a form of metamorphism tending to destroy rocks; other forms of metamorphism, although they change the character of rocks, do not tend to destroy them. The causes of these other forms of metamorphism are many, but in the main are due to stress, vapours and solutions, and heat. Stress may be due merely to the weight of overlying materials or it may result from the action of those forces which in varying degrees dislocate great thicknesses of strata, or bend and fold them, or crush and shear them, or even cause them to flow as if plastic. The solutions which cause metamorphism may be downward-travelling surface waters, perhaps charged with various solvents and capable of abstracting or adding material to the rocks traversed and thus producing new minerals. Other solutions, and vapours also, are associated in origin with intrusive and extrusive igneous rocks. These solutions and vapours rising from below or passing outward from the igneous masses may permeate the rocks over areas of any size up to such as are hundreds of square miles in extent. These invading solutions and vapours may produce only comparatively slight changes in the rocks, or the intensity of change may be of any degree to such as where the mineralogical and chemical composition is radically altered. The igneous rocks themselves may so intimately intrude the older rocks as to produce a hybrid rock mineralogically and chemically intermediate between the igneous rock and the invaded rocks. Heat as a metamorphosing agent may be the heat that escapes from igneous rock bodies, or that is produced by the action of those mechanical forces which dislocate and fold rocks, or it may be the internal heat of the earth as a whole, which becomes effective as rocks become more and more deeply buried. Though blocks of rock engulfed by molten igneous rocks may be melted, and rocks at the immediate edge of an igneous mass may be fused, it is doubtful if heat alone is productive of much change in rocks. On the other hand, increased temperature and also increased pressure, markedly accelerate and intensify the metamorphosing actions of vapours and solutions.

One general class of metamorphic changes is included under the term cementation. This action takes places mainly at and below the ground-water level and extends downward as far as solutions may descend. It is accomplished largely by aqueous solutions. Shales, since they are consolidated mud rocks, probably are not subject to cementation, as they are largely impervious to water. Sands, on the other hand, being porous rocks, are readily penetrated by solutions and in many cases exhibit the results of cementation in a striking fashion. The common cements are calcite and quartz, but other minerals are in some cases important. The cementing materials may come from outside sources or from some part of the rock itself where solution rather than deposition is taking place.

Stress may consist of simple pressure without rock movement and the metamorphic changes produced may then be classed as due to static metamorphism as contrasted with dynamic metamorphism where the pressure is so applied that movements of the rock result. Simple pressure acting on clays hardens them by pressing the grains closer together, by driving out water, and by indirectly or perhaps even directly causing mineral changes to take place—principally the development of minute flakes of colourless mica. By such changes clays are converted into shales and it is conceivable that by increasing pressure due to deep burial, shales may pass into slates characterized by an increase in the size of the mica scales, but the slates more commonly appear to have been produced by dynamic metamorphism. Other types of rocks are susceptible to such changes in degrees corresponding to the compressibility of the rock.

The effects of dynamic metamorphism may be illustrated by the mud rocks. These, when subjected to great stress under conditions that permit of rock movement or flowage, change to slates characterized by a parallel arrangement of the mineral constituents, which imparts a cleavage to the rock. The change is accompanied by a more conspicuous development of the platy minerals, principally muscovite. As the change progresses, dark micas and even hornblende form. In more extreme cases the rock undergoes further mineral change or recrystallization, the grains become larger, and the rock becomes a schist. Still further change results in the production of gneisses in which feldspars and hornblende result from the micas and chlorite. In the course of alteration to slate, or schist, or gneiss, large individuals of minerals such as garnet, staurolite, etc., may form. These changes are not necessarily dependent on depth; they are due to movement caused by stress. As shales are one of the weakest of rocks, they are especially subject to dynamic metamorphism and may exhibit it in a pronounced degree, while adjacent more resistant rocks may be free from its effects. Quartzites, when dynamically metamorphosed, are recrystallized and exhibit some schistosity, and by loss of materials may grade into a gneiss. Limestones change to marbles by recrystallization and if sufficient impurities are present, hornblende, mica, talc, chlorite, etc., may develop with parallel arrangements. In some cases practically all the carbonate may be eliminated, as in the formation of talc schists and possibly certain amphibole rocks. Igneous rocks by dynamic metamorphism may become schists or gneisses. Basic rocks tend to change to chloritic, hornblendic, or micaceous schists. Acid rocks exhibit the same tendency, but in a different degree.

Metamorphic changes such as indicated above may be preceded, or accompanied, or followed by purely physical changes whereby a rock may be fractured and crushed and such deformation may even affect the individual mineral grains of a rock. But all such changes appear to be facilitated by high temperatures and the presence of solutions capable of reacting with the rock constituents.

STRUCTURAL GEOLOGY

On preceding pages the manner of formation of rocks has been discussed. The rocks were divided into two groups, the igneous and the sedimentary. The igneous rocks were defined as having been molten masses which rose from below, penetrated already existing rocks, and either cooled and solidified beneath a cover of the older rocks or overflowed the earth's surface. It was stated that the sediments were formed of materials derived from previously existing rocks and that these materials, either transported in solution and afterwards precipitated, or carried away in the form of mineral grains and larger rock fragments, were for the most part laid down in nearly horizontal beds on land areas or in seas. Of the igneous rocks those which overflowed the earth's surface (the lavas) also formed in layers and these layers, with the beds of fragmental materials due to volcanic explosions (the tuffs and agglomerates), also were for the most part approximately horizontal.

The sediments and lavas, though they once formed nearly horizontal masses of great extent and, in many cases, of great thickness, are now, in most places, no longer horizontal. The strata of most districts lie in broad, gentle undulations or are more steeply tilted and possibly are dislocated and folded in a complicated manner. The Great Plains of western Canada are for the most part floored with strata inclined at a rate of a few feet a mile. But the same beds, as the Rocky mountains are approached, gradually assume a more and more disturbed condition until within the mountains they lie in great folds, are upended, overturned, or thrust in great masses over one another. Such is the general attitude of the rocks of many mountainous regions. Whatever the cause or causes of mountain building may have been, the results, in most instances, are as if great segments, many thousands of feet thick, of the outer part of the earth's surface, had yielded to forces acting in a nearly horizontal plane. In some cases it is apparent that the forces were of the nature of thrusts acting in one general direction. In other cases the result is as if the mountain-built tract had been compressed between opposing forces. In all cases the rocks have the appearance of having been crowded into a narrower space than was originally occupied by them.

The structures exhibited in mountainous areas are also to be seen in regions which in comparison are almost plain-like and, therefore, it is generally assumed that such comparatively level regions were once mountainous, but have since been deeply eroded to a nearly level plane. In many such regions and in mountainous areas, also, the stratified rocks are cut by immense bodies of plutonic rocks now laid bare as the results of erosion. The association of great masses of plutonic rocks with the folded and dislocated strata of regions now or once mountainous, has been noted in so many instances as to suggest that mountain-building and the widespread invasion of plutonic rocks are in some way related in origin. But, on the other hand. igneous invasions have taken place in regions that have not been subjected to mountain building, and mountain-built strata are not everywhere visibly penetrated by igneous rocks.

The structures exhibited by stratified rocks consist of, in the main, folds, dislocations which may be faults or zones of shearing, and flow structures. In mountainous districts and locally elsewhere, the nature of the structures may be clearly visible, but elsewhere the determination of the structure usually depends on observations made at isolated rock outcrops distributed over wide areas. The attitudes of the beds in the individual outcrops are determined in terms of the strike and dip of the rocks. The strike is the direction that the outcrops of a bed would follow on a horizontal plane. The dip is the direction in which the strata are inclined and the amount of inclination expressed in degrees measured from the horizontal. Depending on the nature of the structures, the strata of a district may have nearly uniform dips and strikes. In more cases the strike varies from outcrop to outcrop and the dip changes in direction and amount; the beds may be overturned, and may have revolved through more than a right angle so that what was the upper surface has been turned face downwards. In some cases the strata are so contorted that the strike and dip vary widely within the limits of a small outcrop.

Low angles of dip and a general parallelism of the direction of strike characterize areas where the strata as a whole have been only slightly tilted or have been thrown into broad, gentle folds. Changing directions of strike and dip indicate the existence of more marked folds. Contortions and crenulations of the strata in individual outcrops usually indicate not only comparatively close folding, but also that the rocks have moved or " flowed " as a plastic mass might when subjected to great stress.

Abrupt changes in the attitude of strata on either side of a line indicate that the line represents a plane of dislocation, a fault plane, and that the whole body of strata on one side of the plane has moved with respect to the rocks on the other side. The fault plane may be approximately horizontal or inclined at any angle up to vertical; it may strike in one direction or follow a curving course; it may split to follow two or more directions. In regions of folded strata, a fault may gradually change into a fold. If the fault plane is inclined at low angles the strata on the upper side will appear as if thrust over those below; the apparent thrust may amount to a few feet only or to any amount up to miles and may vary from place to place along the fault plane. If the fault plane is steeply inclined the beds on one side may appear to have dropped with respect to those on the other side, or to have moved sidewise, or to have moved in both vertical and horizontal directions. In all cases the amount of apparent movement may change from place to place and may amount to only a few inches or to thousands of feet. Zones of shearing or crushing are like faults in that they result from differential movements, but the movements instead of being confined to a plane are distributed over a zone which in some cases is very broad. Within such zones the strata are crushed and contorted. Faults and shear zones in places traverse otherwise scarcely disturbed strata or may cut much folded beds. Not uncommonly faulting and folding accompany one another.

Folds are either arch-like structures and are then known as anticlines, or are inverted arches named synclines. Folds may be of any magnitude from such as are a few yards or less broad, to such as involve the strata of many square miles. Low, relatively broad folds may occur singly in a region otherwise occupied by strata dipping at low angles in one direction. More pronounced folds usually occur in groups in which synclines succeed anticlines and they generally occur in regions where the strata as a whole have been subjected to folding and faulting. Some folds are dome-like, but most are elongated. The crown of an anticline or the trough of a syncline may be relatively broad or narrow. The strata on the limbs may dip at low or high angles. A fold may be symmetrical, its opposing limbs dipping at the same rate but in opposite directions; or the rate of dip may be unlike in opposing limbs and in the case of overturned folds the opposing limbs dip in the same direction. Some folds are simple, others are compound and composed of relatively minor folds superimposed on a major fold. In some regions the folding or faulting is complicated as if produced during two or more periods of folding.

The structures presented by igneous rocks have already been referred to. Lavas and sheet-like intrusive bodies known as sills may be folded and faulted in much the same way as sedimentary rocks. The larger intrusive bodies, such as the stocks and batholiths, may be faulted or sheared, but they do not fold. Most of these intrusive masses, certainly all the larger bodies, occur only in regions of folded and otherwise disturbed strata. In some such cases the outlines of the intrusive bodies have no evident relation with the structures of the surrounding folded strata. In other instances, the attitudes of the bordering strata may be such as to suggest that a relation does exist between the folding exhibited by them and the invasion of the igneous body. The visible or inferred general shape of the large intrusive masses is usually that of a body extending downwards with nearly vertical or outwardly inclined sides. The outline in plan may be circular, ovoid, elongated, or quite irregular. The edge may be smoothly curving or irregular. Not seldom the upper surface appears to have been highly irregular, with large masses of the cover rock, known as roof pendants, projecting downwards into the igneous body. In some cases the irregularities of the roof are so broadly developed that projections of the igneous mass now appear as isolated bodies separated by miles from the nearest outcrops of the main mass.

STRATIGRAPHICAL GEOLOGY

Many sedimentary rocks hold traces or remains of plants or animals that existed at the time the containing rocks were being formed. In some cases a considerable part of the organism has been preserved, but more commonly it is represented by a cast or mould. In other instances the animal or plant remains have been replaced by silica, calcium carbonate, or other matter in such a way as to preserve internal structures as well as the external form. These traces and remains of former life are known as fossils and they indicate the composition of the floras and faunas that existed at the time of formation of the rocks holding them.

It has repeatedly been demonstrated in places where considerable thicknesses of fossil-bearing strata are open to inspection, that some or all the forms of life represented by the fossils in any group of beds differ from those in the underlying and overlying strata. It has also been found that the same general assemblage of fossils characterizes any single group of strata as far as they may be traced. It is evident, therefore, that the character of the animal and plant life changed during the great stretches of time required for the formation of thick accumulations of sediments and that the change consisted of the disappearance of some species and the introduction of new species. In some instances the presence of new species and the absence of old forms were of a temporary character and were caused by changes in the conditions of life, as when the waters of a once clear sea became muddy and afterwards reverted to a clear condition. But it has been found that the earlier species of animals and plants do finally disappear never to reappear and that the new forms that constantly arose suffered like extinction. Thus, in any considerable thickness of fossil-bearing strata succeeding groups of beds are distinguishable by different assemblages of fossils; new species appear at different horizons, some confined to a single group of beds and others occurring through successive groups.

Not only are the strata of different levels of any one section of rocks characterized by the presence of different faunas or floras, but it has been found the world over that the same general faunas and floras everywhere succeed one another in the same order. It is concluded, therefore, that in the past the spreading over the world of most new types of life was very rapid in comparison with the slow rate at which sediments accumulated. The fossil contents of a group of beds thus become a means of determining the age of the containing beds relative to the age of fossiliferous strata in other districts and regions. The order in which the different faunas and floras succeed one another has been determined. If the fossil fauna or flora of a set of beds is essentially the same as that contained by the strata of another area, the conclusion is that the fossiliferous beds in both areas are of the same age; if the fossil assemblages differ, then the relative ages of the two sets of beds can be determined by considering the established order of succession of life forms.

The known order in which different species of plants and animals appeared and disappeared has permitted the making of a geological calendar in which geological time is divided and subdivided into intervals, each characterized by the existence of certain forms of life. The lengths in years of the divisions of time in the calendar are unknown, but certainly are very unequal. Fossils are almost lacking in the earliest known rocks. They suddenly become abundant and consist of the same forms in a group of beds known as the Cambrian. All older strata are known as Precambrian; they are essentially non-fossiliferous, and the time of their formation is known as the Precambrian era. This era, in the geological calendar, is succeeded by the Palæozoic era defined as commencing with the Cambrian period when the fossiliferous Cambrian beds accumulated. The other major terms in the geological calendar are given in the following table:

Geological Calendar

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

The strata of each period in the above table are subdivisible into groups whose names become the names of further subdivisions of geological time. For instance the Cambrian period is divisible into Lower, Middle, and Upper Cambrian; further more the strata of the Lower, Middle, or Upper, Cambrian of a district may be divided into a number of formations each with a local name which also becomes the name of the time interval during which the particular formation was laid down. No gaps exist in the calendar. Precambrian time ends at the moment Palæozoic time commences, Cambrian time ends at the commencement of Ordovician time, and so on. In the case of the strata of every district there are gaps, for sedimentation was not continuous the world over; while sediments were forming in one region, other regions were undergoing erosion.

The Precambrian era is not divided in the above table, for no universally accepted nomenclature has yet been devised for the subdivisions of this era. The terms Earlier and Later Precambrian are sometimes used; other equivalent pairs of terms are as follows, the first given name of each pair being that of the earlier division: Archæozoic and Proterozoic; Laurentian and Huronian; Archæan and Algonkian.

The relative ages of the fossiliferous strata of any district may be determined by the aid of their fossil contents, but in the absence of fossils or even if they are present, the structural relations existing between the various rock assemblages must be relied upon. In the case of bedded rocks (i.e., the sediments and lavas), it is obvious, if the strata are not much disturbed, that the first-formed beds are the lowest and that each succeeding layer is younger than the one below. If the beds succeed one another without change of attitudes and no indications that the processes of sedimentation (or volcanic activity) were interrupted, the strata are said to be conformable. But if there is evidence that sedimentation was discontinuous, then the strata of each period of sedimentation are in unconformable relations with the groups of rocks above and below. Unconformities are of various kinds. In some areas, during intervals of non-deposition, the already formed strata were only slightly or not at all disturbed and if eroded were eroded to uniform depths over considerable areas. When sedimentation recommenced in such areas, the newer strata were deposited on the older unseparated by any well-marked structural break. In such cases the upper strata are said to be disconformable to the lower. In other instances the earlier formed strata during periods of non-deposition were tilted, perhaps invaded by igneous bodies, and eroded. Later deposited beds in such areas would lie horizontally upon various horizons of the now tilted, earlier formed rocks; the relations would be those of angular unconformity.

The relative ages of the intrusive igneous rocks of an area are established by examinations made along the borders of the intrusive masses. If an igneous body appears to project into another rock or cuts across its structures, the igneous rock is presumably the younger. An igneous rock is younger than an adjoining rock if it holds inclusions of the bordering rock or if it has been chilled along its edges and, therefore, is glassy or much finer grained than elsewhere. Where igneous rocks adjoin sediments that are much altered at the contact, the sediments are presumably older than the igneous body. If they hold eroded fragments of the igneous rocks, they must be the younger.

By carefully determining the positions of the rock outcrops of an area, by studying the rocks themselves and noting their structures and relations with one another, it usually is possible to determine the order and conditions of formation of the different rock bodies and to learn of the conditions under which they continued to exist. In other words, the geological history of the area can be deciphered or, at least, the order and nature of the main events can be discovered. By tracing one or more formations into adjoining districts or by considering the characters of the rocks and geological histories of several districts, it usually is possible not only to establish the equivalency or non-equivalency of one or more formations, but, also, to correlate the leading events in the geological histories of the several districts and to verify, correct, or extend the historical record of one district by information obtained in another. It also usually is possible to date the various events in terms of the standard geological calendar.

CHAPTER II

FORMATION AND DESTRUCTION OF MINERAL DEPOSITS

Origin and Classification of Mineral Deposits

(H. C. Cooke)

A *mineral deposit* is a geologic body in which certain mineral substances are concentrated. The term commonly implies that the mineral substances thus concentrated are useful and can be mined at a profit; but both implications are variables. The progress of invention and discovery is constantly producing new needs, so that deposits of mineral, once valueless, leap into prominence. The applications of new alloys of steel raised to high values ores of tungsten previously thrown on the dump and the invention of the incandescent mantle for gas burners gave thorium ores an importance formerly unknown. Mining at a profit is dependent on two variable factors: the market price of the product, and the cost of extraction. Many mines opened during the late war when prices were high had to be closed when the unusual demand ceased. On the other hand, improved methods of extraction, such as the cyanide process for gold, have converted once valueless deposits into rich assets.

Certain mineral deposits consist mainly of a single useful substance, such as beds of gypsum, coal, or hematite. Others, like gold deposits, contain one or more useful constituents, disseminated through other undesired minerals.

Geologic bodies not worked for any particular mineral or minerals, but for the rock itself, such as deposits of granite or roofing slate, are not spoken of as mineral deposits, but as granite or slate deposits, as the case may be.

Ore is that part of a mineral deposit which may be *profitably* worked for the extraction of one or more metals. *Ore minerals* are minerals that contain valuable metals, whereas *gangue minerals* are the valueless minerals associated with the ore minerals in a mineral deposit.

A *vein* is a mineral mass, more or less tabular, deposited in or along a fracture or group of fractures.

A *replacement deposit* is a mineral deposit formed by mineral-bearing solutions which, instead of filling cavities as in the case of veins, slowly dissolved some or all of the constituents of a body of rock and deposited other materials in their place. In many instances deposition followed or accompanied solution in such a way that the forms and textures of the earlier substances are preserved.

Meteoric water is water that originally falls as rain or snow. *Juvenile* or *magmatic water* is water given off from a body of molten rock during cooling.

COMPOSITION OF THE AVERAGE ROCK

The outer part of the earth, still commonly referred to as the "crust" although the former conception of a liquid interior is now discarded, is composed of igneous and sedimentary rocks. The latter, however, form only a comparatively thin veneer. Clarke[1] calculates that igneous rocks form 95 per cent of an outer layer 10 miles deep, and sedimentary rocks only 5 per cent, of which four-fifths is shale. The composition of the average igneous rock, according to the same investigator, is as follows:

Average Analysis of Igneous Rock

	Per cent		Per cent
Oxygen	46·42	Sulphur	0·080
Silicon	27·59	Chlorine	0·097
Aluminium	8·08	Fluorine	0·030
Iron	5·08	Barium	0·081
Magnesium	2·09	Strontium	0·034
Calcium	3·61	Manganese	0·125
Sodium	2·83	Nickel	0·031
Potassium	2·58	Chromium	0·068
Hydrogen	0·13	Vanadium	0·041
Titanium	0·721	Lithium	0·005
Zircon	0·052		
Carbon	0·051	Total	100·000
Phosphorous	0·158		

Other metals, such as platinum, gold, silver, copper, lead, zinc, antimony, arsenic, tin, mercury, are present in amounts of less than 0·1 per cent.

It will be observed that the eight elements first named in the above table constitute 98·28 per cent of the igneous rocks, and all the other elements together less than 2 per cent. Since the proportion of most elements of the earth's crust is so small, it is obvious that natural processes of concentration must be active on a large scale before even the leanest ore deposit can be formed. The study of the processes by which valuable minerals have been naturally concentrated, or, as it is generally termed, of *ore genesis,* is one of the principal functions of economic geology.

GENERAL CLASSIFICATION OF PROCESSES OF CONCENTRATION

Study of mineral deposits in many parts of the world has shown that the processes of concentration are of two general types, those active at or near the earth's surface, and those active more or less deeply beneath the surface. In some ore deposits both have been active. The principal agents at work on the earth's surface are air, water in its various forms, heat and cold, plant and animal life. Working together or separately, they disintegrate rocks mechanically, break up the rock minerals into new chemical compounds, and transport the products of both actions from one place to others. Mechanical disintegration is accomplished by the grinding or pounding of waves, running water, and glaciers; by the expansion of water when it freezes in cracks and pores of the rocks; and, in desert regions, by abrasion by wind-blown sand grains. In chemical disintegration the rock minerals are attacked by water, oxygen, and carbon dioxide; feld-

[1] Clarke, F. W.: "Data of Geochemistry," 5th ed., N.S., G.S. Bull. 770, p. 29 (1924).

spars are converted into mixtures of kaolin, quartz, and carbonates of lime, soda, and potash; ferromagnesian minerals into chlorite and various carbonates; and the new substances which are soluble are taken into solution. During transportation the insoluble materials undergo sorting, according to their size and weight. These processes, as will be shown, may under suitable circumstances result in the formation of bodies of mineral substances valuable to mankind.

Almost all mineral concentrations of deep-seated origin have been formed, so far as we know, in only one general way, namely, by physical and chemical processes connected with, and dependent on, the slow cooling of bodies of molten rock deep within the earth. A relatively few deposits, particularly some of sulphur, are formed by volcanic emanations at the surface. Some materials valuable to mankind are formed, in places, by the metamorphism of previously formed rocks by the heat and pressure prevailing at depths. Thus limestones are converted into marbles, sandstone into quartzites, and shales into slates.

CONCENTRATES FORMED BY SURFACE AGENCIES

The action of the surface agents mechanically disintegrates rocks and chemically decomposes their more complex constituents. The new substances formed include the carbonates, sulphates, and chlorides of the metallic elements, iron oxide, kaolin and other clay-forming minerals; quartz, magnetite, garnet, gold, platinum, cassiterite, etc., if present, remain comparatively unaltered. The decomposed mass, subjected to the action of water in its various forms, undergoes a selective separation. Soluble minerals, such as the chlorides, sulphates, and carbonates, are carried away in solution to the sea, although some, particularly the less soluble carbonates, may be precipitated in part below the surface to form veins and other cavity fillings. The more insoluble parts are commonly carried off by running water into the streams, but in a few places where for any reason this does not occur, solution continues to act, leaching out even the only slightly soluble constituents and leaving the least soluble until reasonably pure bodies of the latter remain. Such are termed *residual deposits*. The kaolin deposits furnishing fire-clays and china clays in various parts of the world, the bauxite deposits, used for the manufacture of aluminium, most of the workable manganese deposits, and the rich iron ores of Lake Superior district, are examples.

Normally, however, heavy rains and temporary storm rivulets wash the detrital material down slopes into the larger streams. Here a mechanical separation takes place. The lighest particles remain in suspension, retained there by the eddies and swirls of the current and by other forces, whereas the heavier sink to the bottom. Of the latter, the lighter are easily and rapidly rolled along, but the heavier may be moved only in time of flood. The heaviest particles will tend to find their way downward through the shifting detritus to form a layer adjacent to bedrock. The materials moved downstream by the current will eventually find their way to some body of standing water, such as a lake or the sea. Here wave action and the currents produced by wind and tide continue the sorting processes. These keep the finer material in suspension, or, if it drops, pick it up again during the next storm, until finally it comes to rest far from shore, in water of such depth that waves cannot disturb the bottom. Material such as fine sand will come to rest closer to the shore, at depths where wave and current action just cease to be able to transport it; and coarse sand, gravel, and boulders, which are not shifted greatly even by strong wave action, will remain on and near the shores.

This brief sketch, although not detailing or even mentioning many of the factors of erosion, outlines roughly the action of running water in separating the insoluble parts of rocks. The point of great importance is, that although the separation is purely mechanical, it happens also to be chemical. The principal insoluble constituents of thoroughly decomposed rock are kaolin and other clay-forming minerals, and quartz. The clay-forming minerals tend to form minute particles, whereas the quartz is commonly in coarser grains. Thus, where the rock has been thoroughly decomposed by weathering, and the constituents thoroughly separated by the above processes, the result is the formation of beds of very pure clay in one place, and very pure sand in another. Where weathering or the mechanical separation has been less complete, the resulting materials are less pure. Pure sands thus formed are used exclusively as ingredients in pottery and glass; with certain admixtures of clay, 10 to 20 per cent, they are useful as moulding sands. The more strongly compacted sandstones, and quartzites, are used as millstones, whetstones, and grindstones. The clays, when fairly pure, serve for the manufacture of brick, tile, pottery, and similar products. A particular variety of clay, known as fuller's earth, is extensively used in refining petroleum, and also for decolorizing and clarifying other oils and fats.

Brief reference has been made to the fact that during the movement of insoluble materials downstream, the heaviest particles sink through the shifting detritus of the bottom to come to rest on bedrock. This type of mechanical concentration is of the highest importance, economically considered, for in places the heavy layers so formed are *placer deposits*. Placers contribute some $70,000,000 annually to the world's supply of gold, and the immense gold deposits of the Witwatersrand district of the Transvaal, the largest in the world, are possibly placer deposits consolidated into rock. Diamond placers have been worked in Brazil, India, and South Africa, and in places sapphires and rubies have also formed placers. Most of the world's supply of tin and platinum comes from placers, together with practically all the supply of monazite. In Canada the principal placer deposits have been the gold placers of British Columbia and Yukon territory, and the platinum placers of Tulameen river.

The materials removed from rocks by solution, it has been noted, are for the most part carried down to the sea, although part may be trapped in transit and precipitated to form veins and other cavity fillings. The materials carried in solution include the bicarbonates, sulphates, and chlorides of calcium, magnesium, sodium, potassium, and iron, together with a little silica. On reaching the sea these solutions are attacked by a multitude of organisms that extract the silica or calcium carbonate for the construction of their shells or skeletons. As the animals die the hard parts gradually accumulate on the sea bottoms, forming beds of limestone which commonly contain also some silica. Other organic agencies also precipitate lime carbonate directly. In some way not yet thoroughly understood, a part of the lime of such beds is in many cases replaced by the magnesia still in solution, so that the beds consist eventually of lime-magnesium carbonate, termed dolomite when the proportions of lime and magnesia are approximately equal. Limestone, particularly the purer varieties, is probably one of the most widely used natural products. It is used as a building stone, as a flux in smelting operations, for the improvement of certain soils, and for other purposes. Burnt, it forms lime, which is used in mortar and in the manufacture of a great variety of commercial products such as glass and pottery, paint, paper, sugar, soap, and alcohol, in tanning, etc. Chalk and lithographic stone are special varieties of limestone, the former a loosely coherent variety used for polishing, whiting, marking, etc., the latter a compact variety of very uniform texture used for reproducing drawings, etc.

The silica-secreting organisms of the sea are not commonly present in sufficient numbers for the silica of their shells or skeletons to form more than an impurity in the limestones or other deposits of the sea bottom. In places, however, enough are present to form thin beds or nodules of chert within limestone formations. In places where the supply of silica is very abundant, as in lakes where siliceous volcanic ash has been deposited, a class of algæ, the diatoms, may become so abundant that their minute siliceous shells form thick beds. The material thus accumulated is known as diatomaceous earth, used as a polishing powder, as absorbent for various liquids, and as packing for steam pipes.

Iron carried in solution may under favourable conditions be precipitated and form beds. The necessary conditions are, a large supply of iron-bearing solutions introduced into some body of water so confined that the iron salts are not dissipated by dilution. Inland ponds and lakes, and confined bays of the sea seem to supply the necessary conditions. The iron may be supplied by volcanic waters or by the ordinary processes of solution acting on rocks rich in iron. Precipitation of the iron may occur by the loss of carbon dioxide from the solutions through evaporation or by absorption by plants, by absorption of the iron by iron bacteria, by precipitation by calcium carbonate or other substances in solution, and in other ways. In the case of most bedded iron deposits the processes of formation are, however, doubtful. The iron may be precipitated as the carbonate, siderite, as the hydroxide, limonite, and similar compounds, as hematite, or as silicate. The lean iron deposits of the Precambrian Shield in Canada and south of lake Superior were mainly precipitated as carbonate and silicates; the carbonate in some cases was altered later to hematite or magnetite. Bodies of workable ore have been produced from these lean primary deposits by the gradual leaching away of silica and other impurities by percolating rain waters, leaving the iron compounds in concentrated form.

Throughout the geologic ages, therefore, streams have been carrying soluble materials to the sea, where most of the carbonates of calcium, and magnesium have been precipitated, together with the silica and iron, but leaving in solution the most soluble salts. Constant evaporation from the sea, during the same great length of time, has supplied the water vapour which, recondensing and falling as rain, soon acquires another load of soluble salts which in turn reaches the sea. This great cycle of proceses, indefinitely repeated, has gradually caused a concentration of the soluble salts in sea water until, at present, sea water contains about 3½ per cent of dissolved solid matter. In addition to sodium chloride, which constitutes nearly 78 per cent of this matter, sulphates and chlorides of lime and magnesia, sulphate of soda, and small quantities of bromine and potassium compounds are present, with, of course, a little carbonate.

If a body of sea water is completely or partly cut off from the sea by differential uplift or by the formation of a bar at the mouth of a bay, and if this occurs where the climate is rather dry and evaporation exceeds precipitation, it is obvious that the sea water will rapidly be concentrated to a point where the soluble salts can no longer remain in solution, but must precipitate to form sedimentary beds. The results of such evaporation have been elaborately studied, both in natural deposits and in the laboratory. Calcium sulphate is the first substance to be precipitated; sodium chloride begins to be thrown down when about nine-tenths of the water is evaporated, and finally, if evaporation is continued almost to dryness, the highly soluble chlorides and sulphates of magnesium and potassium, together with sodium bromide, are deposited. Deposits containing the whole series of salts above described are rare, in fact are known only in the case of the great deposits of the Stassfurt region of central Germany, which produce, in addition to salt, the greater part of the world supply of potassium salts and bromine. Salt beds are more common, but in many places the process of evaporation, owing to changes of climate or invasion of the sea, ceased after beds of calcium sulphate alone had been formed.

Calcium sulphate, $CaSO_4$, forms two compounds, anhydrite and gypsum. Gypsum differs from anhydrite in containing chemically combined water. Anhydrite is of little commercial value, but gypsum is an important non-metallic mineral. Ground in its natural state it is employed as land plaster, is used to retard the setting of cement, and for various chemical purposes. Calcined at 350 degrees F. a large part of the water is expelled, and this product, called plaster of Paris, when finely ground, takes up water quickly to form gypsum again, thus setting to a hard stucco. In Canada some of the main deposits of gypsum occur near Windsor, Nova Scotia; Hillsborough, New Brunswick; in Ontario along the basin of Grand river, near Brantford and Paris; and at Gypsumville, Manitoba.

The numerous uses of salt for culinary, preservative, and industrial purposes need hardly be specified. The principal Canadian occurrences of salt are near Goderich and Windsor, Ontario, where deep wells tap thick salt beds, from which the salt is pumped to the surface as brine. Nearly all the salt mined in Canada is produced from these wells; some is produced in Malagash peninsula, Nova Scotia, and salt beds are known to exist at depth near Hillsborough, New Brunswick, and at McMurray, Alberta.

In many places on the earth's surface, streams, instead of continuing to the sea, run into basins where the loss by evaporation equals or exceeds the inflow. It is obvious that, under such conditions, their waters will rapidly be concentrated to form salt lakes, in the bottoms of which beds of the soluble constituents must eventually be laid down. It is also obvious that the beds thus produced will differ radically from those formed by evaporation of sea water, for whereas in the sea the carbonates, the principal soluble constituents of river waters, have been largely removed by the action of organisms, with resultant concentration of chlorides and sulphates, in the inland lakes no such action has occurred. Consequently, the nature of the deposits will depend directly on the composition of the streams entering the basins; and as the soluble load of the average river consists mainly of carbonates, with sulphates second and chlorides third, it might be expected that the deposits would also be of this character. In actual fact, however, it is found that on account of the restricted area of the drainage basins of the streams in dry areas, coupled with the smallness of precipitation, very wide variations from average composition occur; and the principal determining factor appears to be the composition of the rocks of the drainage basin. Consequently, it is impossible to formulate any generalization as to composition. In this way beds of sodium chloride, sodium sulphate, sodium carbonate, magnesium sulphate, potassium sulphate, magnesium chloride, sodium nitrate, and borax are formed in various parts of the world. In Canada the principal deposits of this sort occur on the western plains, in Saskatchewan and eastern Alberta, where deposits of sodium and magnesium sulphates are forming in shallow ponds and lakes. On the interior plateau of British Columbia, also, there are three localities where similar deposits occur, and a number of others in which the principal deposit is sodium carbonate, with some sodium sulphate. These substances are largely used in the paper, glass, tanning, dyeing, and other industries.

Evaporation is also responsible for the formation of the alkali crusts that render large areas in the southern port of the Great Plains unfit for cultivation. The water of the subsoils ascends towards the surface and on evaporation deposits the salts carried in solution. In districts of normal rainfall these salts would be carried into the streams and removed to the sea.

FORMATION OF VEINS

Mention has been made of the fact that surface waters may deposit a part of their load in fissures or other cavities beneath the surface. The causes of such deposition are usually chemical. A solution which at the surface, by reason of its content of carbonic, sulphuric, or humic acids is acidic, becomes neutral or basic at greater depth through interaction with the rock constituents, and certain substances soluble in the acid solution may be less soluble in a neutral or basic solution and, therefore, may be precipitated. Carbonates go into solution as bicarbonates, and if the excess carbon dioxide that goes to make up the bicarbonate is removed by interaction with some rock constituent, the carbonate must be precipitated. Solutions from different sources, and consequently of differing composition, may meet and mix, with resultant precipitation of certain constituents; and many other reactions may occur, discussion of which is beyond the scope of this paper. As the solvent action of the waters is primarily selective, for only certain constituents are dissolved, and the precipitation also is selective, throwing only certain substances out of solution, it is evident that concentrations of certain substances may result from these processes. It is also evident that deposition must, for the most part, go hand in hand with solution because precipitation of some of the dissolved constituents results from other constituents attacking and dissolving the rock materials. This, however, does not imply that the volume of material precipitated must be equal to that taken into solution; on the contrary, the amount precipitated may be more than that dissolved, thereby increasing the volume or reducing the pore-space, or it may be less, creating cavities.

When the cavities filled in this way are the pore-spaces between rock grains, the phenomenon is known as cementation. By it unconsolidated gravels, sands, and muds are cemented into beds of solid conglomerate, sandstone, and shale. The binding materials, for the most part, are calcium carbonate and silica, but in places iron salts may be precipitated, forming ferruginous sediments easily recognized by their red colour. In a few places on the earth's surface the cementing minerals are compounds of copper or lead, forming lean ores of these metals.

Open fissures are commonly soon filled by deposits from the surface waters, resulting in the formation of veins. The majority of such veins consist of quartz and calcite, the substances most largely in solution. The precipitated materials must naturally cling to the walls, so that the fissure is filled from the edges to the centre. As no great quantity of material is carried in a given volume of water, filling is a gradual process, during which the composition of the solutions may undergo changes. As a result, the composition of the material deposited also changes, thus giving the cross-section of the vein a layered or banded structure known as crustification. The central part of such a vein in many cases contains unfilled openings known as druses. The substances of economic value forming veins and originating in this way include barite, celestite, and strontianite, some deposits of magnesite, and certain lead-zinc ores.

Barite, or barium sulphate, occurs principally as veins and other cavity fillings in sedimentary rocks, chiefly in limestones. Witherite, the barium carbonate, is associated with it in places. The occurrences of celestite and strontianite, the sulphate and carbonate, respectively, of strontium, are similar, and in many veins barite and strontianite are associated. Barite is used extensively in the manufacture of paints, paper, and fireworks, and for chemical purposes. Strontium salts are used in sugar refining, and for fire works. In Canada, most of the barite produced comes from Lake Ainslie district, Nova Scotia, but deposits that could be utilized occur in several provinces. Celestite is known to occur in several localities in Ontario, but there is no regular production.

Magnesite, or magnesium carbonate, may form veinlets in serpentine, but such deposits are rarely of economic value. Most of the production of magnesite comes from bodies in which dolomite or serpentine has been replaced by magnesite. The deposits of Grenville township, Quebec, are replacements of dolomite or dolomitic limestone. Magnesite is used for the production of carbon dioxide, which it gives off on being heated to 800 degrees C., and the calcined product is employed extensively for basic furnace lining, in the paper and sugar industries, and for other purposes.

Certain ores of lead and zinc appear to have been formed by meteoric waters. Characteristically these ores fill fissures in limestones, dolomites, or calcareous shales. The minerals in such deposits consist of galena with more or less zinc blende, and usually some pyrite or marcasite. Rarely the galena contains a little silver. The gangue consists of calcite or dolomite with some quartz and, in places, some barite.

The principal deposit of this type in Canada is that near Galetta, Ontario, which produces 1,500,000 to 3,500,000 pounds of lead annually. The Frontenac mine, near Kingston, and the Wright mine on the east shore of lake Timiskaming are also of this type, but are not producing.

SECONDARY ENRICHMENT

Where surface waters have acted on a previously formed mineral deposit, the various processes of oxidation, hydration, and solution commonly unite to alter it profoundly in composition within the zone of movement of the groundwaters. The zone so affected may vary in depth from a few feet to several hundred; and as the net result of the various processes is commonly a concentration of the values within certain parts of the upper zone, it is termed a secondary enrichment.

Mineral deposits, in this connexion, may be roughly divided into two classes, those containing pyrite or marcasite, and those containing little or none of these minerals. In the latter class the changes produced by weathering are simple and analogous to those produced in rocks. Siderite and other iron compounds change to limonite, sulphides like galena and sphalerite alter very slowly to their respective sulphates and carbonates, calcite is dissolved fairly quickly, quartz more slowly, and the rock minerals are converted into kaolin. The whole process proceeds slowly, and under suitable conditions may result in the formation of a thin capping of residual quartz, kaolin, and iron oxide, with a certain enrichment of the vein matter beneath by the metallic salts carried down in solution and reprecipitated. Where, on the other hand, pyrite or marcasite is present its oxidation produces sulphuric acid, a powerful solvent, which attacks most minerals and converts them into sulphates, most of which are readily soluble. The pyrite itself is converted, in part, into ferric sulphate, also a powerful solvent of many metallic minerals. Thus the alteration and leaching of the upper part of the ore deposit goes forward with vastly greater speed and completeness than in those deposits where pyrite is absent.

Where these processes go on for a long period of time, they produce a rather indefinitely stratified body. Its top is a cellular mass of silica carrying a good deal of limonite, which is known as the gossan or "iron hat." If minerals insoluble in sulphuric acid, such as gold, cassiterite, or wolframite, are present in the primary deposit, these are concentrated in the gossan by the removal of the other constituents, so that it may form a rich ore; but otherwise it is barren. Below the gossan is a belt of oxidized ores, extending downward as far as there is active movement of the oxygen-charged waters, which is usually to the average level of the groundwater. In this belt the original sulphides are altered partly or completely to oxides and hydroxides, carbonates, sulphates, and chlorides. Below the belt of oxidized ores and the groundwater level is the belt of secondary sulphides, where the downward moving surface water, having become neutral or basic through reaction with the rock minerals, precipitates its load of metals as sulphides by replacement of the primary sulphides. This zone is apt to be the richest of the deposit. Finally, the secondary sulphide zone passes gradually into the leaner zone of primary sulphides of which the whole deposit originally consisted.

The slowness of the processes of secondary enrichment is shown by the slight extent of post-glacial oxidation. Pyrite deposits on the severely glaciated Canadian shield, which presumably had their oxidized upper parts planed off by the ice, are now oxidized to depths of only a foot or two; although the time since glaciation is estimated as 10,000 to 50,000 years, and pyrite, as already indicated, oxidizes more rapidly than the other common vein minerals.

In districts that have not been subjected to strong glaciation secondary enrichment has produced extremely valuable ore-bodies, many of them where the primary ores have proved too lean to mine. In Canada, where glaciation has been severe almost everywhere, the ice planed away the oxidized upper parts of the rocks and ore deposits, so that examples of secondary enrichment are very few in number. The few that are known all occur in the mountainous districts of British Columbia, in localities that escaped strong glaciation. The mining of secondarily enriched deposits, however, has disseminated the idea that richer ores are certain to be found by sinking on a deposit. This belief is now widely held by prospectors, even in Canada. It is obvious, however, that ores are not likely to become richer with depth, except in accidental instances, unless secondary enrichment has occurred; and secondary enrichment is almost unknown in Canada. Yet millions of dollars have been vainly spent in the past in sinking on lean deposits with the confident expectation of finding better ores at depth. Fortunately the dissemination of knowledge is bringing such waste to an end.

DEPOSITS OF ORGANIC ORIGIN

Certain beds and deposits directly owe their existence to the presence on the earth's surface of animal and vegetable life. Of these, beds of limestone and of diatomaceous earth have already been mentioned. The most important of the others are the deposits of coal, oil, and phosphate. Some deposits of iron, and a few of lead and zinc, also owe their origin in part to organisms.

Coal is composed of vegetable matter which has been preserved, buried, and has lost more or less of its gaseous constituents through the action of compression. Ordinarily dead vegetable matter rots and is destroyed, but this is not so where it is covered by water, as the study of peat bogs shows. The conditions for the formation of a coal bed, therefore, are: (1) preservation of the vegetation in swamps or lakes; (2) growth in a country of low relief, so that little sand or clay will be mixed with the dead vegetation; (3) burial by water-lain sediments before erosion can remove the accumulated material.

W. H. Emmons has calculated from the known rates of accumulation of peat that it would require some 400 years for the growth of vegetable matter sufficient to form a coal bed one foot thick.

About the origin of oil deposits little is yet definitely known. It is generally considered that the oil originated from the bodies of marine organisms, both plant and animal, which were buried during the accumulation of the ordinary marine sediments. Oily materials were probably generated from these remains soon after the death of the organisms, and were retained in pore spaces and other openings to form, on consolidation of the rock, the oil-shales and petroliferous limestones so common in regions underlain by sedimentary rocks. Where deformation of such deposits occurred at some later date, some of the oil was squeezed out, probably distilled in part by the heat produced during deformation, probably fractionated by the mere passage through the pore spaces of the sediments, to accumulate finally in porous strata beneath some impervious bed and form an oil "pool."

Oil was first found in America in 1859, and since that time practically the whole supply has come from the oil pools. The widely increasing use of oil and its distillation products, of which gasoline is chief, together with the anticipated probability that the oil reserves will approach exhaustion in another two or three decades, has led to the search for other sources of oil. These have been found in the oil-shales, of which there are vast deposits containing enough oil to make distillation profitable in places even now. They yield from 15 to 50 gallons of oil a ton, together with varying amounts of ammonium sulphate, a profitable by-product.

Where oils have been subjected to evaporation and oxidation at or near the earth's surface, the more volatile constituents are lost, and a heavy tarry residue produced. The more solid varieties are known as asphalt, and used for paving, manufacturing building paper, roofing materials, etc.

All land animals absorb phosphoric acid and segregate it in their bones and excrements. Many marine animals also have much phosphate in their shells. Phosphate deposits may, therefore, be formed, under suitable conditions, both on land and in the sea.

The deposits formed on land include: (*a*) a few extraordinary accumulations of bones in certain formations known as bone beds; and (*b*) the guano deposits formed by sea birds congregating in enormous numbers on desert coasts and oceanic islands. In places the guano is 100 feet thick. It averages 10·9 per cent nitrogen, 27·6 per cent phosphates, and 2 or 3 per cent of potash.

Most marine sediments contain more or less phosphate on account of the admixture of phosphatic shells they contain, but the highly phosphatic beds found in certain districts, as in Utah and Idaho, are supposed to have been formed in waters of moderate depths in places where conflicting currents have produced numerous and sudden changes of temperature, thus killing unusual numbers of organisms. In Tennessee, North and South Carolina, and Florida there are widespread deposits of phosphatic limestone. In Tennessee some of these are quite high in phosphate content, and can be mined directly; but throughout the most of this region the phosphates mined are residual deposits, from which the limestone has been dissolved by groundwaters, leaving the less soluble phosphates concentrated in a loose, porous, pebbly stratum near the surface.

It has lately been determined that groundwaters at considerable depths in regions underlain by oil-bearing rocks, in many places contain large numbers of certain classes of bacteria that may exist without oxygen. These bacteria appear to feed on the oil, and one result of their life processes is the production of great quantities of hydrogen sulphide. Hydrogen sulphide readily precipitates the heavy metals, lead, zinc, iron, and others, from their solutions, and it is evident, therefore, that if solutions containing these metals were circulating in regions of oil-bearing rocks, deposits of sulphides might be formed. Following these recent discoveries attention has been called to the fact that the lead and zinc deposits of Mississippi valley lie close to oil-producing areas, so that it is very possible that these deposits owe their existence to the reactions above described.

MINERAL DEPOSITS OF JUVENILE ORIGIN

It has been shown that igneous rocks contain small quantities of the various metallic elements. These rocks are termed igneous because they are known to have passed into their present state from a primary molten condition. It is now generally recognized that during solidification, under suitable conditions, there is a tendency for the various constituents of the molten rock, or magma, to segregate themselves so that the mass, when finally hardened into rock, will vary greatly in composition from place to place. This process is known as differentiation, and tends to take place in any magma that cools and solidifies slowly. Slow cooling is the essential condition, as with rapid cooling the igneous magma quickly becomes so viscous as to prevent all movement of material within it. No great amount of differentiation occurs, therefore, in the igneous rocks that have cooled rapidly, such as lava flows, which cooled quickly because they were poured out at the surface, and dykes or other small intrusive bodies, which were quickly chilled by contact with the cold rocks into which they were intruded. The conditions essential to slow cooling, therefore, are large volume and deep burial; large volume, so that the amount of heat immediately lost in warming up the cold wall-rocks is small as compared with the total quantity of heat in the mass; and deep burial, because under a thick cover of rock the heat of the mass can leak away only very slowly.

Various theories as to the manner in which differentiation takes place have been advanced. One of the most plausible is the theory of differentiation by crystallization. A simple example of the process is afforded by the solidification, or freezing, of a pail of water in which a handful or two of common salt has been dissolved. A sample of this solution, when analysed, would consist of water, salt, and a certain amount of dissolved air; and these constituents would be so intimately intermixed that a sample taken from any part of the pailful would have exactly the same composition as one from any other part. Freezing produces remarkable changes. The first thing to separate from solution is pure ice, which clings to the sides or rises to the surface of the pail; and as the separation of ice continues it is seen to contain bubbles. These bubbles consist of the air formerly dissolved in the water; as the air is not soluble in ice, the separation of ice from the solution forces the air out of solution into the gaseous state. Finally the pail of salt solution is converted into a mass of pure ice containing some air bubbles, and at the centre there is a small quantity of still liquid saturated solution of salt. When the temperature is reduced sufficiently to freeze this, an intimate mixture of crystals of ice and salt is formed, composed of 23·6 per cent by weight of salt and 76·4 per cent of ice.

Thus, the uniform mixture of water, air, and salt becomes separated by the freezing process into three phases of entirely different composition. One of these is practically pure water in the solid state, contaminated only by the presence of a little of the salt solution trapped in the spaces between the ice crystals. The second is an ice-salt mixture of definite composition; and the third a gas phase. The pure ice is segregated around the sides and top of the pail, the ice-salt mixture in the centre, while the gas forms included bubbles here and there and, if the ice were subjected to pressure, like the magmas within the earth, it would be driven out of the mass entirely.

The solidification, or freezing, of a magma is supposed to follow exactly the same general course, although the processes and results are more complex because the magma contains a great number of components instead of only two or three. As a rule certain minerals begin their crystallization while the rest of the magma remains liquid, like the ice in the example above. If these minerals are heavier than the liquid from which they separate, as is the case with magnetite, chromite, augite, hornblende, and basic minerals generally, they tend to sink. Thus the lower parts of the magma tend to become gradually richer in the basic minerals, which are mainly the heavy silicates of lime, magnesia, and iron; whereas the upper parts, by the removal of these minerals, become progressively richer in the remaining constituents, namely silica, soda, and potash. There exists a tendency for the crystallizing minerals to segregate into masses of one mineral species, producing large or small aggregates of nearly pure hornblende, augite, magnetite, chromite, etc., and certain ore-bodies have been formed in this way. The magnetite and ilmenite concentrations in the anorthosites of Canada, the chromite deposits of the Eastern Townships of Quebec, and probably the sulphide ores of Sudbury have been thus formed.

If such a differentiating mass of magma remain undisturbed throughout the process of solidification, the resultant rock will possess a sort of stratification. The basal parts will be very basic, composed principally of lime-iron-magnesium minerals, the pyroxenes, amphiboles, and magnetite; and the rock will become progressively more siliceous upward, grading into a highly siliceous granite at the top. If, however, a large mass of differentiating magma be subjected from time to time to pressure, so that parts of it are forced into the overlying crust, a series of dykes of definitely connected compositions will result. The earliest dyke will be the most basic, since it was expelled when differentiation was least advanced; and later dykes will become progressively more and more siliceous. An excellent example is afforded by the complex of porphyry intrusives which form a large mass in the centre of Boischatel township, southeast of lake Abitibi, Quebec.[1]

[1] Gunning, H. C.: "Syenite Porphyry of Boischatel Township"; Geol. Surv., Canada, Bull. 46 (1927).

The solid igneous rocks do not correspond wholly in composition with the liquid magmas from which they originated. The liquid magmas contain certain volatile constituents that are largely lost during consolidation. Of these, water is undoubtedly the largest in quantity, and chlorine, fluorine, hydrogen, sulphur, and carbon dioxide are others. Proof of this rests on two lines of evidence; one, the direct experimental study of the emanations from volcanoes, where today liquid magmas are being poured out at the surface; the other, the study of the course of crystallization in igneous intrusives. It is well known that quartz and the alkaline feldspars, orthoclase and albite, melt only at very high temperatures, yet geological evidence indicates that commonly they were the last minerals to crystallize from a magma, and that the temperatures of their crystallization were comparatively low. Experiment has shown that this contradictory behaviour may be explained by the presence in the magma of water and other volatile constituents, which substances, as it were, can retain the quartz and feldspar in solution at temperatures far below their melting points in the dry state.

As the magma crystallizes, therefore, the upper layers become more and more siliceous, and also contain the greater part of the volatile constituents. As these volatile constituents, such as chlorine, fluorine, sulphur, and so on, readily unite with metals, any metals remaining after the early crystallization and sinking are also likely to be concentrated in these acid upper parts. As crystallization continues, the liquid residues necessarily become more and more aqueous. The cooling of a large igneous mass is invariably accompanied by contraction, which results in the formation of fissures both within the mass itself and in the surrounding rocks, and such fissures naturally become filled with the aqueous residues. As cooling still proceeds, the aqueous material deposits its load of dissolved substances forming veins. The first materials to be deposited are naturally the most insoluble, the quartz-feldspar mixture known as pegmatite; when the solutions have become so cool that all the feldspar is gone, quartz is the main substance precipitated; and with still further cooling and elimination of the silica, the quartz veins may pass into quartz-calcite, and finally into calcite veins.

J. E. Spurr was one of the first to observe and emphasize the fact that many quartz veins are the last products of the differentiation of an igneous magma, and his description[1] of the relations in Fortymile Creek district, Alaska, illustrates well the sort of evidence from which the above conclusions have been drawn:

"The basic hornblende granite which forms the greatest rock masses contains subordinate quantities of biotite. By a very gradual transition the hornblende diminishes in amount as the proportion of biotite increases, so that the rock becomes a biotite granite; and in many dykes the amount of biotite becomes less and less, giving rise to an extremely siliceous granite in which the biotite is an insignificant constituent as compared with the quartz and feldspar. With further diminution of the biotite the granites change into essentially quartz-alkali feldspar rocks—alaskites. . . . In the alaskite series the change is continued by a relative increase in the amount of quartz and decrease of feldspar. One remarkable phase studied is a porphyritic dyke rock whose groundmass consists almost entirely of quartz in small interlocking grains,

[1] Spurr, J. E.: Trans. Am. Inst. Min. Eng. XXXIII, p. 310, 1902.

giving, both in the hand specimen and under the microscope, the exact appearance of a quartzite. Yet this rock contains scattered but regularly distributed porphyritic crystals of feldspar. It is thus not only related by the closest ties to similar slightly less siliceous alaskites of the same district, but it is only removed by its scattered porphyritic crystals from being a typical quartz vein. Moreover, the superabundant quartz in these very siliceous dykes tends to segregate into bunches, which may become large and have all the characteristics of ordinary vein quartz. With the progressive increase in silicification the quartz begins to occupy an important portion, and finally the larger portion, of the dyke. The feldspar becomes restricted to certain places, sometimes occurring irregularly, sometimes collecting near the walls, while the quartz lies in the centre. Finally, by the disappearance of the feldspar, the dyke becomes an ordinary quartz vein.

In one and the same dyke the change from a coarse alaskite to a typical quartz vein may be seen in all its stages. . . . . These veins contain pyrite, argentiferous galena, and free gold."

Since Spurr wrote these words many other geologists have substantiated his observations and extended them. Thus the writer has described the change from syenite porphyry to quartz veins at Matachewan, Ontario;[1] the change in vein composition from quartz and albite within a granite which gave rise to the vein to quartz outside of the granite, and finally to iron carbonate at a distance of 2 to 3 miles from the granite;[2] and the change in a vein from a magnetite-albite-quartz composition close to the intrusive whence it originated, through quartz to quartz, calcite, and chalcopyrite with quartz subordinate.[3]

Where the volatile constituents of the magma do not find suitable fissures through which to escape, or where the country rock is a limestone or some other easily replaceable material, replacement of the country rock may occur, forming what are known as contact-metamorphic deposits. Replacement deposits are also formed in many places where veins cut easily replaceable rocks, particularly in the deeper zones where the ore-bearing solutions are still fairly hot and concentrated.

In the deposits from the aqueous exhalations of igneous magmas there is a definite relation between the minerals formed and the temperatures and depths at which they crystallized. Although it is not within the scope of this sketch to enter into the subject in detail, it may be mentioned that deposits formed at very high temperatures, such as the contact-metamorphic deposits and the deepest veins, are characterized by minerals like albite, hornblende, tourmaline, axinite, garnet, epidote, magnetite, ilmenite, hematite, graphite, pyrite, pyrrhotite, sphalerite, arsenopyrite, chalcopyrite, cassiterite, and free gold. The temperatures at which such deposits were formed probably ranged from 300 to 550 degrees C., except in the contact metamorphic deposits where higher temperatures undoubtedly prevailed. Cooler solutions, ranging in temperature from 175 to 300 degrees C., deposited quartz, carbonate, fluorite, pyrite, chalcopyrite, arsenopyrite, galena, sphalerite, tetrahedrite, pyrargyrite, and free gold, etc., whereas such minerals as magnetite or ilmenite, specularite, tourmaline, garnet, hornblende, and feldspar are absent. Veins of this type yield a large part of the world's gold, silver, copper, and zinc. The silver deposits of Cobalt, Ontario, are an example. Finally, the veins formed by solutions at still lower temperatures, from about 50 to 175

[1] Cooke, H. C.: Geol. Surv., Canada, Mem. 115, pp. 43-56 (1919).
[2] Cooke, H. C.: Geol. Surv., Canada, Sum. Rept. 1921, pt. C, pp. 29-30.
[3] Cooke, H. C.: Geol. Surv., Canada, Sum. Rept. 1923, pt. C I, pp. 47-57.

degrees C., range in mineral content from that of deposits formed at the surface by hot springs to that of the previous class. At the surface, hot springs form opal, chalcedony, quartz, calcite, barite, and fluorite, and these minerals also appear in all the low-temperature veins under consideration, together with adularia, ruby silver, tetrahedrite, argentite, stibnite, galena, zinc blende, free gold, gold tellurides, and cinnabar. Pyrite and arsenopyrite are found only in small quantity, as also are compounds of cobalt, nickel, and molybdenum. These deposits are worked mainly for gold, silver, and mercury.

Although most metals and minerals are widely distributed, and occur in many different kinds of rocks, a few are quite limited in their associations. Thus, the occurrence of asbestos in commercial quantities is largely confined to serpentines; chromite occurs as a differentiation product of very basic rocks, such as peridotite. Bodies of pyrite and pyrrhotite, in many places carrying copper, nickel, or platinum values, are very commonly found near the margins of gabbro or norite masses. Native copper is a constituent of some basic lavas. Molybdenite, cassiterite, and many rare minerals have their origin in pegmatite dykes, whereas others, like mica and feldspar, form crystals large enough for mining only in pegmatite dykes. A knowledge of these associations may at times be of great use to the prospector, by giving some hint of what is to be looked for when rocks of the types mentioned are found.

RELATIONS BETWEEN ORE DEPOSITS AND MOUNTAINS

It is a matter of common knowledge that mineral deposits, particularly those of juvenile origin, are found almost entirely in mountainous districts or, as in the Canadian Shield, in districts that have been mountainous at some period in the earth's history. The reason is that only in such districts do the great batholithic intrusions occur, the cooling of which gave rise to mineral deposits; and in addition erosion, far more active at the high elevations and on the steep slopes of the mountains than elsewhere, strips away the rocky cover and exposes the ore-bodies to view. Although observation thus indicates, however, a connexion between igneous intrusion and mountain building, the underlying causes of the connexion are as yet only matters of theory; and probably no two geologists would agree as to which of the various possibilities is most likely. In the following pages some of the simpler possibilities are briefly outlined; to discuss the subject fully would require a volume in itself.

From measurements taken in mines and bore-holes it is well known that the temperature of the earth increases downward at a rate that averages about 1 degree F. for every 80 feet of depth, a rate which, if continued downward would increase the temperature of the interior 66 degrees F., or nearly 37 degrees C. for every mile of depth, and produce a temperature at the centre of more than 140,000 degrees C. It is highly improbable, however, that any such temperatures prevail in the interior, as the rate of change of temperature would naturally be greatest near the surface; but since molten lavas come from the interior to the surface, it is evident that the interior temperatures must be sufficiently high to melt rock, i.e., above 1,600 degrees C. The minimum depth at which such a temperature could be attained, by the rate of increase mentioned above, is about 44 miles, and since the rate probably decreases downward, the actual depth is probably much more than 44 miles.

The melting of rocks is accompanied by increase of volume, and it is obvious, therefore, that anything opposing such increase would likewise tend to prevent melting, and perhaps stop it altogether. The immense pressure of 45 miles or more of overlying rock strongly opposes increase of volume, and so successfully that melting actually does not occur, but the body of the earth is solid and rigid as steel. This fact is known from a number of lines of evidence, chief among which is the study of the transmission of earthquake waves through the earth. If, however, anything were to occur to decrease the pressure or raise the temperature at a spot within the crust, local melting might take place.

The surface of the earth is divided into continents and ocean basins, the difference between the average height of the continents and the average depth of the ocean basins being nearly 3 miles. Very careful gravity measurements extending over many years have demonstrated that these level differences, together with other level differences on the earth's surface, are very exactly proportional to the average densities of the underlying rocks. In other words, the various continents and ocean basins behave like blocks of different woods floating in a liquid, the lighter blocks floating higher, the heavier lower. Erosion, however, is constantly at work cutting away the surface of the continents and carrying the material thus derived into the ocean; so that weight is being removed from the continental blocks and added to the oceanic blocks. Geologic history shows that the result corresponds exactly to what would happen in the case of the blocks of wood; the light blocks from which material is planed off rise somewhat in the liquid, whereas the blocks to which material is added sink. In addition to this action, the earth is slowly radiating heat into space and consequently shrinking slightly in size, so that both sets of blocks tend to approach slightly nearer the centre of the earth. The continental and oceanic blocks, unlike the blocks of wood, are not floating freely but are jammed closely together; and as they are not parts of a body with a plane surface, but are segments of a sphere, any downward movement must result in the development of great lateral pressure, which can be relieved only by the crumpling of the edges of one or both of the adjoining blocks. These crumpled, or folded, and elevated edges constitute mountain ranges.

The formation of a mountain range in this or any other manner may affect the deeper sub-crust in at least two ways. The pressure from the sides may tend to raise and support the crumpled part of the crust, thus lightening the downward pressure on the heated rocks beneath, which, it has been shown, prevented them from melting. At the same time the friction of the slipping and crushing movements produces immense amounts of new heat, which would likewise facilitate melting. Once melted, the lateral pressures would force the fluid rock up for a certain distance into the crumpled part of the crust, until the weight of the column of liquid and the overlying rock was equal to the lateral pressure. Once in this position two factors would contribute to its further rise. Erosion at the surface, especially rapid in mountainous districts, would lighten the overlying load and thereby permit the body of magma to ascend, probably carrying the roof with it; and crystallization commencing would increase the proportion of volatile materials in the still liquid parts of the magma, thereby correspondingly increasing the pressure it exerted on the surrounding walls.

In dealing with this fascinating subject it has unfortunately been necessary to omit all discussion of facts from which the above briefly stated conclusions have been drawn, in order to keep this paper within reasonable limits. For a more detailed statement of the subject the interested reader must be referred to the various published works. All that the writer has hoped to do here is to indicate some of the possible causes for the intimate connexion between mountain building, batholithic intrusion, and the formation of the mineral deposits of juvenile origin.

GLACIATION

(W. A. Johnston)

The last great event in the geological history of Canada is, perhaps, the most remarkable of all and has affected profoundly the present inhabitants of Canada, the prospector included. The southern part of this continent, and many other parts of the world, have, for a great period of time, lain exposed to rain, frost, and other natural agents of destruction. Under their influence the rocks, in places, have been rotted to depths amounting to several hundred feet and, of course, the mineral deposits have been affected in the same way. All of Canada, however, except the central part of Yukon and some isolated highland areas in other parts of Canada, was covered with ice-sheets in the Glacial (Pleistocene) period. These ice-sheets, which were thousands of feet thick and for the most part moved in a southern direction, scraped off great quantities of the old surface rocks in the central and northern parts of Canada, ground much of this material fine, and spread it, mainly, over the southern part of Canada and the northern states, burying the bedrocks in these parts of the continent under great thicknesses of drift (sand, clay, etc.) and creating great areas of farmlands. The northern part of Canada, especially the Canadian Shield, was planed down to fresh bedrock and left almost free of soil (drift) cover.

Remnants of the ice-sheets are found on Baffin and Ellesmere islands in the Arctic archipelago, and many hundreds of mountain glaciers and small ice-caps in the mountain region of western Canada have persisted since Glacial time. Elsewhere in Canada glaciers no longer exist; climatic conditions have so changed since the Glacial period that snow does not accumulate from year to year to form glaciers. The time that has elapsed since the disappearance of the glaciers from the Great Lakes region is estimated from the rate of cutting of Niagara gorge to be 25,000 or 30,000 years. The Glacial period as a whole is generally estimated to have lasted upwards of 500,000 years. It was not a continuously cold period, but was interrupted by one or more interglacial periods of comparatively mild climate, during which the ice very largely or entirely disappeared.

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The ice-sheets had three main centres of accumulation from each of which the ice moved outwards in all directions. The main centre lay in north-central Quebec east of Hudson bay, whence the ice spread southwest across the Great Lakes region and south and southeast across southern Quebec and the Maritime Provinces. This Labradorean ice-sheet occupied the greater part of Hudson Bay basin, as well as northern Quebec, and extended north across Hudson strait and northeast to the Labrador coast, but did not cover the higher tableland and mountains in northeast Labrador. The highest parts of Shickshock mountains in Gaspe and parts of the highland areas in Cape Breton Island also appear to have escaped glaciation. The ice in the lower part of the gulf of St. Lawrence was at least 2,500 feet thick, as shown by the upper limits of glaciation, and farther west must have been considerably thicker, for it passed over mountain peaks, over 5,000 feet high, in the New England states.

The Keewatin ice-sheet had its main gathering ground in the comparatively low-lying plains west of Hudson bay. It spread south into Mississippi valley and reached the foothills of the Rocky mountains, but, as a rule, did not quite join the glaciers coming from the mountains. It extended beyond the mouth of the Mackenzie and reached some of the Arctic islands. The Keewatin and Labrador ice-sheets during their height coalesced into an immense ice-sheet, the Laurentide ice-sheet as it was named by G. M. Dawson, stretching from the foothills of the Rockies to the Atlantic coast. The centres or places of maximum thickness shifted from time to time towards the south and southwest as the ice-sheets grew; and this shifting may account in part for the remarkable fact that the Keewatin ice moved uphill across the Great Plains for over 700 miles. During the maximum of the final stage of glaciation an important ice centre existed in the district of Patricia (Ontario) and in adjacent parts of Manitoba. Another centre probably existed northeast of the Great Lakes. Shifting of the ice centres is shown by the occurrence in many places of two or more sets of glacial striæ, trending in quite different directions, on a single rock exposure at places where there is no evidence of a retreat of the ice during the time of formation of the sets of striæ. One result of these shiftings of glacial ice centres was that the ice during a single stage of glaciation transported materials sometimes in one direction and sometimes in another. Local ice centres probably occurred at times during the Pleistocene in the higher parts of southeast Quebec, New Brunswick, and Nova Scotia, and a few mountain or valley glaciers may have existed in these regions before the main ice-sheets came into existence and after they melted away. The effects of glaciation by the continental ice-sheet are not nearly so pronounced in the Maritime Provinces as in other parts of Canada, apparently because the thickness of the ice diminished towards the Atlantic coast; the ice was nourished by snow brought by storms coming from the south and west and as the ice spread from the Labrador and Keewatin centres it intercepted at its margin the moisture-laden winds; hence its growth was mainly toward the south and west.

The thickness of the Keewatin ice-sheet in southwestern Saskatchewan is known from the upper limit of glaciation in Cypress hills to have been about 2,000 feet in the surrounding plains. The higher parts of Birch hills in northern Alberta also were not covered by the ice. The ice was considerably thicker towards the northeast, for it must have had a surface slope of a few feet to the mile towards the southwest, else it could not have moved and carried materials for long distances uphill as it did.

The glaciation of British Columbia and Yukon differed from that of the Great Plains and eastern Canada. A Cordilleran system of intermontane, piedmont, and mountain glaciers existed rather than a single large ice-sheet. An ice-sheet occupied the plateau and mountainous country lying between the Coast mountains on the west and the Rocky mountains on the east, and extended a short distance north into Yukon and south beyond the International Boundary. The ice-sheet, however, was hemmed in by mountain ranges, so that, especially in central British Columbia, its motion was sluggish. The inland ice was drained by several huge ice tongues extending through passes to the Pacific coast and to a less extent by glaciers flowing through passes in the Rocky mountains to form piedmont glaciers in the foothill region of Alberta. The ice filled the strait of Georgia and the fiords of the coast region and covered Vancouver and Queen Charlotte islands. The main ice-sheet did not cover the higher mountain peaks and these projected above it as nunataks (insular rock hills surrounded by an ice-sheet). The Coast mountains were severely glaciated by local glaciers which extended down to sea-level. The Selkirks and Rocky mountains on the east were also mainly affected by local glaciers which coalesced in the main valleys to form important ice streams. The mountain glaciers formed many huge cirques or corries (steep-walled recesses on mountain slopes) at comparatively low levels; the existing glaciers or their immediate predecessors have formed new cirques in many places, at higher levels, owing to the raising of the snow-line.

The mountainous parts of southern and eastern Yukon were glaciated, but a belt 50 to 100 miles wide along Yukon river below Rink rapids and including the Klondike placer gold region, was not reached by the ice, nor do glacial outwash gravels occur to any extent in the unglaciated parts. The precipitation in Yukon valley is small because the lofty coast mountains intercept the moisture-bearing winds. Similar conditions probably prevailed during the Glacial period and this may account for the fact that the area was not glaciated, although it is so far north.

The Cordilleran glaciers appear to have been greatest before the Keewatin ice-sheet reached its maximum, for deposits formed by the Cordilleran ice are overlain, in the vicinity of Calgary, by deposits laid down by the Keewatin ice-sheet. The presence of very old glacial drift south of the Great Lakes region, however, shows that the Labrador ice-sheet was in existence in early glacial times, and it may be that the Labrador ice-sheet was the first to become extensive, though the Keewatin ice did not reach the foothills of the Rockies until after the mountain glaciers had begun to retreat. During the final (Wisconsin) stage of glaciation all three ice-sheets were in existence, for the drifts of each are only slightly weathered.

Evidence of at least one interglacial period during which the ice-sheets very largely or entirely disappeared, is found at various places in Canada. The most carefully studied series of interglacial deposits is in Don valley and at Scarborough Bluffs near Toronto. The deposits are alluvial sands and clays and contain many fossils, one hundred and twenty species of animals, and forty-two species of flowering plants. The plants include thirty-four varieties of trees, many of them characteristic of a warmer climate than that of Toronto today. Interglacial peat beds occur in Moose and Albany River basins in northern Ontario, in Fraser Delta region, and in southwest Alberta. It is not known whether all the deposits are of the same age, but this seems probable as only one series of interglacial deposits has been found in any part of Canada.

GLACIAL LAKES

Several large lakes existed in the Great Plains and Great Lakes regions, during the time of final melting away of the ice-sheets. They were formed by the blocking of the northeast drainage by the receding ice. The lakes overflowed into valleys to the south, and were finally drained, either suddenly or gradually, as the ice melted back and successively lower outlets were uncovered to the north and northeast.

The earliest lakes occupied large areas in Alberta and Saskatchewan. When the ice-sheet had melted back into northern Manitoba, Lake Agassiz covered the greater part of southern Manitoba. This lake for a long time drained south into the Mississippi and when it was largest had an area of over 100,000 square miles; the rich prairie soils of Manitoba are formed from the glacial silt and clay deposited in this lake. Lake Algonquin occupied the basins of the three upper Great Lakes (Superior, Michigan, and Huron) and extended considerably beyond their present borders except in the south. This great lake had outlets simultaneously or successively past Chicago into the Mississippi, through St. Clair river and Niagara, and from Georgian bay to the Ontario basin. A successor or lower stage known as Lake Nipissing had its outflow past the present lake Nipissing in Ontario and down the Ottawa valley. Uplift of the land shifted the outlet back to Niagara. The upper great gorge of Niagara river—the part extending for 1½ miles from the falls down to the whirlpool rapids—has been formed since this happened and is estimated from the rate of recession of the falls to be about 4,000 years old. The age of the whole of the post-glacial gorge of Niagara river, which is 7 miles long, is not definitely known. The rate of formation of the gorge varied from time to time depending upon variations in the rate of flow of the river and upon other factors which cannot be accurately determined.

A series of glacial lakes, which were the latest, came into existence in northern Ontario and adjacent parts of Quebec, when the ice-sheet melted back beyond Hudson Bay watershed, but still covered parts of James Bay slope and James bay itself. Glacial lake deposits, known as the Clay belt, extend across the present divide in Lake Timiskaming district in northern Ontario; the divide has shifted towards the north because of differential uplift of the land. All the shore-lines of the glacial lakes rise progressively towards the north, which shows that uplift of the land has taken place and that uplift was greater in the north than in the south.

POST-GLACIAL MARINE INVASIONS

When the ice-sheet melted, parts of St. Lawrence and Ottawa valleys were below sea-level and were flooded with marine or brackish waters, so that over much of eastern Ontario and the low-lying parts of Quebec, marine sands and clays were laid down. A wide belt around the southern and western sides of Hudson and James bays, and extending along the Arctic coast to the mouth of the Mackenzie, was also submerged to a maximum depth of about 400 feet. In the west, the coast of British Columbia was submerged several hundred feet. These marine invasions were comparatively short-lived, but the deposits of sand, silt, and clay formed as a result of the invasions are in many places extensive and thick.

GLACIAL DEPOSITS

The term "glacial drift" includes all deposits formed directly or indirectly as the result of glaciation. It includes the materials deposited in the glacial lakes, and in the areas covered by the sea, and also those formed during the interglacial warm periods, for these were derived, for the most part, by erosion of glacial deposits. Boulder clay (glacial till) is the most extensive deposit of the ice-sheets. It is unstratified and was laid down at the margins of the ice-sheets, in the form of moraines, and beneath the ice as it melted. Moraines of the ice-sheets also include in places stratified sands and gravels formed by streams issuing from the ice. The surfaces of the moraine are characterized by innumerable irregular hills and small, enclosed basins which in many places contain ponds. They extend in narrow or wide belts which usually have some slight relief above the surrounding country. Moraines are well developed at many places in the Great Plains region where they extend northwest in broad belts parallel to the former ice margins as they existed during halts in the general melting back of the ice-sheet. Moraines formed by valley glaciers in the mountain region of western Canada are different from those formed by the ice-sheets. They usually have considerable relief and contain a great deal of angular rock with little or no boulder clay. Most of the material has been transported on or near the surface of the valley glaciers, whereas in the case of the broad ice-sheets most of the material was transported in the ice and, therefore, was well worn and parts of it were ground to powder by movements of the ice. Moraines of the larger mountain glaciers, however, and of the piedmont glaciers in many cases contain large quantities of boulder clay.

The boulder clay that was deposited beneath the ice as it melted and at its margin during times of rapid melting back of the ice front, is usually referred to as ground moraine or simply as boulder clay. It forms "till plains," some of which have surfaces nearly as level as lake beds. In other places the surface is rolling and is characterized by occasional undrained basins. The lower part of the ground moraine in most places is compacted and was formed from materials locally derived. The upper part is looser and may contain numerous far-travelled blocks of rocks. The ground moraine is clayey in regions where soft rocks occur, such as shale and limestone, that were easily ground up by the ice. In other places, as over a large part of the Canadian Shield, where the rocks are hard, boulder sand and silt are the chief materials forming the drift.

Erratics are boulders that were transported by the ice. Conspicuous examples are the boulders of granitic and other rocks that are scattered over the Great Plains and were transported from the northwestern part of the Canadian Shield. They occur in places as " perched blocks " or " rocking " stones and were evidently deposited in their peculiar positions by the ice gradually melting from around them. Many of the large boulders on the prairies were " rubbing " stones for the American bison and have depressions around them excavated by the feet of the animals. Large numbers of boulders were transported from rock outcrops in some localities and form boulder " trains " that are spread out in the direction in which the ice moved.

The stratified deposits of the glacial drift form sand-plains (outwash aprons); kames, eskers, and lake and marine beds. Outwash plains of sand and gravel in many cases lie adjacent to moraines on the side away from the former ice-margin. Sand and gravel plains that are terraced in places, also occur in valleys that carried drainage waters from the melting ice or, in other places, as deltas or alluvial fans formed where streams entered bodies of standing water such as glacial lakes or the sea. Kames are irregular hills of stratified drift formed near the margin of the ice-sheet by streams issuing from the ice. Eskers are long, winding ridges of gravel and were probably formed by streams in tunnels in the ice near its margin when the ice was rapidly melting. The lake bed and marine deposits are distinguished by the even character of their stratification and by the fact that they contain only occasional stones and boulders dropped from floating ice. Sand and gravel deposits were formed along the shores of the water bodies and silt and clay were deposited in deeper water. Much of the material deposited in the glacial lakes and as alluvial fill in the valleys was silt, the particles of which are intermediate in size between fine sand and clay. This material is rock flour formed from rocks that were ground up by the glaciers. It is most abundant in the mountain regions where much hard, fresh rock was ground up. In places, as in the Lake Agassiz basin in Manitoba, where soft, clayey rocks occur, the lake deposits contain a great deal of fine clay along with greater or less amounts of silt.

The Recent swamp and pond deposits, dune sand, and alluvium of the present streams are usually considered as being distinct from the glacial drift. In many places, however, no sharp dividing line can be drawn between the deposits of the present streams and those of their predecessors of late Glacial time. There are also glacial deposits that are Recent in age.

GENERAL EFFECTS OF GLACIATION

The ice-sheets and mountain glaciers during the Glacial period greatly modified the surface features and especially the drainage systems of Canada. The soil, formed by rotting and crumbling of the bedrock, and which almost certainly covered a large part of Canada before the Ice age, especially in the southern parts, was almost entirely scraped off by the ice. The solid bedrock was ground away in many places and, as there has not been time since the Glacial period for much weathering, fresh and unweathered bedrock is found over large areas at or very near the surface.

In places, however, the bedrock is weathered to considerable depths and it is not easy to determine whether such weathering has taken place since the ice-sheet disappeared or whether it is preglacial or interglacial and was preserved in spite of glaciation.

The average thickness of bedrock removed by the ice from the surface of the Canadian Shield was probably less than 100 feet, judging by the amount of drift derived from the Shield. In places, as in Lake Timiskaming basin, the Saguenay gorge, and in the fiords of the Labrador coast, where the ice flowed in relatively deep valleys, erosion was much more pronounced than over the general surface of the Shield and resulted in

PLATE I

U-shaped glaciated valley, north fork of Klondike river, Yukon.

over-deepening of the valleys. The bedrocks of the Shield do not weather easily and were eroded by the ice-sheets less than the Palæozoic rocks of the Great Lakes region and St. Lawrence valley. In these regions the average thickness of the glacial drift probably is between 100 and 200 feet. It varies greatly from place to place; the drift in the range of hills paralleling lake Ontario on the north side is 500 to 600 feet thick in places, and thick drift deposits occur in southwestern Ontario, whereas in north-central Ontario there is comparatively little drift. The bedrocks in the Great Plains region are easily eroded and have furnished a thick blanket of glacial drift which in many places is over 200 feet thick.

Glacial ice erosion in the mountain region of western Canada took place on a much larger scale than in eastern Canada; for glaciers confined to mountain valleys and draining large ice and snow fields at their sources are much more effective agents of erosion than are ice-sheets of wide extent, because they flow much faster. Many of the mountain valleys were widened and deepened by the ice and have in consequence a rounded or U-shaped cross-section (Plate I) in contrast with the V-shaped valleys formed by streams. Many of the deep lake basins in parts of the mountain valleys and the fiords of the coast region were formed in part, if not very largely, by ice erosion. Cirque action or headward erosion of mountain glaciers has sculptured the higher mountainous parts into deep recesses that have nearly vertical head walls and are in many cases separated from one another by extremely narrow rock divides. One result of the very marked glacial erosion in the Cordilleran region was that a great abundance of glacial drift was supplied to the streams when the ice was melting and in consequence many of the river valleys, for example the Fraser, were filled with drift to depths of several hundred feet; when the supply of materials diminished owing to melting away of the glaciers, the rivers began to erode the deposits, and in many places have terraced the valley sides and cut down to bedrock in the valley bottoms.

Though glacial ice erosion was very marked at many places in the Cordilleran region, there are places, for example in Barkerville district and in Cassiar, where the valleys were only slightly eroded by the ice. Some of the valleys are V-shaped and contain ancient gold-bearing gravels; others have rock benches, remnants of old channels when the streams flowed at higher levels, which were not destroyed by glaciation.

No other region of the world possesses so many lakes as the Canadian Shield, and most of these bodies of water, if not all, were caused by glaciation. They occupy basins formed by uneven deposition of the glacial drift, by ice erosion of the bedrock, or by the damming of river valleys by drift deposits. Waterfalls and rapids are very numerous in Canada and are also a result of glaciation. Very few of the rivers of Canada have had time since the Ice age to grade their channels and most of them are no more than spillways between lakes. There are large areas that have practically no surface drainage because of their low relief and because sufficient time has not elapsed since the Glacial period for the development of stream channels.

The "Clay belts" of northern Ontario, Quebec, and Manitoba, are thick glacial and glacial lake deposits. In these areas the bedrock is almost entirely concealed. The surface is undulating, for it reflects to some extent the uneven surface of the underlying bedrock, and, therefore, is in part naturally drained. In many places, however, in these areas, as well as in other parts of Canada, the character of the surface of the drift gives little or no indication of the shape of the bedrock surface beneath. The topography of the deeply drift-covered areas is a "built up" one and may show greater or less relief than the bedrock surface. The areas of least relief are those in which glacial lake or marine deposits were laid down, for deposition in water tended to fill the depressions in the old surface. The areas of greatest relief are the morainic areas where the drift was piled in irregular heaps at the front of the glaciers.

EFFECTS OF GLACIATION UPON MINERAL DEPOSITS

The bedrock in unglaciated regions is rotted and broken into fragments to a considerable depth and the upper parts of mineral deposits are oxidized. The commonest product of subaerial weathering in such regions is residual clay which differs from the clays of glaciated regions in that it contains little or no soluble constituents such as lime and magnesium. Weathering (oxidation and hydration) of mineral deposits produced residual ores and enrichment zones and released from the bedrock and mineral deposits gold, platinum, and other minerals which after being released were concentrated by streams into placers. Weathering of rocks rich in aluminium, as granite and syenite, produced clays that consist in part of kaolin (hydrated aluminium silicate), the purest form of clay. Weathering, possibly combined with other processes, produced the deposits known as lateritic ores which include bauxite (hydrated aluminium oxide) and certain kinds of iron and other ores, containing little or no free silica.

Glacial ice erosion entirely or partly removed the oxidized upper parts of mineral deposits and residual deposits such as clays and placers, which probably occurred at many places in Canada before the glacial period. It can scarcely be doubted, for example, that rich gold placers formerly existed in or near the Porcupine and Kirkland Lake gold fields in northern Ontario and at other places in the Canadian Shield, but only lean placers have been found in these regions. The placers were destroyed by the ice-sheets and the gold is now scattered through the glacial drift over wide areas. This scattering action of the ice-sheet occupying a broad area of low relief such as the Canadian Shield, is shown by the fact that boulders derived by glacial action from outcrops in a single locality, for example the jasper conglomerate on the north shore of lake Huron, are spread out in a fan that widens to hundreds of miles in the direction of ice movement. Glacial ice movement in the mountain region of western Canada was restricted mainly to the valleys. Most of the pre-Glacial placers in the valley bottoms were eroded by the glaciers and the placer gold was mixed with the glacial drift, but was not scattered to any great extent. Part of the gold remained in the valleys. A few pre-Glacial placers were preserved in narrow V-shaped valleys which happened not to be severely glaciated. There are places, also, as at Cedar creek in Cariboo district, where parts of ancient placers on the upland were preserved though they were overridden by the ice-sheet.

The products of pre-Glacial or inter-Glacial weathering are preserved at many places in Canada in spite of the effects of ice erosion. Ancient gold-bearing gravels occur in Beauceville district, Quebec, as well as at places in Cariboo and Cassiar districts, British Columbia. Quartz sands and refractory clays of Mesozoic age occur in the upper parts of Moose River basin in northern Ontario, and Tertiary gravels, sands, and clays, only slightly cemented, occur at many places in the Great Plains region and in the mountain region of western Canada. Enrichment zones formed at the base of the zone of oxidation also occur, for example, at the Premier and Dolly Varden mines, British Columbia. They were not entirely removed by ice erosion. As a rule, however, the oxidized mineral deposits found in Canada are of small thickness and extent owing partly to the effects of glaciation and partly to adverse climatic conditions; and in many places, for example at Flinflon and Schist lakes in northern Manitoba and at Rouyn in western Quebec, unaltered sulphide deposits occur at or near the surface.

The gold placers of the Klondike, Yukon, were not affected by glaciation, but the ground in this region is frozen to depths of 50 to over 100 feet and probably has remained frozen since Glacial time, except for summer thawings to shallow depths. The ground at many other places in northern Canada and in the region around Hudson bay is also permanently frozen, but probably to shallower depths than in Yukon. Breaking up of the bedrock by frost action and the formation of talus slopes is the dominant process in these regions and there has been little oxidation since or during the Glacial period. Pre-Glacial weathering, however, must have occurred in both the glaciated and unglaciated parts of northern Canada and the products of this weathering may have been preserved.

The thick drift deposits of the clay belt in northern Ontario and western Quebec conceal the bedrock and thus hinder prospecting. Much of the bedrock in an area of about 10,000 square miles traversed by the centre section of the Hudson Bay railway is concealed by lake clays and glacial deposits. The bedrock in a belt about 100 miles wide on the west and south sides of Hudson and James bays is deeply buried beneath glacial, marine, and swamp deposits and there are few rock exposures except in the river valleys. Glacial lake clays are abundant in southern Manitoba and in southwestern Ontario and post-glacial marine deposits cover the low-lying parts of Ottawa and St. Lawrence valleys. Drift deposits cover the bedrock over much of the Great Plains and thus hinder the search for rock structures favourable for the accumulation of oil and gas. The marked glacial ice erosion in the mountain region of western Canada caused filling of many of the river valleys with glacial drift, only parts of which have been eroded by the present streams. The chief economic value of the deep drift deposits is that they form excellent farm lands. They furnish few clues as to the presence or absence of mineral deposits in the rocks beneath them. Irregularities in thickness of the drift over magnetic and other mineral deposits, and the presence of mineral fragments in the drift cause uncertainty in the results of magnetic, electrical, and gravity surveys for the location of mineral deposits.

On the other hand, the fresh, unweathered bedrock is exposed over large parts of the Canadian Shield and of the mountain regions. This is especially the case in far northern Quebec where the drift deposits as a rule are very thin or are almost absent, and in parts of the mountain region above timber-line. The absence of any thick drift covering in such regions renders the finding of mineral deposits easier than would be the case if the region had not been glaciated. Faults and shear zones in the rocks are more easily found in glaciated regions than in unglaciated areas, if the drift be thin, because of the obscuring effects of deep weathering in unglaciated regions.

There has been some oxidation since the Glacial period, especially in areas of considerable relief where conditions are favourable for the circulation of groundwaters and in areas where mild climatic conditions prevail. In places, as over much of the Canadian Shield where the permanent groundwater level is near the surface, oxidation extends, as a rule, only to shallow depths. Oxidation of minerals such as pyrite and other sulphides goes on very rapidly, for the sulphides are readily altered to hydrous oxides by contact with the surface or underground circulating waters, but little or no oxidation can take place below the levels of stagnant groundwater and once an "iron hat" or gossan is formed the process goes on much more slowly than when the sulphides are freshly exposed. Limonite deposits 10 to 15 feet thick occur in Zymoetz and Taseko River valleys in British Columbia and similar deposits of post-glacial age occur at other places in Canada. They are not true gossans, for they have been formed by small streams or springs issuing from rocks containing disseminated pyrite, whereas gossans are formed by weathering of mineral deposits in place. Gossans, however, occur at many places, but as a rule have no great thickness or extent. Their presence in Sudbury and Michipicoten districts, Ontario, led to the discovery of the nickel-copper and iron ores of these districts. In Cobalt district the apple-green stain (annabergite), which results from oxidation of nickel-arsenic minerals, and the pink Cobalt bloom (erythrite) occur and are due to post-glacial weathering.

Indirect effects of glaciation on prospecting are produced by the numerous swamps and lakes that cover large areas, especially in the Canadian Shield. They conceal the bedrock, but the numerous lakes are an aid in travelling in remote parts of Canada.

The chief effects of glaciation upon mineral deposits may be summarized as follows:

Adverse effects	Favourable effects
Glacial ice erosion entirely or partly removed the oxidized and enriched upper parts of mineral deposits, ancient placers, and residual deposits such as clays.	Gossans formed on mineral deposits in post-Glacial time are thin: some enrichment zones, placers, and residual clays were preserved in spite of the effects of glaciation: placers were formed as the result of concentration by Glacial and post-Glacial streams.
Thick drift deposits conceal the bedrock over large areas and this hinders prospecting for mineral deposits.	Removal of the weathered surface of the bedrock by ice erosion and non-deposition of drift in places favour prospecting for mineral deposits.
Thick drift deposits are heterogeneous and furnish few clues regarding the character and surface form of the underlying bedrock.	Ore boulders in the drift furnish evidence of the existence of mineral deposits somewhere in the region whence the drift was derived.
Glacial deposition tends to obscure significant rock structures such as faults.	Removal of the products of weathering by ice erosion aids in the recognition of structural features such as faults, in places where the drift is thin or is absent.
Irregular deposition of glacial drift and glacial ice erosion cause disorganization of the drainage and obscure the old valleys and other physical features which may have been of significance for the occurrence of mineral deposits such as placers.	The numerous lakes, rapids, and falls in Canada, nearly all of which are a result of glaciation, indirectly affect mineral deposits as the lakes afford a means of travel in remote parts of Canada and rapids and falls are sources of hydroelectric power, of value for mining purposes.

TRACING OF MINERAL DEPOSITS BY GLACIAL DEBRIS

Most of the "float" minerals (ore boulders) found anywhere in Canada, except in the mountainous and unglaciated regions, were transported by glacial ice. They were carried in the direction in which the ice moved, uphill in some places and downhill in others. Transportation of float was also accomplished, to some extent, by streams issuing from the ice, as well as by the present streams and by soil creep and slides. The occurrence of float mineral, therefore, usually indicates that similar deposits occur in place somewhere in the region traversed by the ice which transported the float. Iron ore in Lake Superior region, fluorite in Madoc district, Ontario, corundum in Bancroft district, Ontario, gold-bearing quartz veins in Nova Scotia, and other mineral deposits in Canada have been found by tracing glacial float to its source. This method of prospecting has not been used to any great extent in Canada, however, and few important discoveries have been made in this way. There can be little doubt that many mineral deposits occur of which no clues exist other than the ore boulders found in the drift. Prospecting by the tracing of ore boulders should prove of value in Canada, as it has in other countries, and is the chief method to be used in those areas in which the exposed bedrock has been thoroughly examined.

The tracing of glacial float may be aided by a study of the glacial striæ and other evidences of the direction in which the ice moved in the area in which the float is found. Striæ and grooves impressed on the bedrock by moving ice or rather by boulders and stones held in the bottom of the ice, in many cases do not show in which of the two possible directions the ice moved. Certain kinds of striæ, however, and other features of ice-work,

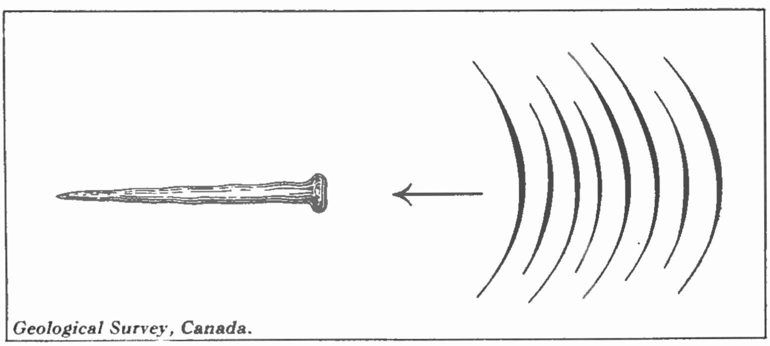

Figure 1. Nail-head striæ and crescentic fractures (chatter marks); arrow shows direction of ice movement.

do show the direction of movement. Nail-head striæ (*See* Figure 1) caused by exceptionally hard particles in the rock, for example chert or flint in limestone, have a long tail extending in the direction of ice movement. Crescentic fractures (*See* Figure 1) which occur as a rule only in fine-grained, homogeneous rocks, as limestone or quartzite, are good guides. The horns of the crescents point approximately in the direction of ice movement. Rock ledges and hills usually are more eroded and scoured or polished on the side whence the ice came than on the downstream side, which may be irregular and unpolished owing to the removal of rock blocks by the plucking action of the ice. Tails of glacial drift in many cases occur in the lee of rock hills and boulder trains fan out in the direction of ice movement. Moraines of the continental ice-sheets trend approximately at right angles to the direction of ice movement, that is parallel to the former ice fronts. Drumlins (oval-shaped hills of drift) have their longer axes in the direction of ice motion. Eskers trend in the direction in which the ice melted back, which in many places, but not in others, was the direction in which the ice advanced. Two or more sets of striæ trending in quite different directions in many cases occur on a single rock exposure. It is important to determine the relative ages of the striæ, for float found at or near the surface is likely to have been transported as a result of the latest ice movement. This determination can be made with certainty only, as a rule, in places where striæ cross and descend into grooves. In such cases the grooves are evidently older than the striæ that cross them. The latest ice movements were due to readvances during the period of final melting and were influenced to a greater extent by the local topography than were the movements during the maximum stages of glaciation.

In attempting to trace float to its source it is important to consider whether the material was locally derived or was transported a considerable distance. Boulders of granite and other rocks were transported for hundreds of miles and scattered over the Great Plains, and minerals were transported from northern Ontario and Quebec and deposited in the Great Lakes region or farther south. They may have been transported in different directions at different times, so that their source in most cases cannot be determined. It is rather hopeless for example to attempt to trace to their source the dozen or so rough diamonds that have been found in the glacial drift at widely separated localities south of the Great Lakes. It would be better for the prospector to bear in mind the fact that diamonds are most likely to occur in volcanic necks or pipes of peridotite and to carefully examine any such occurrences.

The greater part of the glacial drift in most localities was derived locally. It follows, therefore, that float occurring in abundance has not travelled far. If, on the other hand, there are only a few occurrences it is probable that the float has come from a considerable distance. If boulders of similar character are found abundantly the source of them is, as a rule, not far off, in a direction indicated by the striæ. Boulders of gossan are not likely to have travelled far. Ore boulders derived from a single locality are distributed in a more or less fan-shaped form; hence the area to be prospected decreases as the source of the mineral is approached. By plotting on a map the locations of the ore boulders, and drawing lines through the outermost localities, in the direction indicated by the striæ, the apex or approximate source of the float may be determined. The character of other boulders in the drift should be noted, also, as they may indicate the character of the rocks in which the mineral deposits occur. If all the float mineral is in the upper layers of drift and the drift be thick, the source of the float probably is remote; if it is all confined to lower layers of deep drift or if the drift be very thin and the float abundant the source probably is not far away. Ore boulders found in glacial outwash plains bordering moraines, and in kames and eskers, are of little significance, for the materials forming these deposits have been derived, as a rule, from considerable distances. Ore boulders found in glacial lake and glacio-marine deposits were transported by floating ice and there is no way of telling whence they came.

Tracing of ore boulders in the mountain region of western Canada is easier in some respects than in other parts of Canada, for transportation of drift by the ice was restricted, for the most part, to the mountain valleys. Most of the boulders found in the valleys, therefore, were derived from rocks occurring in place higher up the valley. Some of the drift, however, was transported from one valley to another. The direction of movement of the ice-sheet which transported this foreign drift was a few degrees east or west of south throughout practically all the interior of British Columbia. In Yukon the ice-sheet flowed north and northwest. Drift that was not local in origin was also transported by glaciers flowing west through Stikine, Skeena, and Fraser valleys to the Pacific coast and east through the Rockies by way of Bow and Athabaska valleys. Most of the drift found in the Coast mountains and in the Selkirks and Rockies was transported by local glaciers. It is in many cases difficult, however, to determine whether boulders found in a mountain valley are glacial in origin or were derived by slides from the mountain sides. If the boulders are well worn they are likely to have been transported by the glacier. The moraines of mountain or valley glaciers indicate the character of the rocks in the upper parts of the valleys and thus may furnish valuable clues as to whether mineral deposits are likely to occur in the basins drained by the glaciers.

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EROSIVE AGENTS OTHER THAN GLACIERS

(W. E. Cockfield)

Glaciation in Canada is now limited to places in the high mountains and in the far north. There are, however, other mechanical forces which are at work wearing down exposed rock masses. They break off pieces of bedrock and gradually diminish them in size. These forces are, chiefly, changes in temperature, frost, wind, rain, streams, waves, currents, and gravitation. The effects are twofold: (1) exposed rock masses are worn down; and (2) the pulverized material so produced is carried away and deposited elsewhere.

EROSION

CHANGES OF TEMPERATURE

Heating by day and cooling by night have a disruptive effect upon rock, like, though much milder than, the sudden heating of cold glass, or the sudden chilling of hot glass. Under the influence of the sun's heat the surface of the rock expands more than the interior, and a strain is set up which, repeated often enough, weakens and crumbles the rock or even breaks off flat flakes. Forest fires greatly accelerate this process. In rocks composed of several minerals which expand unequally when heated, stresses are set up between the component minerals and have a disruptive effect on the rock. Quick and great changes of temperature are more effective than slow and slight ones. The annual changes of temperature are thus of slight effect as compared with daily changes. Great daily changes of temperature are found especially in high regions and in arid regions, and it is in such places that the breaking of rock by changes of temperature is most effective.

FROST

If the changes of temperature range above and below the freezing point of water, they may be still more effective, for if the pores and cracks of the rock are full of water, its expansion on freezing may break the rock. Minute crevices and pores which have been opened by solution are more likely to cause breaking through freezing than large fissures.

RAIN

Clayey soils which have been baked under the action of the sun are softened by rain, and are thus more easily removed by running water. Alternate wetting and drying of soil causes it to expand and contract on slopes, and to creep slowly downward. After a heavy rain innumerable rills, each carrying a load of sediment removed from the soil cover, reach the streams and supply them with sediment.

WIND

Wind itself has almost no abrasive effect upon solid rock, but if it carries sand and dust it acts like a mild sand blast. If a rock is made up of layers of unequal hardness, the blown sand digs out the softer layers and leaves the harder layers projecting. In this way the harder layers are gradually undermined, and fall off, to be gradually broken up and carried by the wind to undermine other rock projections. The work of the wind is confined principally to arid regions. In Canada the most notable examples of wind erosion are found on the Great Plains.

STREAMS

The eroding power of streams is very great. There are numerous examples of streams in Canada which in comparatively recent times have cut deep trenches through unconsolidated material or even through solid rock. The canyon of Fraser river might serve as a good example of the cutting power of streams. Where the water is clear, its cutting power is very slight; it is the load of sediment carried which enables a stream to cut its channel. Practically all streams carry a certain amount of material in suspension, and also roll pebbles and boulders along their beds. This material attacks the bed of the stream, with the tendency to wear it down, and also to break up the material carried.

WAVE ACTION

In the dash of the waves against a shore the wear is effected both by the impact of the water, and by the debris that the water carries. If the land at the margin of the water consists of unconsolidated material, the action of the water alone is sufficient to wash it away. But against rock, the erosive power of water is weak, unless helped by the cutting action of the detritus carried. Sand, pebbles, and such stones as the waves can carry are used as weapons of attack, and are hurled against rock faces which thereby are gradually worn away. If weak rock is associated with resistant rock, the removal of the former may lead to the disruption and removal of the latter, particularly if the resistant rock is undermined. Rock affected by joints is likewise easily attacked, for the blocks bounded by joints are loosened and quarried out. The material loosened from cliffs and rock faces is attacked in the same manner, until it has become small enough for the waves to move, when it is in turn used as a weapon.

SHORE CURRENTS

Shore currents as a rule have little erosive power, except upon unconsolidated material. They act chiefly as transporting agents, sorting and depositing the material supplied to them.

GRAVITATION

The force of gravitation is chiefly a transporting, and not an erosive, force. Blocks that have become loosened or undermined by the action of other forces fall, and in doing so either break themselves or break other rock masses on which they fall.

TRANSPORTATION AND DEPOSITION

Of the above forces, wind, streams, shore currents, and gravitation are most active in transporting and depositing material. The work of wind as a transporting agent is confined to moving small particles such as sand and dust. The carrying power of the wind is well illustrated on the Great Plains, where soil drifting occurs in many places as a result of cultivation and the removal of the organic binding material and in the drifting sands of the Great Sand hills north of Cypress hills, and other areas.

The amount of material that a stream can carry depends chiefly upon its velocity, and the velocity in turn depends upon the gradient, volume of water, and the load of sediment. Generally speaking a stream that is supplied with more sediment than it can carry will deposit part of its load, and a stream that has less sediment than it can carry will erode its channel, until in both cases an adjustment between velocity, volume of water, and amount of sediment carried is reached. These processes can be seen in different parts of the same stream; thus, in the upper part where the gradient is steep, the stream is actively cutting and the material removed is transported down stream to where the grade diminishes and where a part of the load is dropped to build up deltas, flood-plains, and so forth.

The shore material removed by waves is transported by the joint action of waves, undertow, and shore currents. The incoming wave begins to shift material where it drags bottom, and the detritus is moved shoreward, whereas the undertow tends to carry it back again. The result of these opposed tendencies is to keep material moving between the shore and the line of breakers. There is thus a certain amount of material which is kept in a constant state of agitation. The advance and retreat of waves which come at right angles to the shore do not move material along the shore, but oblique waves do. A long shore current is set up by wind action and is most pronounced in the direction of the prevailing winds. The source of the material transported must, therefore, be sought, in general, in the direction whence the prevailing winds come.

The action of gravitation as a transporting agent has already been pointed out. Material falls, rolls, slides, or gradually creeps downhill as a result of this force, and the source of such material must always be sought uphill from the float. As evidence of the action of gravity in transporting material it is only necessary to point to the piles of talus that occur at the foot of nearly all cliffs. The same general action also takes place on much more gentle slopes and there is everywhere a tendency for loosened material to creep gradually downhill.

EFFECTS OF EROSION ON MINERAL DEPOSITS

The forces that wear down exposed rock masses also act on mineral deposits. Generally speaking, the outcrops of mineral deposits are worn down in the same manner as the surrounding country rock. If the deposits consist of material that is softer and less resistant than the surrounding country rock, their position under a light soil cover may be marked by hollows or depressions. On the other hand, deposits, such as quartz veins, which are composed of resistant minerals, may stand above the surrounding country rock. The iron ranges of northern Ontario are a good example of hard mineral deposits that are left in the form of prominent ridges by more rapid erosion of the softer rocks on either hand. The configuration of the ground, therefore, may be of some assistance in judging where to trench when it is believed that float has been traced to its source.

Erosive agents frequently expose large sections of rock in what is otherwise a drift-covered country. The cliffs facing seashore or lake shore and the canyons cut by rivers and streams, afford exposures where rock outcrops elsewhere are scarce, and some valuable deposits have been discovered in this way. To cite only one example, the Silver King mine in Mayo district, Yukon, a mine that proved to be an important producer of silver and lead, was discovered by means of outcrops in a canyon cutting across an area where the drift cover was 50 to 70 feet thick, and where discovery by any other means was at that time out of the question.

RIVER FLOAT

The sand, gravel, boulders, and mineral particles that occur in the deposits of a river valley, furnish more or less accurate evidence of the kinds of rock and mineral deposits existing within the basin of the river. As a general rule the coarser the material, the closer it is to its place of origin which must always be sought upstream. When a point is reached where the material no longer occurs, the search must extend up the tributaries and up the hillsides until the source of the material is located, when trenching should be undertaken. River float is of greatest assistance in the search for mineral deposits in regions that have not been glaciated, such as parts of the Yukon plateau, as in such cases no material occurs that is foreign to the drainage basin. River float may also be used as an indication of ore to some extent in glaciated regions, but in such places it must be remembered that some or much of the mineral may have been transported from afar by glaciers.

In unglaciated regions panning of the sands and gravels is of greatest assistance. As an example, placer deposits of the tungsten material, scheelite, occur on Dublin gulch, Yukon. The scheelite was traced, by panning, up the tributary streams to the upland surface. There where the amounts of scheelite proved most abundant, the veins from which this material came were located by means of shallow trenches.

Harder or less soluble minerals such as gold, platinum, copper, galena, pyrite, magnetite, and quartz, are more likely to be found in placer form than softer and more soluble minerals such as hematite and chalcopyrite. In panning it is well to remember that certain minerals are common constituents of rocks and their presence does not necessarily point to deposits occurring in the district; such minerals are, chiefly, magnetite and pyrite. The presence of gold, silver, copper, and lead minerals, and a number of other minerals, nearly always signifies deposits of these minerals in the vicinity, though the deposits may be too poor to work. Thus, the concentration of gold in placer deposits does not always signify the presence of commercial ore when the veins from which the gold comes are located. In Klondike region gold has been traced by the method outlined, to stringers and veins of quartz in schist, but none of these stringers and veins has yet proved of sufficient size or richness to be profitably exploited. Panning should be conducted on material secured from as close to bedrock as possible, for the concentration of the heavier ore minerals takes place close to bedrock. In general, the smaller streams with few tributaries offer the best sites for the application of this method, as the drainage basin is smaller, the material is closer to its source, and the evidence is not confused by the mingling of the products of several streams.

Beach deposits are a form of placer deposits. In tracing such material to its source it is essential to ascertain the direction of prevailing winds and shore currents, and also to determine if tributary streams contribute the material. Beach deposits such as the magnetite sands on the north shore of St. Lawrence river are concentrations, by waves and currents, of material fed to the river by tributary streams.

GRAVITATION

It is axiomatic that the source of material found in talus at the foot of steep slopes should be sought in the cliffs and slopes above. Such talus accumulations are of materials recently fallen from above and, therefore, give good indications as to whether mineral deposits are to be expected. In the case of hill-side float, the material should be traced up hill to where it ceases, trenches dug there and continued up hill until the mineral deposit is located.

In Gaspe, Quebec, lead-zinc ore-bodies were found by tracing float up hill to its source. The higher parts of Gaspe were not glaciated, so that the movement of loose blocks cf rock or mineral must have been due to other causes. " The country is covered by heavy overburden, and, in consequence, outcrops are few. The presence of ore is detected by finding galena in the float... This as a rule has not travelled far and by trenching up hill from such float, vein outcrops can usually be uncovered. In other cases actual outcrops of veins are exposed."[1]

Float was also used in connexion with the discovery and exploitation of the Keno Hill ores, Yukon. The upland surface in this case has escaped glaciation and as the soil is perpetually frozen, the materials forming the overburden travel slowly, but the frost heaves up through the soil freshly broken pieces of rock and mineral. The original discovery was made by tracing talus uphill. In developing the properties it was found that well-defined lines of float occurred, consisting of manganese oxide derived from the manganiferous siderite of the ore-bodies, iron minerals, and galena. These lines of float marked virtually the site of veins, the trenching necessary to uncover the outcrops extending as a rule only a few feet up hill from them.

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CHAPTER III

TYPES OF MINERAL DEPOSITS

This chapter consists of a series of essays dealing with certain types of mineral deposits that occur, or may occur, in Canada. The various types are grouped in two classes, deposits largely igneous and deposits largely sedimentary in origin.

DEPOSITS LARGELY IGNEOUS IN ORIGIN

VEINS

(W. F. James)

The discussion of mineral and ore deposits (*See* Chapter II) has indicated that many commercially valuable mineral substances are disseminated in relatively minute quantities throughout the earth's crust, and that by natural processes of concentration and deposition they are locally collected in such quantitv as to repay mining cost.

When solutions deposit and concentrate mineral substances in a crack or other narrow space in the earth's crust, the resulting body is called a vein. When the solutions involved are surface waters percolating through the upper part of the earth's crust and deriving their dissolved substances from the rocks through which they pass, the vein is said to be of meteoric origin. When, on the other hand, the solutions are hot waters emanating from a body of igneous rock, generally far below the surface, and carrying in solution substances derived from the fluid igneous rock, the vein is said to be of juvenile or thermal origin.

Cracks and other openings which may later be filled with vein material, may form in various ways. Near the surface openings may form by solution but perhaps the majority of openings form as a result of tension or compression. The outer crust of the earth is subject to movements, some of which are indicated at the present time by earthquakes. Compressional and tensional forces, that is forces that tend to press together and forces that tend to stretch, act during such movements and give rise in some cases to dislocations that are apparent even on the surface. Earthquakes in Japan have produced faults that can be traced on the surface for more than 35 miles and show displacements of more than 10 feet. Throughout geological history movements of this sort have occurred frequently.

Some rocks, such as limestones, contain minerals that are relatively easily dissolved by the waters circulating in the upper part of the earth's crust. In such rocks openings are formed by solution and removal of the soluble minerals, and formation of openings is comparatively rapid where the circulating waters follow small cracks and gradually widen them. The numerous caves and sink-holes of limestone and gypsum areas are striking evidence of the solvent power of the groundwaters. Cavities of this sort chiefly exist at shallow depths, where pressure of overlying rock is not so great as to close them and where movement of the groundwaters is relatively rapid.

Compressive forces give rise to the jointing that is so conspicuous in many rocks. They also cause faults of the overthrust type. When compression causes the folding of sedimentary rocks, openings may form; for example, if beds of unequal strength are folded into an anticline, an open space is in some cases formed at the crest. The saddle veins of Nova Scotia fill openings of this sort. Under certain conditions faulting may occur in the crest of an anticline, thus providing an opening suitable to contain a later vein. Compressive faulting may also produce sheared and crushed zones that provide paths for mineralizing solutions.

Contraction or shrinkage of a rock body produces cracks or fissures, similar to the cracks that form in a quickly cooled slag or in drying mud. Such contraction may occur during the change of a limestone to dolomite, or during the drying out of an argillaceous sediment. Fissures form also in igneous bodies as they contract on cooling. Small cracks of this sort occur in the small porphyritic intrusives in northern Ontario. They are healed with quartz, which locally contains native gold. Some authors maintain that openings may be formed by the pressure of the vein solutions working their way away from the parent magma to zones of lower pressure, such action being confined to the deep zones where pressure is intense.

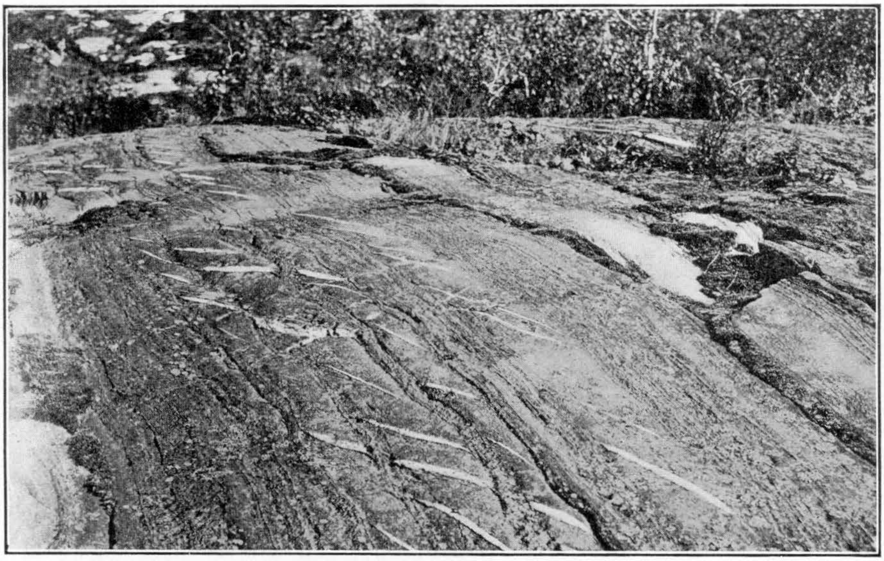
Certain rocks are structurally strong and do not easily fracture, but will preserve a fracture when it does form. Others, such as slates, are so weak and soft that, although they yield easily, a fracture is soon closed by rock flowage. At extreme depths the weight of overlying rocks is so great that all unsupported rocks will flow like putty under a considerable weight, and no openings can exist in which veins might form. Experiments indicate that cavities may remain open in a strong rock such as a granite, to depths of 11 miles or more, but it is rather general opinion that veins form at much shallower depths, probably not exceeding about 3 miles.

The influence of the strength of rocks on the openings formed in them is shown in veins traversing rocks of different strengths. In hard rocks the fissures are straight, with clean-cut walls, whereas on passing into softer rocks, they tend to be smaller and may disappear altogether. Veins near the edge of a granite body are, in some cases, fairly regular in the intruded rock, but feather out, in a short distance, in the intrusive.

As a rule a fissure in a rock body will not remain empty for a very long period, but is filled by materials afforded by solutions of meteoric or thermal origins. In the upper part of the earth's crust waters are constantly circulating and dissolving various elements contained in the rocks. Common minerals such as quartz and the carbonates are easily taken into solution and very commonly form the gangue for such sulphide deposits as are formed by surface waters circulating just below the surface. Deposition from the solutions may occur by reason of chemical reactions, supersaturation, or other causes, resulting in the formation of a solid mineral body whose form and location depend on the form and location of the opening in which the solutions deposit their mineral content. In the vicinity of igneous intrusions, mineral bearing solutions originating with the intrusive rock tend to rise towards the surface by way of open fissures in which they deposit masses of mineral as suitable conditions are encountered. In both these cases a suitable opening existed before the advent of the mineral-depositing solutions, which followed the channels provided and gradually filled them with solid mineral material to form mineral veins.

Not all veins are formed in pre-existing cavities by the introduction of mineral substances. Some veins result from the replacement of the country rock by solutions carrying mineral-forming elements. During the process of replacement, the minerals of the original rock body are dis-

PLATE II



Quartz veins in alternating beds of brittle quartzite and more plastic argillitic material near Cutler, Ontario, illustrating the influence of competent (hard), and incompetent (plastic) rocks on vein formation.

solved and their place taken by the minerals that crystallize out of the dissolving solution. Deposits of this sort become of interest to the prospector when such ore minerals as gold and the copper minerals, etc., are among the minerals replacing the original country rock. Either cold or hot solutions may replace a rock, though probably hot solutions act more thoroughly and more rapidly than cold. Replacing solutions are in many cases rich in silica and carbonates, and may contain various metals which may be deposited as silicates, sulphides, native metals, etc. Solutions may percolate slowly through openings of microscopic size and replace, crystal by crystal, the rock through which they pass, but replacement will tend to act more rapidly in a rock in which the solutions make or find a well-established channel and come into contact with a well-brecciated country rock. As replacement generally renders the replaced rock more porous, the process takes place at an accelerating rate and becomes progressively more and more thorough.

Replacement by cold solutions passing downward through a rock fissure is less intense than that by hot ascending solutions. Under the influence of downward circulating cold solutions, kaolin replaces the feldspars, quartz and chlorite are deposited, and such sulphides as pyrite, galena, and zinc blende replace silicates. Silicification of limestones commonly occurs under the influence of such cold, weak solutions. Where rocks are affected at depth by hot, ascending solutions, more intense reactions occur; sediments such as the greywackes are replaced by silica to such an extent that certain more permeable and less resistant beds may be changed into almost pure quartz containing bands of unreplaced silicates and of sulphides brought in by the replacing solutions. The banded appearance of the original greywacke is retained in the replacement. Some of the gold-bearing veins within the Timiskaming sediments in western Quebec are of this type. Intrusive rocks may also be replaced by minerals such as quartz and the carbonates, and these may carry gold values, as in the case of the Larder Lake gold deposits where tuffs are replaced by quartz, carbonate, pyrite, arsenopyrite, and gold.

The selective action of replacement is observed where a replacement vein cuts across beds of different composition. In a bed that is more easily replaced the vein tends to widen, whereas it narrows in beds less easily replaced. Where the same system of fissuring cuts a granite and sedimentary rocks, the vein in the granite may be only a fissure filling, whereas in the sediments the vein may be largely formed by replacement. The result of replacement is the formation of an assemblage of minerals stable under the conditions existing at the time and place of formation. Certain previously existing resistant minerals may be unaffected, and hence will be found in approximately the same quantity in the replacement vein and in the adjoining country rock; on the other hand, complex minerals may form from elements originally present in the rock and with little or nothing added by the invading solutions, or some elements may be added and others removed. In a replacement vein it will be found that the sharp boundaries that mark a filled fissure vein are lacking, in other words the vein has no distinct walls and values, if present, will decrease laterally until barren country rock is reached.

Although a distinction is made between filled veins and replacement veins, they have much in common. Replacement of the country rock is noticeable on the walls of most fissure veins that formed as the result of filling by solutions, and in replacement veins some of the vein matter has resulted from the same processes that yield normal fissure veins.

A *vein* in the restricted sense is a tabular mineral body: (1) that occupies or is closely associated with a fracture or set of fractures; (2) and that formed from solutions that deposited materials in the fracture, or replaced the wall-rock, or acted in both ways. There is a tendency to restrict the term vein to a body in which replacement has played little or no part. The term *lode* may be applied to veins, but it emphasizes rather the tabular character of an ore deposit than its origin. *Replacement vein* is a term applied to a vein-like body resulting from a process of substitution of original rock minerals and not by introduction of material into an existing fissure. *Gash veins* are small veins that fill minor fissures with no great depth or length. The term is in many cases applied to small calcite veins seen in limestones. *Bed vein* indicates a vein that is parallel to the strike and dip of the enclosing rock, whereas a *bedded vein* is one made up of a number of beds or layers of different mineral content. *Lens* describes a vein or part of a vein, wide in its central part and narrow at both ends. Lenses of vein matter commonly occur in schist, parallel to the schistosity, and may be expected to have a depth not much greater than the surface length, which is usually short. *Saddle veins,* properly so called, consist of two limbs with opposite dip, whereas the crest is considerably thicker than the limbs. They are best developed in the spaces formed between sedimentary beds folded into an anticline. The gold veins of Nova Scotia show excellent examples of saddle veins.

Simple veins of the type mentioned above are probably not so common as veins that may be designated as *compound.* A type of common occurrence is the *stockwork* which is a mass of rock intersected by innumerable veins, large and small, that intersect each other irregularly. The individual veins are usually too small to work singly and a deposit of this type is of value only when the veins are closely spaced and the country rock itself contains values. The cooling of small, intrusive masses sometimes produces cracks which when filled with vein material constitute a stockwork, the tendency of which is to be a large, low-grade deposit. Deposits of gold-bearing quartz in some cases form stockworks.

A *fractured zone* is a mass of rock cut by a large number of irregular breaks. The area of fracturing has a considerable length compared with its width. The fissures may be filled with vein material and the country rock may also be replaced by ore minerals. If the fractured zone contains a system of small veins paralleling the strike of the zone and intersected by shorter veinlets at right angles, the deposit is known as a *reticulated vein.* When the fractured zone contains a large number of closely spaced parallel veinlets, with some replacement of the intervening country rock, the zone is called a *sheeted zone.* A *shear zone* is a band of rock which has suffered severe crushing and compression, in other words it is a zone of well-developed schist. The openings tend to be parallel to the direction of the schistosity and are generally small compared with the volume of the sheared rock. The importance of the shear zone as an ore deposit is due to the fact that mineralized solutions in many cases find the shear zone a favourable channel and replace parts of the schist with ore minerals and fill the openings with gangue minerals and ore.

A vein may lie within a fissure, but the fissure may not be completely filled. For instance, a vein lying in a fissure may appear as a series of disconnected bodies separated from one another by short distances along the strike and individually swelling and diminishing irregularly. Along a fissure of this kind occurrences of vein quartz appear at intervals, separated by stretches in which no vein matter is present. Down the dip of the vein, a similar relation is in many cases maintained. Some vein matter may persist to the maximum depth reached by such a fissure. The condition outlined above is in many cases complicated by faulting which has taken place subsequent to the deposition of the vein. Fault fissures are known to persist for several miles in length, but seldom carry vein matter throughout their length.

The mineral content of a vein is classified as: (1) *ore minerals,* which contain the elements that yield a profit; and (2) *gangue minerals,* which are useless and may even be troublesome. Thus in a gold-bearing vein, the ore minerals may be free gold and sulphides which contain gold, whereas the gangue minerals may be principally quartz with other minerals, such as calcite, tourmaline, scheelite, or sulphides, that contain no gold. Large parts of the vein may contain so small an amount of gold as not to repay the cost of mining, whereas other parts may contain values that are at least workable and possibly very rich. Those sections containing the higher values are known as *ore shoots.* In evaluating a vein deposit, care must be taken to determine the extent of the ore shoots and to estimate what proportion they constitute of the total volume of material that must be mined.

Terms have been suggested to describe the dimensions of an ore shoot. The *pitch length* is the distance between the extreme ends of the shoot. The *pitch* is the angle between the direction of the pitch length and a horizontal plane. The *thickness* is measured perpendicular to the plane of the vein.

The outlines of ore shoots exhibit the greatest variety. They may vary from large, irregular bodies to long, cylindrical bodies, known as *ore chimneys,* or to small pocket-like masses called *kidneys* or *nests.* A certain degree of similarity is in many cases noticeable in the nature of the ore shoots in any camp.

The ore shoots in some cases have resulted from the reopening of parts of a vein and the injection along the later set of fractures of ore and gangue minerals of a second period of mineralization. In such cases the bulk of the vein matter may carry low values except where the later solutions entered the vein through the secondary fractures. Evidence of the reopening of the vein are presented by its shattered condition and the existence of later minerals confined to the fractures or their immediate neighbourhood.

The manner in which a vein outcrops at the surface depends on several factors, but chiefly on the rate of weathering and erosion of the vein as compared with that of the surrounding rock. If the vein is more resistant to weathering than the country rock, the vein will tend to form prominent outcrops, but this tendency may be counteracted if the vein lies within a rock much softer than surrounding rock bodies, since in such a case the relatively rapid erosion of the immediately surrounding rock will also lower the surface of the vein. A case in point is that of some gold quartz veins in carbonated and mineralized porphyry cutting resistant silicified rocks. Though the gold quartz veins are rather slow weathering, they are found in low country because of the rapid weathering of the enclosing porphyry relative to that of the intruded rocks.

Veins of high carbonate content usually weather more rapidly than the rocks they cut. Those with a high content of such minerals as pyrite and copper pyrite disintegrate rapidly because of the oxidation of the pyrite and consequent slumping of the non-metallic vein material. Veins of these types are apt to lie in depressions, for such veins oxidize rapidly and the soft gossan, the product of weathering, is easily removed by the agents of erosion. Veins apt to stand up on a rock surface are chiefly those composed of quartz without much metallic mineral.

In some mining camps, the veins follow one or a few definite directions, whereas in others the veins are disposed in a most irregular fashion. Generally in any given mining camp it will be found that the veins follow certain directions related to the folding or faulting suffered by the strata.

The study of veins the world over has made it possible to classify them according to the temperatures existing at the times at which they formed. Conclusions regarding the temperature and pressure prevailing deep in the earth and obviously beyond direct observation, are based on a number of lines of evidence. Experiment has given some notions of the temperatures and pressures at which some minerals form and of the conditions under which they are stable. The combinations of minerals in bodies of rock known to have formed at great depths and at high temperatures are different from the combinations found in rock bodies formed at lower temperatures and pressures. In mountainous regions, changes take place in the mineral assemblages of deposits which can be observed at successively deeper levels. One result of the study of these and other lines of evidence is that it has been learned that certain minerals form only under fairly definite conditions of pressure and temperature and so have a certain diagnostic value, whereas other minerals form under a long range of temperature and pressure and hence are called persistent minerals. Thus, minerals such as gold, pyrite, quartz, and chalcopyrite form under many conditions, whereas such minerals as tourmaline, pyrrhotite, and scheelite are considered to originate only where a certain requisite high temperature and pressure existed at the time of their formation.

Lindgren's classification of veins according to the temperature and pressure existing at the time of their formation is, briefly stated, as follows:

HIGH TEMPERATURE VEINS

Temperature 300 degrees C. to 500 degrees C.; pressure, very high; replacement action on country rock, intense; minerals, such as various rock-forming minerals usually met with only in igneous rocks, tourmaline, pyrrhotite, oxides; form of veins irregular and lenticular due to high pressure.

VEINS OF INTERMEDIATE TEMPERATURE AND PRESSURE

Temperature 175 degrees C. to 300 degrees C.; pressure as at depths of from 4,000 to 12,000 feet; replacement action less intense, but marked, effecting more susceptible sediments, intense near vein; form of vein more regular than in high temperature veins; ore minerals, sulphides, arsenides, sulphantimonides, sulpharsenides; oxides rare; gangue minerals, quartz and carbonates.

VEINS FORMED AT SHALLOW DEPTHS

Temperature 50 degrees C. to 150 degrees C.; pressure, moderate; rock alteration extensive because of ease of passage of solutions in porous rock; form controlled by irregularities of zone of shattering near surface; minerals somewhat similar to above, barite, fluorite, carbonates, quartz, and adularia.

In the case of high temperature veins, the depth of formation is hard to estimate, since proximity to large, intrusive bodies at a relatively shallow depth may supply conditions of temperature and pressure, which in localities where intrusives are more distant would obtain only at much greater depths.

Examples of high temperature veins in Canada are the veins of Porcupine, where the gold occurs in quartz and schist associated with intrusive quartz porphyries and other acid rocks. High temperature minerals such as tourmaline, feldspar, scheelite, and pyrrhotite occur. The Rossland deposits are replacement veins in monzonite and augite porphyrite, and carry values in gold, silver, and copper and such minerals as biotite garnet, pyrrhotite, and molybdenite.

Veins of the intermediate type have many representatives in Canada such as the gold quartz veins of Nova Scotia, the silver-cobalt-nickel veins of Cobalt, and numbers of the silver-lead-zinc-gold veins of British Columbia. Veins of the high and intermediate temperature types are found chiefly in regions that have suffered considerable erosion. Veins of the shallow type occur in regions that have suffered little erosion and generally in areas of fairly recent volcanic activity. Most of Canada has been too deeply eroded to produce veins of this type, but areas in the Pacific Coast region exist where mineralization of this type occurs.

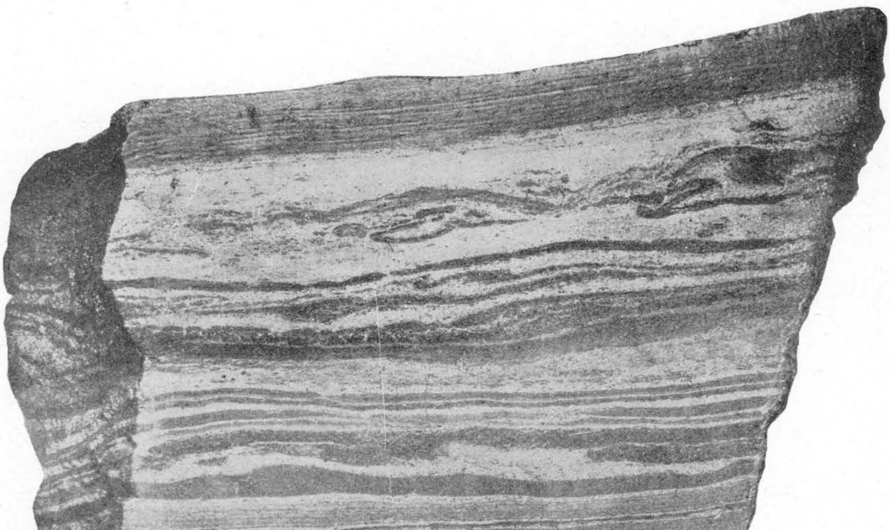
REPLACEMENT DEPOSITS

(Victor Dolmage)

It has been pointed out in the section devoted to veins that the solutions filling cracks and other cavities, in a less or greater measure also attack the wall-rock and replace it, the rock matter being dissolved out and the mineralizing substances in the attacking solutions taking the place of the rock matter. Many deposits of copper, lead, and zinc, as well as some of silver and gold, are formed by this process of replacement, or metasomatic replacement, or metasomatism, as it is variously called. By this process one rock or mineral is replaced by another of different composition and the form of the earlier body retained. As most of the metallic minerals composing these replacement deposits are combined with sulphur to form sulphides the deposits are known as sulphide replacement deposits. Some of the largest sulphide deposits of the world belong to this class and many of Canada's greatest mines, such as the Sullivan, Britannia, and Hidden Creek, of British Columbia, the Flin Flon of Manitoba, and the newly discovered deposits of copper, zinc, and gold in Quebec are of this type. There are carbonate replacements, of which the siderite iron formations of Michipicoten district and other parts of northern Ontario are large-scale examples; in fact, in these iron formations carbonate replacement and sulphide replacement occurred together. Silicate replacement is believed to occur commonly in the pegmatitic deposits and there can also be replacements of various other sorts; but the sulphide replacements are the commonest and the most important.

Replacement is accomplished by waters charged with compounds of the metals soaking through minute fractures, dissolving the rocks and minerals already there, and, at the same time, depositing in their place the metallic minerals. The process is continued for long periods of

PLATE III

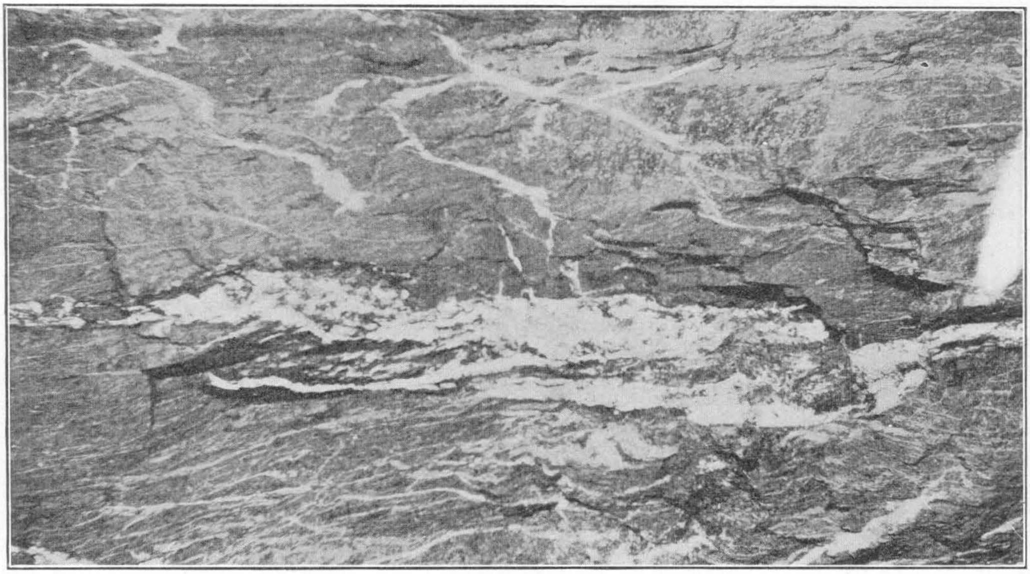


Sullivan mine ore, composed of galena (white), zinc blende, and pyrrhotite, illustrating the replacement of a banded sedimentary rock by sulphides, with the retention of original banded structure of the rock; $\frac{2}{3}$ natural size.

time and slowly but gradually immense quantities of material may be removed and replaced by others. The process is so delicate in operation that the structure of the original rocks is usually well, and in some cases very perfectly, preserved in the ores that take their place. The nature of the process is well shown in petrified wood, a silicate replacement, where the grain, the fibres, and even the cells of the wood can in many cases be easily seen, although the substance of the wood has been entirely replaced by silica. One good example where the process formed a very large mineral deposit is the Sullivan ore-body, of Kimberley, B.C. There, a finely banded bed of sedimentary rock from 50 to 100 feet thick has, in places, been completely replaced by iron, lead, and zinc sulphides and yet the original banding of the sedimentary rock with all its folds and contortions is faithfully preserved (*See* Plate III).

The ore of sulphide replacement deposits is largely made up of one or more of the following minerals, pyrite, pyrrhotite, chalcopyrite, zinc blende, galena, and bornite. Some replacement bodies are essentially copper deposits, in which chalcopyrite or bornite are the predominant ore minerals, and such bodies almost always contain small but important amounts

PLATE IV



Replacement of chlorite schist by quartz (white), main level, Britannia Mines, British Columbia.

of gold, in some cases small amounts of silver, and in a few cases important amounts of zinc. Others are essentially lead or lead-zinc deposits composed mainly of galena and zinc blende. These in most cases have important amounts of silver, but rarely gold. Still others consist largely of pyrite, but contain valuable amounts of gold or a mixture of gold and silver, such as for example the "Premier" deposit of northern British Columbia.

The gangue minerals are usually sparse and are largely remnants of the original wall-rocks more or less changed into such minerals as sericite, chlorite, biotite, quartz, and zoisite, depending somewhat on the nature of the replaced material and the temperature and pressure under which the replacements were formed. The Sullivan ore-body has little or no gangue, whereas the Britannia has large amounts of chlorite and quartz (*See* Plate IV). Where volcanic rocks are replaced, chlorite, sericite, and quartz are usually most abundant; where limestone was the original rock one finds large amounts of garnet, epidote, calcite, and quartz. Quartz is almost always present and in some deposits, such as the Britannia, it completely replaces the country rock, forming wide bands scarcely distinguishable from true quartz veins (*See* Plate IV). In most deposits of this class, however, the replacement is somewhat incomplete and one finds the sulphide and gangue minerals thickly scattered through the original rock, which is always much altered, not only in and adjacent to the ore but for considerable, and in some cases great, distances in all directions. These wide belts of altered rock, consisting of chlorite, sericite, biotite, quartz, or garnet may often be of assistance in prospecting for a deposit.

Because of the manner in which they formed, replacement deposits have not as clear-cut walls as vein deposits, but usually fade into the country rock. Also, they are more irregular in shape, usually wider and shorter than vein deposits. Many of them are lens-shaped or made up of a series of lenses either continuous or disconnected.

Replacement is a chemical reaction between solid rock matter and a mineral solution. The reaction will be more vigorous in proportion as the strength and chemical activity of the mineral solution increases and, therefore, replacements are usually caused by hot solutions. The solutions usually come from bodies of rock such as granite, granodiorite, monzonite, and other similar coarse-grained rocks; therefore, deposits of this kind are to be looked for in regions like the Canadian Shield, the Appalachian region, and the Cordilleran region, where rocks of this type are abundant. However, it may happen, as at the Sullivan mine, that the rock from which the ore came is not exposed at the surface, but buried at some depth below the deposit. But as replacements are usually formed near the parent rock it is generally exposed somewhere near. As might be expected, there is a close relationship between replacement deposits and other kinds of mineral deposits, especially with vein deposits and pegmatitic deposits. The wall-rock on each side of a vein is not uncommonly partly replaced and impregnated with ore values from the solutions that filled the veins.

In most, but not all, replacement deposits, the mineral-bearing solutions escape from the parent rock into the surrounding rocks before the metals are precipitated to form ore deposits and consequently the deposits are found in many kinds of rocks. However, some rocks such as schists, volcanic tuffs, and any rock that has been fractured or sheared, are more porous than others and it is natural that the solutions seek out the porous rocks and there deposit their metals. Limestone is not only porous, but is easily dissolved by the ore-bearing solutions and is, therefore, especially susceptible to the replacement process. Some of the largest deposits of this type are found in limestone.

In searching for mineral deposits the prospector should favour contact zones between granite, granodiorite, monzonite, and porphyritic phases of such rocks on the one hand and porous rocks such as tuffs, limestones, or sheared rocks on the other, and special attention should be paid to such contact where the rocks show evidence of having been altered by solutions.

In this connexion stress must be laid on the fact that it is the zone of contact rather than the actual line of contact itself that is of importance. The contact zone of a large intrusion is in some cases very wide, as the intrusive may be considered to extend at depth beneath the rocks that border the intrusive on the surface. Consequently, deposits may be found at considerable distances from the outcrops of the intrusive. Most replacement deposits contain iron sulphide which is converted at the surface into iron rust. This stains the ore and surrounding rocks a characteristic reddish brown colour which can often be seen at great distances. This so-called "iron hat" is an excellent guide to prospectors and almost always worthy of investigation.

Replacement deposits, perhaps more than any other class except pegmatitic deposits, vary greatly in richness. If the replaced rock were not uniform, but consisted of different varieties of rock, or if it were sheared or fractured in some parts and solid in others there would probably be correspondingly rich and lean streaks in the ore deposits. For this reason it is important that samples should be large and be taken fairly over as much of the deposit as possible. Small, selected samples are apt to yield erroneously large or erroneously small values for the deposit as a whole.

CONTACT METAMORPHIC DEPOSITS

(M. E. Wilson)

From time to time in past geological ages magmas (molten rock) have been intruded into the earth's crust and have cooled at depth as masses of igneous rock that are known according to their form and relationships chiefly as dykes, sills, stocks, or batholiths, but collectively in contrast with sedimentary rocks are usually called intrusives. The prolonged action of weathering, running water, and other agencies at work on the earth's surface in course of time wears away the rocks covering these intrusions, so that in many places they are now exposed where we can study their character, form, and relationships in detail. As a rule, the intrusion of these masses of molten material has a marked effect on the intruded rocks, developing a contact metamorphic zone or aureole of varying widths adjacent to the intrusive. The changes effected by the intrusive may consist: (1) in the recrystallization of the elements composing the adjacent rocks; (2) in chemical reactions between gaseous or liquid emanations from the intrusive and the constituents of the adjacent rocks; and (3) in the deposition of materials emanating from the intrusive in the contact zone, or combinations of these processes. By the first of these changes a sandstone is transformed to quartzite, a shale or greywacke to garnetiferous mica schist, and a limestone to crystalline limestone. If the invaded rock is similar in composition to the emanations from the intrusive, as for example when a sandstone or quartzite which consists almost entirely of silica is intruded by granite, the principal emanation from which is also silica, the possibilities for chemical reactions in the contact zone are small. On the other hand, if the composition of the intruded rock is different from that of the emanations (from the intrusive) a great variety of minerals may be formed. This reaction phenomenon is best exemplified by the intrusion of granite or other acidic igneous rocks into limestone or dolomite, for the carbon dioxide of the limestone or dolomite may pass off as gas, leaving the lime and magnesia free to unite with the silica emanating from the intrusive, so that an abundance of lime-silicate minerals results. In most cases, various elements other than silica are given off by the intrusive, which enter into combination with one another and with the lime and magnesia or other constituents of the invaded rock, thus multiplying the variety and complexity of the resulting minerals. Mineral aggregates of this class, or aggregates consisting in part of minerals of this class, are called contact metamorphic deposits. Their development may be accompanied by the deposition of metallic oxides such as magnetite and hematite or sulphides such as chalcopyrite, pyrite, zinc blende, molybdenite, arsenopyrite, and galena, or other material emanating from the igneous rock, and in this way contact metamorphic deposits merge into replacement deposits. It is customary, however, to regard all mineral deposits containing typical contact metamorphic minerals such as garnet, epidote, diopside, and tremolite as contact metamorphic deposits. Mineral deposits of this class, as one might infer from their mode of development, are, as a rule, irregular in form and discontinuous. They may occur either on the margin of the intrusive or elsewhere in the contact zone, wherever emanations from the intrusive penetrate.

Contact metamorphic mineral deposits are widely distributed in Canada, but they occur most abundantly in the Cordilleran belt of British Columbia and the Yukon and in the territory lying along the southern border of the Canadian Shield between Georgian bay and the strait of Belle Isle (Grenville Precambrian subprovince). The most important known deposits in the Cordilleran region are found in southern British Columbia, and in the territory adjacent to the Coast Range batholith, especially on Vancouver, Queen Charlotte, and other coastal islands. Typical metallic mineral deposits of the contact metamorphic class are exemplified in southern British Columbia in the Phoenix, Franklin, and Hedley camps. The principal contact metamorphic minerals composing these deposits are garnet, epidote, calcite, diopside, and tremolite. The chief ore minerals are chalcopyrite, pyrite, hematite, and magnetite at Phoenix, chalcopyrite, pyrite, magnetite, zinc blende, and galena at Franklin, and auriferous arsenopyrite, pyrrhotite, chalcopyrite, and sphalerite at Hedley. At Phoenix and Franklin the deposits are associated with granodiorite and at Hedley with diorite-gabbro. The intruded rock, as the mineralogy of the gangue minerals shows, at these camps is limestone. Near mount Whymper, close to the Alberta boundary line, southwest of Banff, there is a deposit of massive talc (soapstone) that is a typical example of a contact metamorphic deposit of the non-metallic class. This deposit is associated with dolomite and has evidently been formed by the reaction of siliceous emanations from intrusions of syenite and related rocks that outcrop in Ice River district a few miles to the northwest but which probably occur much closer to the deposit at depth. The predominant mineral of commercial value found in the contact metamorphic deposits of the coastal belt of British Columbia is magnetite. Other minerals found in the deposits are garnet, pyroxene, calcite, epidote, hornblende, pyrite, and chalcopyrite. They are chiefly associated with granodiorite and diorite intrusives belonging to the Coast Range batholithic belt, and are found for the most part where these rocks have invaded Triassic limestone.

The contact metamorphic mineral deposits found along the southern border of the Canadian Shield in southeastern Ontario and Quebec, include a variety of mineral deposits chiefly of the non-metallic class. The most important are those of graphite, magnesite, amber mica (phlogopite), apatite, talc, molybdenite, and magnetite. The graphite deposits are found chiefly in zones along contacts of intrusions of pegmatite, syenite, diorite, gabbro, and anorthosite. The principal associated minerals in most deposits are diopside, scapolite, wollastonite, and pyrite, but at the Black Donald mine near Calabogie, Ontario, the most important deposit of graphite so far discovered in Canada, the principal gangue mineral is a pale green mica (muscovite). The known magnesite deposits in this belt occur in Grenville district, Argenteuil county, Quebec. They consist chiefly of magnesite mingled with varying proportions of dolomite and serpentine. Talc and diopside are also present in the deposits, in places. These deposits are believed to have been formed from the Grenville limestone by reactions with magnesia and silica-bearing solutions emanating from nearby intrusions of gabbro, some dykes of which are associated with the deposits. Deposits of amber mica and apatite (calcium phosphate) are found chiefly in Kingston-Perth district, Ontario, and in Quebec northeast of Ottawa. They consist largely of diopside in which the mica and apatite occur either as scattered crystals, or in aggregates, or in veins of calcite. The most common associated minerals are calcite and scapolite. The less common are feldspar, tremolite, fluorite, tourmaline, titanite, pyrite, and pyrrhotite. These mineral aggregates occur for the most part as masses in the crystalline limestone of the Grenville series in regions where it has been intimately intruded by pegmatite, syenite, diorite, and anorthosite, or related rocks. In a very few places the deposit is developed in a zone along the contact of a pegmatite mass and the limestone. Masses of pegmatite, called " boulders " by the miners, are also common in the deposits. The magnesian silicate, talc, is known to occur in several localities in this region, but the most important deposit is a crumpled mass 1,300 feet long and up to 60 feet wide, associated with dolomite, in the contact zone of a batholith of granite at Madoc, Hastings county, Ontario. This deposit has evidently been formed by the interaction of siliceous emanations from the granite with the magnesia of the dolomite. Molybdenite is found in the Grenville belt disseminated in zones of green pyroxene, developed along the contacts of intrusions of granite and pegmatite with the Grenville limestone. Deposits are especially abundant in Quebec to the northwest of Ottawa, and Haliburton, Hastings, and Renfrew counties in southeastern Ontario. Deposits of magnetite of the contact metamorphic type are found chiefly in southeastern Ontario at points where either gabbro or granite has intruded the Grenville or Hastings limestone. The most common associated minerals are garnet, amphibole, pyrite, and pyrrhotite.

Mineral deposits of the contact metamorphic class are found only in regions where igneous rocks have been intruded and only in rocks that have been metamorphosed. They may be found in Canada, therefore, in the Cordilleran region of British Columbia and the Yukon, in the Canadian Shield, and in the eastern belt of folded rocks included in the Appalachian and Acadian regions. They will not be found in the Great Plains or the St. Lawrence lowlands. Since they are most commonly associated with limestone or dolomite they will be found most abundant in regions where limestone and dolomite occur, and especially where they have been intruded by igneous rocks.

In the Cordilleran region contact metamorphic mineral deposits are to be found most abundantly in its western and southern parts. They may also be found in the northern part of the central belt where the basal complex is not hidden beneath unaltered or only slightly altered Tertiary or later formations. They will probably not be found in the northern part of the Rocky Mountains belt, for, so far as known, igneous intrusions are almost entirely absent in this region. In the Canadian Shield, except for a few isolated occurrences, metamorphosed limestone or dolomite is known only in the Grenville belt lying along its southern border in southeastern Ontario and Quebec (already mentioned), in Baffin island, and along the south shore of Hudson strait. It is, therefore, chiefly in these localities that contact metamorphic mineral deposits may be found. In the eastern belt of folded rocks, that is, in that part of Canada lying east of the Logan or Champlain fault which extends from lake Champlain to Quebec, the districts where crystalline limestone or dolomite is known to occur and hence where contact metamorphic deposits are most likely to be discovered, are: here and there in the Appalachian mountains; in the southern highlands of New Brunswick; and in the (pre-Carboniferous) uplands of Cape Breton Island and of the northern part of the mainland of Nova Scotia.

MINERAL DEPOSITS OF THE PEGMATITES

(J. F. Wright)

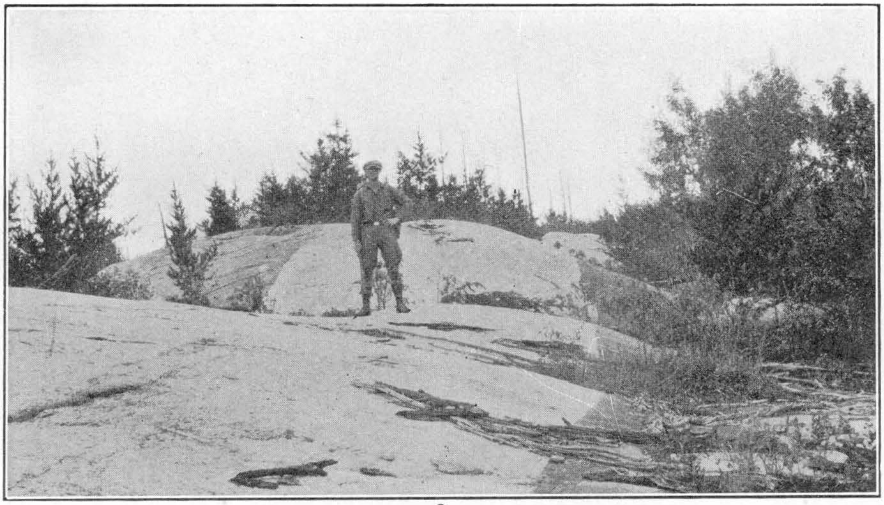
Under the name of pegmatite are grouped dykes and small lenticular bodies of extremely coarse and irregularly grained rock found within deep-seated intrusive masses or the country rock surrounding bodies of intrusive rock. Both acidic and basic intrusives are accompanied by pegmatites of special types, and it is generally agreed that the pegmatites represent parts of the magma left after the main mass had crystallized, and, therefore, that they are one of the end phases of the intrusion. Many pegmatite bodies have a mineral content very similar to that of the parent intrusive mass and, consequently, are of no commercial value. A few pegmatite bodies, however, are of considerable economic value, as they contain deposits of the common minerals, such as quartz, feldspar, and mica, in exceptional size of grain and purity. Other pegmatites carry small bodies of metallic ores, and some pegmatites contain rare-earth minerals and gemstones of considerable economic value, and not found elsewhere. A great variety of minerals of commercial value are found in the pegmatites, and, therefore, prospectors working in areas where pegmatites are abundant, and especially in areas within the Canadian Shield, should examine thoroughly each pegmatite dyke.

The granitic pegmatites are by far the most important and abundant group and in the field are easily recognizable. They are usually white or pink, although greyish, cream, or buff varieties may be found. Crystals of feldspar (orthoclase, microcline, albite), quartz, mica, and one or more other minerals such as tourmaline, magnetite, molybdenite, or beryl are easily recognizable in most outcrops. In a variety of granitic pegmatite, called graphic granite, the quartz and feldspar are intimately intergrown, so that the weathered surface of many outcrops resembles in pattern the writings on ancient tablets. A conspicuous feature of many outcrops of granite pegmatite is the large size of the individual crystals and the marked variation in size. Some granite pegmatites contain very large crystals, 40 feet or more in length, but the normal type seldom shows crystals over 2 feet long. In the normal igneous rock the crystals of the same mineral vary but little in size, whereas in pegmatite a crystal of feldspar 2 feet long may have as neighbours crystals less than 2 inches long.

In size the pegmatitic bodies vary from stringers an inch or so in width up to masses several thousand feet in width and traceable along the strike for several miles. It is customary to speak of pegmatite dykes, but only a few pegmatite bodies are known to have the regular tabular form generally associated with the term dyke. Mining development has shown that a pegmatite body with a long, narrow outcrop may pinch out within a hundred feet below the surface, whereas, on the other hand, a mass with a short outcrop may continue in pipe-like form to great depth. Many pegmatite ore-bodies, which have been developed for their content of valuable minerals, have been found to be lenticular or irregular in form, and the valuable minerals have been found in pockets and irregularly shaped masses with an erratic distribution throughout the pegmatite mass. These characteristic features of the mineral deposits in the pegmatites make the estimation of reserve tonnages of the ore minerals almost impossible, and, for this reason it has been found advisable to develop the deposits of valuable minerals in the pegmatites on a small scale and without incurring large expenditures for mining machinery and the construction of permanent roads.

In distribution, pegmatites are associated with deep-seated intrusive rocks, and, therefore, will be found only in areas where erosion has exposed intrusives of this type. In large areas of the Canadian Shield deep-seated intrusives are exposed, consequently pegmatites are abundant. Up to the present, however, the pegmatites of this extensive area have been prospected only at a few localities near the main transportation routes. However, the pegmatites already prospected have yielded a great variety of minerals, and there is every reason to believe that in the future other deposits of valuable minerals will be discovered in the pegmatites of many other areas within the Canadian Shield. In New Brunswick and Nova Scotia deep-seated intrusives are also exposed and pegmatites are present, but up to the present these pegmatites have been only sparingly prospected. In western Canada, deep-seated intrusives are exposed widely in the

PLATE V



A. Pegmatite dyke near Falcon lake, southeastern Manitoba.

B. Pegmatite dyke showing fine-grained edges and coarse-grained centre. From near Minaki, Ontario.

Cordillera of British Columbia, and a few mineral deposits have been found associated with these pegmatites. On the prairies and in the mountains of western Alberta and eastern British Columbia erosion has not yet uncovered deep-seated intrusives and no pegmatites are known in this part of Canada.

The valuable minerals heretofore extracted from the pegmatites may be classified roughly as the useful silicates, phosphates, and oxides, metallic ores, gemstones, and the rare-earth minerals. Under the first group are included quartz, used in making fused silica ware, and feldspar, used for pottery and a flux in metallurgy. For many years the feldspars in the pegmatites from north of Kingston, Ontario, and recently from near Buckingham, Quebec, have been quarried and sold for use in the American pottery industry. The feldspars of pegmatites would be in great demand in this country, if a commercial process could be evolved whereby the alkali metals, potassium and sodium, could be extracted from them for use in the manufacture of fertilizers. About thirty years ago the large masses of apatite within the pyroxene pegmatites north of Kingston and along Gatineau valley were an important source of phosphate for fertilizers. Also, the pegmatites of these two areas have been for many years an important source of the large flakes of phlogopite mica, extensively used as electrical insulators and for stove, lamp, and automobile windows. For many years corundum, for use in the abrasive industry, was extracted from the nepheline syenites and their associated pegmatites in Renfrew, Hastings, and Haliburton counties, Ontario, but recently artificial abrasives have replaced the naturally occurring mineral.

In 1924 promising deposits of lithium-bearing minerals were discovered in several pegmatite bodies in Manitoba, on Winnipeg river east of Pointe du Bois, and pegmatitic dykes carrying lithia minerals are known over a considerable area in southeastern Manitoba. The important lithia minerals of these deposits are lepidolite, spodumene, and amblygonite, but the development and prospecting completed to date have not been extensive enough to determine the future of this district as a producer of lithium. The wide distribution of the lithia minerals in the pegmatites of Manitoba area illustrates admirably an important fact that prospectors should always bear in mind when prospecting the pegmatites; namely, that the pegmatites have a tendency over quite wide areas to hold the same suite of minerals, therefore, if a small amount of some valuable mineral is found in a pegmatite dyke, all the dykes of the area should be searched, as one or more may contain this mineral in commercial quantity.

Minor occurrences of metallic ores in pegmatites are reported from many localities in Canada, but few of these are of economic value. Bornite occurs in pegmatites at Yale, British Columbia, and at Drum Lummon mine, 100 miles southeast of Prince Rupert, B.C., chalcocite, bornite, silver, and gold are reported associated with a pegmatite dyke. The pegmatites near Falcon and Star lakes, Manitoba, contain a small percentage of molybdenite, and in Abitibi district, Quebec, pegmatitic quartz veins carry some molybdenite. In many areas pegmatitic dykes grade along the strike into quartz veins. However, the quartz veins closely associated with the pegmatites are easily differentiated from the typical gold-bearing quartz veins by the white, glistening crystals of feldspar the former usually carry. Although gold is locally present in the pegmatitic quartz veins, these deposits have seldom proved commercially valuable. In southeastern Manitoba tungsten has been found in the pegmatites near Falcon lake, and a small pocket of cassiterite has been found in a pegmatite dyke on an island in Shatford lake. Cassiterite also is found as small grains within a pegmatitic zone in aplitic muscovite granite near New Ross, Nova Scotia. It is surprising that cassiterite has not been discovered at more localities within the extensive granite areas of the Canadian Shield.

Minerals containing rare metals, some of which are radioactive, have been discovered in the pegmatites of Ontario, at a number of localities in the area of Precambrian rocks south of French and Ottawa rivers, and west of a line between Ottawa and Kingston. Radium-bearing minerals were discovered near Parry Sound, Ontario, early in 1921, and since that date considerable sums have been expended in search for commercial occurrences of these minerals, but without marked success. The most important radioactive minerals found in the Ontario deposits are uraninite, ellsworthite, hatchettolite, cyrtolite, columbite, and allanite. The reader is referred to the section of this book descriptive of the physical properties of the radioactive minerals for information as to how to identify and prospect for radioactive and other rare-earth minerals.

Up to the present no commercial deposits of gemstones have been discovered in the pegmatites of Canada, although many of the gem minerals of the world are extracted from the pegmatites. Among these may be mentioned beryl and its green variety emerald; green and pink tourmaline; coloured varieties of spodumene; sapphire and chrysoberyl; topaz; some varieties of garnet, amethyst, and rose quartz. For information on the possibilities of commercial gemstone deposits being found in Canada, the reader is referred to the description of gemstones on pages 91-99 of this report.

The foregoing brief description of some of the mineral deposits of the pegmatites indicates the great variety of these and is intended to emphasize to the prospector the importance of searching carefully each pegmatite dyke encountered for commercial deposits of the common minerals or of the rare and little known minerals. Specimens should be collected of all the minerals in the pegmatite unknown to the prospector and forwarded for determination either to the Director of the Geological Survey, Ottawa, Canada, or to the Department of Mines of the province wherein the discovery is made. In addition to the minerals already mentioned prospectors should be on their guard for commercial deposits of cryolite, columbite, monazite, muscovite, rutile, zircon, beryl, and pollucite in the pegmatites.

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DEPOSITS ASSOCIATED WITH THE BASIC AND ULTRABASIC ROCKS

(J. B. Mawdsley)

Basic and ultrabasic igneous intrusions give rise to a characteristic series of minerals which in some places occur in concentrations of economic importance. Such minerals are ilmenite, magnetite, chromite, nickeliferous pyrrhotite, chalcopyrite, and platinum. Many of the gemstones, which are dealt with in a following section of this report, are closely associated with the basic and ultrabasic rocks. The alteration of the ultrabasic rocks may also result in the formation of deposits of asbestos, talc, and soapstone. Hence, bodies of these rocks, especially large bodies, are well worth prospecting.

Igneous rocks, that is, rocks formed by the cooling and crystallization of a molten magma, range in their mineral and chemical composition from granites to dunites. The rocks grouped as basic are the more basic diorites, and the diabases, gabbros, norites, and anorthosites. Excepting the anorthosites these rocks are texturally like granites and syenites and have a grain, commonly, of $\frac{1}{8}$ to $\frac{3}{8}$ inch. As the basic rocks are poorer in silica and alkalis and richer in iron, lime, and magnesia than the granites and syenites, their mineral content is naturally different. Quartz is absent or almost so, and the feldspars are those high in lime such as andesine and labradorite. The principal dark mineral in the diorites is usually hornblende, in the gabbros augite, and in the norites hypersthene or enstatite. The rocks are apt to be dark coloured owing to the high content of dark mineral. As the dark minerals weather easily the rock outcrops are usually rusty and rotted to a depth of a few inches.

Anorthosites are commonly associated with gabbros or norites, but differ from them in that dark minerals are nearly absent and the basic plagioclase feldspars andesine, or labradorite, or sometimes bytownite, are in large crystals from $\frac{1}{2}$ to 3 inches in diameter. When fresh they vary from nearly white, through mauve, to nearly black, corresponding to the increased proportion of microscopic black ilmenite rods in the feldspar. Owing to their simple mineral content the anorthosites are not subject to deep weathering, and the weathered surface of their outcrops is, normally, white or light grey.

Among such basic rocks as norites and gabbros are types that grade imperceptibly into the group of rocks known as ultrabasic. The ultrabasic rocks are poorer in silica and lime than the basic and have a higher magnesium content. Mineralogically they are composed mainly of the dark iron-magnesium minerals hornblende, pyroxene, enstatite, hypersthene, and olivine, with small quantities of plagioclase feldspar. The group includes hornblendites, pyroxenites, enstatites, peridotites, and dunites. The grain, like that of the basic rocks, is coarse, from $\frac{1}{8}$ to $\frac{1}{2}$ inch in diameter. The colour of the fresh rocks is naturally dark, like that of the constituent minerals; but in many of the rocks the dark minerals are partly or completely altered to chlorite or serpentine and the colour is dark with a green cast, or distinctly dark green. These rocks weather easily and their outcrops are friable or soft, and rusty where the iron content is high, and almost white when the magnesium content is high.

Pyroxenites, hornblendites, and enstatites are composed essentially of pyroxene, hornblende, or enstatite respectively. Peridotites usually grade into and are closely associated with olivine diorites, olivine gabbros, and olivine norites. In typical peridotites feldspar is usually absent and olivine is the prominent constituent. The pyroxenes, hornblendes, and enstatite form an appreciable part of the rock. When olivine is practically the only constituent of the rock it is called dunite. The ore minerals ilmenite, magnetite, and chromite are common accessory constituents in these rocks.

The magnesium and iron minerals of the ultrabasic rocks are susceptible to change and many serpentine masses are the product of the alteration of these rocks.

Masses of the basic rocks are found in or closely associated with the igneous terrains of the Cordilleran region of British Columbia and the Yukon, throughout the Canadian Shield, and in the Appalachian region, particularly in the Eastern Townships of Quebec and Gaspe peninsula. Particularly large masses of anorthosite are found along the southeastern margin of the Shield in Quebec, but smaller areas are known in other parts. No such igneous rocks occur on the Great Plains or the St. Lawrence lowlands.

Rocks of different composition may be formed from a once homogeneous magma by differentiation. Petrologists differ with regard to the way this differentiation takes place. The most widely accepted theory is that in the main, differentiation is caused by the tendency of different minerals to crystallize at different times during the slow cooling of the magma. The basic minerals normally crystallize first and among them are the ore minerals ilmenite, magnetite, chromite, nickeliferous pyrrhotite (pentlandite carrying pyrrhotite), chalcopyrite, and platinum minerals. These minerals are heavy, that is they have a specific gravity, and tend to sink to the bottom of the molten mass. As a result the lower part of the mass becomes basic and the upper progressively richer in silica and alkalis. Ultrabasic rocks such as dunites, peridotites, pyroxenites, and enstatites will, in an ideal case, be overlain by gabbros, norites, or anorthosites and in turn by diorites, syenites, and granites. A rude arrangement of this sort is sometimes found in sills that have cooled slowly; in eroded batholiths, the rocks in places have a zonal arrangement, corresponding to the above sequence. Disturbance during consolidation may cause one type of rock to be intruded by another differentiate and the simple relationship mentioned above will not be so obvious. Mountain building and folding after consolidation may also disturb the arrangement of the rocks.

As the ore minerals other than talc and asbestos, which as previously stated are due to the alteration of some of the original rock minerals, form only a very small percentage of the original magma, large, relatively pure deposits are to be expected in the larger masses of the basic and ultrabasic rocks rather than in the smaller ones. Also, it is in the larger masses that cooling is slowest and it is, therefore, in these masses that the most perfect differentiation would take place. In some of the large intrusive masses the base may not be exposed and the heaviest differentiate of the mass may not be visible or accessible. However, the heavy differentiates in such cases may be intruded into the overlying rocks by some earth movement and thus rendered visible after erosion. This is the case with deposits of ilmenite near Baie St. Paul, Quebec, which occur as dykes cutting anorthosites. A laccolith or sill is a sheet-like intrusive body, with both a floor and roof; and any bodies of heavy minerals that may have separated from it are naturally found near the floor, or in cracks or other openings of the floor. Dykes are vein-like bodies, usually long and narrow. These bodies cool relatively quickly, differentiation is slight, and the chances of mineral deposits forming from them are small. Batholiths, laccoliths, and sill masses that are here considered as large, are those whose areal dimensions can be measured in miles rather than in hundreds or thousands of feet.

The following table illustrates the chemical relationship of the basic and ultrabasic rocks to one another and to the granitic rocks. It brings out the high iron (Fe) content of gabbros and norites with which magnetite deposits are so commonly associated. The high content of titanium (Ti) of the rocks also shows why such iron deposits are usually titaniferous. It is not as plainly evident why ilmenite should be found as dykes in anorthosites, but when it is realized that anorthosites are closely related to the high titanium-bearing rocks, gabbros and norites, the reason is more clearly evident. Analyses of the ultrabasic rocks usually include significant amounts of chromium (Cr) and nickel (Ni), corresponding with the occurrence of commercially important deposits of these metals along with such rocks.

The oxide of manganese (Mn) is shown to occur in the basic and ultrabasic rocks. Manganese does not form a heavy sulphide in the magma and consequently does not segregate into primary masses like the metals previously mentioned. However, the disintegration of the basic rocks gives rise to secondary manganese deposits.

The high magnesium (Mg) content of the ultrabasic rocks is clearly shown and for this reason it is in these rocks that the magnesium rich minerals, asbestos and serpentine, are formed in places in great quantities.

Table of Analyses Showing Chemical Relationships of Granitic, Basic, and Ultrabasic Rocks

—	Granite[2]	Syenite[3]	Diabase[6]	Anorthosite[1]	Gabbro[1]	Norite[5]	Pyroxenite[4]	Peridotite[1]
SiO_2	72·0	58·6	50·1	50·4	48·2	47·2	50·8	41·1
Al_2O_3	13·1	16·4	15·7	28·3	17·9	14·5	3·4	4·8
Fe_2O_3	1·5	3·6	1·4	1·1	3·2	1·6	1·4	4·0
FeO	1·8	3·1	6·9	1·1	6·0	13·8	8·1	7·1
MgO	0·6	3·1	11·3	1·3	7·5	5·2	22·8	32·2
CaO	1·5	4·5	9·5	12·5	11·0	8·1	12·3	4·4
Na_2O	3·5	3·5	2·9	3·7	2·5	3·1	....	0·5
K_2O	4·8	4·8	1·1	0·7	0·9	1·2	....	1·0
H_2O	0·7	1·1	1·2	0·7	1·4	0·6	0·5	3·5
TiO_2	0·3	0·9	0·5	0·1	1·0	3·4	....	1·2
MnO	0·1	0·1	....	....	0·1	0·2	0·2	0·1
P_2O_5	0·1	0·3	....	0·1	0·3	0·6	....	0·1
	100·0	100·0	100·6	100·0	100·0	99·5	99·5	100·0

Throughout Canada instances are found where basic and ultrabasic rocks are the country rocks for deposits that are not primarily due to these rocks, but are due to other controlling factors. In the following sections only deposits directly related to basic or ultrabasic rocks are described.

ILMENITE

Ilmenite is a heavy black mineral resembling magnetite, which contains titanium and iron. It is at present used in small quantities for making titanium oxide paint, which has certain advantages over the usual paint bases now used. If its manufacture can be cheapened, accessible high-grade deposits of this mineral will be of value. Ilmenite ore has been found very refractory in the ordinary processes of iron making, but in areas where cheap electrical power is available, it may eventually become a useful ore of iron since recent research has shown that by electric smelting processes this mineral affords a very high-grade product.

Ilmenite deposits in Canada in practically every instance are closely associated with large areas of anorthosite. Where sufficiently exposed it is found that the ilmenite masses are irregular, dyke-like bodies intruding the anorthosite. Large ilmenite bodies occur in the anorthosite intrusives in the vicinity of lake St. John and St. Urbain. There are other bodies found in anorthosite along the north shore of the St. Lawrence. Great bodies of anorthosite are known to occur at many places in Quebec north of St. Lawrence river.

The most fruitful method of finding other deposits of ilmenite is probably to prospect in the vicinity of known bodies. As the mineral affects the dip needle, a dip needle survey will be of value as a means of locating masses covered by drift. The extent of such masses might be determined by some method of electrical prospecting.

[1] Tyrell, G. W.: "The Principles of Petrology," 1926, p. 120.
[2] Tyrell, G. W.: "The Principles of Petrology," 1926, p. 112.
[3] Tyrell, G. W.: "The Principles of Petrology," 1926, p. 117.
[4] Clarke, F. G.: U.S. Geol. Surv., Bull. 770, H, p. 467.
[5] Clarke, F. G.: U.S. Geol. Surv., Bull. 770, D, p. 465.
[6] Collins, W. H.: Geol. Surv., Canada, Mem. 33, Table col. II, p. 76.

MAGNETITE

Magnetite or titaniferous magnetite in areas where cheap electrical power is available may eventually be used as an ore of iron. Magnetite is an accessory constituent of many of the basic or ultrabasic rocks and in some cases is so concentrated as to form a high percentage of the rock. The magnetite grades in composition into ilmenite.

Magnetite deposits, unlike those of ilmenite, form segregations or bodies in large gabbro, norite, or pyroxenite masses, rather than in anorthosites. Some bodies also occur in peridotites. These magnetites all contain a small percentage of titanium. The magnetites related to basic and ultrabasic rocks which have any promise of commercial value are confined to the Precambrian Shield and chiefly to its southern margin. Large deposits are associated with a gabbro near Seine bay, Rainy River district, Ontario, and in many parts of Quebec, for instance Bourget township, in Lake St. John district, and Seven Islands bay, on the lower St. Lawrence.

As this mineral is strongly magnetic, prospecting with a dip needle is the best method for locating drift-covered bodies of ore.

CHROMITE

Chromium is the element obtained from the mineral chromite. It is used for hardening steel and in the preparation of chromium salts for the chemical industry.

Chromite is a common accessory of the ultrabasic rocks and in places the concentration in peridotites or in serpentine rocks derived from peridotites is on such a scale that economic deposits exist. Commonly these ores must be further concentrated after mining to form a marketable product. A marketable product must contain by analysis at least 50 per cent chromium oxide.

The ore-bodies occur as zones of separate lenticular bodies. They usually have no sharp boundaries and grade into peridotite. In other cases they form vein-like lenses with sharp boundaries within peridotites or pyroxenites. They are usually concentrated in the more basic parts of these rock masses. In the chromite-bearing peridotites of southern Quebec they are found in places along the margin of the peridotite masses; but in other places the distribution is not thus limited, and deposits occur throughout these rock masses. Chromite ore has been discovered in other parts of Canada as well as in Quebec; for instance in the Tulameen peridotites of British Columbia.[1]

The larger bodies of peridotites and pyroxenites are probably the most promising places in which to prospect for these deposits; for it is in large bodies that this commonly finely disseminated mineral has a chance to accumulate in any quantities. Large-sized masses of these rocks are not widespread. The chief deposits of chromite that have been worked in Canada are in the asbestos region in the Eastern Townships of Quebec.[2] Deposits have also been worked in the Tulameen region of British Columbia.

[1] Camsell, C.: Geol. Surv., Canada, Mem. 26, p. 168 (1913).
[2] Dresser, J. A.: Geol. Surv., Canada, Mem. 22, pp. 74 to 92 (1913).

The mineral is feebly magnetic and a good conductor of electricity, so that a dip needle or magnetic survey would assist in the location of ore-bodies in drift-covered areas. A reliable electrical prospecting method might also be of assistance.

NICKELIFEROUS PYRRHOTITE AND CHALCOPYRITE

Nickeliferous pyrrhotite is finely disseminated in some basic and ultra-basic rocks and in the case of some of the larger bodies of these rocks is concentrated with chalcopyrite in relatively pure and large masses. At present the world's production of nickel is mainly derived from the nickeliferous pyrrhotite of Sudbury with which chalcopyrite is closely associated and forms an important ore of copper.

At Sudbury a large 36-mile long and 16-mile broad norite mass has been intruded between Precambrian crystalline rocks and overlying sedimentary rocks. The central part is overlain by sediments, erosion having exposed only the edge in the form of an elliptical ring. The thickness of the sheet is from 2,000 to 10,000 feet. The upper part is granitic in composition, but rapidly grades downwards into norite. Where the sheet is thin, the norite phase is absent. Pyrrhotite is so concentrated in the lower part of the norite that it has been called a pyrrhotite norite. The ore-bodies usually occur at the base of the pyrrhotite norite. Most of them are in or next to the norite, but some of the so-called offset deposits are in the neighbouring rocks. Successful prospecting for deposits in Sudbury basin has been largely confined to following the contact of the norite and the underlying rocks.

Elsewhere in the Canadian Shield, as at the Alexo mine (Dundonald and Clergue townships, Ontario), and on Maskwa and Oiseau rivers (southeast Manitoba) nickeliferous pyrrhotite occurs with norite, peridotite, or serpentine derived from peridotite. These basic rocks are to be expected only in areas composed of intrusive rocks such as areas of the Precambrian shield and the intrusive areas of British Columbia. The known occurrences of these rocks are widely scattered. The larger known ones are associated with the previously mentioned nickeliferous pyrrhotite deposits.

Pyrrhotite is magnetic and a good conductor of electricity, so that a dip needle or an electrical survey of likely drift-covered country might help to indicate the position of any existing ore-bodies.

PLATINUM

Platinum is one of the rare elements and is highly valuable commercially for the manufacture of jewellery and scientific instruments and chemical apparatus. It is usually associated with other rare metals, iridium, osmium, palladium, rhodium, and ruthenium. Platinum is usually found in peridotites and pyroxenites, but so disseminated that it cannot be extracted at a profit. The world's supply is mostly obtained from placer deposits that have been formed by breaking down of the platinum-bearing basic rocks and concentration of the resultant heavy substance in the beds of streams that cross these rocks. In British Columbia, particularly in Tulameen district, platinum occurs in placers derived from the breaking down of peridotite and pyroxenite bodies. As indicated by available assays, the richest platinum-bearing rocks of Tulameen district are the chromite-rich peridotites. The large masses of ultrabasic rocks found in the vicinity of Tulameen and adjacent Similkameen rivers are the only known large masses of such rocks in British Columbia. No platinum has been so far found in peridotite masses of southeastern Quebec. The copper-nickel ores of Sudbury which, as previously mentioned, are associated with basic rock "norite," contain an appreciable amount of platinum, which is nearly all the platinum recovered in Canada. This is recovered as a by-product during the recovery of the copper and nickel content of the ore. Some placer platinum has also been found on Burwash creek, Yukon territory.

Except for the platinum found in association with the gold of the Klondike, Yukon territory, the above-mentioned areas of basic or ultrabasic rock are at present the only areas known in which platinum is to be expected to occur in Canada. Further mapping or prospecting may, however, discover other likely areas in the igneous rock terrains of the Dominion.

As the platinum-bearing minerals normally occur in minute quantities disseminated through the peridotites and pyroxenites, it is difficult to determine if they are present or absent in such rocks. Panning of river gravels and sands in the vicinity of ultrabasic rock masses is, perhaps, the best method to employ, since it is in placer deposits that platinum is likely to be found in commercial quantities.

SILVER AND COBALT ASSOCIATED WITH DIABASE

Silver, cobalt-bearing minerals, etc., occur in calcite veins in close connexion with diabase sills in Cobalt region, Ontario. These deposits are related to the basic rocks, but are vein deposits whose general characteristics are discussed in a preceding section. Silver is more commonly found in connexion with acidic rocks like granite than with basic rocks, but cobalt seems, like nickel, to come from basic rocks. It is noteworthy in this connexion that nickel and cobalt are very similar in their chemical behaviour.

ASBESTOS

The fine, flexible, silky fibre of the mineral asbestos is used for a great variety of purposes where materials of a fireproof or non-conducting nature are required. Toughness and elasticity are essential and length of fibre an important factor. Freedom from impurities that would affect its properties as a non-conductor of heat and electricity is essential in high-grade asbestos.

Asbestos is found in various parts of Canada, but so far the only deposits that have proved economical to work on a large scale are those in the Eastern Townships of Quebec. These deposits supply a large part of the world's asbestos supply.

In every instance in Canada, asbestos is found in dunites, peridotites, or pyroxenites that have altered to serpentine. The mineral occurs in veins that in most places follow a definite direction or set of directions, believed to be joints, which formed during cooling of the ultrabasic country rock, along which fluids escaping from these rocks, or surface waters, or emanations from granite and aplite intrusives, have recrystallized the serpentine to asbestos, without altering the chemical composition. Where the asbestos occurs in any large quantity, ultrabasic intrusives are large and have been more or less completely altered to serpentine. In Quebec the asbestos forms from 1 to 10 per cent of the rock mined. The mineral occurs in two distinct forms, as " cross fibre " and " slip fibre." " Cross fibre " occurs in veins as minute fibres arranged parallel to one another and at right angles to the vein walls. " Slip fibre " has no definite arrangement, but is scattered throughout the rock and in many cases forms a large proportion of the rock masses. Both these forms of asbestos occur in a deep green serpentine, which at times forms the whole mass of the containing rock or else zones in it. The " cross fibre " veins are usually the central part of much wider serpentine veins that traverse the rock mass.

Small masses of ultrabasic rocks containing asbestos are commonly found throughout the igneous terrains of the Dominion, but large masses containing commercial quantities of the mineral have so far only been found in the Eastern Townships, Quebec.

Large masses of the ultrabasic rocks that contain asbestos should be prospected preferably in their more basic or serpentinized parts. As serpentine rocks are easily eroded, promising areas for prospecting may very possibly be covered by dirt.

TALC AND SOAPSTONE

Talc is extensively employed in many industries. The colour and physical condition of any body of talc largely determine the uses to which it may be put. Other important properties are its smoothness or slip, its chemical inertness, its low conductivity for heat and electricity, and its high temperature of fusion. The most valuable variety is white talc which, in Canada, has formed from dolomite, a sedimentary rock. Grey or green less valuable varieties are associated with ultrabasic rocks.

Soapstone is a massive variety of talc, more or less pure.

Deposits of green or grey talc and soapstone are common in the ultrabasic rocks of Canada. They occur within or at the edge of serpentinized sills, dykes, or lava flows. The serpentine rocks may be altered to talc in areas that have suffered metamorphism by folding or by intrusion of acid rocks, or by both. Talc and soapstone are high in magnesia (MgO) and are to be expected to occur in the rocks high in magnesia such as the ultrabasic intrusives.

Talcose rocks are in many places converted into schist. The zones of talc or massive soapstone in the known deposits are usually from a few feet to 20 to 30 feet in width. Talcose rocks are widely distributed throughout Canada. A thorough review of the talc deposits of Canada has been made by M. E. Wilson.[1]

Prospecting for these deposits, except for the varieties associated with dolomites, should be confined to areas of the ultrabasic rocks that have suffered deformation, for it is in these areas that the processes of metamorphism have taken place that result in the formation of talc.

[1] Wilson, M. E.: " Talc Deposits of Canada"; Geol. Surv., Canada, Econ. Geol. Series 2 (1923).

GEMS AND RARE MINERALS OF ECONOMIC VALUE

(E. Poitevin)

Although Canada has supplied museums of the world with spectacular mineral specimens and possesses a wealth of ornamental material, it is not a gem-producing country. Valuable deposits of gems probably do occur, but have yet to be found. The Canadian Shield probably holds deposits of gem material. Sedimentary formations at their contacts with some intrusives, pegmatites rich in lithium and sodium, ultrabasic rocks and metamorphic rocks should be prospected very carefully.

The St. Lawrence region is mostly occupied by nearly horizontal sedimentary rocks and is not a promising field for prospecting for gems. The Appalachian and Acadian regions are worthy of being prospected for gem materials and these should be sought for where geological conditions are like those enumerated in the case of the Canadian Shield. The Arctic archipelago is not well known, but in part it appears to offer the same prospects as are afforded by the Canadian Shield. The Interior Plains region is largely occupied by sedimentary strata which in some horizons may contain gem debris from older formations, but otherwise the region does not appear to be promising. The Cordilleran region is one of the most promising to prospect for gemstones. It is quite possible that some stream deposits contain gems which may not have travelled far from their point of origin.

The world's annual production of gemstones is estimated at about $80,000,000. The following table is by Kraus and Holden.[1]

[1] "Gems and Gem Materials," by Kraus and Holden.

Annual Value of the World's Production of Gems Classified According to Their Geological Sources

—	$	$	$
Igneous rocks	....	....	50,785,000
Basic rocks	....	50,029,000	
Diamonds	50,000,000		
Other gems	29,000		
Pegmatites	....	662,000	
Emerald	520,000		
Beryl	46,000		
Tourmaline	35,000		
Other gems	61,000		
Other igneous rocks	....	94,000	
Secondary deposits	....	....	28,209,000
Stream gravels	....	28,199,300	
Diamond	26,112,500		
Sapphire	1,104,000		
Ruby	348,500		
Jadeite	144,000		
Rock crystal	88,000		
Tourmaline	54,000		
Beryl	54,000		
Agate	53,000		
Chrysoberyl	44,000		
Amethyst	40,000		
Other gems	157,300		
Beach and desert gravels, glacial deposits	....	9,700	
Fossil matter	....	....	825,000
Amber	800,000		
Other gems	25,000		
Deposits from water	....	....	595,000
Hot waters, principally ascending	....	289,000	
Opal	208,500		
Quartz	46,000	....	....
Other gems	34,500		
Cold waters, principally descending	....	306,000	
Turquoise	290,000		
Other gems	16,000		
Metamorphic rocks	....	....	282,000
Contact metamorphosed limestone	....	56,500	
Lapis lazuli	37,500		
Other gems	19,000		
Contact metamorphosed schists and gneisses	....	175,500	
Jadeite	150,000		
Other gems	25,500	....	....
Regionally metamorphosed schists and gneisses	....	50,000	
Nephrite	30,000		
Other gems	20,000		
Grand total	....	....	80,696,000

This useful table shows that basic rocks yield in value more than 60 per cent of the total gem production. This large production is almost wholly accounted for by the diamond-bearing South African peridotites. Mining for gems in igneous rocks is not confined to the basic rocks. Granite pegmatites, especially those rich in lithium and sodium, are considered to be the third most important gem source. Secondary deposits, that is those in gravels and their partly or wholly consolidated equivalents, are second place in the list of most important gem sources. Gem-bearing gravel deposits occur in many parts of the world and in most cases the gems have come from gem-bearing rocks of no commercial value, either because they are too poor in the precious crystals or are of such a nature that the valuable minerals can not be extracted without breaking or otherwise destroying them. Nature, by slow but efficient processes, liberates and concentrates the gems without impairing their value.

Minerals substances known as precious stones or gems are those that possess beauty of appearance, considerable hardness, and a power of resisting external influences. In addition to their natural characteristics, rarity and fashion are most important factors governing the commercial value of gem minerals. Some gems are worth more than $500 a carat, whereas others are available at less than 25 cents a carat. Thus, precious stones or jewels are divided according to their value—hardness and other physical properties—into two main groups known respectively as precious and semi-precious. These in turn are subdivided into minor groups. The following table illustrates the classification.

Precious stones	Semi-precious stones
1st Rank	*4th Rank*
Diamond, ruby, sapphire, chrysoberyl, spinel	Quartz, chalcedony, opal, feldspar
2nd Rank	*5th Rank*
Zircon, emerald, topaz, tourmaline, garnet, opal (precious)	Jet, nephrite, serpentine, pyroxene, aragonite, marble, malachite, gypsum, rhodocrosite, prehnite, etc.
3rd Rank	
Cordierite, idocrase (vesuvianite), chrysolite, axinite, cyanite, staurolite, andalusite, epidote, and turquoise	

The value attached to a precious stone depends largely on the size of the specimen and this is estimated from its weight. The unit of weight universally used is the carat. This is supposed to be the weight of a seed of an African leguminous tree. The exact weights in milligrams of the carat at different places are as follows:

	Milligrams
Paris	205·500
London	205·409
Berlin	205·440
Amsterdam	205·700

The fractions of the carat used in weighing precious stones are $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, and $\frac{1}{64}$. In France, 144 carats equal 1 ounce, in England 151·707 carats equal 1 ounce troy.

Beautiful as some gems are in their natural form, they may be improved by cutting and polishing, and it happens in many cases that only a small part of a gem crystal can be used for this purpose, the rest being flawed and of poor colour. Even if the whole crystal is of gem quality, its value is greatly enhanced if it is cut and polished into a symmetrical stone giving the maximum pleasing effect to the eye. The following figure and accompanying list give the names of the different styles of cutting.

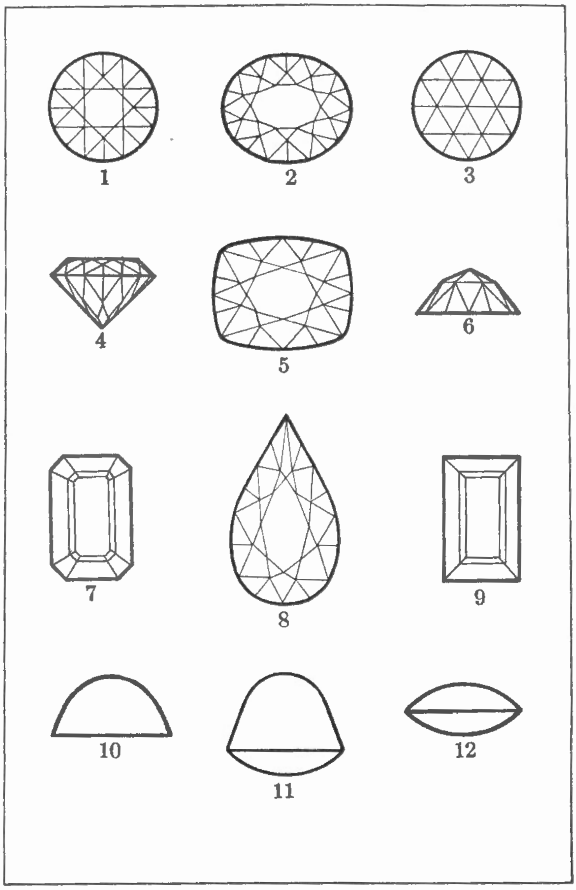

Figure 2.

1. Round brilliant (top view)
2. Oval brilliant (top view)
3. Rose cut (top view)
4. Round brilliant (side view)
5. Cushion brilliant (top view)
6. Rose cut (side view)
7. Step cut (octagon)
8. Pear brilliant (top view)
9. Step cut (oblong)
10. Cabochon (side view)
11. High cabochon (side view)
12. Lentil shape (side view).

The cabochon cut is desirable for minerals that have a sheen, a play of colours, opalescence, or asterism as shown respectively by tiger's eye, opal, moonstone, sapphire, and ruby. Stones such as garnet, turquoise, tourmaline, etc., whose charms depend entirely on colour, are also cut in this way.

The brilliant style is commonly used for such stones as diamond, ruby, sapphire, etc.

The step and cushion cuts are commonly adapted to coloured stones in which fire and brilliancy are unimportant, as emerald and tourmaline.

The term, cameo, is used to designate stones composed of differently coloured layers, generally two, in one of which a raised figure has been cut, while the layer of the second colour forms a background. Agate, onyx, etc., are generally cut cameo style.

The following is a short glossary of gem names:

Agate. Price 50 cents to $4 each. Hardness, 6·5. Agates are varieties of chalcedony. The name agate is usually applied to chalcedony, with parallel bands, or spots, or patches, of different colours. Occurs generally in the vesicles of volcanic rocks, rarely as vein fillings. Found in Canada.

Alexandrite. Hardness, 8·5. A variety of chrysoberyl. Green by daylight, red by artificial light. Occurs in mica schist close to granite contact, also in gravels. Ural mountains, Russia.

Amazonite. Price 50 cents to $4 each. Hardness, 6. A verdigris-green, opaque feldspar. Occurs in coarse-grained granite rock. Found in Canada.

Amethyst. Price 25 cents to $2.50 a carat. Hardness, 7. A purple variety of transparent quartz. Shading from pale violet to dark plum colour. Occurs, like rock crystal, on the walls of crevices and joints in rocks. Found in Canada.

Aquamarine. Price $4 to $20 a carat. Hardness, 7·5. A pale blue to sea-green emerald. Occurs like emerald.

Aventurine. Price 50 cents to $5 a carat. Hardness, 6·5. A sub-transparent to sub-translucent, pale green quartz with iridescent spangles to mica displayed throughout. Occurs in mica schist.

Azurite. Price 20 cents to 50 cents a carat. Hardness, 4 to 5. Azure blue copper carbonate.

Beryl. Price 50 cents to $10 a carat. Hardness, 7·5. Various colours. The green variety is known as emerald; the sea-green as aquamarine; the name beryl is usually applied to golden yellow and colours other than green. Occurs in pebbles in sand; in coarse-grained granite and in siliceous veins cutting granite.

Bloodstone (Heliotrope). Price 50 cents to $8 each. Hardness, 6·5. An opaque, rich dark green chalcedony with spots of red like blood. Found in Nova Scotia.

Cairngorm. Price 25 cents to $2 a carat. Hardness, 7. A smoky, yellowish brown variety of crystal quartz. Its rich dark colour makes it much desired for jewellery. It is generally found in coarse-grained granite. Found in Canada.

Carnelian. Price 50 cents to $8 each. Hardness, 6·5. Derives its name from its colour, that of raw flesh. It is a translucent variety of chalcedony. Its uniform colour makes it valuable for intaglios, etc. Found in Nova Scotia.

Cat's Eye. Price $25 a carat and up. Hardness, 8·5. A variety of chrysoberyl. Cut cabochon possesses a peculiar effect, similar to that in the iris of a cat's eye. Once very popular, but later replaced by Tiger's Eye, a brown variety of quartz. Found in Ceylon and in Ural mountains, Russia.

Cat's Eye (A variety of quartz). Price 50 cents to $2 each. Hardness, 6·5 to 7. Somewhat resembles the true Cat's Eye, but much less beautiful. Found in India, Ceylon, and Hungary.

Chrysoberyl (Proper). Price $5 a carat and up. Hardness, 8·5. A beautiful transparent gemstone, in different shades of brown, yellow, sage-green, etc. Cut faceted, it is very effective in gold jewellery. Cat's Eye and Alexandrite are two most valuable varieties. Found in Brazil.

Chrysocolla. Price $1 to $10 each. Hardness, 4 to 5. This stone is opaque, combining the beautiful colours of azurite-malachite and turquoise. Cut and polished cabochon, it makes a beautiful stone for jewellery. The finest examples are from the copper mines in the Urals and the Allouez mine in the copper region of lake Superior. Very ordinary specimens have been found in British Columbia, Ontario, and Yukon.

Chrysoprase. Price $1 to $5 a carat. Hardness, 7. Chrysoprase is a beautiful apple-green chalcedony. The colour is due to about 1 per cent nickel oxide. Fine specimens resemble translucent cabochon emeralds. Found in Canada.

Diamond. Price $200 to $700 for one carat stone. Hardness, 10. The most important diamond-producing country is South Africa, 95 per cent of the world's diamonds being mined there. The first diamonds from that field were discovered in the sands of Orange, Vaal, and Modder rivers and led to the discovery of the primary deposits of Kimberley district on a plateau between the two last-named rivers. At present there are four large mines in Kimberley area. Other important mines in South Africa are the Jagersfontein in Orange Free State and the Premier near Pretoria in the Transvaal. At these mines the diamonds occur in large, vertical, pipe-like bodies of an igneous rock known as kimberlite and which is a variety of peridotite. More than eighty different minerals occur in the rock. It is sometimes known as "blue ground" and in some cases is very much altered at the surface, so that it is an easy matter to extract the diamonds. The altered rock is worked by open pits. However, below 100 feet from the surface the blue ground is a hard rock and has to be mined. Most companies allow the extracted rock to lie in the open until after a number of years the "blue ground" becomes soft and friable and the diamonds are easily extracted. At the Premier mine, the largest known diamond mine, the "blue ground" is crushed and washed directly after being mined. Although this method involves the risk of destroying valuable diamonds. it has the advantage of not tieing-up a huge capital for a number of years while the mined rock is allowed to weather.

The other deposits in which diamonds are found are secondary deposits. They occur on the west coast of Africa, in the Belgian Congo, Brazil, in Ural mountains, British Guiana, Colombia, and Mexico.

Rough diamonds, owing to their high index of refraction and adamantine lustre, do not attract attention. The specific gravity is rather high—3·3–3·7—and the rough diamonds have a peculiar, greasy lustre. Cutting reveals the beauty of the stone. Although diamond is generally colourless, it has been found with green, blue, orange, rose, and black colours. The black-coloured stone is called bort, which when powdered is employed in polishing the colourless diamonds and other gemstones. Carbonado is the name of a black, opaque, very compact diamond, with no cleavage and used largely in diamond drills; chief source is Bahia, Brazil.

Emerald. Price $10 to $500 and up a carat. Hardness, 7·5–8. The present demand for green stones, and the increasing scarcity of emeralds, make this stone the most precious of all gems. The most valuable specimens of this transparent gem have the well-known velvety, emerald-green colour, but the lighter shades are found. Flawless emeralds of large size are extremely rare and, therefore, only small stones are available for cutting as gems. Compared with other precious stones, the emerald, as regards its mode of occurrence, is unique, for it is found almost exclusively in its primary situation, that is to say, in a rock in which it was formed. It occurs in crystalline schists. The famous occurrence at Muzo in Colombia is the only exception to this rule. the emerald being here embedded in calcite veins in limestone. This valuable gem has been found in Egypt, in the Urals. in the Alps. and in Colombia. It has also been found to a lesser extent in Australia and the United States.

Garnet. Price 50 cents to $25 each. Hardness, 6·5 to 7·5. The most common colour is red; red stones when cut cabochon are known as carbuncle. Many other colours are found including violet, brown, delicate pink, and green. Garnet is widely distributed throughout Canada. It is a common constituent of the wash of many streams, of schists, pegmatite dykes, and metamorphic rocks. The principal varieties are: almandite, deep-red; pyrope, deep blood-red with a tinge of yellow; demantoid, beautiful green, ranging from a fine emerald-green to a brownish or yellowish green and in some cases almost colourless; essonite or cinnamon-stone and spessartite, rich yellowish red colour.

Jade (Nephrite). Price 50 cents to $1 each and up. Hardness, 6·5 to 7. This sage-green and green-and-white stone is particularly valued by the Chinese, who fashion rings, bracelets, and many other ornaments from it. The best jade comes from Upper Burma, but the darker green variety is also found in New Zealand. Jade is very popular for jewellery of all kinds, especially seal rings.

Jade, not of gem quality, occurs in water-worn boulders in the valley of Fraser river near Lytton, British Columbia, and also on Lewes river, Yukon.

Jasper. Price 50 cents to $5 each and up. Hardness, 7. An opaque, massive variety of chalcedony, usually red, in some cases yellow, brown, or green.

Kunzite. Price $8 to $25 a carat. Hardness, 7. A variety of spodumene found in lithium pegmatites in Madagascar and California.

Labradorite. Price 50 cents to $5 each. Hardness, 6. A variety of feldspar, first found in Labrador. It exhibits bright splashes of colour, particularly blue, when turned to the light, otherwise has a dull grey or brownish appearance. Found in Canada.

Lapis Lazuli. Price 50 cents to $15 each. Hardness, 6. Occurs in white, granular limestone along the contact with granite at lake Baikal, Siberia. In the Chilean Andes the material occurs in blocks of various sizes in a thick bed of white and grey limestone, which rests on slates and is overlain by a bedded rock rich in iron ore and garnet.

Also occcurs in Afghanistan and San Barnardino, California.

Malachite. Price 40 cents to $4 each. Hardness, 4-5. An alteration product of other copper minerals. Fine specimens are obtained from Ural mountains, Russia, and Australia. Occurs at many other places but is of poor quality for decorative purposes. Found in Canada.

Moonstone. Price 50 cents to $10 each. Hardness, 6. Colourless or almost perfectly transparent feldspar, which, held at a certain angle, reflects a bluish, milky light. Occurs in Switzerland, Madagascar, Brazil, Virginia, and elsewhere.

Moss Agate. Price 50 cents to $5 each. Hardness, 6·5. Instead of the parallel bands of colour exhibited by common agate, moss agate contains particles of iron oxide which gives it the appearance of containing a vegetable growth.

Olivine. Price $5 to $100 a carat. Hardness, 6·5-7. A trade name given to a garnet of a beautiful olive-green colour and mostly derived from Russia. The real olivine is known as peridot.

Opal. Price $1 to $50 a carat and up. Hardness, 6. The cause of the opalescence displayed by this well-known stone is unknown. The best opal comes from Australia, Hungary, and Mexico. Common opal, of no commercial value, is found in Canada.

Peridot. Price $2 to $10 a carat. Hardness, 6 to 7. A clear yellow-green gem which is a variety of crysolite. It is very effective and may be had in a number of sizes and shapes. It has been found at Timothy mountain, British Columbia, in volcanic bombs.

Quartz. Price 50 cents to $5 each. Hardness, 7. To this family belong rock crystal, rutile quartz, amethyst, rose quartz, yellow quartz (called Spanish topaz), smoky quartz called cairngorm, milky quartz, aventurine, etc. It is a common mineral, usually transparent and hard enough to be cut as a gemstone. Some of the above sub-varieties are very beautiful and widely worn.

Rhodonite. Price \$1 to \$5 each. Hardness, 6·5 to 7. A silicate of manganese, pink or flesh-red; in some cases containing back markings caused by iron oxide. Opaque to translucent. Occurs in large pieces suitable for cutting jewel boxes, paper weights, etc. When cut cabochon it makes a beautiful stone for cuff links, scarf pins, and artistic jewellery.

Rubellite. Price \$5 to \$30 a carat. Hardness, 7. *See* red tourmaline.

Ruby and Sapphire. These are varieties of corundum. *Ruby.* Price \$10 to \$500 a carat. It is also sold as high as \$1,500 a carat. Hardness, 9. *Sapphire*, \$5 to \$150 a carat and up. Hardness, 9.

Ruby is a red corundum, varying in colour from rose to a purplish red colour. The most valuable colour is the well known pigeon's blood red.

Sapphire is the name applied to blue corundum. The most prized colours for the sapphire are corn flower and royal blue. Pale pink corundum and deep green corundum are also known as sapphire. Translucent varieties of sapphire or ruby, which when examined in a certain light show a six-pointed star, are cut cabochon and are known as star sapphires and star rubies. Yellow corundum is known as yellow sapphire or oriental topaz; and purple corundum is known as oriental amethyst.

Ruby and sapphire occur in placers and in situ in metamorphic rocks such as crystalline limestone, gneiss, schist, granite, nepheline, syenite, and peridotite. The minerals commonly associated are spinel, tourmaline, cyanite, magnetite, chlorite, and nephelite.

The best rubies are mined in Upper Burma, where the stones occur in granular limestone in sand, gravel, and soil with spinel ruby, sapphire, and tourmaline. Rubies also occur near Bangkok, Siam, associated with red spinel and sapphire. In Ceylon, few rubies are mined in comparison with sapphires. The sapphires occur here with garnet in gneiss, whereas the rubies are found in limestones; the two varieties of corundum are in many cases found side by side in the gravels. Other sources are Afghanistan, China, Ural mountains, and Queensland. In the United States fine rubies have been found in the crystalline rocks of North Carolina; near Helena, Montana, sapphires are found in river sands. Corundum is a very common mineral in Canada, but no rubies have been found. Corundum is of no commercial value as a gemstone, it is mostly used as an abrasive.

Serpentine. Price \$1 to \$5 each. Hardness, 4. High-grade serpentine, known as noble serpentine, is an opaque stone varying from rich olive to pistachio green and is of waxy lustre. Small quantities of high-grade serpentine have been found in Canada, but there does not seem to be any special market for it.

Sodalite. Price 50 cents to \$5 each. Hardness, 6. A blue, opaque stone with vitreous lustre, otherwise resembles Lapis Lazuli. It is cut cabochon. This mineral is generally found in connexion with nepheline syenite rocks. Excellent material has been found in Ice River district, B.C., and in central Ontario.

Spinel. Price \$10 a carat and up. Hardness, 8. This beautiful transparent gem is not properly appreciated. It is found in many colours, but the well-known flame-red variety is the best known. Spinel is closely allied to corundum and in some cases is mistaken for ruby. Blue spinels are also found and are often mistaken for sapphire, but spinel is softer and lighter in weight.

The following gem varieties are distinguished: ruby spinel, deep red and transparent; balas ruby, rose-red to pink; rubicelle, yellow to orange-red; almandine, violet to purple; sapphirine, blue spinel; chlorospinel, iron-bearing of a grass-green colour.

Spinel occurs in metamorphosed rocks, such as limestone, serpentine, and gneiss, and in gravels. The principal occurrences are in Ceylon, Burma, and Siam. They also occur in India, Tartary, Afghanistan, and Brazil. Blue spinels are found in Sweden and France. Good specimens have been found in limestones and serpentines of northern New Jersey and southeastern New York.

Spodumene. Price \$6 to \$20 a carat. Hardness, 7 to 7·5. A clear, transparent, canary-coloured stone; resembles oriental topaz. Its disposition to cleave or split makes it difficult to cut. Two of its varieties are rather valuable as gems. These are hiddenite, of a yellow-green to emerald-green colour, and kunzite, of a delicate pink to lilac colour. Spodumene is found in lithium-sodium pegmatites in California, Madagascar, North Carolina, and Brazil. Spodumene has been found in Canada in connexion with lithium-bearing pegmatites, although no gem material has yet been discovered.

Sunstone. Price $1 each and up. Hardness, 6 to 7. Belongs to the feldspar group. It comes in different shades of brown and contains minute scales of mica which scintillate in the sun, giving the stone a unique appearance.

Thompsonite. Price $1 to $25 each. Hardness, 5. This opaque, vari-coloured stone resembles an assortment of different coloured stones closely packed together. The different sections vary in colour from pistachio to sage-green, shrimp-pink, greenish yellow, and Chinese white. Thompsonite is cut cabochon. This material occurs in the basic igneous rocks of Lake Superior district. Its popularity is largely confined to the country about lake Superior.

Topaz. Price $2 to $20 a carat. Hardness, 8. There are several kinds of topaz. The true or precious topaz is a bright, transparent stone of different tints of yellow and light pink. Topaz is found in gneisses, schists, granites, and pegmatites. It is commonly associated with tourmaline, quartz, fluorite, apatite, beryl, and ores of tin and tungsten. The mineral is also found in placer deposits. The most important localities for topaz are Ural mountains, Ilmen mountains, Scotland, Ireland, Saxony, Cornwall, Ceylon, Japan, Mexico, and United States.

Tourmaline. Price $1 to $10 each and up. Hardness, 7 to 7·5. This transparent stone may be of almost any colour, red and green predominating. Different colours may be displayed by the same crystal. Dark-red tourmaline is called rubellite and is cut faceted and cabochon. Tourmaline occurs in metamorphic rocks, such as gneiss, schist, and crystalline limestone, and in granites and also in alluvial deposits. It is in pegmatites that the gem varieties are principally found. The principal localities are India, Burma, Madagascar, Ceylon, Siberia, Brazil, and United States. The pegmatites of Canada have furnished a few tourmalines of gem quality.

Turquoise. Price 50 cents to $12 a carat. Hardness, 6. Colour, light shades of blue. This gem is probably the most popular of the opaque stones. Sky blue is the shade preferred. Cut in cabochon, scarab, and cameo, the stones are particularly effective. Some have a greenish colour due to impurities. Turquoise is formed by deposition from solutions, and its most common associates are limonite, quartz, feldspar, and kaolin. It is found in Persia, Egypt, Australia, Turkestan, and United States.

Idocrase or Vesuvianite. Price 50 cents to $4 each. Hardness, 6·5. A translucent brown, green, or yellow mineral. A variety found in California is known as californite. Cut cabochon. Vesuvianite occurs in metamorphic rocks. The principal localities are in Italy, Siberia, Hungary, Norway, and California. In Canada, very fine specimens of vesuvianite are found, but they are not of value as gems.

Williamsite. Price 50 cents to $4. Hardness, 5·5. A green stone resembling New Zealand jade. It is translucent and some examples are mottled with specks of other minerals. It takes a high polish, and is applicable for distinctive settings. It is a variety of serpentine.

Zircon. Price $2 to $20 a carat. Hardness, 7·5. In certain properties this gem is unique. It is the most brilliant of all minerals, and has the adamantine lustre of diamond. It is the heaviest of gems and is found in a variety of colours, brown predominating. White varieties, called jargoons, are in some cases mistaken for diamonds. Hyacinth and jacinth are the terms applied to the clear, transparent, yellow, orange, red, and brown varieties. Gem zircons are largely found in secondary deposits. They are found in Ceylon, Australia, France, Russia, and United States. Canada has furnished most beautiful zircon specimens, especially from Renfrew county, Ontario, where they are found in metamorphic rocks.

Cordierite, Axinite, Cyanite, Staurolite, Andalusite, Epidote, Jet, Serpentine, Aragonite, Marble, Gypsum, Rhodocrosite, Prehnite, etc., are common minerals for which there is not much demand, but which are in some cases sufficiently transparent and attractively coloured to be cut and polished and put on the market as semi-precious stones.

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DEPOSITS LARGELY SEDIMENTARY IN ORIGIN

PLACERS

(W. A. Johnston)

Nearly four-fifths of the gold production of Canada from 1858 to 1892 was from placers. For a few years following 1892 the production of lode gold was greater than that from placers, but in 1900 the value of the placer gold, mainly from the Klondike, was $22,275,000 and was 84 per cent of the whole. Since 1900 placer gold production has gradually declined and in 1925 was less than 5 per cent of the total gold production of $35,880,826. A great deal of prospecting for placers has been done in Canada and no new fields have been discovered in recent years. Fresh discoveries in the old placer mining regions have been made from time to time, however, and it is probable that other discoveries will be made and that the introduction of modern mining methods, as dredging, will result in at least a small production of placer gold for many years to come.

Placers are deposits of sand, gravel, or other alluvium containing particles of gold, platinum, or other valuable minerals in payable quantities. Native gold is the most important placer mineral in Canada. Platinum has been found along with gold in the placers of Tulameen district and at a few other places in British Columbia and Yukon, but not now, as a rule, in paying quantities, especially as most of the platinum was recovered in the early days of mining when it had little value.

Three conditions are necessary as a rule to form placers: (1) occurrence of valuable mineral in the bedrock; (2) release of the mineral from the bedrock by weathering; and (3) its concentration by stream or wave action. Residual placers may be formed by the weathering in place of mineral deposits, but are of rare occurrence. Most rich placers are concentrations from 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. As placers containing gold are the only deposits of this type of great importance in Canada the following account applies to them.

The occurrence of placers in any region may or may not indicate that workable lode deposits occur in the region. The gold may have existed in the oxidized upper parts of sulphide deposits or in veins that were entirely removed by erosion, or the remnants may be too small to mine. No important lode gold deposits have been found, for example in the Klondike. The placer gold was derived from gold-bearing quartz veins, the remnants of which are unworkable. The great quantities of residual quartz gravels derived from erosion of the veins shows that many cubic miles of bedrock was eroded from the region. The average gold value of the material eroded, as estimated by the amount of placer gold recovered, was less than 5 cents a ton. Some of the gold in residual placers may have been formed by deposition from solution, but nuggets in stream gravels were not formed in this way. Most nuggets are well worn; the gold crystals and unworn fragments that are found in some placers were protected from erosion by burial or were released from enclosing bedrock by weathering of the gravels.

The distribution of gold in placers is irregular. Coarse gold, usually accompanied by some fine or moderately coarse gold, may be scattered through the lower 10 or 15 feet of gravels, especially if they contain much clay or other fine material, but usually it is concentrated on or near the bedrock; for coarse or even moderately fine gold deposited along with gravels in a stream channel tends to work down through the gravels until it reaches an impermeable stratum. Gold is never distributed uniformly through a great thickness of gravel. Paystreaks may occur at any elevation in a gravel deposit on a false bedrock of clay or other impervious bed. They may or may not occupy the deepest part of a stream channel. Pay gravel may occupy the whole width of the stream bottom in narrow, V-shaped valleys; in broad, flat-bottomed valleys the paystreak is likely to be much narrower than is the valley flat and its course may be quite different from that of the present stream. Most paystreaks in broad valleys were originally formed in narrow valleys of fairly high gradients. As the gradient became less and the valley widened by the meandering stream the paystreak became buried beneath alluvium. A stream of low gradient tends to meander and the bends tend to move downstream, so that the materials in the valley bottom are reworked many times by the stream. A paystreak may be shifted in the process of reworking by the stream, or, if it be coarse or become somewhat cemented or hardened after the shifting of the stream, it may remain in its original position. Paystreaks are not continuous and may split or terminate abruptly because gold is concentrated chiefly at places, as on the inside of bends, where alternate deposition and erosion take place and where the bedrock forms good "riffles". Uplift or some other agency may cause the stream to deepen its valley and the old paystreak, depending on its location, may descend into it or remain in its original position to form a bench or old channel placer. Barren ground may occur, therefore, in the bottom of the present stream valley in the stretches that are bordered by one or more rock benches, and exceptionally rich ground may occur in the places where the stream has cut down beneath the old channel. Pot-holes and other irregular depressions in the bedrock in the bed of a stream rarely contain any gold. They are formed by erosion and any gold carried into them by the stream is likely to be ground fine by the action of current-transported sand and gravel and to be floated out. Gold does not occur in payable quantities in the subaqueous parts of deltas. Some gold may occur in alluvial fans that frequently form the upper parts of deltas, but only fine gold can occur in fans and there is little opportunity for its concentration into paystreaks because of frequent shiftings of the stream channels.

Flood (bar or very fine) gold is sufficiently fine or flaky to be transported in muddy water. It ranges in size from a few to several thousand "colours" to the cent. In regions where fine gold is supplied to the streams by erosion of their banks or beds, paystreaks may occur in the bars and banks of the streams. The paystreaks as a rule are only a few inches to 1 or 2 feet thick and lie at or near the surface between extreme low water and high water marks, in places, as on the upstream side of bars, where conditions are favourable for alternate deposition and erosion of material transported by the stream. They may occur in bench deposits at various elevations above the streams. As erosion and deposition go on from year to year the bars shift downstream; old paystreaks are destroyed and new ones are formed, but at a very slow rate. The rich flood gold deposits mined in the early days on the Fraser and on other streams in Canada represented the concentration of gold by these streams in post-Glacial time. The placer deposits of Saskatchewan and Athabaska, in Alberta, as well as most of those along Fraser, Stikine, and Columbia rivers in British Columbia are of this type. Many of the richer bars on these streams have been worked over several times. The first harvest, of course, was the richest and the work in recent years has rarely paid. Very little gold occurs below extreme low water in stream valleys containing flood gold deposits with no coarse or moderately coarse gold, and the flood gold paystreaks are thin and discontinuous. Many attempts at placer mining on a large scale by dredging and by other methods on such streams, for example the Fraser, failed owing to failure to recognize the character of the paystreak or to inadequate testing of the ground.

Gravel plain placers are formed in broad valleys or alluvial plains containing gravels that have been repeatedly worked over by meandering streams or by streams of fairly high gradients that tend to shift their channels. The gold is derived by erosion of the banks and headwaters of the streams and is likely to be moderately fine and fairly evenly distributed through the gravels. Such placers are best developed in unglaciated areas, but occur on a small scale in glaciated regions, for example at a few places in Cariboo district, British Columbia. They can be profitably mined as a rule only by dredging.

Glacial gravels may contain gold, but have little economic value unless they have been concentrated by stream action or have been derived in part by erosion of pre-existing placers. Glaciers dissipate the gold which they pick up instead of concentrating it. Moraines, kames, eskers, and glacial outwash plains do not contain gold in paying quantities. Scattered pieces of gold and isolated masses of gold-bearing gravels may occur in boulder clay. Stratified glacial silt and clay contain no gold. Interglacial paystreaks formed by stream erosion during times of retreat of the ice may occur in glaciated regions. Much of the gold found in glacial gravels is moderately coarse and is fairly uniform in size, as if sorted by powerful streams. The re-sorted glacial gravel placers of the old placer mining regions of British Columbia and of Beauceville district, Quebec, have been mined chiefly by hydraulicking and rarely can be profitably mined in any other way.

Buried placers are paystreaks that are covered with younger deposits of glacial drift, lavas, and tuffs, or barren alluvium. Gold-bearing gravels, buried beneath great or small thicknesses of glacial drift, may occur in the bottoms of valleys or on rock benches and in old stream channels bordering valleys that were not severely glaciated. Such valleys are V-shaped.

Rounded, U-shaped valleys are not likely to contain buried paystreaks, because of the effects of glacial erosion. Glacial gravels in the bottoms of such valleys may contain some gold, but usually the pay is so scattered that mining of it cannot be done profitably. Most of the rich paystreaks mined in the early days in Cariboo and in other districts in British Columbia were buried beneath glacial drift and were mined chiefly by drifting. Lava-buried placers have not been found in Canada, but gravels containing some gold occur beneath lavas in Stikine River valley above Telegraph Creek. They may occur at other places in British Columbia. Overloading of streams may cause deposition of barren alluvium above the pay gravels in the valley bottom and in Arctic and sub-Arctic regions, as in the Klondike, where the ground is permanently frozen, thick deposits of muck may overlie the gravels. Muck consists of slightly decomposed organic matter mixed or interbedded with fine sand, silt, and clay. It is formed partly by growth of vegetation in place and by soil creep and partly by deposition from overflowing streams. It contains in places much ground ice. As it is a good insulator it prevents thawing of the ground during the summer. Ground from which the muck has been removed by hydraulicking or by some other method becomes naturally thawed in three or four years to depths of 10 to 30 feet.

Beach placers are formed by wave erosion and concentration of the materials in sea cliffs. Rich beach placers occur as a rule only in places where stream or residual placers are eroded by the waves. No rich beach placers are known along the coast of Canada and are not likely to occur, except possibly very locally, as much of the material eroded by wave action is glacial drift.

Placers in the glaciated parts of Canada differ from those in the unglaciated parts of Yukon in several ways that affect their mining possibilities. The presence of large boulders in some placers in the glaciated areas may render impossible the use of a dredge, steam shovel, or drag-line scraper. The bedrock in glaciated areas is likely to be hard and unweathered and this may cause difficulties in the recovery of all the gold in dredging. Large boulders are absent and there is no overburden of glacial drift in the placers of the unglaciated parts of Yukon. There are thick deposits of muck, however, and thawing of the ground is necessary in mining operations.

The most favourable areas in Canada for prospecting for placers probably are the unexplored parts of Yukon and northern British Columbia (*See* Figure 3). Unglaciated areas in which igneous or metamorphic rocks occur, that are mineral-bearing, at least to some extent, are the most favourable. In glaciated areas narrow, V-shaped valleys, preferably those that are bordered by rock benches, should be sought for, and rounded, severely glaciated valley avoided. Valleys that were only slightly glaciated usually lie transverse to the general direction of glacial ice movement and do not head in glacial cirques. In estimating the value of placer ground for mining it is important to determine the type of deposit to which the deposit belongs, for certain kinds of deposits, as outlined above, require much more thorough testing to determine their value than others. Each type of deposit can be profitably mined as a rule only by one or two methods. It may be that certain kinds, for example, bar deposits, can be profitably mined only by hand methods. Preliminary testing of the ground may be done by panning,

Figure 3. Limits of glaciation in Yukon.

estimating 150 pans to the cubic yard, or by sinking test pits and shafts and washing channel samples from the faces of the pits or preferably all the material excavated. The swell of material excavated varies greatly, but on the average is nearly 50 per cent. The most efficient means of testing placer ground is by drilling. As the Keystone drill cuts a somewhat larger hole than the outside diameter of the casing it is necessary to allow for this in estimating the volume of materials removed in drilling. The common practice is to consider 100 linear feet of 6-inch hole (the size of casing ordinarily used being 6 inches) as having a volume of 1 cubic yard. Therefore,

$$\text{value of gravel per cub. yd.} = \frac{\text{value of gold obtained} \times 100.}{\text{depth of hole in feet}}$$

When drilling has been carefully done, 75 to 80 per cent of the estimated yield can be recovered by dredging. This includes all losses, not only those in the tailings, but unrecoverable " islands " and corners left behind in the course of operation. The recovery of the gold in hydraulicking may be greater or less than 75 per cent, depending on whether the bedrock can be reached and how thoroughly it can be cleaned.

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COAL

(B. R. MacKay)

ORIGIN OF COAL DEPOSITS

Coal is formed from ancient swamp vegetation, which, like that of present day peat bogs, either grew on the spot now occupied by the coal deposit, or has been floated from a greater or lesser distance and deposited in water close to land. For this reason coal deposits are always associated with sediments of freshwater or brackish water origin, and most of them occur as beds or "seams," which are generally traceable for great distances. With few exceptions each coal seam may be considered as an ancient peat deposit, which through bacterial and other chemical agencies and the heat and pressure developed through burial beneath later sediments and crustal movements of the earth, has been converted into a compact mineral fuel. Thus the extent of a coal field corresponds to the area covered by the peat bog or bogs, which gave rise to the coal seams. A few coals, such as splint coals, cannel coals, and boghead coals, which are composed largely of wind and water-borne plant cuticles, spores and pollen coatings, waxy, fatty algæ have been formed principally of aquatic organisms, both plant and animal, but the majority of ordinary coals designated the humic or xyloid coals, are believed to have been formed mainly from terrestrial vegetation consisting largely of forest growth. In this respect a coal-forming bog differs somewhat from the common present-day peat bogs, the vegetation of which consists principally of grasses, mosses, and turf. The most typical existing example of a coal-forming bog is the Great Dismal swamp which lies on the coastal plain of North Carolina and Virginia and which before reclamation covered about 2,200 square miles. One of the most important fuel-peat bogs in Canada occurs at Alfred, 45 miles east of Ottawa.

CLASSIFICATION OF COALS

Coals range in physical appearance from soft, friable material in which the leaf, plant, and tree fragments are distinctly discernible, and in many cases separable, to the hardest of mineral fuel in which little, if any, of the original vegetable structure can be recognized. Only within recent years through the perfecting of the process of making thin sections of hard coal has their vegetable constitution been finally satisfactorily proved.

Regarded chemically, coals consist of an organic complex derived from the destructive distillation of the two principal plant constituents, lignin and cellulose, and composed of the elements carbon, hydrogen, and oxygen in various combinations combined with minor amounts of nitrogen and sulphur. For practical purposes of classification the proximate analysis of the coal, along with its physical character, is deemed sufficient to differentiate coals into different ranks.[1] All coals may be considered as composed of four principal components—moisture, volatile matter, fixed carbon, and ash, the latter consisting largely of transported mineral matter. The proportions of these four ingredients vary in different coals, but, with the exception of the ash content, which is largely accidental, are relatively the same in coals that have a common origin and that have been subjected to about the same degree of metamorphism. In Figure 4 is shown the progressive increase in carbon and the corresponding decrease in moisture and volatile matter in the evolution of coal

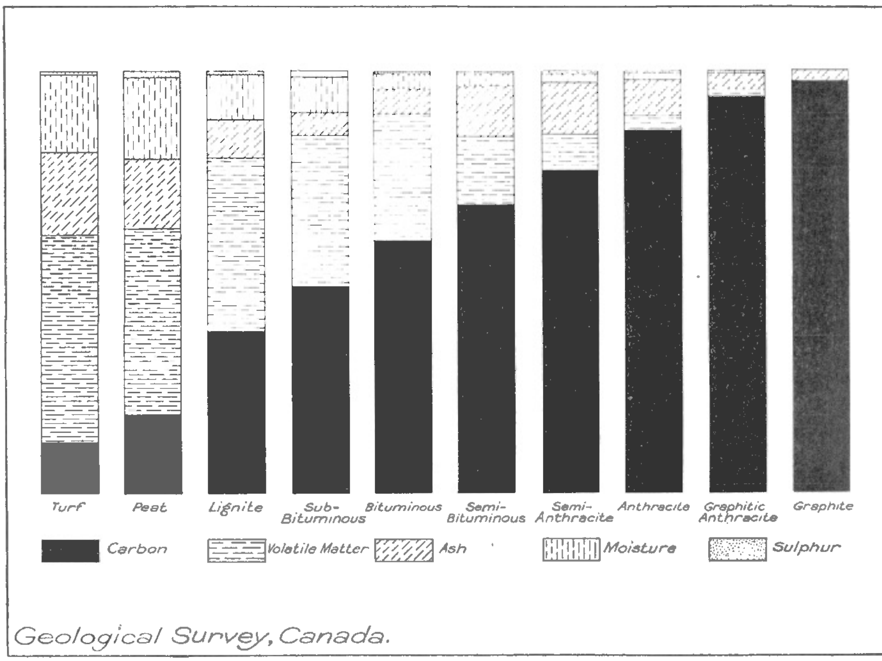


Figure 4. Successive chemical changes in the evolution of coal.

from turf to the hardest anthracite. Accompanying the change in physical and chemical character, there is a corresponding change in the heat value of the coal as determined in calories or British Thermal Units, the maximum heat being attained in the coals in which the fixed carbon and the volatile matter components are most effectively balanced, rather than in those coals in which the percentage of fixed carbon is highest.

On physical character, chemical composition, and heat value coals of various modes of occurrence may be grouped into seven separate classes

[1] Rank is the term proposed by M. R. Campbell of the U.S. Geol. Surv., and adopted by the American and Canadian classification committee, to designate the differences in coal due to progressive change in carbonization or metamorphism from lignite to anthracite. Type is the term adopted by this committee to designate the original material from which the coal was formed and the manner of deposition.

or ranks. These are: lignite, sub-bituminous, bituminous, semi-bituminous, semi-anthracite, anthracite, and super-anthracite. These seven classes of coal fall into four main groups, namely, the lignite, sub-bituminous, bituminous, and anthracite groups. No hard and fast division line can be drawn between coals of adjacent ranks, there being naturally a progressive change from one rank of coal to the other; in fact, at present, coals of similar physical and chemical composition are placed by different official organizations under different ranks. The definitions of the different ranks of coal given below are those in use by the Geological Survey, Canada. The various ranks of coal with the more important properties and physical characteristics are indicated in the following table:

Classification of Coals

Rank of coal	Physical and chemical characteristics
Lignite	These coals are brownish black to black in colour and in many the plant and woody structure is clearly discernible, which gives to the coal a lustrous appearance. They are very brittle, and on exposure to the atmosphere readily lose their moisture, which causes them to slack or break up into irregular-shaped fragments. Their moisture content in some cases reaches up to over 45 per cent. The coals do not soil the fingers on handling.
Sub-bituminous	These coals show a more advanced stage of metamorphism and carbonization than do the ordinary lignite coals, and rarely contain more than 25 per cent moisture. In Canada this rank is at present restricted to those low rank coals that have less than 10 per cent moisture, but in the United States coals having as high as 35 percent moisture are classified as sub-bituminous. These coals are black in colour, do not slack as readily as does lignite, but more rapidly than bituminous coals.
Bituminous	Coals of this rank generally show more distinctly than do the other coals the banded appearance of dull and bright layers. When crushed they break up into little cube-like or rectangular blocks by splitting along the bedding and joint planes. They are very sooty and soil the fingers on handling, but are only slightly affected on exposure to the atmosphere. They burn with a smoky flame. In the United States, bituminous coal has been defined as all coals above the rank of sub-bituminous, whose fuel ratio (fixed carbon divided by volatile matter) does not exceed 2·5; in Canada a fuel ratio of 3 is taken as the limiting line. The ordinary cannel coal of commerce falls into the bituminous rank. It is a dense, hard, dry variety of coal, which breaks with a conchoidal fracture. Most cannel coals when viewed under the microscope show abundant spore remains and the fatty plant parts, and hence are considered to have been formed under sub-aquatic conditions. In some, fish remains have been found. Being high in volatile matter, they burn readily with a candle-like flame (hence the name cannel coal), and give off black, oily fumes.
Semi-bituminous (Super-bituminous)	These are the "low volatile" coals or so-called smokeless coals, the fuel ratio of which ranges from just above that of the bituminous coals up to 5. Through metamorphism most of their volatile matter has been driven off and consequently the coals are not well adapted to coking or to treatment for the recovery of their volatile by-product. They possess the highest heating value of all coals. They are generally so highly jointed that they are extremely friable, and break down largely to fine coal in mining.
Semi-anthracite	These coals are intermediate in rank between semi-bituminous and anthracite, being harder than bituminous and not so hard as anthracite. The fuel ratio ranges from just over 5 up to 10. They have a higher heating value than anthracite.

Classification of Coals—Continued

Rank of coal	Physical and general characteristics
Anthracite	Black, hard, clean, heavy, shiny coals that do not soil the fingers on handling. In many cases all evidence of layering has been obliterated and the coals break with a conchoidal fracture. They are so low in volatile matter that they burn without visible smoke, and on account of their smokeless character and cleanness form the favourite domestic fuel. The fuel ratio ranges from 10 to around 50.
Super-anthracite	Coals of this rank have passed beyond the anthracite stage. They have a sub-metallic lustre and a black to graphitic grey colour. They generally contain more moisture than anthracite and consequently their heating value is considerably lower. In some cases they can be burned only under a forced draught, so that their value from a fuel standpoint is extremely limited. They are of principal interest in that they form the final metamorphic product in the long (evolutionary) line of fuel.

DISTRIBUTION OF COALS OF DIFFERENT RANKS, IN CANADA

Coals of practically every rank defined above are to be found in Canada, but due to differences that obtain in the methods of sampling and analysing certain deposits may later receive slightly different ranking than here indicated.

Lignite coals form the enormous reserves of southern Saskatchewan and southeastern, central, and northern Alberta, a few deposits in the southern and most northern parts of British Columbia, a number of small fields in Yukon and the Arctic islands, and the deposits of northern Ontario.

Sub-bituminous coals, as at present defined, embrace most of the coal deposits westward to the narrow belt of deposits that outcrop along the foothills of western Alberta, extending from the 49th parallel to the 54th, also a few isolated fields in southern British Columbia.

Bituminous coals embrace the deposits of Nova Scotia and New Brunswick, most of the coal fields within the mountain area of Alberta, and southeastern British Columbia, those of Vancouver island, and those of the few scattered fields in central British Columbia, and southern Yukon.

Semi-bituminous (or super-bituminous) coals embrace those of Peace River area, British Columbia, and of Smoky River, Brûlé, Luscar, Nordegg, and Kananaskis areas of Alberta.

Semi-anthracite coals occur in Canmore-Anthracite area, Alberta, Groundhog area, British Columbia, and Wheaton area, Yukon.

Anthracite is confined, so far as known, to small deposits on Graham island, and in Groundhog area, British Columbia.

Super-anthracite is represented by small deposits that lie in close proximity to igneous intrusions on Graham island, Telkwa and Groundhog areas, and Kathlyn lake, near Smithers, all in British Columbia.

GEOLOGICAL AGE OF COAL-BEARING FORMATIONS

The coal deposits of Canada occur in several formations ranging in age from Carboniferous to Tertiary.

A few thin, non-commercial coal seams in Nova Scotia and some cannel coal deposits of the Arctic islands are thought to be of Lower Carboniferous age, but the extensive bituminous coal deposits of Nova Scotia and those of New Brunswick are of Upper Carboniferous age, although these deposits are not all contemporaneous.

The deposits of bituminous, semi-bituminous, semi-anthracite, and anthracite coals of Bulkley River, Groundhog, Peace River, and Crowsnest Pass areas of British Columbia, of the Yukon, and of western Alberta, and the lignite deposits of the James Bay slope, Ontario, are of Lower Cretaceous age.

The bituminous coals of Vancouver island and the bituminous and anthracite coals of Graham island, B.C., and the sub-bituminous coals of the Belly River and Edmonton formations, Alberta, are of Upper Cretaceous age.

The lignite deposits of southern Saskatchewan and southwestern Manitoba, the bituminous, sub-bituminous, and lignite deposits of several small isolated basins in central and southern British Columbia, the lignites of Graham island, of northern British Columbia, of Yukon, and of the Arctic islands are of Tertiary age.

No commercial coal deposits of Quaternary age occur in Canada.

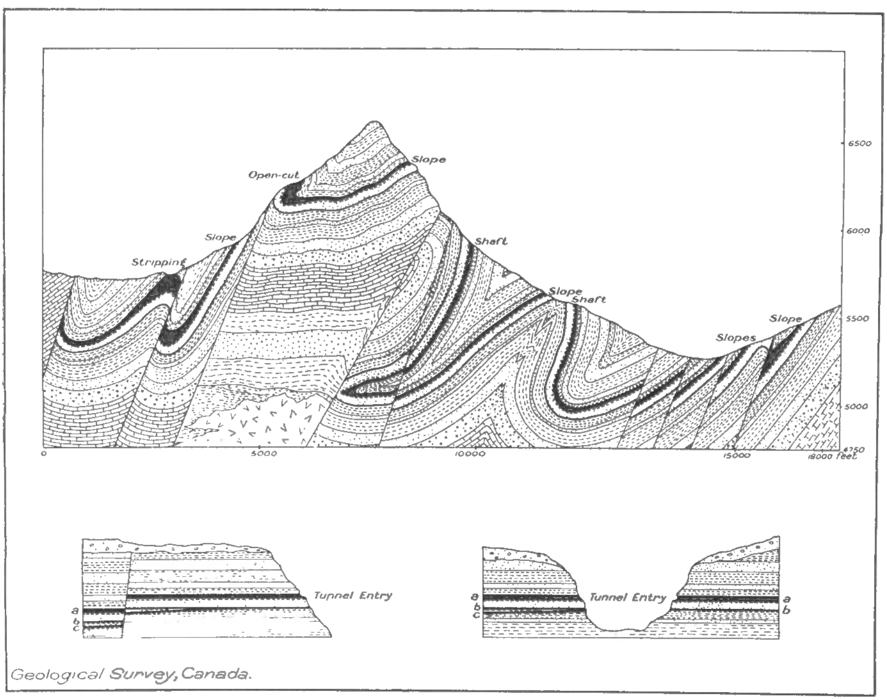


Figure 5. Simple and complicated structures produced by folding and faulting.

STRUCTURE OF COAL SEAMS

Due to earth crustal movements very few coal seams have retained the horizontal attitude they originally possessed, but they now lie in positions ranging from slightly tilted to vertical and in some cases to even completely overturned, as shown in Figure 5, which diagrammatically represents the structural conditions that obtain in several of the Rocky Mountain coal basins of Canada. Here, in addition to being tilted and tightly folded, the coal seams are cut by dislocation planes or faults, along which one part of the seam is in many cases considerably displaced both horizontally and vertically from the contiguous part. Folding and thrust-faulting of coal seams, shown in Figure 5, increase the chances of natural exposures of coal, but form a considerable handicap in their exploitation.

PROSPECTING FOR COAL

The best natural exposures of coal seams are to be found in localities where there is a continual removal of the obscuring material, such as in the beds and banks of rapid-flowing streams, at waterfalls, sea-cliffs, and land-slide scarps. These localities should be the first visited. In following up the streams and ravine courses, cut-banks, stream scars, up-turned tree stumps, pits, gopher burrowings, lines of springs, and patches of water-loving vegetation should be closely examined to see whether the alluvium contains coal fragments or fine particles of coal, commonly called " coal wash", "coal bloom", or "slum". Should one or more of such evidence of coal be found the possibility of finding a coal seam in the neighbourhood is good, and by following up the stream until a point is reached where the coal indications cease, its source can generally be located in the near vicinity. In many localities the presence of coal may be detected by a fused or baked, brick-red clinker shale or sandstone which has resulted from the spontaneous combustion of the coal seam along its outcrop. Should the coal seam not be exposed, its position can in many cases be determined by sinking a line of prospect pits or trenches at short intervals across the measures. In many cases the position of a concealed coal seam can be readily recognized by a trained prospector by the configuration of the topography, the position of the coal seams on the hill-slopes being generally indicated by a bench, terrace, or shallow trough caused by the more rapid erosion of soft coal than the adjacent sediments. Exceptions to this rule exist where the coal seam through metamorphism has become more resistant to weathering than the surrounding sediments, and projects above them. In glaciated areas the drift in many cases conceals such signs in the underlying solid rock topography, in which case recourse must be had to trenching, pit-sinking, or drilling. To reduce the amount of such work as far as possible every clue at the prospector's disposal must be made use of. In many cases the drift contains large glacial boulders of coal or coal shale. The location of these may, or may not, indicate the proximity of the coal-bearing strata, but if the direction of ice movement is known, the trail formed by such glacial debris may be followed back until the source of the coal fragment is located. Not uncommonly a coal showing in glacial drift, taken as indicating the location of a coal seam, on later investigation has proved to be a large buried boulder of float coal, which had been carried a considerable distance from the parent seam. Care should be taken, therefore, in seeing that an actual seam has been discovered. Where the overburden so obscures the rock as to make pit prospecting too expensive, diamond drilling may be resorted to to determine the position, attitude, thickness, number, and character of the coal seams. In some fields the coal seams are so badly broken by faults that a great many drill holes have to be put down before these data are obtained.

A coal seam having been discovered, sufficient of the obscuring material and weathered coal should be removed to determine its thickness, character, dip, and strike, as well as the character of the immediate overlying and underlying beds. In order to have some idea of the continuity of the seam, if concealed, it should be traced by means of prospect pits, trenches, or boreholes as far as possible, the approximate location of the seam being determined either by projecting the strike of the seam at the last-observed prospect or by accurate measurements from some easily traceable horizon marker in which the stratigraphic interval between it and the coal seam had been previously determined. The seam should be opened up and sectioned at a sufficient number of widely separated localities, in order that as accurate an idea as possible may be had of the average thickness, character, and continuity of the seam as a whole.

SAMPLING OF COAL SEAMS

As the analysis of a coal seam is commonly accepted as an index to its quality and rank, and as the value of an analysis depends in the first instance on the method adopted in the selecting of samples, the sampling of coal seams should receive careful consideration. A seam of coal is generally made up of a series of layers possessing markedly different properties and a small piece chosen from one band is apt to give very misleading results where the average analysis of a thick seam is required.

On the other hand, a sample chosen from the weathered and deteriorated outcrop of a seam may give quite inferior results to one taken from a newly cut fresh face beyond the zone of weathering. Although perfectly fresh samples can not always be procured, especially in undeveloped fields distant from transportation, care should be taken to make the sample as representative as possible of the mineable seam.

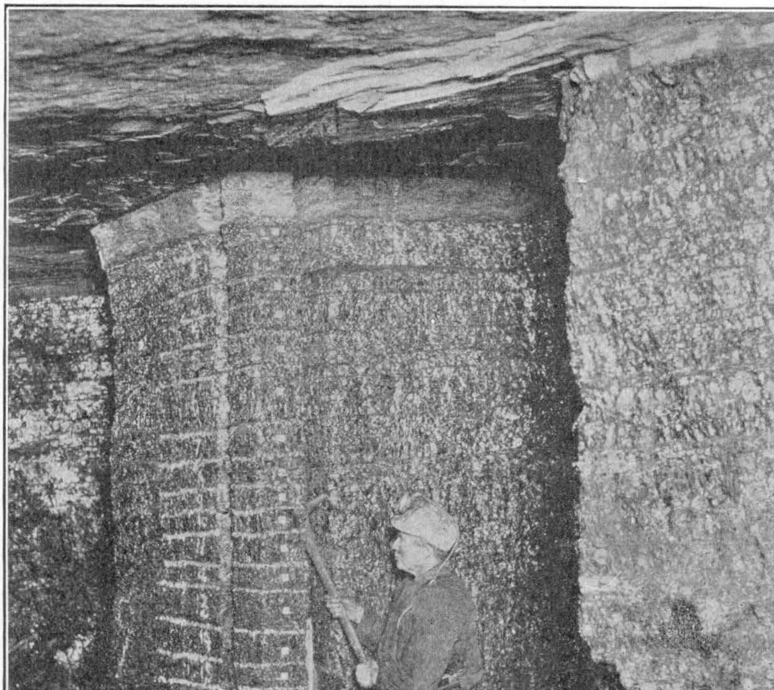
The method of sampling coal seams followed by the Geological Survey, Canada, agrees closely with that proposed by the United States Bureau of Mines, hereunder described. A fresh face of coal having been exposed, sufficient of the coal seam is cleared to prevent loose coal, fragments, and foreign matter from falling into the sample. On this face a strip of about 1 foot in width is cleared perpendicularly across the seam in order to remove all weathered coal, and any other impurities such as powder stains, etc. A waterproof or canvas sheet about 5 feet square is then spread on the ground, close to the face of the seam, so as to catch all particles of coal that are cut, the waterproofing being to prevent any excessive moisture of a wet floor from affecting the coal. A channel 6 inches in width and 2 inches in depth is chiselled or picked out along the middle of the cleared strip from top to bottom of the seam, care being taken to see that the width and depth of the channel are uniform throughout, regardless of the material cut through and that only such material be excluded as is likely to be discarded in the mining of the seam. When the sample has been obtained a detailed record should be made of the coal seam from top to bottom, in which is noted every detectable parting and variation in the seam and especially the presence of any slate, shale, or bone partings, and sulphur or coal balls not included in the sample. The sample should be at least 20 pounds in weight. Should the sample so obtained be too bulky, it is reduced by quartering. This process consists in pulverizing the coal to pass through a screen of ½-inch mesh, screening and thoroughly mixing on the canvas sheet, spreading the sample into circular form, dividing it into quarters, discarding opposite quarters and thoroughly remixing the remainder, this process being repeated until the required amount is obtained. The sample so obtained is placed in an air-tight container which is shaken vigorously so that it may be completely filled, thus excluding as much of the atmosphere as possible. A label giving the essential information of the sample as to locality, what the sample represents, thickness, character, and moisture condition of seam, date, and name of collector, is enclosed in an envelope placed on the top of the coal, the cap screwed on tightly, and further sealed by wrapping a band of adhesive tape around the screw cap so as to completely cover the joint. This is to prevent the admission of air as well as loss of moisture and gases. The sample is then numbered and shipped to the Fuel Testing Laboratories, Ottawa, for analysis. Other things being equal the larger the sample the more representative will it be of the seam, so, where possible, such samples should be procured, leaving the reduction to be effected in the laboratories. Should inaccessibility or other conditions necessitate only small samples being shipped, the quartering down should be done with the utmost care in order that they will be truly representative of the seam as a whole.

As it is seldom that seams remain uniform over great distances, a number of samples of the same seam should be taken from as many different localities as possible in order that an approximately correct analysis of the whole seam may be had.

In the case of thick seams, it may so happen that certain thin layers of the seam are so high in impurities, ash, sulphur, phosphorus, etc., as to make the seam as a whole unmarketable for coke making, whereas by discarding these layers by selective mining a high-grade product will result. In such cases it is advisable to divide the seam at each location sampled into its different benches or subsections and to sample and analyse each sectional bench separately, in addition to obtaining an average sample of the seam as a whole. This procedure is being followed by the Geological Survey and Mines Branch of the Federal Department of Mines in their chemical physical survey of the coal seams of Nova Scotia. Plate VI illustrates the method of extracting a 10½-foot pillar from the Phalen coal seam, No. 5 Colliery Reserve, Cape Breton, N.S., and shows the sandstone roof and shale floor of the seam and the twenty-four sections into which the seam was divided for such examinations.

In sampling a field where mines exist at least three channel samples should be taken from each mine, the samples being chosen at widely separated localities where fresh faces are obtainable.

PLATE VI



Extracting 10½-foot coal pillar, Phalen seam, No. 5 Colliery Reserve, Cape Breton, N.S.

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NATURAL GAS AND PETROLEUM

(*G. S. Hume*)

Carbon and hydrogen combine in many different proportions to give a wide variety of compounds called hydrocarbons, that may be gaseous, liquid, or solid at ordinary temperatures and pressures. Both natural gas and petroleum are composed of hydrocarbons, but different groups of these hydrocarbons enter into each substance and account for the fact that whereas one compound is a gas the other is a liquid. One of the lighter hydrocarbons, called methane or marsh gas, is usually the predominant constituent of natural gas, but others also generally are present, whereas heavier hydrocarbons, not always of the same composition and present in variable amounts, constitute petroleum. Petroleum is thus a mixture of hydrocarbons and on account of the varying proportions and compositions of the different hydrocarbons present may occur either as light, medium, or heavy oil in different localities, or even may occur as different grades of oil in the same field.

Petroleum and natural gas, however, in spite of differences in composition, are thought to have a common origin from plant and animal remains. It is known that certain plants of low order yield materials resembling oil and waxy and fatty substances under bacterial decay may give minute globules of oil. These little drops of oil have a tendency to cling to small particles of silt or mud and may in consequence be carried by water until deposited with the silt and mud in strata which later are transformed to shales. It is also possible that the waxy, resinous, and fatty materials of plants and animals may become deeply entombed in sediments in swamps, bays, or along sea coasts. The deformation of these sediments in crustal warpings produces sufficient heat under high pressure to cause a generation of gas and oil from any possible source material buried with the sediments. Anerobic bacteria work best in the presence of salt water to destroy the cellulose of plants, leaving the waxy and fatty materials, so that the formation of oil is generally connected with marine sediments.

Fossils of relatively high forms of invertebrate life are found in strata as old as the earliest Palæozoic and since plant life preceded animal life it is quite in harmony with the organic theory to find petroleum and natural gas in sedimentary rocks of all ages from early Palæozoic to Recent, although in many cases the petroleum and gas have undoubtedly migrated from the place of origin. One of the properties of gas and oil is that they can flow and hence they may be found under conditions quite unlike those under which they formed.

The migration or flow of natural gas and petroleum takes place through the pores between the grains that constitute sedimentary rocks and is caused in various ways. In the consolidation of sediments, the oil and gas may be squeezed out of the finer pore spaces into parts of the rock where the pore spaces are larger and where the pressures are least. Gas has the property of diffusion and hence moves freely under the action of weak forces. The movement of oil which is a liquid, is resisted by friction. If gas associated with petroleum is subjected to severe pressures, a part of it dissolves in the oil and some of it may be transformed into the lighter liquid hydrocarbons. Such a fluid, with its associated gas, markedly expands when the pressure is reduced and hence moves readily in the direction of least resistance even through minute openings. Oil clings as thin films to bubbles of gas and there is no doubt its movement is greatly assisted and accelerated by movement of the associated gas, although, as would be expected, movement through a finely porous medium causes a filtering out of the oil and, consequently, gas under similar conditions may readily migrate for much greater distances than oil. A property of liquids known as surface tension tends to cause them to penetrate minute pore spaces called capillary openings, but it so happens that pure water has a capillary attraction about three times as great as oil. Thus, if water and oil are in contact in a medium with capillary openings, water tends to enter all the pores and to drive the oil into other media where the pores are too large to exert the capillary attraction. Shales are usually finely porous, whereas sands contain coarser pore spaces. Capillarity, therefore, tends to force the oil out of shales into adjoining sands if both sediments are saturated with water. When the oil has been driven by capillarity into the coarser pore spaces it is probable that gravity becomes much more effective as a cause of movement. Gas is lighter than oil, which in turn is lighter than water, and if oil and gas have been forced into inclined strata saturated with water, they will tend to move upwards, just as cream tends to collect at the top of a milk bottle. It commonly happens that underground water is moving through the strata containing the oil and gas. If this water movement is in the direction in which oil and gas will move on account of their buoyancy, the movement of the oil and gas will be greatly promoted; if, on the other hand, the water movement is in the opposite direction, the movement of the oil and gas will be greatly restricted and under strong water movement the oil and gas may even be carried along by the water.

Oil and gas will concentrate where there is a trap in the path of movement. Traps have many forms. The most common is an arch (anticline) in the strata (Figure 6), or some modification of this structure such as a dome (Figure 7). Another form is due to a barrier which restricts or prevents movement. Such a barrier may be a fault (Figure 8) or it may be a sand

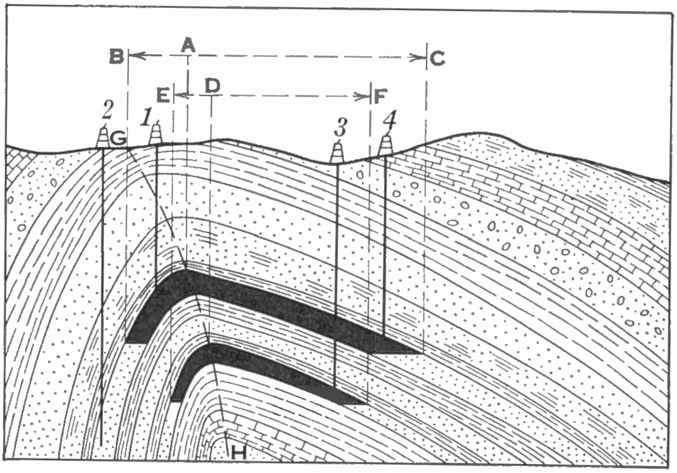

Figure 6. Simple asymmetric anticline with two oil-bearing strata (after Uren). G-H shows change in dip of axis of fold; B-C, width of productive area for the upper sand, E-F for lower sand. Axes of folds at A and D lie near left edge of productive area. Well No. 1 is productive; No. 2 is barren; No. 3 produces from upper and lower sands; No. 4 produces from upper sand.

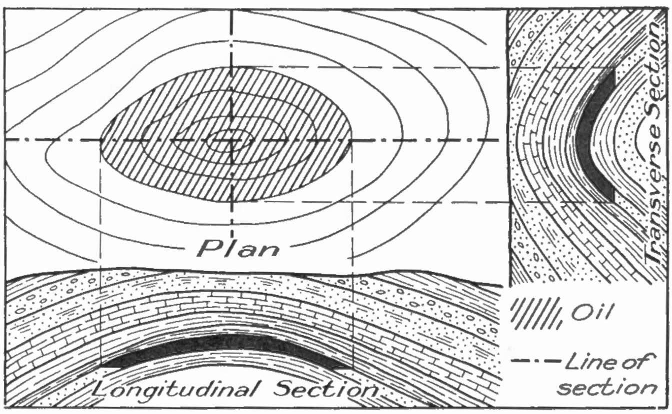

Figure 7. Dome structure illustrated in plan view by structure contours and by vertical sections through the major and minor axes (after Uren).

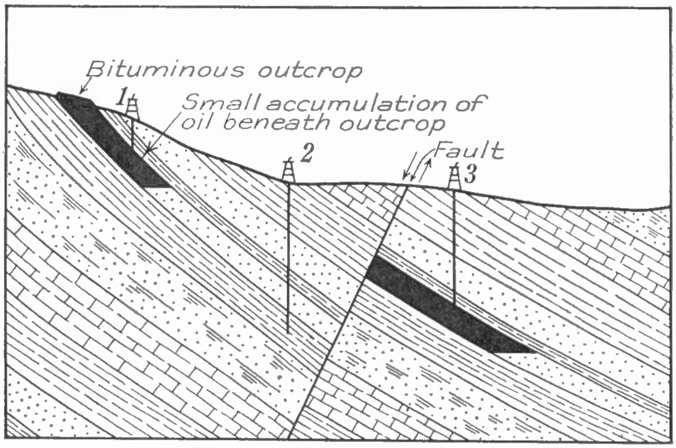

Figure 8. A faulted monocline (after Uren). Shows how a fault may interpose an impervious stratum across the lower part of an oil-bearing stratum, permitting accumulation of a deposit of petroleum, which is sealed by the fault "gouge" and prevented from escaping up the dip of the structure. Wells Nos. 1 and 3 are productive; No. 2 half-way between, encounters edgewater.

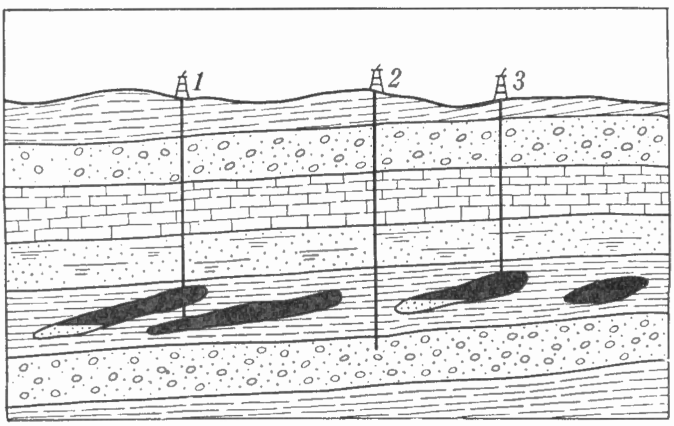

Figure 9. Lenticular deposits (after Uren). Lenses of coarse sand embedded in oil-bearing shales serve as local centres of concentration. Well No. 1 produces from two lenses; No. 3 from one; No. 2 is unproductive.

lens (Figure 9) surrounded by more compact sediments in which the smaller pores are capillary in size and are filled with water. Thus, if for any reason the migration of oil and gas is arrested there will be an accumulation of these materials, giving a potential oil and gas field.

Whatever the form of the geological structure or trap in which the oil and gas collects there must be impervious strata above and below the porous oil horizon to prevent the oil and gas escaping. The overlying and underlying rocks are in many cases shales which besides being impervious to oil can be bent into anticlinal folds without any great amount of fracturing, especially if under load of superposed sediments.

Since oil and gas collect in anticlines or other suitable structures, prospecting for these substances resolves itself into a search for structures capable of containing them in areas where petroleum bearing beds are known to be present. The recognition of favourable structures is essentially a geological problem involving the determination of underground conditions from a study of rock outcrops and borings. In a dome the rocks are inclined outwards from the central part as in an inverted bowl. In certain cases such a structure may show as a conical hill, but if the top has been eroded the structure may have no topographic expression. In the case of an elongated arch or anticline the rocks on the flanks incline outwards from a median axis. It happens in many cases that the middle of such a fold is fractured and, therefore, easily eroded; consequently, as in Turner Valley field of Alberta, the central part of the structure is occupied by a valley. For the same reason valleys in many cases form along faults, but it by no means follows that all valleys in a faulted and folded area are the sites of anticlines or faults.

In the study of the oil-producing possibilities of an area it is very important to attempt to determine if there are present petroliferous rocks which under favourable conditions will yield a supply of petroleum. The strata at their outcrops may show oil-bearing shales or sands and even oil or gas seepages may be present. Seepages are, of course, the best evidence of the presence of petroleum or natural gas in quantity, because if a seepage has been active for a long period the renewal of material must have come from a comparatively large reservoir. Since the main constituent of natural gas is methane or marsh gas and considerable quantities of this gas are commonly given off from decaying vegetation in stagnant pools and swamps, much confusion concerning the significance of gas seepages exists and although in the majority of cases it is not difficult to decide whether the gas is coming from a deep-seated source giving promise of a supply at depth or from a superficial source with no hope of commercial production, great care should be exercised in deciding from the presence of marsh gas alone whether or not a true seepage exists, and in case of doubt expert advice should be sought. Scums of iron compounds in many cases form on water in stagnant pools or in swamps and are commonly mistaken for oil seepages. The iron compounds produce an iridescent scum superficially resembling that formed by oil. If the scum consists of petroleum it will be found to be soluble in petroleum solvents such as ether, chloroform, or carbon tetrachloride, whereas the iron scum is not soluble in these materials.

If petroliferous strata are found in any area and if favourable structures for oil and gas accumulations have been located it then becomes possible to choose proper sites for drilling wells. Even under such conditions it by no means follows, however, that every well will produce commercial quantities of either natural gas or petroleum. It is often said that, other factors being favourable, production depends on the porosity of possible producing horizons. This is true, but the porosity of the rock both as regards quantity and the size of the pores, should be considered. A sand in which the grains are fine will have exactly the same amount of porosity as a sand in which the grains are large, provided that in each the sand grains have the same shape and are arranged in the same manner. In the fine-grained sand there are a large number of small, inter-grain spaces, whereas in the coarse sand there are a smaller number of larger spaces, but the porosity in each case is the same. Gas and oil flow more readily through large spaces than through small spaces, and since the gas or oil must flow to a well if the well is to be productive, it follows that the coarser sand will have a much greater *effective* porosity. As the effective porosity of sands, even in the same horizon, is variable, it sometimes happens that one well may be highly productive and another well only a short distance away may obtain little or no production. Another cause for difference in the productivity of nearby wells is that in certain parts of an oil or gas stratum, for reasons not determinable from surface observations, the sand grains may be cemented by foreign materials that completely fill the intergrain spaces. In such cases the sand is said to be *tight* and will yield no production. Since gas pressure or hydrostatic pressure within an oil stratum is necessary to force oil into a well if it is to become a producer, the yield depends to a large extent on the amount of pressure and on its conservation during the life of the well. In a fine-grained, oil-saturated sand the movement of the oil through the pore spaces is retarded by friction to a much greater degree than in a coarser sand, and consequently wells in oil-bearing fine sands are apt to yield smaller initial or flush production than wells in a coarser-grained sand; but if the pressure is conserved the fine-grained sands will yield for a longer period, although the ultimate production is not likely to be as large as from the coarser sands.

Thus, even after the geologist or prospector has located a favourable structure in strata known to have oil-bearing prospects, only drilling will prove whether or not oil production can be secured. The advantage of the properly located well is, of course, that it makes a fair test possible, whereas a well located in a haphazard manner usually does not. It is essential, though, that all information bearing on production should be collected and studied when wells are drilled and for this reason the Geological Survey, Canada, maintains a Borings Division. When drilling wells, samples of the strata penetrated should be taken at regular intervals, usually every 10 feet. The information derived from the study of such samples and of the drilling records makes it possible to correlate the horizons penetrated by different wells, to determine the details of the structure on which accumulations of oil and gas depend, and to study differences in sedimentation that affect production. The results obtainable are of value to oil companies or operators in making new selections for wells, in predicting the depths to the possibly productive horizons, and also make it possible to give advice regarding the economic development of any field.

Since petroleum and natural gas are of organic origin and are related to sedimentary rocks, it is not to be expected that they will occur in igneous rocks nor in rocks formed from sediments deposited prior to the Palæozoic era. The reasons for their absence in the older formations may be attributed to the possible scarcity of plant and animal life, but, probably, the main reason is that older rocks have, in general, been subjected to such severe metamorphism that petroleum and natural gas, if ever present, have been entirely destroyed. Since the Canadian Shield consists of igneous and highly metamorphic rocks, no oil or gas will be found there. The same may be said of the igneous and highly metamorphosed rocks in the mountain areas of both eastern and western Canada. In the west it is possible that intermontane areas such as, for example, the Flathead valley of southeastern British Columbia, where metamorphism of the younger rocks is relatively slight, may offer possibilities. It has been shown that a certain amount of deformation of sediments is necessary for the accumulation of oil and gas, hence the foothills of Alberta, which occupy a position between the severely deformed rocks of the mountains on the west and the relatively slightly folded sediments of the plains on the east, are thought to offer favourable prospects for fields of high-grade oil. The possibilities of the Maritime Provinces in the case of the Palæozoic sediments that have been involved in Appalachian folding, should not be overlooked. High-grade oil and gas have been produced for many years in the Stony Creek field of New Brunswick and seepages of oil are known from Gaspe. The remainder of Quebec and eastern Ontario offer prospects that are only slight on account of the thinness of the Palæozoic sediments, but the peninsula of southwestern Ontario, where thicker sediments occur, has been, to date, the most productive area in Canada. The Great Plains of the Prairie Provinces are known to be underlain by petroliferous rocks. Many areas are now producing large quantities of gas and several areas, including Skiff and Wainwright fields, have already been shown to have favourable oil prospects. Production from the plains may be expected only where favourable folds occur and it is considered that the best prospects occur in rocks of Mesozoic age. To the north, in the Mackenzie lowlands, in a great area stretching from the northern boundary of Alberta to the Arctic ocean and from the Precambrian Shield on the east to the Cordillera on the west, the best prospects appear to be in the Palæozoic rocks of Devonian age in which drilling at Norman has already demonstrated the presence of oil and from which many seepages are known elsewhere. The main difficulty with Mackenzie area is the lack of easy and cheap transportation. In the present state of the oil industry the area is not attractive because of its relative inaccessibility.

Canada produces less than 2 per cent of her present consumption of petroleum and petroleum products, so that a ready market is available for many years for all the oil that can be produced. The oversupply of natural gas in the Turner Valley field of Alberta at present constitutes a serious problem, for not only is the gas, on account of its fuel value, too valuable a national asset to be wasted, but its conservation in order to get the maximum oil yield is a matter of the utmost importance. At the present time a number of fields that would probably yield large volumes of gas could be opened up in Alberta, but the demands for gas in comparison with the available supply are very limited. This is not the case, however, in other parts of Canada, and although natural gas is being produced in southwestern Ontario and New Brunswick an increased supply could be advantageously used.

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BITUMINOUS SHALES

(G. S. Hume)

Bituminous shales are, in a strict sense, shales that contain bitumen, a black substance that is fusible, soluble in certain solvents, and is composed of hydrocarbons. In contrast with these shales from which oil can be extracted by solvents there are others that yield oil only on distillation and in which the oil is derived from pyrobitumens, that is materials that on the application of heat produce bitumen-like substances. The pyrobitumens are insoluble in reagents that will dissolve bitumens and are infusible. They belong to two classes, asphaltic and non-asphaltic. To the first of these belong the so-called "oil-shales" in which the oil is not present as pretoleum but is contained in certain asphaltic materials that yield it only on the application of heat. In practice, however, most oil-shales contain some free oil, but the amount is small in comparison with the volume obtained by distillation. To the second class or non-asphaltic pyrobitumens belong the carbonaceous materials including peat and coal. No oil can be extracted from these bý solvents and yet shales containing carbonaceous matter may yield considerable oil when distilled. However, it is customary to say that *bituminous substances* embrace both bituminous and pyrobituminous materials, so that the name bituminous shales, according to usage, is a broad term to include all shales from which oil may be obtained, although true oil-shales and carbonaceous shales contain no bituminous materials in the form of bitumen.

Black shales are found in many parts of Canada and it is probable that in most cases the coloration of such shales is due to bituminous substances. Most of these shales are not commercially valuable as sources of oil under present conditions and with present methods of extraction, and, therefore, only the better known shale deposits are mentioned here. In Canada all the shale deposits of prospective value as sources of oil by destructive distillation are Palæozoic or Mesozoic, although Tertiary shales are very important in western United States. In the Precambrian rocks carbonization of the black shales due to metamorphism has proceeded to such a stage that the shales have no value as a possible source of oil.

The best known Canadian shale deposits that will yield ore are the so-called oil-shales of New Brunswick and Nova Scotia. In Albert county, N.B., a pyrobitumen called albertite was formerly mined. This material occurred in veins cutting the oil-shales of the Albert series, but has been mined out. In the oil-shales small veinlets of albertite have been reported and it has been suggested that albertite is the material in the shales that yields oil when these are distilled. The shales are of two types, paper and massive shales, with gradations from one to the other. The paper shales are grey to brown and thin laminæ may be quite flexible. If sufficiently rich in bituminous substances they may be ignited by placing in a fire. In certain cases the paper shale is considered to be merely a weathered, massive shale. The massive shale is black to brown, has a brownish streak, and in many cases shows conchoidal fracture. Varieties with contorted or minutely folded laminæ are called "curly" shale; otherwise the shale is said to be "plain."

Distillation of these shales yields gas and oil and, as a by-product, ammonium sulphate. The value of the shale, therefore, depends not only on the quantity and quality of the oil yielded, but also on the quantity of the by-products. The yield of oil and by-products necessary to constitute a commercial deposit depends on local conditions such as costs of mining and transportation, the continuity and thickness of the shale body, and the character of the shale. In certain cases the oil-shales of New Brunswick have been reported to yield on distillation 60 gallons of 26° Baumé oil and over 100 pounds of ammonium sulphate per ton, but possibly no large shale body would afford an average yield as high as this. The amount of oil-shale in New Brunswick is large.

Oil-shales occur in a number of localities in Nova Scotia. They are probably somewhat different from New Brunswick shales. In Pictou county a material called stellarite occurs in a shale deposit associated with bituminous coal. Stellarite yields a large amount of oil on distillation and was formerly mined.

In Gaspe, along York and St. John rivers, certain shale layers are highly bituminous and analyses show a possible yield of 30 to 35 gallons of oil and 40 to 60 pounds of ammonium sulphate per ton. The largest known continuous thickness of shale is 14 inches. The thickness is usually much less and, probably, commercial exploitation would not be possible unless much thicker deposits were discovered.

The Utica shale which outcrops on lake St. John, Que., along St. Lawrence river between Montreal and Quebec, on certain parts of the shore of lake Ontario, and on Georgian bay near Collingwood contains considerable amounts of what is probably carbonaceous matter. The shales near Collingwood were formerly distilled, but yielded less than 10 gallons of oil a ton. All operations have been discontinued.

Black shales of Devonian age occur in Ontario at Kettle point on lake Huron and along Sydenham river. Fossil plants occur in the shales. A distillation test yielded 4·2 per cent of oil, a large amount of inflammable gas, and some ammonium sulphate. The shales have been estimated to contain 10 per cent of combustible matter and over a limited area have a known thickness of 200 feet.

Shales, supposed to be of Mesozoic age, and which occur in Pasquia hills and on Carrot river in Saskatchewan, yield oil and ammonium sulphate on distillation, but the yield is small in comparison with that of the oil-shales of New Brunswick and Nova Scotia. So far as known these shales at present are not of commercial importance as a source of oil.

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SALINE DEPOSITS

(W. A. Bell)

The saline deposits comprise those salts of the alkalis (soda and potash) and of the alkaline earths (lime and magnesia) that are more or less readily soluble in water and that are commonly found in solution in natural surface waters. The chief saline deposits are the chlorides, sulphates, carbonates, borates, and nitrates of sodium, potassium, calcium, and magnesium. Of these the following are of major importance:

Chlorides: Halite or rock salt ($NaCl$); sylvite (KCl); carnallite ($KMgCl_3 \cdot 6H_2O$).
Sulphates: Gypsum ($CaSO_4 \cdot 2H_2O$); glauberite ($CaSO_4 \cdot Na_2SO_4$); mirabilite ($Na_2SO_4 \cdot 10H_2O$); epsomite ($MgSO_4 \cdot 7H_2O$); polyhalite ($2CaSO_4 \cdot MgSO_4 \cdot K_2SO_4 \cdot 2H_2O$).
Carbonates: Natron ($Na_2CO_3 \cdot 10H_2O$); trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$).
Nitrates: Soda nitre ($NaNO_3$).
Borates: Borax ($Na_2B_4O_7 \cdot 10H_2O$); ulexite ($NaCaB_5O_9 \cdot 8H_2O$).

If pure these various minerals are transparent to white and grey and occur in crystalline aggregates or masses. But if they contain, as they commonly do, clay, iron oxides, or organic matter, the colours on that account may be blue, red, green, black, etc.

The natural salines on account of their ready solubility are normally in a state of solution in surface or subsurface waters such as the oceans, lakes, spring, or groundwaters. Generally, however, it is only in arid or semi-arid regions that these solutions become *naturally* evaporated or that the degree of concentration in solution becomes sufficiently high to permit of economic extraction. Salt, however, is recovered artificially from sea water in some warm regions. With few exceptions all deposits of saline salts are precipitates or saline residues thrown down either by evaporation or freezing from existing or former bodies of surface or groundwaters. In prospecting for salines, therefore, the controlling factor of origin, *climatic aridity*, must be considered of first importance. Second in importance is interior or impounded drainage whereby deposits are stored up and saved from re-solution.

On a basis of origin, saline deposits may be classified as follows:

(1) Evaporation deposits of marine waters in arms of past or present seas partly or completely cut off by bars or by crustal movements. Grabau[1] subdivides such deposits as: (*a*) marginal salt pans that receive broad, frequent, periodic floods of sea water; (*b*) marine salinas that receive constant additions of sea water by seepage through bars or intervening porous rocks; (*c*) lagoonal deposits with accessions of sea water through narrow, shallow, open channels; (*d*) relic sea deposits in basins entirely severed from, although formerly connected with, the main body. Chief among the deposits that originated from sea water are those of rock salt, gypsum, and the chlorides and sulphates of potassium.

(2) Evaporation deposits of enclosed lakes other than relic seas. These include like those of the first class both present and past deposits. The lakes may contain water the year round or may be *playas,* subject generally to seasonal dryness. The saline residues of this class depend on the waters of the region, the nature of the country rock, the kinds of salts contributed by the wind, seasonal variations of temperature, etc., and thus show great quantitative as well as qualitative variety. Halite, mirabilite, trona, natron, borax, and gypsum are the chief substances formed.

(3) Efflorescences on, or just beneath, the surface as a result of deposition from groundwaters. Sodium and potassium nitrates are the most valuable deposits of this class.

(4) Wind deposits. Consist mainly of gypsum in the form of dunes.

(5) Deposits from springs. Deposition may be effected either by evaporation or freezing. These may add to deposits of other types, but in themselves are usually too restricted to be of economic value.

(6) Replacements of other substances. These are not important except perhaps replacements of limestone by gypsum.

The following notes deal with the most important saline deposits.

ROCK SALT AND GYPSUM

Rock salt, in common with gypsum and anhydrite, forms rock masses and these three minerals are commonly interbedded or closely associated as a result of a common origin from sea water. Economic beds of rock salt belong mainly to either the first or second types of saline deposits enumerated above. Those of the first type, which originated from evaporation of sea water, should be given special attention, in view of the possibility of associated potassium salts within the same formation or within later sediments of the same region, in which secondary concentration of potassium salts may have taken place.

A marine origin of the salt beds may be recognized by (*a*) presence of interbedded limestone, dolomite, anhydrite, and gypsum; (*b*) presence of fossiliferous limestone or dolomite directly beneath or above the deposits; (*c*) presence of normal fossiliferous marine beds at the same horizon in a neighbouring part of the region; (*d*) presence of appreciable amounts of lime carbonate within the associated gypsum beds.

[1] Reference at end of chapter.

Rock salt on account of its ready solubility will not outcrop in humid regions. Hence its discovery in the past has largely been made by chance while sinking wells for water, oil, coal, or for some other purpose. Although gypsum and rock salt may occur singly, a formation known to contain beds of gypsum or anhydrite is favourable ground for the salt prospector, particularly if salt springs are present in the same region. The presence of thick red sandstones and shales is most commonly an indication of aridity during deposition and such formations are worthy of attention. Favourable factors of aridity having been proved, further prospecting for rock salt has necessarily in most regions to be done by boring. Costs are consequently high and a high percentage of failures may be anticipated, particularly where the rocks are tilted or disturbed. Careful stratigraphic studies are a preliminary necessity for the economical location of drill sites. Drilling in the near vicinity of salt springs commonly ends in failure, as the waters from such springs may perhaps have travelled long distances. Diamond drilling, preferably with a 2½ to 3-inch core barrel, is advisable, or churn drilling might be employed in the initial stages for greater speed and economy. When salt is once encountered the diamond drill should be used to core the salt beds. For the latter purpose a saturated brine solution should be prepared for use as drilling water and where there are any indications of potassium chloride this brine should be replaced by a 30 per cent solution of magnesium chloride. Where cable tools are used in the initial stages or otherwise, samples of both cuttings and drill water should be taken at close and regular intervals, and care taken to bail the hole clean at each bailing. Changes in the rate of drilling and ineffectual shutting off of water by improper setting of casing should be avoided. All samples of salt and drill waters should be carefully labelled as to depth and placed in the hands of a competent chemist, or forwarded to the Department of Mines.

Many salt deposits the world over are present as salt domes, which are intrusive masses upthrust from one or more salt beds lying at a lower level. Only close stratigraphic study of the rocks will determine whether the salt has thus migrated or is present in its normal bedded position.

Gypsum is only sparingly soluble in pure water, but much more so in a solution of common salt. It outcrops commonly; or its presence beneath the soil, like that of salt, may be indicated by ponds and sinks as a result of underground solution and caving-in of surface matter. Investigation of the marketable value of a gypsum deposit includes drilling, as well as surface or mine sampling, as masses of anhydrite are commonly irregularly intermixed and if abundant may seriously impair the quality. Crystals of selenite are common in gypsum beds and if abundant are deleterious, as they clog grinding machinery.

POTASH SALTS

Prospecting for potash salts may follow two lines of exploration: (1) deep boring for buried deposits; (2) investigation of surface salt deposits, brines, and bitterns. The first method of prospecting should be undertaken only after thorough study in a formation or formations that are known to contain rock salt. The procedure parallels that already mentioned for search of rock salt. As the second investigation is concerned with surface accumulations that are characteristic of present day desert or dry regions only, it should be confined to areas where saline lakes, playa lakes, alkali flats, alkaline efflorescences, etc., are already known to occur. As potassium chloride is much more soluble in saline solutions than either common salt or sodium carbonate the potassium salts are more likely to be found in the residual liquor that impregnates the crystalline sodium salts in the lake deposits. A thorough investigation will comprise not only a sampling of the salts and brines on the surface, but trial borings in the bottom deposits and analyses of the salts and brines thereby obtained. Such borings may be done with an auger and bit within a casing provided with a toothed shoe and sunk by a light drill[1], or by means of a light portable diamond drill outfit[2]. As accurate determination of the potash content in alkaline waters requires skill in analytical technique all samples should be entrusted to competent chemists. As this work will prove expensive, preliminary field tests may be performed by dipping the loop of a platinum wire in a solution of the salt rendered slightly acid by the addition of hydrochloric acid, drying, and igniting over a flame of an alcohol lamp or gasoline blow torch, and observing the resulting flame colour through a Merwin colour screen. If potassium salts are present the flame will appear reddish violet. Rough quantitative tests may be made by comparisons with a prepared standard solution as outlined by W. B. Hicks.[3]

SODIUM SULPHATE, SODIUM CARBONATE, MAGNESIUM SULPHATE, ETC.

These salines occur today in semi-arid or arid regions, either as deposits or as concentrated solutions, in independent or impounded drainage basins not provided for long intervals of time with exterior outlet. Originally present in the soils and rocks, they have been leached out by the natural drainage waters and concentrated by evaporation in the lowest depressions. Such areas of concentration, as already stated, may be saline lakes, playas, salt marshes, mud flats, etc. Generally the deposits consist of an alternating succession of clay, sand, and salt layers. As the muds seal up previously deposited salts, lakes of relatively dilute water may overlie extensive saline deposits, a circumstance that suggests the necessity for testing the bottom deposits by drilling. As some of the salts are extremely soluble the more massive crystalline beds should be sought where complete evaporation of a large and deep saline lake took place. In most of the deposits sodium salts predominate. Seasonal or even daily changes in the temperature exert an important influence on the precipitation of some of the salts, particularly of the sulphates and carbonates of sodium, and as layers of such salts deposited in a cool dry season are subject to re-solution in the warmer wet season, harvesting of these salts may of necessity be seasonal.

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[1] U.S. Geol. Surv., Bull. 530, p. 333 (1911).
[2] Mines Branch, Dept. of Mines, Canada, Pub. No. 646, p. 80.
[3] Hicks. W. B.: Mineral Resources U.S., pt. 2, p. 129 (1915).

As surface salines of this class are openly exposed to view their investigation is largely a matter of areal surveys and of intensive systematic sampling of the salts and of the associated brines and bitterns. The precise method of procedure is well illustrated by L. H. Cole.[1]

Deposits of this nature in Canada are limited climatically to parts of the Great Plains and to the interior of British Columbia, and as they are post-glacial in age only a few are over 100 feet thick.

REGIONAL DISTRIBUTION

The factor of aridity in the past as well as in the present was so important in the formation of saline deposits that the prospector may safely restrict his activities to certain areas and formations. Salt and gypsum, for example, were extensively formed in North America towards the close of Silurian time (Salina epoch), and in Canada areas underlain by strata of Salina age are of chief importance to the salt or gypsum prospector. Such areas are present in the southwestern peninsula of Ontario. Gypsum beds are more likely to outcrop or to be found nearer the surface than the much more soluble rock salt. The location of the latter must generally depend upon costly drilling through considerable thicknesses of younger strata. The probable area underlain by salt in western Ontario lies west of a line from lake Erie through London to lake Huron north of Kincardine, and the depth of the salt from the surface may be expected to increase in a southerly direction. The only other area in Ontario where salt or gypsum is likely to occur is in that part of James Bay basin drained by the lower reaches of Moose, Albany, and Kapiskau rivers. Gypsum outcrops on Moose river and drilling through the Devonian formations may at some time locate further beds or even lead to the discovery of salt as well.

Surrounding the lake basin of Winnipegosis in Manitoba there is a large district underlain by Upper Silurian and Devonian rocks. Gypsum is already mined at Gypsumville, and salt springs commonly issue in this district from rocks of Devonian age. This district, therefore, is a favourable one for further prospecting and may be extended by following the area underlain by Devonian rocks northwestwards to Athabaska River valley and to the district drained by the lower parts of Peace and Slave rivers.

The above are the areas underlain by marine Salina strata at no great depths from the surface. There was a later epoch of aridity that coincided with shallow invasions of Atlantic sea waters over Magdalen islands and the Maritime Provinces. The marine sediments laid down at the time are known as the Windsor series of Lower Carboniferous age. Gypsum and anhydrite are widely spread within this series, and rock salt in commercial quantity was discovered by drilling at Malagash, N.S. The Windsor series offers a fertile field for the prospector for salines, but on account of the high dips and generally disturbed condition of the strata such prospecting is expensive and many failures are to be anticipated. There is some basis for hoping that potash may occur locally in some areas underlain by the Windsor series.

[1] Cole, L. H.: "Sodium Sulphate of Western Canada"; Mines Branch, Dept. of Mines, Canada, Pub. No. 646.

In the search for salt and gypsum in either the Salina or Windsor groups of strata, surface indications of salines in the form of sink-holes, undrained depressions, and ponds, as well as in the abundant presence of saline springs and well waters, merit careful attention. The outlook for economic bodies of saline potash in Canada is not altogether discouraging.

The known distribution of the sulphates and carbonates of sodium and magnesium coincides fairly closely with present-day surface undrained depressions in the dry belts of western Canada, particularly in southern Saskatchewan and in south-central British Columbia. Where the drainage of a large area is impounded by surface drift in such dry belts or where there is not sufficient rainfall to cause overflow of the basins and through drainage to the sea, chemical analyses of shallow pond and lake waters may prove fruitful, and high salt content of the waters may be revealed, especially in cold weather, by crystallization of salts on the surface of the waters or at the outlet of springs.

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LIMESTONES AND ASSOCIATED MATERIALS

(E. M. Kindle)

CALCAREOUS DEPOSITS

Limestone is one of the most abundant and widely distributed rocks. The many uses to which limestone and its products are applied give it a position of practical importance probably second to that of no other rock. Its use for structures of all kinds, the manufacture of cement lime, the smelting of iron and other ores, manufacture of glass, calcium carbide, and the building of roads may be mentioned in indicating the great rôle which it fills in the industrial world.

The gas, carbon dioxide, produced by burning limestone, affords when reduced to the solid state under high pressure conditions, a very efficient refrigerating material, which is popularly known as " dry ice ". Solidified carbon dioxide produces the chilling effect as it slowly resumes the gaseous form, just as ice does in returning to the liquid form, but without leaving moisture or other trace of its former presence.

The manufacture of commercial sodium carbonate, known as soda ash (Na_2CO_3), is also dependent upon the use of limestone. Sodium sulphate, calcium carbonte (limestone), and coal when mixed in the proper proportions, produce when heated to fusion according to the Leblanc process, reactions resulting in sodium carbonate or soda ash.

Caustic soda, which is used in the manufacture of soap and in many other ways, is produced by heating together quicklime and soda ash. Caustic soda plays an important rôle in paper manufacture, the process being known as the " sulphate pulp process ". The wood fibre is digested in this process by caustic soda. When sulphite pulp is prepared by the Jensen tower system a high calcium limestone is required, whereas the milk-of-lime system demands a limestone high in magnesium.

Bleaching powder, commonly called " chloride of lime ", is another product of limestone. Hydrated lime, produced by slaking burned limestone, is treated in specially designed chambers.

Limestone is extensively used in the form of cement—a calcined product of a natural cement limestone or of limestone or marl and clay. Marl is not much used for this purpose in Canada since limestone affords a more uniform and dependable raw material; possibly the difficulty of working marl deposits in winter is also a deterrent factor; but this difficulty should not obtain in southern British Columbia and southern Ontario where marl lakes are not uncommon.

Limestones extend in geological range from the oldest to the youngest rocks. The simplest type of limestone, which is called coquina, is formed by the cementing together of wave-broken seashells. Calcareous algæ and coral reef debris contribute largely to the production of some limestones. The microscopic shells of foraminifera have produced the chalk. By the evaporation of thermal spring waters holding much calcium carbonate in solution, masses of compact limestone of great beauty—the so-called " onyx marbles " and " Mexican onyx "—are formed. The calcareous tufa formed round the hot springs at Banff, Alberta, has originated in this way. The limestone of certain localities holds a small percentage of hydrogen sulphide, which causes a fetid odour and gives rise to the name " stinkstone." A bed of calcite in Chatham township, Ontario, furnishes a good example of this type of limestone. In many freshwater lakes certain algæ, *Potamogetons* and other water plants, have the power, through excessive abstraction of carbon dioxide, of separating calcium carbonate from the water and depositing it upon their stems and leaves. Beds of marl are in large part the product of the accumulation of plant-separated lime. Some fine-textured limestones are doubtless the product of biochemical agencies in which supersaturation with calcium carbonate of the surface layers of the sea water in which they formed was a large factor. This type of limestone, which in texture approaches a lithographic limestone, is present in Kingston district. Limestone when altered to a crystalline form by metamorphism is called marble. The high polish which marble readily takes makes it a popular stone for interior decoration, monuments, building fronts, and for the walls of many handsome structures. Various colours of marble are used, varying from the pure white demanded by the sculptor to the mottled grey or brown commonly used for structural purposes.

Various experiments cited by Clarke[1] show that the highly crystalline structure which distinguishes marble from ordinary limestone may be produced by pressure alone, by heat alone, or by a combination of the two. In one of these experiments a quantity of dry white chalk was placed in a screw press and kept under a pressure of from 6,000 to 7,000 atmospheres for about 17 years. At the end of that period the chalk was

[1] Clarke, F. W.: " The Data of Geochemistry"; Bull. U.S. Geol. Surv., 491, p. 531 (1911).

found in part to resemble a crystalline limestone. Such experiments appear to indicate that the highly crystalline limestones and the marbles of the Precambrian and other Canadian horizons have been produced by the pressures and high temperatures incidental to the action of mountain-making forces on ordinary limestones.

Over great areas, like the Ontario peninsula, the eastern ranges of the Rocky mountains, and in various parts of Canada, limestones are the dominant and in many cases the only kind of bedrock. But in other extensive regions they are either wanting or represented only by lenticular masses in the midst of a series of non-calcareous sediments or in Precambrian schists and gneisses. In the Cordilleran region of British Columbia, limestones are as abundant as they are rare on the Great Plains of western Canada. The location of even small, lenticular deposits of limestone in the midst of rocks such as those of the Alberta and Saskatchewan prairies may be a matter of considerable importance as a means of furnishing lime for local use or limestone for ore flux in a mining region.

Over most of the James Bay slope and the area southwest of Hudson bay, limestones are limited to a zone within or near the coastal plain, where they are generally concealed by Pleistocene clays, sands, and gravels. The limestone belt bordering the southwestern side of Hudson bay, and the St. Lawrence Valley limestones, are separated by the crystalline rocks of the Canadian Shield in which the calcareous deposits when present are distinctly crystalline, representing marbles in many cases. The deformation and metamorphism to which the roots of these old Precambrian mountains of the Canadian Shield have been subjected have altered their limestones so that they show only a slight physical resemblance to the Palæozoic limestones of such slightly disturbed regions as south-eastern Ontario. In the Appalachian region of the Maritime Provinces the limestones are also in many places altered in some degree by the mountain-building forces, and by intrusive and other igneous rocks.

The simplest test for recognizing a limestone is the use of cold dilute hydrochloric acid which gives free effervescence when applied to any variety of calcareous rock. Dolomites and magnesites may be distinguished by their failure to effervesce in cold acid. When powdered they show feeble effervescence as they do in warm dilute acid.

Topographic features will in some cases give a clue to the presence of limestone formations in Precambrian areas where they are associated with rocks like granite, schist, and various intrusives. The greater relative solubility of limestones and their more rapid weathering may in such associations result in the development of basin-like valleys in areas underlain by limestone where they are concealed by superficial deposits.

Examination of limestone in a natural ledge that has been subjected to long weathering, affords the best possible basis for judging its value for building purposes. The freshly exposed quarry ledge gives little indication of the behaviour of the rock under frost action, but the weathered ledge is very apt to show either a solid face only slightly affected by weathering or a bed with numerous joints, bedding plane fissures, and masses of strata well on the way to disintegration.

Detailed information regarding the limestones and other building stones of Canada may be found in the volumes on this subject by Prof. Parks.[1]

MAGNESIAN LIMESTONES

Many ordinary limestones include a small percentage of magnesian carbonate. A small or moderate quantity of magnesium in a limestone does not interfere with its use in the industrial world except for certain things. The presence of magnesium in certain ratios with calcium affords a limestone which, with the addition of argillaceous material, produces on calcining an hydraulic cement. The DeCew limestone, or "waterlime" of the Niagara escarpment, is a good example of this type of rock. It was formerly extensively worked by tunnels for cement at Thorold, Ontario. A well-known cement manufactured in Ohio valley uses a limstone having the $CaCO_3$ and $MgCO_3$ in the proportions of 44·60 and 36·20 respectively. When the magnesian content is considerable the rock is called magnesian limestone or a dolomite: the latter term, however, should be restricted to rocks in which the molecular ratio of lime to magnesia is 1:1. Magnesian and non-magnesian limestones are not easily distinguishable without a chemical test. The former dissolve with difficulty and the latter rapidly in cold dilute HCl. Magnesite, the carbonate of magnesia, dissolves in acids with even greater difficulty than dolomite. Calcite and dolomite may also be distinguished by a reagent which consists of aluminium chloride and haematoxylin. A violet coating in the presence of this re-agent forms on calcite, whereas dolomite remains uncoloured.

The Mottled limestone, which is quarried at Tyndall, Manitoba, is a magnesian limestone which has great beauty when dressed. It may be seen to advantage in the corridors of the New Dominion Parliament Building. The drab, coffee-coloured formation called the Lockport dolomite of Niagara peninsula affords a good example of a very common type of highly magnesian limestone.

ANHYDRITE AND GYPSUM

In some regions special conditions have favoured the development of sulphate of calcium, which is called anhydrite ($CaSO_4$), instead of the carbonate of calcium or limstone. We consequently find in some regions a limestone series interrupted by beds of anhydrite or gypsum. The hydration of anhydrite produces $CaSO_4 \cdot 2H_2O$, a soft, easily scratched mineral called gypsum.

Calcined gypsum furnishes the familiar plaster of Paris, alabastine, and other trade mixtures used for interior wall decoration. Gypsum is used as the retarding agent in Portland cement. Bolted through a 200-mesh screen, white gypsum is used for paper filler and paint, under the

[1] Parks, W. A.: "Report on the Building and Ornamental Stones of Canada"; Mines Branch, Dept. of Mines, Canada, vol. 1 (1912).

"Report on Building and Ornamental Stones of Canada; Maritime Provinces"; Mines Branch, Dept. of Mines, Canada, vol. 2 (1914).

"Report on the Building and Ornamental Stones of Canada; Province of Quebec"; Mines Branch, Dept. of Mines, Canada, vol. 3 (1914).

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"Report on the Building and Ornamental Stones of Canada; Province of British Columbia"; Mines Branch, Dept. of Mines, Canada, vol. 5 (1917).

name of terra alba. Common school crayon, known as chalk, is made from finely ground uncalcined gypsum. Ground gypsum has also been extensively used as a soil fertilizer.

Extensive deposits of gypsum occur in the Lower Carboniferous rocks of Nova Scotia and New Brunswick, where they are in some cases 200 feet or more thick. Gypsum occurs abundantly in the Devonian rocks along Moose River valley in northern Ontario. One of the largest deposits of gypsum now being exploited is located at Gypsumville, Manitoba.

Large deposits of anhydrite and gypsum, which remain undeveloped, occur at Peace point on lower Peace river, and at mount Charles on Great Bear river in the Northwest Territories.

The presence of gypsum deposits is generally indicated by sink-hole topography and subterranean drainage. The relative softness of the rock serves to distinguish it from limestone which it may resemble in colour.

ROCK PHOSPHATE

Few mineral deposits occur under a greater variety of circumstances than the workable deposits of phosphates. Only those known to be associated with limestones in Canada are considered there.

Penrose has used the following classification (Bull. U.S.G.S. No. 7, p. 22) of deposits of phosphate of lime:

(1) Mineral phosphates	(A) Apatites	Fluor-apatites Chlor-apatites
	(B) Phosphites	
(2) Rock phosphates	(A) Amorphous nodular	Loose nodules Cemented nodules or conglomerates
	(B) Phosphatic limestone beds	
	(C) Guanos	Soluble guanos Leached guanos
	(D) Bone beds	

The deposits to be considered in this discussion fall in group 2B of this classification.

The best known phosphates in Canada are the apatites which were described first by T. Sterry Hunt in the Can. Geol. Survey Reports for 1848. They occur in Precambrian rocks in Hull county, Quebec, and in the counties of Leeds, Lanark, Frontenac, Addington, and Renfrew, Ontario. Most of these deposits which are workable have been regarded as fissure veins and pockets. They generally occur in syenite pyroxene and gneiss, and hence are outside the limits of the present discussion; but they are in some cases associated with limestone and Dawson believed that many deposits of the Ontario district are true beds.

A thin bed of phosphate rock or phosphorite has been known for some years in the Rocky mountains of southern Alberta. This bed occurs at about the same horizon as the extensive and well-known commercial deposits found in four of the northern Rocky Mountain states. This material occurs in the midst of limestone formations and may resemble the associated limestones closely enough to be easily mistaken for them.

Phosphorus, the valuable element in phosphorite, is one of three elements, viz.: nitrogen, potassium, and phosphorus, which are taken from the soil in large quantities by growing plants. Their removal by agricultural activities results in a progressive loss of fertility unless they are returned to the land.

Although nitrogen may be supplied to the soil through the agency of clover crops, phosphorus in the form of some phosphate must be returned to the fields in the shape of manufactured or other fertilizers if their fertility is to be maintained. Phosphoric acid is abundant in the seeds of plants. More than 49 per cent of the ash of wheat is composed of phosphoric acid. The ashes of bones contain as much as 40 per cent of this important plant food. On the Atlantic coast of Canada where cod fishing is an important industry the heads and bones of the cod are spread over the land as a means of returning to it the phosphorus removed from it in the crops.

The origin of stratified deposits of phosphorite is still imperfectly understood. It is known, however, that certain organic forms are much richer in phosphates than others. Bones are richest, but some molluscan shells are high in phosphates. W. E. Logan and T. S. Hunt found 85·79 per cent of calcium phosphate in shells of the recent Lingula. Changes attending the hardening of limestone sediments rich in highly phosphatic organic remains appear to have been instrumental in phosphatizing certain beds of limestone by concentrating the phosphates abstracted from sea water by molluscan and other forms of life.

The rock phosphate of Melrose, Mont., Gale describes as resembling somewhat a dark, coarse, granular limestone which might even be mistaken, on casual examination, for a dark, fine-grained basalt. It has an oolitic structure, with a dark grey to black colour, and is noticeably heavy in comparison with the sedimentary rocks associated with it. Many weathered surfaces show a bluish white coating or "phosphate bloom," probably of a secondary phosphate mineral. The oolitic structure, though constituting one of its most distinctive features, is in places somewhat obscured.

A thin band of phosphorite may be seen in the Banff section very near the base of the Rocky Mountain quartzite at the roadside just east of Spray falls, on Bow river. This occurrence at Banff near the top of the Palæozoic seems to approximate the position held by phosphate beds in the Montana section at Melrose, where it is stated to be 100 feet below the top of the Palæozoic. In Idaho and Utah it is also found in the Park City formation of Carboniferous age.

Dr. Adams gives a description of the phosphate rock found near Banff which is quite similar to that of the Montana phosphate. He states

"The phosphate rock found in the bed of Fortymile creek is very fine grained and massive in character, black in colour, and looks like basalt. A careful examination of its broken surface with a good lens shows the oolitic structure—which has been referred to as characterizing this rock—quite distinctly, with the occasional dark, rod-like objects. . . ."

Commercial development of phosphate rock has been undertaken in Elk River valley in southeastern British Columbia.

The geological occurrence of the known deposits of phosphate in British Columbia and the states to the south, indicates that it may be sought for near the top of the Palæozoic sediments within the limits of the Rocky

Mountain quartzite formation, with greater prospects of success than elsewhere. Some acquaintance with the fossils which distinguish this from adjacent formations will be helpful to the prospector in selecting the horizons worth examination. The pencil-shape *Plagioglypta canna* is one of the index fossils of this formation.

In recognizing the phosphate rock the generally oolitic character and penetrating fetid odour should be borne in mind. It is heavier than the chert with which it is closely associated, having at Banff a specific gravity of 3 and a hardness " around 5 " according to Spence, who states that at Banff it weathers to a somewhat rusty or blacker colour and is without the bluish " bloom " of the Montana phosphate.

The chemical test recommended by Adams and Dick for the certain recognition of phosphoric acid is as follows:

"Powder some chips of rock in a mortar until the material will pass through a 100-mesh sieve. Place as much of the powder as can be taken up readily on a twenty-five cent piece in an ordinary small enamel cup, add about 30 cc. of water and 10 cc. of concentrated nitric acid. Cover the cup with a large watch glass and warm gently for ten minutes. Filter, or decant off the fluid if it is clear into a glass beaker and add 100 cc. of water, then a few cubic centimetres of a saturated solution of carbonate of ammonia. This will probably make the clear solution somewhat cloudy. Nitric acid should then be added drop by drop until the solution clears up again and gives a faint but distinct acid reaction with blue lithmus paper. The solution is then warmed again to a temperature of 70 degrees or 80 degrees C. and 50 cc. of concentrated solution of molybdate of ammonia is added drop by drop, while the solution is being stirred. This solution is allowed to stand in a warm place for 15 minutes, if phosphoric acid is present, a bright yellow granular precipitate of phospho-molybdate of ammonia will appear."

IRON

(T. L. Tanton)

Next to aluminium, iron is the most common and widely distributed metal of the earth. Four iron-bearing minerals are the chief constituents of iron ores. They are: magnetite (magnetic ore), $FeO \cdot Fe_2O_3$, Fe 72·4 per cent; hematite (red and specular), Fe_2O_3, Fe 70·0 per cent; limonite (brown hematite, brown ore), 2 $Fe_2O_3 3H_2O$, Fe 59·8 per cent; siderite (carbonate, spathic ore), $FeCO_3$, Fe 48·3 per cent. Large masses of rock made up chiefly of one or more of these minerals have been formed at various times in the earth's history. They are of the following different kinds:

MAGMATIC SEGREGATIONS

All basic igneous rocks contain iron either in the form of magnetite, iron-bearing silicates, or sulphides. In some large intrusives these iron-bearing minerals, which are heavy and are also among the first to crystallize out of the molten magma, have collected together. It is supposed by some that segregations of this sort result from the sinking of crystals in a liquid medium toward the bottom of the rock mass; other theories of magmatic differentiation have been advanced to account for the same phenomenon. These magmatic segregations are commonly masses of irregular shape and variable size, showing no relation, so far as known, to the shape, size, or structure of the igneous mass of which they form a part; they are of variable composition and their boundaries are not sharply defined where they pass by gradations into other phases of the rock. Magnetite is the iron mineral most apt to collect in this fashion, and when it does so it usually contains titanium and in some cases rare elements such as vanadium.

Magmatic segregations of titaniferous magnetite are found in anorthosite and gabbro masses in Lake St. John district and elsewhere in eastern Ontario and Quebec. The largest of those known are the Cran de Fer deposit in Saguenay county and that at the St. Charles mine in Lake St. John district, estimated to contain at least 300,000 and 1,000,000 tons, respectively, of material containing about 50 per cent iron and 10 per cent titanium. Deposits of this type are not being mined. Blast-furnace operators dislike using ore high in titanium, because it increases the viscosity of the slag and prevents a complete recovery of the iron.

Closely related to the titaniferous magnetites and occurring like them as basic segregations in anorthosite are the *ilmenites* found in Charlevoix and Terrebonne counties, Quebec. These deposits carry from 40 to 45 per cent iron and 21 to 25 per cent titanium. They have been mined and treated in the electric furnace for the production of titanium alloys. Recent researches in electrolytic smelting and an appreciation of the value of titanium oxide in paint lead to the expectation that these deposits may be used as a source of iron and also titanium oxide.

To find a deposit of this type: proceed to the general vicinity of known occurrences, examine areas known or inferred to be underlain by gabbro and anorthosite, and search for concentrations of magnetite and ilmenite. The surface indications are: the abundant occurrence of these minerals in rock outcrops and the readings obtained by a dip-needle survey.

DEPOSITS FORMED BY HOT SOLUTIONS

Some igneous intrusives give off iron-bearing solutions which traverse cracks, or permeate the neighbouring rock. The resultant mineral deposits, known as contact metamorphic deposits, may take the form of veins or dykes, or replacement bodies. The latter may attain considerable dimensions; they are of irregular shape with variable compositions. Several of these masses may be more or less regularly distributed around the contact of intrusive bodies in certain formations such as limy rocks which are particularly susceptible to replacement.

Deposits of magnetite are formed in this way. Many occur along the western border of the Coast Range batholith distributed at intervals along the whole length of the Pacific coast of British Columbia. They have been described in a recent publication by the Geological Survey.[1]

To find a deposit of this type: examine areas underlain by limestone or limy sediments in the immediate vicinity of the western border of the Coast Range batholith. Surface indications are: the occurrence in outcrops of rock rich in magnetite; and readings obtained by a dip-needle survey. A peculiar garnet-bearing rock containing garnet and other lime silicates commonly occurs around the margins of magnetic deposits of this

[1] Young, G. A., and Uglow, W. L.: "Iron Ores of Canada," vol. 1; Econ. Geol. Series No. 3, Geol. Surv., Canada (1926).

type; outcrops of this material may be regarded as an indication of favourable prospecting ground close by. In Madoc district, Ontario, the Hastings limestone around the margins of the Deloro batholith is known to be a favourable prospecting ground for deposits of this type.

Some of the lavas associated with the early Precambrian banded iron formation in northern Ontario have been converted locally into siliceous iron carbonate by solutions of igneous origin. Deposits of this type attain lengths measurable in miles and widths measurable in hundreds of feet; their outlines are irregular, though broadly speaking they conform with the structure of the associated lavas and pyroclastics. Relatively small bodies of iron-bearing carbonate of similar origin occur within the Hastings limestone in Madoc district, Ontario.

Detailed descriptions of the iron carbonate bodies in Michipicoten district, Ontario, have been published.[1] Huge masses occur at Helen and Magpie mines and the material from the latter has been used as beneficiated ore after sintering.

To find a deposit of this type prospectors are advised to search in the vicinity of known deposits, and, generally in the Keewatin lavas of northern Ontario and Quebec in the neighbourhood of banded iron formation. The surface of iron carbonate rocks is normally coated with a rust-coloured alteration product.

IRON ORES FORMED BY WEATHERING

Weathering affects all rocks at or very near the earth's surface and in the course of time it causes profound alterations in rocks that contain minerals that are not stable under surface conditions. *Residual iron ores* are formed where as a result of weathering the ferruginous constituents of a rock become altered to hydrated iron oxides (which are stable under surface conditions) and freed of its non-ferruginous constituents. In certain countries ores of this type have been derived from igneous rocks such as peridotite. In Canada, ore of this type has resulted from the alteration of iron formation as described below, and also from the weathering of masses of iron carbonate rock, previously described. In the latter, the carbonate rock has altered to brown ore to variable depths beneath the exposed surfaces, giving rise to irregular pockets of variable size.

A big pocket of this type was mined on the Helen iron range, Michipicoten, prior to 1918. It yielded over 2,500,000 tons of ore. Several undeveloped occurrences are known in Michipicoten district.[2]

The alteration of ferruginous phases of the Hastings limestone in Madoc district, Ontario, has resulted in the formation of numerous pockets of hematite ore, several of which have been mined; the largest was at Wallbridge mine and yielded 100,000 tons.

Favourable prospecting grounds for ore of this type are in areas underlain by rocks rich in iron carbonate, such as are known in Madoc and Michipicoten areas and at numerous other localities where Keewatin rocks have been mapped in the Canadian Shield. The surface appearance is rusty brown, earthy, and more or less porous material.

[1] "Michipicoten Iron Ranges"; Geol. Surv., Canada, Mem. 147 (1926).
[2] Geol. Surv., Canada, Mem. 147 (1926).

The ore concentrations differ from the common rusty coating over weathered ferruginous rocks only in respect to depth and size. Any extensive coating of brown ore which cannot be readily penetrated down to the unaltered rock by the use of a prospector's pick is worthy of test pitting and drilling in the hope of proving a body of commercial size.

SEDIMENTARY DEPOSITS

(i) *Placers.* The type of ore known as *magnetic sands* is produced by a combination of weathering and mechanical concentration. The former process does not cause a chemical alteration of the magnetite in primary or igneous rocks, but by decomposing the surrounding minerals it sets the magnetite free as grains. As the rock disintegrates these grains may either be washed free of impurities by wave action or concentrated during transportation in water, due to their great density, hardness, and chemical stability.

Extensive deposits of magnetic sand occur on the north shore of St. Lawrence gulf and river in Quebec[1] and these have yielded important quantities of iron ore. Deposits a few feet in thickness and several thousand feet in length occur along the east and west shores of Black bay and near Peninsula harbour, lake Superior. These deposits are of recent age and are not consolidated. An ancient deposit of the same type occurs embedded in the Cretaceous rocks at Burmis, near Blairmore, Alberta.

In addition to the general areas referred to above, prospectors for this type of deposit would be warranted in examining beach and river deposits formed in the vicinity of highlands on which magnetite-bearing rocks occur. The material can be readily identified by its black colour and magnetic properties. The size of the deposits can be more readily estimated than can any of the previously mentioned types of iron ore; the beds usually have the shape of plates or lenses and the character of the material is relatively uniform over considerable parts of any one bed.

(ii) During weathering certain iron compounds are taken into solution by oxidizing underground waters that contain carbonic and other acids. The mineralized waters circulate through the pore space in the rocks under the action of gravity and they precipitate their iron content upon the escape of carbon dioxide from the solution.

Bog ores of limonite are formed where the iron-bearing underground waters issue as springs from hill sides or in valleys and meet the carbonaceous reducing agents, which commonly occur at such places in ponds or bogs. The precipitate first forms as a flocculent, jelly-like mass of rusty brown, hydrated iron oxide. It becomes consolidated in time and may form hard, nodular masses of limonite. The size and shape of bog deposits are dependent largely on the course taken by the mineralized spring water after it issues from the ground; if the point of emergence is in the bottom of a depression the deposit will spread out as on the bottom of a pond; if the point of emergence is on a slope the deposit will be relatively

[1] Mackenzie, Geo. C.: "Magnetic Iron Sands"; Mines Branch, Dept. of Mines, Canada (1912).

thin and will spread out as a fan on the lower part of the slope. Bog ore deposits commonly contain variable amounts of manganese oxide, phosphoric acid, and organic matter, which are precipitated by chemical process, and also contain mechanically contributed impurities such as sand and clay.

Deposits of this type are found in great abundance in many localities in Canada, particularly in St. Lawrence valley, Quebec. In the vicinity of Knowlton, Ontario, 90 miles northwesterly from Fort William, bog ores are reported as occurring extensively in numerous lakes and ponds. The earliest iron-making industry in Canada was based on the bog ore used at Three Rivers, Quebec. The deposits that were known to be of commercial value have been exhausted and no ore of this type has been mined in recent years.

Bog ore deposits are found by observing either the flocculent hydrous iron oxide or limonite in bogs; and the extent and thickness of the deposits are found by drilling with an auger or a peat drill. The present scale of operations in the iron-making industry is such that there is no likelihood that bog ore deposits of sufficient size and richness to be of commercial value will be found in Canada.

Underground precipitation of limonite occasionally occurs in porous rocks due to processes that are equivalent to those operative in forming bog ore deposits, except that precipitating conditions are encountered by the circulating, iron-bearing, underground waters before they issue at the surface.

Examples of this type of deposit are known near Londonderry in Nova Scotia.

(iii) Extensive sedimentary deposits consisting chiefly of iron minerals and silica occur among the stratified rocks of Precambrian age at intervals throughout the Canadian Shield. These rocks are known as iron formations. Beds made up largely of oolitic hematite occur interbedded with other (early Palæozoic) sediments in Canada. These ferruginous beds are of the same type as those in the Clinton (Silurian) formation which has yielded large quantities of ore in Alabama and other Appalachian states.

The Clinton type of deposits are in well-defined beds and are characteristically made up of oolites consisting of thin concentric shells of fine-grained silica and hematite disposed alternately. The chief iron ore of British origin now used in Canada comes from a deposit of this character mined at Wabana, Newfoundland. Beds of this type of iron ore also occur in Annapolis valley, Nova Scotia, and in New Brunswick.

The great iron formations of Animikie or Late Precambrian age, as known near Thunder bay, and Sutton lake, Ontario, and on Belcher islands and around Richmond gulf in Hudson bay, consist in part of oolitic hematite intimately associated with fine-grained silica, and in part of various other phases, both oolitic and finely laminated, in which one or more of the following iron minerals occurs along with silica: magnetite, siderite, and greenalite.

In the areas underlain by Early Precambrian formations which occur at intervals throughout the Canadian Shield, there are extensive belts of iron formation that have the appearance of folded and steeply inclined beds. They characteristically consist of layers of hematite and magnetite averaging between $\frac{1}{4}$ and $\frac{1}{2}$ inch in thickness, interlaminated with layers of fine-grained silica of equivalent thickness; groups of these layers make up thicknesses of the order of 100 feet, and in some areas they have been traced along their strike for thousands of feet.

The Early Precambrian iron formations are commonly associated with andesitic lavas; the other iron formations occur along with shaly or carbonate sediments.

Generally speaking, the main part of any large body of iron formation is too lean in iron to be considered as an ore, the average iron content is usually less than 25 per cent. These iron formations are, however, the source of the largest and richest iron ore deposits known; the latter occur within the iron formations and are believed to be parts of the rock that have been subjected to the action of certain geological processes that have caused an alteration and rearrangement of the original constituents in such manner as to make the iron commercially available.

Where iron formation has been subjected to intense heat and pressure there is normally a development of magnetite in greater proportion than in the original formation, and the materials may become recrystallized and rearranged in such manner as to produce a local concentration of the magnetite. A considerable tonnage of magnetically separated ore has been produced from a highly altered iron formation of this type at Moose Mountain mine, Sellwood, Ont. On the Atikokan Iron range in northwestern Ontario, where iron formation has been folded and intimately intruded by a fine-grained gabbro, it has been estimated that there are millions of tons of sulphur-bearing magnetic ore. Ore produced from Atikokan Iron mine in 1907, 1909, 1910, and 1911 was roasted before being smelted.

There are undoubtedly enormous tonnages of magnetite in several of the known iron ranges that are distributed through northern Ontario, and where the material is not naturally rich it would be possible to produce a high-grade ore by magnetic concentration or some other process of beneficiation. Experience with beneficiated ores has been gained at places that are well situated with respect to transportation facilities and markets, namely Moose Mountain and Port Arthur, and no ore is now being produced at these places. Until operations of this character are found to be more profitable there is no incentive for prospectors to search for ore of this type.

Iron formation, consisting of silica and one or more of the following minerals, iron carbonate, greenalite, and hematite, when subjected to a long-continued process of weathering and leaching by circulating underground waters, is converted into hematite ore. The iron-bearing minerals alter to hematite and the associated silica which is relatively more soluble in under ground waters is removed in solution. The ferruginous rock becomes consolidated in time, due to slumping and chemical rearrangements of its constituents. Ore-bodies of this type outcrop at the rock surface at some place within the iron formation during the period of their formation, and they extend underground to variable depths and along devious courses as developed by the circulation of underground waters within the original iron formation.

Ore of this type is the chief source of iron at present, but the known Canadian occurrences, e.g., Loon, Ontario, and at Josephine mine, Michipicoten district, are small in comparison with those of Minnesota, Wisconsin, and Michigan and they are not being mined. In order to be of the quality of the Lake Superior iron ore it is necessary that the material contain over 50 per cent iron and very little sulphur and phosphorus. In ores used for acid bessemer pig the permissible phosphorus maximum is 0·001 part of the percentage of iron.

To find an ore of this type an examination should be made of outcrops in areas underlain by iron formation (any geological age) with a view to finding a part of the formation deficient in silica and rich in hematite. The surface appearance of the material may be red, brown, or dark bluish grey, yielding in all cases a red powder when pulverized. Since the deposit is not an unaltered sediment no regular continuity nor great extent can be predicted between or beyond the observations. Chemical analyses should be made of channel samples taken across material identified in the field as probable ore. The determination of the size of ore-bodies requires a systematic exploration by diamond drilling. The core is usually split longitudinally in half and analysed in lengths representative of each 5 feet.

In areas, which are mostly drift-covered, where iron formation is believed to occur extensively on the solid rock surface, as shown by geological mapping, experience has shown that iron ore-bodies of this type may be found by systematic drilling explorations through the drift. Nearly all of the large iron mines of Mesabi and Cuyuna districts, Minnesota, are in deposits found in this way; there were no surface indications either in outcrops or in the character of the drift to give a clue to the position of the ore. If a consideration of the geological history of an area led to the conclusion that ore-forming processes had been operative in the iron formation of that region and that the ore had not been subsequently scoured away by glaciation, the results obtained in Minnesota would appear to warrant equivalent explorations in the similar rocks that occur in Canada.

MANGANESE

(T. L. Tanton)

Ores of manganese consist chiefly of pyrolusite (MnO_2) with Mn 63·2 per cent and psilomelane or wad, an hydrated oxide of variable composition. Concentrations of these minerals occur in types of rock similar to those in which limonitic iron ores are found, and the geological processes involved in their formation are the same. They occur as residual ores and as chemical precipitates from solutions either as sediments or in underground cavities. Manganese is usually carried in solutions as a carbonate or sulphate. These salts are more soluble than the corresponding salts of iron. When underground solutions, mineralized with both iron and manganese, encounter precipitating agents, the iron and manganese oxides are thrown down separately. Thus, although limonite is commonly associated with manganese ore, there is a wide variation in the intimacy of their association.

Residual managanese ore consists of black manganese oxide, usually concretionary nodules, formed by the weathering of manganese-bearing rocks. There is an occurrence of this type in the quartzites of the Sicker series near Cowichan lake, Vancouver island. Here the manganese-bearing mineral in the unweathered rock is rhodonite, the silicate of manganese.

Soft bog manganese ores or wad are deposited by springs near their places of emergence on the surface of the ground. The principal known occurrences in Canada are in New Brunswick and they there have surficial extents up to several acres and depths varying from a few inches to 20 feet.

Underground deposits of hard ore occur in weathered granite and in sediments in forms that have been described as veins, kidneys, streaks, and large pockets. The manganese dioxide of these deposits was precipitated from circulating underground waters prior to their emergence at the surface, in part as a cavity filling and in part as a replacement. Examples of deposits of this type are known in the Carboniferous sediments in New Brunswick and Nova Scotia, and as a vein in biotite granite in New Ross district, Nova Scotia.

There is a possibility that new discoveries of manganese ore may be made in the general vicinity of the known deposits in Canada. A statement regarding these numerous localities, together with the manner of occurrence at each, is given in the Final Report Munitions Resources Commission, Canada, 1920.

There is also a possibility that manganese ores, similar to occurrences in Cuyuna district, Minnesota, may be found in weathered iron formations of Precambrian age in northern Ontario.

The surface appearance of the deposits is notably the black colour of the rock. It is also jet black when pulverized. In bog deposits it may be gelatinous or earthy in texture, or it may show a skeleton structure of hard, glossy, black material with earthy black material in the meshes. There is a tendency toward nodular and botryoidal forms in the well-crystallized material. Any rock containing an abundance of black, earthy or glossy, fairly heavy mineral should be assayed for manganese. Merchantable ore contains 40 per cent or more of manganese.

CLAYS, SANDS, AND RELATED DEPOSITS

(W. A. Johnston)

Clays are used for making bricks of various kinds, tile, sewer-pipe, pottery, earthenware, and for modelling. They are also used in the manufacture of cement and paper and in many other ways. There are many kinds of clays and the use to which a deposit of clay can be put depends partly on the character of the clay. For example, clay, which contains appreciable quantities of fluxing impurities such as lime and magnesia, cannot be used with success in the manufacture of firebrick. Chemical analyses may be of some value in determining the value of a clay deposit for certain purposes, but the best method is by actual tests; for the physical character of a clay does not depend entirely on its chemical constitution. Testing of clay to determine its value for the making of bricks, or for other purposes, is done in the laboratories of the Mines Branch, Department of Mines, Ottawa. Samples of at least 2 pounds are required for preliminary testing.

The clays of Canada may be broadly divided into three classes: (1) glacial drift clays, (2) residual clays, and (3) shales (hardened clays). The clays of each of these classes have definite characteristics which determine to some extent the value of the clays for industrial uses.

Glacial drift clays include stratified deposits formed in glacial lakes and in arms of the sea, interglacial deposits formed during times of retreat of the ice, unstratified clays deposited by the ice-sheets, and alluvial clays (flood-plain deposits of streams). All of these deposits, except the alluvial clays, were formed during the glacial period. A part of the alluvial clays was deposited by the present streams and a part by streams during the closing stages of glaciation.

All these clays contain a large amount of fluxing impurities (lime, iron, magnesia, and alkalis); consequently, they need be burned at only a comparatively low temperature in making structural materials, but none of them is suitable for making vitrified clay products. They are of value for the manufacture of common brick and field drain-tile and in the making of cement. They are also occasionally used for modelling and for the manufacture of pottery, but not, as a rule, for other purposes.

The character of the clays varies greatly from place to place and depends largely on the character of the rocks from which the material was derived by glacial action. In areas that are underlain by shales or impure limestones, the clays are "fat," that is they contain a great deal of very fine clayey material. In regions where hard crystalline rocks are abundant, as in the Canadian Shield, the clays are "lean"; they contain considerable silt and fine sand. Plasticity in clays is caused by the presence of large amounts of extremely fine materials and some clays, for example the underclays in Red River valley, Manitoba, are so highly plastic that they cannot be manufactured into bricks without special treatment. On the other hand, some clays contain so little very fine material that they are not sufficiently plastic to be workable. If the clays are high in lime the resulting brick is white or pale buff, the lime taking up the iron to form a colourless silicate. Iron is the chief colouring agent and if the lime in the clay is low in proportion to the iron, the resulting brick is some shade of red. In most areas the surface clay to a depth of 1 to 3 feet contains little or no lime because of the effects of weathering and bricks made from it are some shade of red.

Glacial lake clays occur at many places in the Great Plains and in the Great Lakes region. Glacio-marine clays are abundant in Ottawa and St. Lawrence valleys and occur in places in a wide belt around Hudson and James bays. Interglacial clays are known to occur only at Toronto, but may be found at other places. They are distinguished from the Glacial lake clays by their low content of lime. They are, therefore, red burning. Glacial clay (boulder clay) is free enough from stones and coarse rock particles to be used for the manufacture of brick and tile at a few places in southern Ontario. Boulder clays as a rule are too stony to be used in the manufacture of clay products and the lime concretions and pebbles that occur in places in the glacial lake and glacio-marine clays are a detriment to these clays. Alluvial clays occur along many of the larger streams that overflow their banks in times of flood. They are derived for the most part by stream erosion of the glacial drift, usually contain considerable amounts of organic matter along with fine sand and silt, and, therefore, are open in texture and more easily worked than the glacial lake or marine clays, but have little "body." Glacial lake and marine clays suitable for use in the manufacture of cement occur at many places in Ontario, Quebec, and the Great Plains. The raw materials used in the manufacture of cement consist of about 75 per cent of calcium carbonate (limestone, marl, or chalk) and 25 per cent of clay. The clay should be as free as possible from coarse rock particles, gravel, and concretions and should have a fairly low and uniform content of the fluxing impurities.

Residual clays are the result of weathering and leaching of rocks by surface and ground waters. Certain types may have been formed by the action of chemically active vapours, or by hot solutions ascending from below. These agencies tend to cause alteration of the aluminous minerals in rocks, as feldspar, to kaolin the purest form of clay, and to remove the soluble constituents, as lime, magnesia, soda, and potash. The clay may be impure and contain iron compounds and resistant minerals as quartz, mica, and associated minerals, or may consist mostly of kaolin (depending on the character of the rock from which the clay was derived). The residual clay most highly valued is kaolin from granites and pegmatites. Pure kaolin is white, remains white in burning, and is the most refractory of all clays. Most kaolin deposits are impure and the crude kaolin must be prepared by a washing process which removes the impurities. The fine white clay thus obtained is known as china-clay. Most residual clays have been formed in place above or in the rocks from which they have been derived; some were transported by streams and redeposited in beds. The known deposits in Canada are Tertiary or Mesozoic in age.

Residual clays occur only rarely in Canada, partly because of the effects of glaciation. A deposit of kaolin due to the decomposition of a diabase dyke occurs in the abandoned Helen iron mine, Michipicoten district, Ontario. The only kaolin deposit that has been worked in Canada is at St. Remi-d'Amherst, Quebec. Fairly extensive deposits of Mesozoic high-grade clays that probably are transported residual clays occur along Missinaibi and Mattagami rivers in northern Ontario. There are small areas of somewhat similar clays at Middle Musquodoboit and Shubenacadie, Nova Scotia, large areas in southern Saskatchewan and in northern Alberta, north of McMurray, on Athabaska river and its tributaries. Residual clay, which is of a refractory character, occurs at Kyuquot on Vancouver island. The presence of residual clays formed in place at a few localities indicates that others may occur in spite of the effects of glaciation. Transported residual clays are most likely to occur in slightly consolidated Tertiary and Mesozoic deposits. They may occur also as the result of weathering of lava and tuffs. Some residual clays are fire-clays, that is they have the ability to withstand a high degree of heat without softening; others are refractory as fire-clay, but burn to a very dense body at temperatures at which fire-clay remains open and porous, and are called stoneware clays. There is no way of definitely determining in the field the character of a clay, but most high-grade clays are white or light grey. Some, however, are mottled, pinkish or even black.

The underclays of coal seams and occasionally clays overlying coal seams have been leached in places by circulating groundwaters and, therefore, may be regarded as, in part, residual clays. It is customary for miners to apply the term fire-clay to all clays and shales found underlying coal beds; but although underclays in parts of the world are fire-clays, many are not. A high-grade fire-clay associated with thin coal seams occurs near

Clayburn in Fraser valley, British Columbia. Of the great number of clays and shales underlying coal seams in the Maritime Provinces that have been tested, only one proved to be fire-clay; and the same is true in Alberta and Saskatchewan.

Shales that develop plasticity when they are ground fine form the raw material in the manufacture of clay products, as well as clays, and are more extensively used than are clays. Many shales are only slightly hardened and are frequently referred to as clays. They are used in preference to clays as they give in many cases a denser and stronger product. Their drying properties are better than those of clay, their shrinkage is less, and they are not so easily overfired. On the other hand shales cannot be worked by the simple methods and equipment commonly used for clays. As in the case of clays the character of the shales largely determines the kinds of clay products that can be manufactured from the shale.

Shales of various kinds and ranging in age from the Precambrian to the Tertiary are used in Canada in the manufacture of clay products either alone or mixed with clay. Shales of the Lower Carboniferous and of the Coal Measures in the Maritime Provinces are used for the manufacture of pressed brick, sewer-pipe, drain tile, and semi-refractory bricks. In Quebec shales of the Sillery, Levis, Utica-Lorraine, and Medina formations are used for the manufacture of common brick, paving brick, and sewer-pipe. The Lorraine and Queenston (Ordovician) shales are the chief shales used in Ontario, the clay products being dry-pressed, rough-faced, and wire-cut bricks and various kinds of tile. In the Great Plains, shales of the Pierre, Belly River, Edmonton, and Tertiary formations are used or have been found of value in the manufacture of clay products. A valuable series of refractory and semi-refractory clays occur in the Whitemud and Ravenscrag formations in Dirt Hills and Willowbunch areas in southern Saskatchewan and semi-refractory in Cypress hills. Semi-refractory clays also occur in the Belly River formation in Medicine Hat district, Alberta. Tertiary shales at Sumas mountain and at Blue mountain in Fraser valley, British Columbia, yield refractory and semi-refractory clays suitable for the manufacture of firebrick and vitrified products.

Geological maps show the distribution of the shale-bearing formations in many parts of Canada and are an aid in prospecting for clays.

Sands are used for sandlime brick, for mortar, cement, and concrete work, for admixture in clay, and as a parting sand in the manufacture of brick, as a filler in stucco work, for moulding and core sands, for glass manufacture, and for many other purposes. For structural uses, sands do not require to be pure and are obtained for the most part from the glacial drift. There are certain definite requirements in sands, however, for moulding practice, in glass manufacture, and for other special purposes, as the manufacture of silica brick and carborundum. Moulding sand is a mixture of sand and a bonding material that is ordinarily impure clay containing iron oxide. The degree of coarseness and fusibility of the sand and the amount of bonding material depend on the purposes for which the sands are required. For high temperature work such as steel castings, refractory sand of relatively coarse grain with limited bonding material is most satisfactory. For small iron castings, intermediate types of sand are used: for heavy iron castings, sand with a very heavy clay bond is necessary.

For the manufacture of glass, high silica sands low in iron are required, preferably of medium coarseness, of uniform grade and angular. The sand should contain over 99 per cent silica. Iron oxide is the commonest impurity; it should not exceed 0·20 per cent except in the case of sand used for the manufacture of dark bottles.

Sands for use in the manufacture of silica brick and carborundum require to have even a higher percentage of silica than glass sands. It is necessary that they contain practically no fluxing impurities.

Sands that are nearly pure silica do not occur as a rule in the glacial drift; the only known occurrence being at Beausejour in eastern Manitoba, where sand was formerly obtained for the manufacture of bottle glass. They are found at a few places in slightly consolidated Mesozoic deposits in northern Ontario. Their chief source is in quartzites of the Precambrian, as at Sault Ste. Marie, in the Potsdam sandstone of Ontario and Quebec, in the Winnipeg sandstone on lake Winnipeg, in the Lower Cretaceous sandstone in northwestern Manitoba and northern Saskatchewan, and in the Cambrian quartzites of the southern Rocky mountains. Moulding sand occurs in the glacial drift at a number of places, as at Melbourne siding, Manitoba, and near Brockville, Ontario.

Fuller's earth is a clay-like material that is greenish white or grey, olive green, or brownish, soft, and with a greasy feel. It has a high absorbent power for many substances and is used for bleaching cotton oil and lard oil. It is not known to occur in Canada.

Bauxite is hydrated aluminium oxide, whereas pure clay is hydrated aluminium silicate. It is the only ore of aluminium at present in use. It is in some cases very like clay in appearance, but in more cases it has a pisolitic structure, that is, made up of small, rounded masses. The best grades of bauxite contain 57 or 58 per cent of aluminium oxide. Bauxite has not been found in Canada. Deposits allied to bauxite, however, occur near Sooke on Vancouver island. They contain 20 to 30 per cent of aluminium oxide.

Diatomaceous earth is a siliceous earthy material composed of the siliceous parts of diatoms deposited in ponds. The material is white or grey and some is greyish brown. It is used as an abrasive material, as a heat insulator, and for filtration, as well as for other minor purposes. It occurs at many places in Nova Scotia and New Brunswick. All the worked deposits have been rendered accessible by the draining of the lakes in which the earth had been found. It also occurs as beds in Tertiary deposits in Fraser valley near Quesnel, British Columbia.

Marl. In Canada the term marl is applied only to chalky, friable deposits of lime carbonate, found in many places beneath peat beds or in the bottoms of small lakes. On account of its softness, whiteness, and slight plasticity it may be mistaken for kaolin.

Bentonite is a light-coloured, extremely plastic clay that has the property when wetted to saturation of swelling to several times the dry bulk. It occurs as thin beds at many places in the Cretaceous and Tertiary deposits of the Great Plains and British Columbia. Possible uses are as an absorbent, as a filler for explosives and fertilizers, for use in the manufacture of lubricants, paints, paper, soaps, and in other ways.

Natural cement is an impure limestone that contains approximately 75 per cent of calcium carbonate and 25 per cent of clay. It requires only burning and grinding to produce a slow setting cement. It occurs in the Niobrara formation at places in southwestern Manitoba, and has been used for the manufacture of cement near Leary, Manitoba.

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STRUCTURAL MATERIALS

(F. A. Kerr)

Under this heading is included a large number of products, mainly of quarrying rather than mining. The more important materials can be classified under three general headings: sedimentary, igneous, and metamorphic.

—	Important uses
Sedimentary	Sandstone—building stone, grindstones, pulpstones, silica brick, refractory stone
	Limestone (and dolomite)—building and ornamental[1] stone, cement, riprap, rubble, terrazzo flooring, stucco dash, concrete facing, flux
Igneous	Granite, etc.—building and ornamental[1] stone, crushed stone, riprap, rubble, paving blocks
	Basalt—crushed stone, paving blocks, pulpstones
Metamorphic	Slate—roofing, blackboards, billiard table tops, switchboards, flagging, vaults, granules for prepared asphalt paper roofing (composition shingles), paint, stucco dash filler in oil cloth, school slates, concrete facing, terrazzo flooring
	Marble (including coarsely and finely crystalline limestone)—*See* Limestone
	Gneiss—building and ornamental[1] stone
	Quartzite—paving blocks, building stone, silica brick, refractory stone
	Serpentine—ornamental[1] and building stone, granules for roofing
	Talc and soapstone—wash tubs, sanitary appliances, laboratory tables and tanks, switchboards

[1] "Ornamental" includes exterior and interior decorating, partitions, table tops, monuments, carved works.

CHIEF REQUISITES

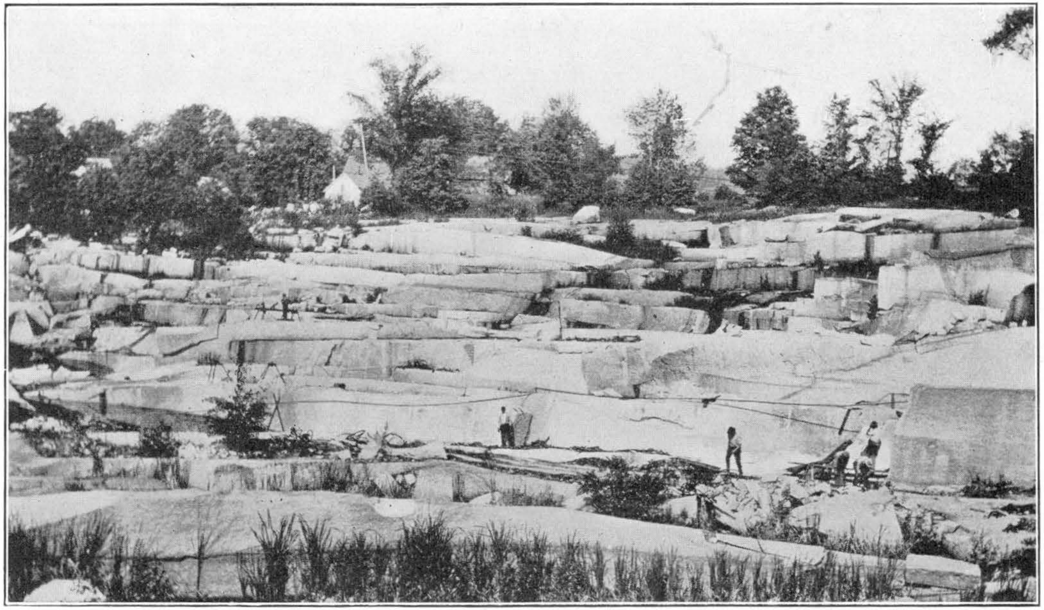
The chief requisites for building stone are strength, durability, colour, and facility of cutting. Almost any stone has sufficient strength for ordinary building purposes. However, it should be fairly free of joints, shear planes, cavities, distinct bedding planes, and other weaknesses that are liable to develop fractures. Durability can be ascertained somewhat in the field by observing the effect of weathering on exposed surfaces: hardness, porosity, composition, impurities, and lack of uniformity have an important bearing on this quality. The stone should be of a pleasing and durable colour and if selected for some special purpose should harmonize with the surroundings. Marcasite, pyrite, and iron carbonates if at all abundant are serious defects, as is also the presence of much bitumen in limestone or marble. They weather rapidly, weaken the stone, and cause rust spots. Unless a rock can be cut easily it is of little value. Sheeting or more or less horizontal fracturing is essential in granite quarrying.

Some vertical joints and, in sediments, a few distinct bedding planes, are sometimes desirable, but most of the quarry operators using modern cutting machines prefer none at all. The best granites have a well-developed grain and rift—two directions at right angles along which the rock can be broken fairly easily. Many of the most valued sedimentary stones when first exposed are rather soft and easily cut, but harden on seasoning. Uniformity in colour, texture, hardness, and other characteristics is generally desired. Nodules, concretions, veins, segregations, streaks, all impair the value of the stone.

For ornamental purposes the requisites are in general the same as for building stone. Colour and colour design are very important considerations. Lack of uniformity in design, especially in marbles, is sometimes an asset instead of a detriment. The value of decorative material lies largely in its beauty and freedom from blemishes and the facility with which it can be cut or carved and, usually, polished.

In slate for roofing and similar purposes most of the factors that affect the worth of building stones are also important considerations. The value of slate depends mainly upon its cleavability, or the tendency to split into thin sheets. The smoother and more even the surface of these the better is the slate. The grain, or a tendency to split at right angles to the cleavage, should be developed well enough to permit splitting, but not so well as to break under strain. Good slate when suspended and struck yields a distinct ringing sound. Its strength can be tested by supporting a sheet of ordinary thickness at both ends and exerting pressure in the centre. Bending without breaking is an asset, for slates with considerable elasticity are less liable to break on splitting. The material should not be so friable as to crack when nail holes are punched in the sheets. Conspicuous bedding or banding is often a sign of weakness. The presence of much calcium carbonate, which can be ascertained by testing with dilute hydrochloric acid, in many cases renders a slate less durable. Spotting, which is the result of the presence of organic material in the original deposit, causes an inferior product. Deterioration in colour is a detriment, though it does not necessarily mean a loss of strength and when uniform is not serious.

PLATE VII



Stanstead Granite Company's quarry, Graniteville, Quebec. Granite quarry showing sheeting.

Green slates are the most susceptible to fading. Abundant magnetite, which can be detected by grinding and extraction with a magnet, renders slate unsuitable for switchboards.

For granules to be used in the manufacture of prepared asphalt paper roofing, green and red slate, greenstone, and serpentine are commonly used. The waste from roofing slate quarries is not as a rule utilized for this purpose, though its use would seem feasible. Although some of the characteristics of good building stone and roofing slate are desirable, many are unnecessary because the material is ground very fine and embedded in asphalt. It should be fairly easily ground, but at the same time should not produce too much very fine material. So far as possible it should have the same qualities that make for durability as roofing slate.

For stucco dash, concrete facing, and terrazzo flooring slate of various colours, limestone, and marble find favour. The fact that they are easily broken and crushed and as a rule are as durable as any matrix used to cement them gives them preference over other types of material, though many other kinds of igneous and metamorphic rocks can be used. Brightly coloured rocks, such as green and red slate, white and grey marble, are as a rule preferred. Coarsely crystalline limestone, because of its numerous sparkling facets, is used for ornamental purposes. Granite and other igneous rocks often serve to give a finish like genuine stone. Although many kinds of material will serve the purposes selection of a rock to be used should be governed to some extent by the same requirements as for other structural materials.

For grindstones, pulpstones, and other abrasive stones, sandstone is most commonly used. The most essential characteristic, besides those which are fairly general for structural materials, is that of always presenting a rough surface while in use. The grains of the sandstone should be firmly held in place, but the cement should be sufficiently soft or scarce to wear more quickly than the grains, thus permitting them to protrude always. For pulpstones the grains should be of medium size and subangular; angular grains cut the fibre and rounded grains tend to polish. The size of grain desirable varies somewhat with the grade of pulp required. The rock must be sufficiently uniform and free from fractures, first, to make it possible to obtain the large blocks required, and second, to ensure even wear. It must have strength to resist considerable stress and strain, yet be of such a nature as to be easily chipped and shaped. The stone generally hardens considerably on seasoning. Pulpstones are manufactured from vesicular lava in Germany. The same characteristics would be required of this as of the sandstone.

In all cases, if extensive operations are contemplated there are a large number of exacting laboratory tests which should be carried out upon the product before any great outlay is made. These are fully outlined in several of the references given at the end of this section. The Mines Branch of the Department of Mines, Ottawa, has facilities for carrying out most of these tests or can supply information as to where they could be made.

The most important properties of crushed stone for road materials are hardness, toughness, abrasion resistance, and cementing value. Hardness is the ability to stand up under abrasion by sand. Toughness is the resistance to impacts such as the striking blow of a shod horse. Abrasion resistance is the ability of the stone to wear when fragments of it are rubbed together. By cementing value is meant the binding power of the road material. The quality of the stone in these respects, as for other structural materials, can be ascertained, other than through actual use, by certain laboratory tests which are described in the publications listed and can be made by the Mines Branch, Department of Mines, Ottawa.

A very great number of different kinds of rocks have been used and tested; in fact there are few which have not been brought into service. The tests of each kind show considerable range of merit, and if possible it is better to demand rock which meets certain specifications rather than a definite kind of material. In general the following order of preference may be cited: (in all cases fresh material is superior to weathered).

Trap, and, in general, fine-grained basic rocks (mainly dark in colour): hard, tough, of high abrasion resistance, and good cementing value if traffic is heavy enough to wear the stone.

Coarse-grained basic rocks (mainly dark in colour); wearing qualities not as good as preceding group. Their cementing value and hardness about equal those of trap, but they are inferior in toughness.

Coarse-grained acid rocks, such as granite (mainly light in colour): low toughness, and poor cementing value; the wearing qualities are about equal to the second group. In general, the finer the grain the better is the quality of the material.

Slates, argillites, etc.: these in general show moderately good wearing qualities, low hardness and toughness, and only fair cementing value. Slates and schists split readily into chips, which is objectionable.

Quartzites and sandstones: these have good wearing qualities and toughness, but are low in cementing value, and consequently are not good when used alone.

Limestone: low toughness, low hardness, poor wearing qualities except where traffic is light, and good cementing value.

For paving blocks the essential properties are resistance to weathering and sufficient abrasion resistance to prevent their wearing round and smooth under traffic. Granite is used most extensively because it splits easily. Trap, however, is harder and tougher and wears fairly uniformly, not round as granite does.

PROSPECTING FOR STRUCTURAL MATERIALS

The low value in comparison with the bulk and weight of all these products makes it essential that any deposit should be easily accessible to cheap transportation and not too distant from prospective markets, though an abundance of material of exceptional quality will in rare cases overcome serious obstacles in the way of transportation and distance.

The sedimentary structural materials are derived from strata of Palæozoic and Mesozoic age which have been greatly folded or altered. In prospecting, inclined beds present an advantage by exposing a greater number of layers for inspection; also in quarrying operations by a decrease in the amount of stripping necessary. However, slightly inclined or horizontal beds are as a rule superior in quality. They are less likely to be much fractured or jointed. They usually provide just three lines of fractures: the bedding planes and two systems of vertical joints which make it comparatively easy to quarry rough rectangular blocks. Folding in many cases develops irregular fractures and systems of joints which cut the bedding obliquely. The distance apart and clean development of bedding planes are important considerations. Strata that have been intruded by igneous masses or cut by dykes or veins should be avoided. The presence of these adds to the waste and causes difficulty in quarrying, and their injection may have developed fractures, altered the rock, and otherwise detracted from its value. The layers of rock at the surface are seldom good because of the effect of long-continued weathering, but they may serve to give some idea of the durability of the material, and in a general way may indicate the nature of the deposit.

Igneous rocks may be of any age. It is generally important that they should not have been greatly deformed by folding or faulting, nor intruded nor cut by other igneous rocks or veins. The quality of the stone in intrusive bodies such as granite is governed largely by its position within the igneous mass. Practically all the important characteristics of the rock itself are more variable near the contact, and segregations, inclusions, veins, and other things that affect the quality of the stone are more prevalent there. Consequently the stone that is most uniform and, therefore, as a rule best, should normally be found at some distance from the contact; that is, at those points within the exposures that are farthest from the sedimentary or other intruded rock. Occasionally this is not the case, for the roof of the igneous mass may have been flat or concave, so that the centre of the exposure would not represent the part of the mass farthest from the original contact. Dykes and small masses rarely provide good material. Deposits with relatively flat-domed surfaces as a rule provide the best sheeting—more or less horizontal fractures that are essential in granite quarrying. The character of the sheeting can rarely be ascertained without development work, though an artificial cut, as on a railway, or a natural cut, as a stream canyon, may show it in rare cases. For other uses than building and ornamental purposes many of the foregoing considerations need not affect the selection of a quarry site. Although the character of igneous rocks at the surface is never a fair criterion of their true merit, in many parts of Canada where clean glaciated surfaces have been left it will generally give a fairly good idea of what may be expected below.

Metamorphic rocks, other than serpentine, talc, and soapstone in eastern Canada are confined to the series older than the Carboniferous, but in British Columbia those of Mesozoic age also may fall within this group. Materials of this type occur only in areas where the rock has been subjected to great heat and pressure with, as a rule, intense folding. The strike and dip of the bedding do not greatly affect quarrying operations except where the band to be worked is relatively thin and must be followed carefully—then the strike and dip are very important. Work on a deposit of this sort is costly and is not attempted unless the material has special merit. The cleavability of slate varies greatly along and across the strike, due to variations in composition and in the conditions that developed the cleavage. The friable nature of slate renders improbable the obtaining of good stock near the surface, and marble due to its solubility is generally of poor quality where subjected to surface waters. Areas of igneous intrusions, of veins and faulting, should be avoided as much as possible. Owing to the deformed nature of the rocks it is always important to make a careful examination to ensure a fairly large area, preferably not narrow in any direction, in which the quality is good.

In the selection of a quarry site great care must be taken to ensure the quality and uniformity of the material, to provide good drainage and areas for waste, and to avoid unnecessary stripping. The outlay in setting up a plant and starting operations should never exceed that warranted by the known supply of suitable material. In other words, some fairly definite idea of the possibility of securing the quantity and quality desired must be ascertained first. Quarries located in low ground almost invariably have the additional expense of pumping water in order to keep the workings dry. If the location is made on high or sloping ground or near a deep valley natural drainage will as a rule carry away the water. However, at the same time an adequate supply of water for operating is essential. Some quarries cut a sump hole for this purpose, but it is far better to secure the water from another source and keep it out of the workings. So far as is possible the location of the quarry should be made where the overburden is least. In some cases a site on a slight slope will involve less stripping. A slope, also, in many cases affords better working conditions, as the quarry assumes the form of a cut. The top and one side of the blocks to be cut are easily exposed and transportation is somewhat simpler. The areas provided for waste should be selected far enough away so that it will not interfere with future quarrying operations.

Further information on these subjects as well as others, such as quarrying operations, may be obtained from the following publications:

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CHAPTER IV

OUTLINE OF THE GEOLOGY OF CANADA

(F. J. Alcock)

From the point of view of topography and geology, Canada falls naturally into six major divisions or provinces. The largest is the Canadian Shield, a vast area of almost 2,000,000 square miles surrounding Hudson bay. It is a plateau-like region that in few areas rises more than 1,500 or 2,000 feet above the sea, except in the northeastern part of Quebec and Labrador. It is covered with innumerable lakes of all sizes and is underlain mainly by rocks of Precambrian age. To the south it is bordered by the St. Lawrence lowland, a plain-like region developed on gently dipping strata of Palæozoic age extending from the lower St. Lawrence westward through Ontario to lake Huron. To the west of the Shield lie the Great Plains which stretch westward to the Rocky mountains and from the United States northward to the Arctic ocean. They form a plain and plateau region underlain by nearly horizontal or only slightly disturbed beds of Palæozoic, Mesozoic, and Tertiary ages. A fourth physiographic province lies north of the Shield. It comprises the islands of the Arctic archipelago and is made up of a series of plateaux formed of gently dipping strata. With this province is included the lowland along the southwest margin of Hudson bay developed on flat-lying Palæozoic measures.

The two remaining provinces are situated at the extreme east and the extreme west of Canada. Both are largely underlain by disturbed strata. The eastern province includes the Maritime Provinces and part of the province of Quebec south of St. Lawrence river. It is known as the Appalachian and Acadian physiographic province and is in large part a mountainous or hilly country. The western province is the great Cordilleran region of British Columbia and the Yukon, a region of mountain ranges and plateaux, with great differences of relief.

THE CANADIAN SHIELD

The Canadian Shield receives its name from the fact that it forms a triangular, shield-shaped area with its apex to the south. It is also commonly described as a V-shaped region with one arm on either side of Hudson bay. The area of this vast province is 1,825,000 square miles, or about one-half of the 3,729,665 square miles occupied by the whole of Canada. It stretches from Labrador on the east to the great lakes of the Mackenzie system on the west and from southern Ontario or latitude 44 north to the Arctic ocean.

Though its area is so great there is a remarkable sameness about the whole region. This is especially true as regards the topography. Throughout nearly its whole extent the most characteristic feature is the low relief.

Standing anywhere on an elevation, a sky-line almost as even as that of the sea meets the eye in every direction. In some parts, e.g., northern Manitoba, an elevation of 100 feet above the general level stands up as a prominent hill. Throughout most of the region the hills and ridges rise no more than 100 or 200 feeet above the level of the adjacent lakes and valley floors. Along the southern margin of the Shield and in northeastern Quebec along the Labrador border, the relief is considerably greater. Along the coast of Labrador some cliffs are 1,000 to 2,000 feet high and inland summits rise to 5,000 feet. These, however, show the same flat-topped character exhibited by the rest of the plateau, the greater amount of relief in this section being due to the fact that a higher uplift of the edge of the continent has allowed a larger degree of dissection of this even-topped plateau region.

Though the topography in general shows this remarkable uniformity, in detail it is very irregular. It is one of low hills and ridges separated by depressions which are occupied by lakes or muskeg swamps. The ridges are never continuous for long distances, but are commonly interrupted by cross depressions, so that travel except along the waterways is uniformly difficult.

The second most striking feature about this region is the large amount of it that is covered with water. Lakes of all sizes and shapes dot practically the entire region. Parts present the appearance of a drowned area with only the ridges projecting. The lakes as a rule are shallow and are marked by numerous islands. The outlets are frequently difficult to find, since long, narrow, blind bays are common. Many of the rivers are merely series of lake expansions connected by reaches in which rapids and waterfalls are numerous. In places the drainage takes place by a spilling from basin to basin. In this region of waterways, the common method of travel and transportation away from the railway or steamer routes is by canoe. It has been the means by which exploration, trade, and prospecting have been carried on, and though to a certain extent it is now being superseded by the hydroplane, it will long continue as an important means of travel in this vast district.

The climate throughout the Shield shows wide variations, as would naturally be expected from the wide range of latitude, and from the fact that a part borders the ocean and a part occupies the centre of the continent. In general it may be said that the summers are warm, the winters cold, and precipitation (rain and snow) from 10 to 25 inches yearly. In the southern part the lakes freeze about October and winter travel except in the settled districts along the railway is with dogs.

As regards vegetation, the region falls into two divisions, a southern wooded belt and a northern zone known as the Barren Lands. A line drawn diagonally from the mouth of Churchill river northwestward to the mouth of Mackenzie river is an approximate boundary between these two zones. The important trees of the wooded belt are white and black spruce and balsam fir. Jack-pine is abundant on the sand-plains, which occur along many of the lakes, on sandy terminal moraines, which cover wide areas, and on granite ridges. Tamarack, also, has a wide range and is especially common in the muskegs or swampy areas. Of the deciduous trees, aspen poplar and white birch are much the most important.

PLATE VIII

Typical view of the Canadian Shield. *(Photograph by the Air Board of Canada.)*

Except along its southern margin, settlement on the Canadian Shield is very sparse. The railways that cross Quebec and northern Ontario, the mining and lumbering industries of these regions, and a certain amount of agriculture in the clay belts are responsible for the chief activities. To the north, hunting, trapping, trading, and fishing have been the chief occupations of the scattered population. Now, however, prospecting is taking place over practically the whole of the shield and future development will doubtless depend on mineral discoveries.

The Canadian Shield consists of rocks of Precambrian age. It is part of a continental mass which, in Precambrian time, extended in all directions beyond the present limits. During succeeding geological periods the Canadian Shield was several times flooded, at least partly, by seas that advanced over it and later retreated. During these periods, sediments, including limestones, sandstones, and shales, were deposited. Later erosion removed nearly the whole covering and exposed the surface of Precambrian rocks. A few patches of the younger capping rocks still remain, as for example the Palæozoic outliers at lake Timiskaming and lake St. John.

Since the beginning of the Cambrian, the Canadian Shield has been a stable mass. It has suffered vertical movement, but has been unaffected by any folding or mountain-building revolutions. The Precambrian history is, however complicated. Precambrian time was very long, probably longer than all the time since the beginning of the Cambrian, which according to the latest estimations began about 700,000,000 years ago. During the long Precambrian era, volcanism and sedimentation on vast scales took place, and during at least two periods mountain ranges were built, which were subsequently eroded away to plains of low relief. The mountain-building periods were also characterized by the intrusion of igneous rocks, and these were responsible for the formation of many varieties of ore deposits.

Precambrian time can conveniently be divided into two major divisions which may be termed early Precambrian and late Precambrian. The former has been also described under such names as Archæan, Laurentian, and Archæozoic, and the latter under the terms Algonkian, Huronian, and Proterozoic.

Early Precambrian time is divisible into two periods. In the earlier period volcanism took place on a vast scale and lavas, commonly called Keewatin, accumulated in thicknesses measured in thousands of feet. Contemporaneous sedimentation also took place, so that with the lavas are interbedded tuffs and sediments, which in places have been altered to garnet-bearing gneisses and mica-schists. In Rainy River district of western Ontario, a thick series of such rocks, known as the Couchiching, underlies the Keewatin volcanics. In northern Manitoba and Saskatchewan similar altered sediments lie both beneath and interbedded with volcanic rocks.

In eastern Ontario and southwestern Quebec a thick series of sediments in which limestone is an important member may have been deposited in this period. This series is known as the Grenville and consists of limestone, quartzite, and sedimentary gneisses commonly carrying garnet and sillimanite.

This early period of volcanism and sedimentation was followed by widespread but gentle folding accompanied by the intrusion of granite. Succeeding this a series of sediments, known in different districts under various names such as the Timiskaming, the Windegokan, the Pontiac, accumulated. This period of sedimentation was succeeded in turn by a mountain-building revolution which was accompanied by widespread and general intrusion of granite, forming one of the great metallogenetic epochs of the Precambrian. A long period of quiescence succeeded, in which long-continued erosion reduced the mountainous region to low relief.

Late Precambrian time included the long period during which the Huronian and Keweenawan rocks accumulated on this eroded complex of igneous rocks. North of lake Huron the Huronian rocks consist of an older series known as the Bruce, consisting of from 10,000 to 15,000 feet of quartzites with, however, a limestone member and in places a basal conglomerate, and a younger series called the Cobalt, consisting of conglomerate, greywacke-conglomerate, slate, and quartzite, in places 10,000 feet thick. Part of the lower portion of the Cobalt series is made up of materials believed to have been derived by continental glaciation.

The Huronian rocks are intruded by thick sills of quartz diabase. In Lake Timiskaming district there is usually only one sill exposed in any given area. The sills vary in thickness up to 1,000 feet. In Sudbury region the intrusive of corresponding age is a norite which was intruded between the base of the Huronian rocks and the complex of older rocks on which these rest. In the district around lake Timiskaming the Huronian strata lie nearly horizontally. From the latitude of Sudbury south to lake Huron the sediments and sills are folded and faulted and locally intruded by the Killarney granite of late Precambrian age.

Bordering the north shore of lake Superior is a series of nearly flat-lying sediments consisting of conglomerate, iron formation, and dark slates. These are known under the name of Animikie, and are thought to be of the same age as the Upper Huronian rocks of other areas. East of Port Arthur these rocks are overlain by red conglomerate, sandstone and shale, calcareous beds, and tuffs with acid and basic lava flows on top. The whole are cut by dykes of diabase. These rocks, which are of Keweenawan or late Precambrian age, in places rest with a slight angular unconformity on the rocks of the Animikie series.

The Keweenawan was a period in which volcanic activity and intrusion took place on a vast scale. On the south shore of lake Superior lavas accumulated to a thickness of over 22,000 feet in the lower part of the series. Dykes of this age are common throughout most of the Shield. South of lake Superior the Duluth gabbro forms a laccolithic mass 100 miles in diameter.

Reference to the Sudbury nickel eruptive, which by most workers in the field has been considered Keweenawan, and to the Killarney granite, which belongs to this period of intrusion and mountain-building, has already been made.

These igneous rocks made the Keweenawan a very important period from the point of view of mineralization. The native copper ores of Keweenaw point in Michigan are in lava flows of this age and those of

Coppermine River region of northern Canada are similar and probably of the same age. The silver ores of Cobalt are related to the diabase intrusions and the copper-nickel ores of Sudbury to the norite intrusion.

The period of intrusion and folding in the Keweenawan was followed by a long period during which erosion once again reduced the topography to one of low relief, over which successive invasions of the sea were to take place in the succeeding Palæozoic and Mesozoic eras. The sediments deposited in these seas were in turn largely swept away by erosion in the Tertiary period. The last great event in the geological history of the Shield was continental glaciation during the Pleistocene. Huge sheets of ice moved out in all directions from their central gathering grounds on the two sides of Hudson bay. They smoothed down the topography, removed the old residual soil, polished, striated, and grooved the rocks, and by the irregular scattering of the debris over the surface completely disorganized the old drainage system. The result was the damming of old river channels, with the production of lakes and new drainage lines. Though the present low relief of the surface dates from Precambrian time, the present appearance of the country, with its lakes and rapids and waterfalls and its smoothed and rounded hills, dates from Pleistocene.

The mineral resources of the Canadian Shield are varied. In 1924 it produced 82 per cent of the gold of Canada, 57 per cent of the silver, 35 per cent of the copper, and all the nickel and cobalt. The various deposits may be grouped in four main classes: (1) certain pyrite deposits and banded iron formations which have the appearance of sedimentary formations but were probably of volcanic derivation. (2) Gold, gold-arsenic, pyrite, chalcopyrite, sphalerite, iron and titaniferous ores, corundum, apatite, mica, molybdenite, feldspar, graphite, all associated with granitic rocks or their differentiates. The most important period of mineralization was the period of granitic intrusion preceding the deposition of the Huronian rocks, though the later or Killarney granite included in Keweenawan times may in part be responsible for some of the deposits. (3) Nickel, copper, gold, and silver ores, and deposits of barite, associated with dykes, sills, and other intrusive masses of gabbro, and norite of late Precambrian age. (4) Ores of lead and zinc and deposits of barite, fluorite, and celestite in veins cutting Precambrian rocks for the most part, but also in places cutting Ordovician sediments along the margin of the Shield and hence deposited in post-Ordovician time.

The deposits of the second and third types have proved the most important. The borders of basic intrusions any place in the whole region should be searched for deposits of the class three type. For the number two type the borders of large and small intrusions of porphyry, granite, and granodiorite should be carefully prospected. Figure 10 suggests the reason why it is especially important to map small intrusions and to prospect around their borders. Since the intrusive rock supplied the solutions that produced the ore-bodies, the natural place where the minerals would be expected to be deposited is in the roof over the cooling magma. The removal by erosion of the overlying rock, finally exposed the intrusive rock. The deeper the dissection has gone, the more of the intrusive rock is there exposed and the greater are the chances that any ore-bodies that were formed above it have been destroyed by the erosion. Wide areas of granite, hence, offer less hope to the prospector than a field where small intrusive masses are found cutting an older series of rocks.

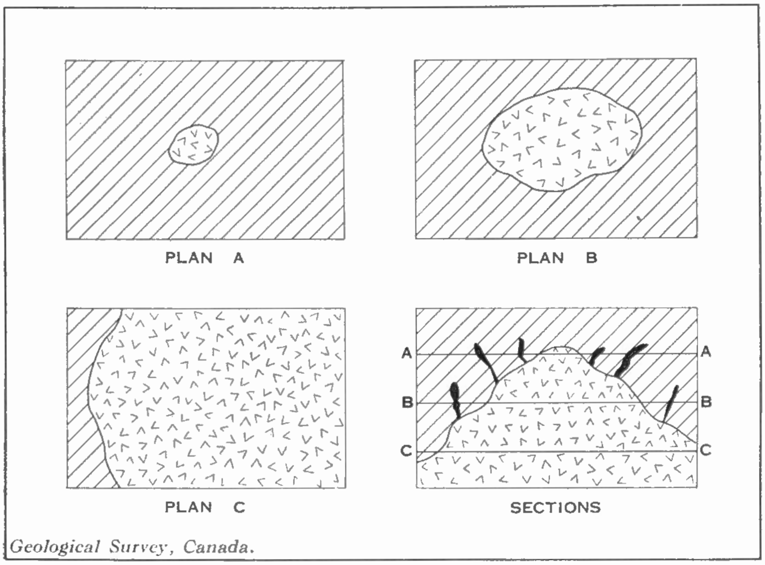


Figure 10. Stages in the erosion of a batholith with destruction of mineral deposits. Intruded rocks shown by oblique lines; intrusive rocks, angle pattern; mineral deposits, solid black.

The general succession of rock formations in the better known geological sub-provinces of the Canadian Shield is indicated in the following tables. The main mineral occurrences are shown opposite the country rock in which they are more commonly found. It must be emphasized, however, that a deposit is not necessarily confined to any one formation or rock type. For example, where granite is the source of the solutions that produced a deposit any of the older rocks that it intrudes may be mineralized.

Table I

Timiskaming Region and James Bay Slope

Formations	Mineral deposits	Geological habit
Palæozic	Coal Refractory clay Quartz sand	In beds
Keweenawan Olivine diabase Killarney granite Diabase, norite Conglomerate, sandstone	 Copper, nickel Silica, cobalt, arsenic	 Differentiates of norite In veins genetically related to the diabase
Whitewater series Conglomerate, tuff, slate, sandstone	 Zinc	 Veins in tuff
Cobalt series Quartzite, conglomerate	 Silica Silver, cobalt	 Upper part of Lorraine quartzite In veins related to diabase
Bruce series Quartzite, limestone, conglomerate (Granite intrusions)		
Timiskaming series (Windegokan, Pontiac, etc.) conglomerate, greywacke, arkose	 Gold	 In veins related to intrusive granite
Schist-complex Volcanics and derived schists	 Gold, copper, arsenic Copper, gold, zinc, pyrite Iron	 In veins Replacements related to granite Iron formation

Northwestern Ontario

Formations	Mineral deposits	Geological habit
Killarney granite		
Diabase	Silver, lead, zinc, barite	In veins related to the diabase
Kaministikwian Osler, conglomerate, sandstone, tuff Sibley, sandstone, shale, tuff Animikie, shale, iron formation	 Copper Silver Iron	 Veins and amygdules In veins In beds
Algoman granite	Lithium	In pegmatite dykes
Steeprock series Conglomerate, sandstone, limestone, slate, volcanics	 Iron	 In beds
Laurentian granite	Gold	In veins
Keewatin, volcanics	Gold, copper Iron Copper, nickel, platinum	In veins In beds Replacements derived from the crystallizing magma of the intrusive granites
Couchiching, mica-schists, garnet-gneisses		

Southeastern Ontario and Southwestern Quebec

Formations	Mineral deposits	Geological habit
Granite, Grenville and Rigaud stocks		
Diabase		
Lamprophyre		
Granite, syenite, etc	Feldspar, beryl, radium-bearing minerals	In pegmatite dykes
	Corundum	With nepheline syenite
Buckingham series (igneous)		
Peridotite, gabbro		
Anorthosite		
Syenite		
Hastings series		
Conglomerate, argillite, limestone		
Grenville series		
Limestone	Lead, barite, fluorite, celestite	In veins
Quartzite	Graphite, apatite, mica, magnesite, talc	In veins and disseminations from action of granites
Sillimanite-garnet-gneiss	Kaolin, molybdenite, magnetite	

Manitoba and Saskatchewan

Formations	Mineral deposits	Geological habit
Diorite, diabase		
Granite		
Gabbro, diorite, lamprophyre, amphibolite, peridotite		
Upper Missi series		
Arkose, conglomerate		
Lower Missi series		
Slate, greywacke, conglomerate, quartzite		
(Granite?)		
Kisseynew (Wekusko)		
Sedimentary schists and gneisses	Garnets	In schist
	Copper, zinc, lead	Replacements derived from granite
Amisk series		
Volcanics and derived schists	Copper, zinc, gold	Replacements
	Gold	In veins

Arctic Region

Formations	Mineral deposits	Geological habit
Coppermine River series Amygdaloidal basalts, ash beds, conglomerates	Copper	Amygdules, veins, and disseminations
Goulburn series Quartzite, conglomerate		
Kanuyak series Ash beds and tuffs		
Epworth dolomite		
Granite-complex Granite, granite-gneisses, and included older rocks		

ST. LAWRENCE REGION

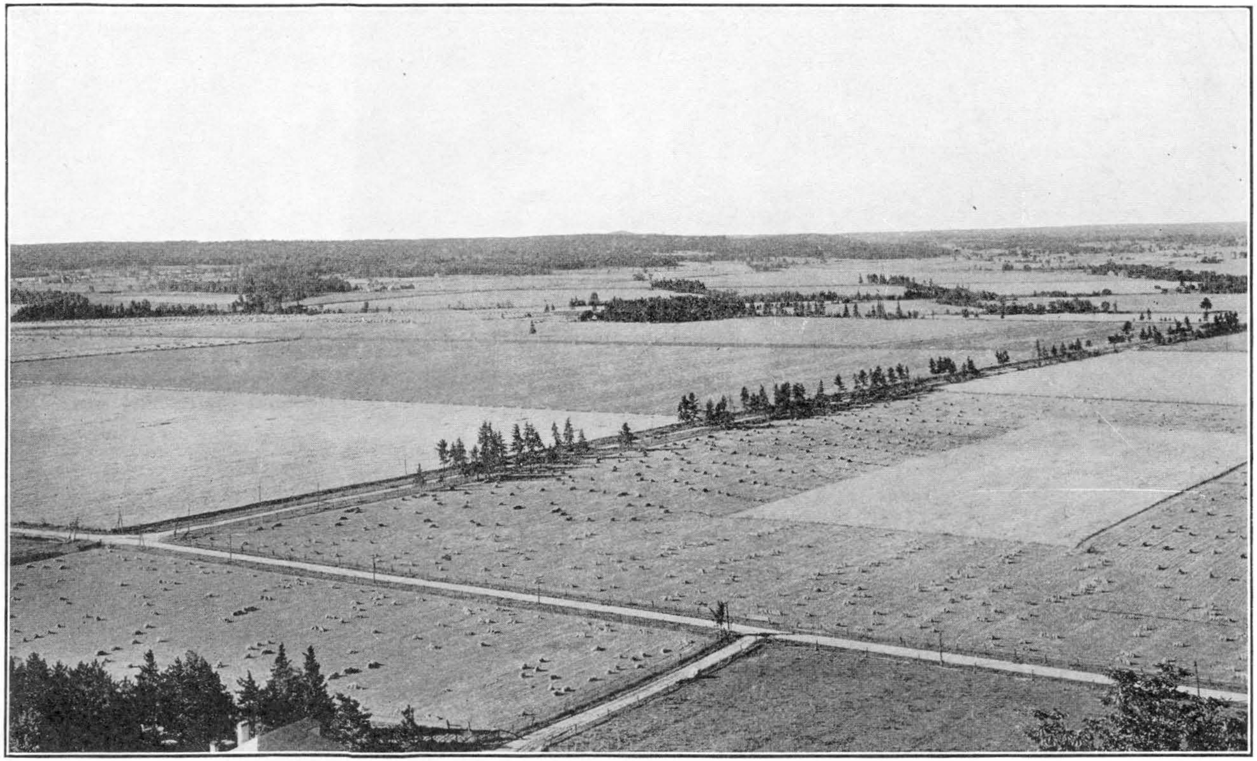
The St. Lawrence Lowland region is made up of three divisions. The first extends from the city of Quebec to about 50 miles above the city of Ottawa on Ottawa river. Below Montreal the average elevation of the division is about 100 feet except for eight hills composed of igneous rocks which rise to elevations of from 600 to 1,200 feet above the sea. The second division extends westward from Kingston to the Niagara escarpment and rises gently from 246 feet at lake Ontario to an elevation of 850 feet. It is bounded on the north by a marked escarpment of 50 to 100 feet in height and on the west by the Niagara escarpment 250 to 300 feet high. The third division lies between lake Huron and lake Erie. It has a maximum elevation of 1,700 feet, sloping down to the lakes on either side. These three divisions, totalling an area of 35,000 square miles, were once heavily wooded, but now the forests are largely removed, giving place to an agricultural country containing the larger part of the population of Canada. Travel in this region is facilitated by roads and railways, so that it is comparatively easy for the prospector to reach any desired locality.

The underlying rocks of the belt are sediments, mostly little disturbed, ranging in age from Cambrian to Devonian. The Cambrian rocks consist of sandstone derived by the weathering of the old Precambrian surface. The Ordovician, Silurian, and Devonian rocks consist largely of limestones and shales deposited during inundations by the sea. Since the Devonian, the history of the region has been one of erosion. The region was overridden by the ice-sheets of the Pleistocene.

In general the rocks of the district lie flat. In places they are broken by faults, and locally they are thrown in low folds. The dip over most of the region is seldom more than 200 feet to a mile, which is, however, enough to permit the accumulation of oil and gas.

The only intrusive rocks of the region are the igneous masses forming the Monteregian hills. These are eight in number, six of which occur along an east and west line stretching eastward from Montreal. The flanks of the hills consist of altered and hardened sediments and the centres are composed of the intrusive rocks, which include various alkali types such as nepheline syenites, essexites, etc.

PLATE IX



Typical St. Lawrence lowland topography—Bonnechère valley near Renfrew, Ont.

The chief natural resources of St. Lawrence region from a mineral point of view include gypsum, salt, petroleum, and natural gas, occurring in the district between lakes Huron and Erie. Other materials, such as limestone, shale, sandstone and clay, and sand of the glacial and post-glacial deposits are also made use of in different industries.

The undisturbed character of the rocks has not been favourable for the development of deposits of metalliferous minerals. In eastern Ontario, however, certain lead-bearing calcite veins, though lying for the most part in Precambrian rocks, are known to be post-Ordovician in age, since the upper parts of several cut limestone strata of that age. The Ramsay veins at Carleton Place and the Kingdon vein at Galetta are examples. It is probable that the deposits are related to Devonian intrusives which have not reached the surface in this region, but which correspond to the intrusives of the Monteregian hills to the east.

Table II

St. Lawrence Region

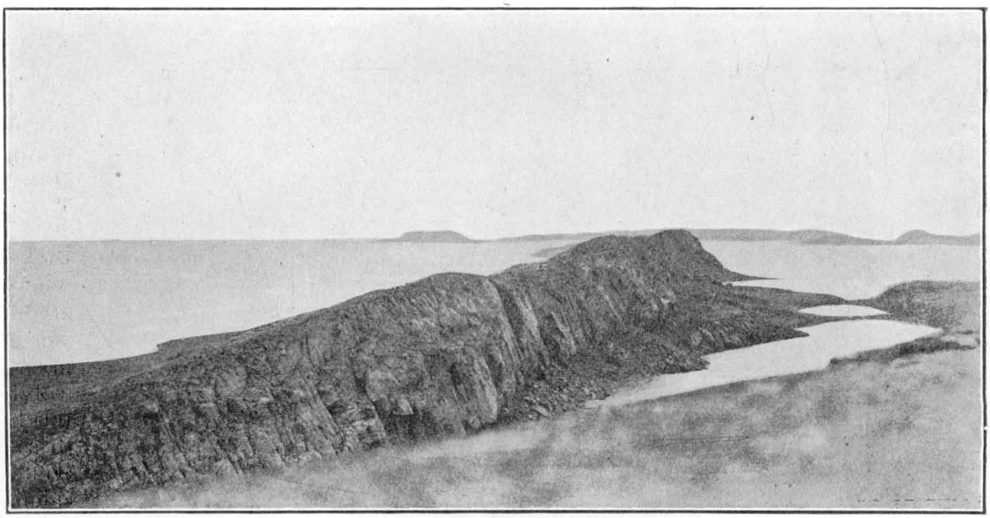
Formations	Mineral deposits	Geological habit
Devonian		
Port Lambton		
Shales and sandstone		
Huron shale		
Hamilton		
Limestone, shale	Petroleum and natural gas	
Delaware limestone	Petroleum	
Onondaga limestone	Petroleum and natural gas	
Oriskany sandstone		
Upper Munroe dolomite		
Sylvania sandstone		
Silurian		
Cayuga		
Lower Munroe dolomite and shale	Salt, gypsum	In beds
Salina, shale, dolomite		
Guelph	Petroleum and natural gas	
Niagara		
Lockport dolomite		
Rochester shale		
Clinton		
Shales and dolomite	Natural gas	
Medina		
Sandstone, shale, limestone	Petroleum and natural gas	
Ordovician		
Richmond		
Shales and limestone		
Lorraine shales		
Utica shales		
Collingwood shales and limestone		
Trenton limestone	Petroleum and gas	
Black River limestone		
Chazy sandstones, shales, and limestone		
Beekmantown dolomitic limestone		
Basal sandstone		
Cambrian		
Potsdam sandstone		

ARCTIC ARCHIPELAGO AND HUDSON BAY LOWLAND

The islands of the Canadian Arctic region cover a land area of more than 500,000 square miles. There are at least twenty having areas each of over 500 square miles, of which Baffin island, 211,000 square miles, Ellesmere island, 76,600 square miles, and Victoria island, 74,000 square miles, are the largest.

Baffin island rises abruptly from the coast to elevations of more than 1,000 feet. In the south the general elevation of the tableland is from 2,000 to 3,000 feet, but northward it rises to 5,000 feet with peaks over 6,000 feet in height. Still farther north it sinks again to an elevation of about 3,000 feet. In North Devon and Ellesmere islands peaks rise to over 3,000 feet. Victoria island to the west has an elevation of about 500 feet.

PLATE X



Franklin's Snug harbour, Kater point, Arctic coast.

The higher regions are composed largely of Precambrian rocks. Cambrian strata are exposed on the east side of Ellesmere island. At other places, horizons ranging from Cambrian to Silurian are found resting directly on the Precambrian. The most widespread Palæozoic formation is the Niagara, or mid-Silurian. On the south side of Ellesmere 8,000 feet of strata ranging in age from Middle Silurian to Upper Devonian are found. Carboniferous sandstones occur on the southwest side of Ellesmere and on Parry islands. Triassic sediments consisting of limestone and calcareous shale with some volcanic rocks are found on the western coast of Ellesmere island, and Tertiary sands and lignites are also found here and in northwest Baffin island. All of these measures have only gentle dips.

The lowland underlain by Palæozoic strata on the west side of Hudson bay has a length in a southeast direction of 800 miles, a width of from 100 to 200 miles, and an area of 120,000 square miles. It rises from sea-level with a scarcely perceptible gradient to an elevation of about 400 feet. The strata are nearly horizontal and range in age from Ordovician to Mesozoic.

The severe climatic conditions and the inaccessibility have permitted but little prospecting in the northern islands; gold has been reported from the head of Wagner inlet; native copper has been brought back from Baffin island; mica and graphite have been found on the north side of Hudson strait; bituminous coal is known to occur in Carboniferous strata on the islands north of Lancaster sound and lignite occurs in the Tertiary beds on the northern and eastern shores of Baffin island as well as on Bylot island. In southwest Greenland, territory belonging to Denmark, an important deposit of cryolite, mineral containing aluminium, occurs in a vein traversing grey gneiss; in the Hudson Bay lowland lignite and refractory clay occur in the Mattagami series of latest Jurassic or early Cretaceous age.

Table III

Arctic Archipelago and Hudson Bay Lowland

Formations	Mineral deposits	Geological habit
Tertiary		
Miocene, sands and clays	Coal	In beds
Mesozoic		
Cretaceous	Coal and refractory clay	In beds
Triassic		
Limestone and shales		
Palæozoic		
Pennsylvanian,		
Limestone, tuffs and lavas		
Mississippian		
Sandstones and shales	Coal	
Devonian		
Limestone		
Silurian		
Limestone		
Ordovician		
Limestone		
Cambrian		
Limestone		
Precambrian		
Batholithic granites and gneisses	Mica	Veins and disseminations
Limestone, schists, and gneisses	Graphite	

THE APPALACHIAN AND ACADIAN REGIONS

The Appalachian and Acadian regions include all of Canada lying south of St. Lawrence river and east of a line running from Quebec city south to the foot of lake Champlain. The Appalachian region is a continuation of the great Appalachian Mountain system of eastern United States. In Canada its eastern boundary is Restigouche river and Chaleur bay. To the southeast of this, the Acadian region comprises the provinces of New Brunswick, Nova Scotia, and Prince Edward Island. The total area of the two regions is 84,000 square miles. The country for the most part is mountainous or hilly. The valleys, lowlands, and coasts are well settled and, except for certain areas like the interior of Gaspe peninsula, railways and roads offer good means of communication. Much of the territory is still forested, drained by swift-flowing streams, and locally lakes are numerous. Agriculture, lumbering, fishing, mining, and manufacturing are all important industries. Most of the region is of easy access to the prospector, but parts, such as the interior of Gaspe and portions of New Brunswick and Cape Breton Island, necessitate back-packing expeditions to reach certain points.

The Appalachian Mountain system beginning not far from the gulf of Mexico and extending to the tip of Gaspe peninsula has a length of 1,700 miles. It is a region of Palæozoic rocks which have been folded, broken by both normal and thrust faults, intruded by deep-seated and dyke rocks, and mineralized with a variety of deposits. The general structural trend is northeast and southwest. South of New York the system is represented by two parallel ranges, the Alleghenys and Appalachians. In northern New York, New England states, and in Canada the system is less regular. Green mountains of Vermont reach an elevation of 4,430 feet and mount Washington in White mountains of New Hampshire has a height of 6,291 feet.

In southeastern Quebec, the continuation of these ranges forms three roughly parallel ridges with isolated hills, known as Notre Dame mountains. They run in a northeast direction, have an average elevation of about 2,000 feet, and are separated from each other by deep valleys. The highest point is Sutton mountain, 3,100 feet, near the Vermont border in the most westerly of the ridges. Northeast to a point opposite Quebec city the country is lower, but in Gaspe peninsula it again rises and a belt of flat-topped country along the central part of the peninsula, known as Shickshock mountains, reaches elevations of from 3,500 to 4,200 feet. Bordering this elevated tract on either side is a plateau region with an elevation of around 1,000 feet, entrenched by steep-sided valleys.

The topography of the Acadian region is also one of plateaux, ridges, and valleys. The Gaspe plateau is represented by similar country in northwestern New Brunswick, deeply entrenched, however, by the valley of St. John river. To the southeast in central New Brunswick is a more rugged area with ridges and hills rising to elevations of over 2,000 feet. Still farther to the east is a lowland of about 10,000 square miles, nowhere higher than 600 feet above the sea. This lowland forms the whole eastern coast of New Brunswick and all of Prince Edward Island. To the south in New

PLATE XI

Peninsula point, Chester, N.S. Typical of the Acadian coast topography.

Brunswick it is bordered by flat-topped ridges which rise steeply from the northwest shore of the bay of Fundy to elevations of over 1,000 feet.

The peninsula of Nova Scotia is an upland running in a northeast direction. Along its axial line it has a general elevation of about 1,000 feet. On its southeast side it drops gradually to the ocean. On the northwest, the slopes are steeper to a lowland region surrounding Cobequid hills and extending west into New Brunswick. To the south this lowland is represented by the narrow Annapolis-Cornwallis valley which extends for a distance of over 100 miles. To the west of the valley is an abruptly rising ridge whose surface slopes seaward to the bay of Fundy. Cape Breton Island is a continuation of the main upland, but is divided into a series of isolated, flat-topped ridges and plateaux, which in the north reach elevations of 1,500 feet.

The rocks of the Appalachian and Acadian region include sediments, volcanics, and intrusives, chiefly of Palæozoic age. Considerable areas in Nova Scotia are, however, underlain by Precambrian rocks, and along the border of the bay of Fundy Mesozoic sediments and volcanics occur. The broad New Brunswick lowland is underlain by flat-lying Carboniferous measures. Elsewhere, however, throughout the region, except in a few places, the rocks are thrown into folds with axes trending in a northeast direction and are broken by faults giving rise to a complex structure typical of the Appalachian region in general. The chief period of mountain-building in Canada was, however, in the Devonian, whereas farther to the south in the United States, the main period of deformation was the Permian at the close of the Palæozoic.

Precambrian rocks consisting of limestones, quartzite, and gneiss outcrop in New Brunswick along the bay of Fundy. In Cape Breton Island are a number of areas underlain by altered volcanics and sediments cut by granitic rocks. Precambrian rocks have also been described as occurring in central New Brunswick and in southeastern Quebec. Some of the occurrences may, however, be of Palæozoic age.

In Nova Scotia an extensive series of altered sediments, known as the Gold-bearing series, is considered to be of late Precambrian age. This series, with its large intrusive areas of Palæozoic granite, occupies most of the mainland of the province. Its thickness is over 35,000 feet, of which the lower half consists dominantly of quartzites and the upper of slates. The series is folded along northeast lines and also broken by northwest faults, the horizontal displacement of some of which exceed a mile. The series is intruded by dykes and sills of diabase and batholiths of grey and red granite of Devonian age. Around the borders of the granite, the series is altered to gneisses and schists often containing staurolite, garnet, hornblende, sillimanite, and pyrite.

Lower Cambrian strata occur in southeastern Quebec and Upper Cambrian measures are found in northeastern Cape Breton and in New Brunswick near St. John city. In early Ordovician time, sedimentation was in progress in St. Lawrence River region. The Sillery formation, consisting of red and green shales with interbedded sandstone, has at Quebec a thickness of 2,000 feet. A younger series, named the Levis, consisting of dark shales and thin-bedded limestones, has a thickness possibly as great as 5,000 feet. These rocks form a band 6 to 35 miles in width. They have been closely folded, in places overturned, and are broken by faults often of considerable throw. Trenton, or mid-Ordovician beds outcrop in southwestern Quebec and at the east end of Gaspe peninsula. Late Ordovician strata are know along the northeast coast of Gaspe. During the Ordovician, volcanic activity took place on a great scale in Gaspe. The region was also deformed and intruded by masses of peridotite. Erosion followed the folding and then the region subsided beneath the sea in the succeeding Silurian period.

Silurian rocks are found in Gaspe, in New Brunswick, in southeastern Quebec, and in Nova Scotia in the northeast at Arisaig and also farther west and in the southwest of the province. Succeeding the Silurian in Gaspe, in northwestern New Brunswick, and locally in Nova Scotia, are deposits of Lower Devonian age, consisting of limestones and shales. In Gaspe, during Middle Devonian time a thick series of sandstones accumulated. These are accompanied by contemporaneous lava flows and dyke intrusives of basic composition. A group of conglomerates, sandstones, and shales of Upper Devonian age occurs on the Gaspe coast in the vicinity of Maguaska. One member is noted for the fossil fish it has yielded. In late Devonian time the whole Appalachian and Acadian region was affected by mountain-building movements accompanied by the intrusion of batholiths of granite on a great scale. Subsequent erosion wore down these mountains and locally exposed the upper portions of these deep-seated intrusions.

In Carboniferous time a thick series of conglomerate and sandstone was deposited along Chaleur bay in Gaspe, over the wide lowland of New Brunswick, on Prince Edward Island, the Magdalen islands, and over considerable portions of Nova Scotia. These deposits, which are of continental origin, in places reach thicknesses of thousands of feet. Marine Lower Carboniferous rocks also occur in parts of New Brunswick and Nova Scotia and locally contain deposits of gypsum. In late Carboniferous or Pennsylvanian time, a series of shales and sandstones was deposited over the lowland of New Brunswick and in Nova Scotia along Northumberland strait. At Joggins, along the east shore of the head of the bay of Fundy, is a section of Carboniferous rocks over 14,000 feet in thickness, consisting of shales, limestone, sandstone with gypsum beds at the base, coal seams in the middle part, and conglomerates at the top.

At the close of the Carboniferous the Nova Scotia region underwent deformational movement resulting in faulting and local folding. This movement, however, affected the New Brunswick area only slightly. During the succeeding Triassic period beds consisting of reddish conglomerate, sandstone, and shale were deposited in New Brunswick along the bay of Fundy. On the opposite side of the bay in Nova Scotia are more extensive deposits, consisting of several thousand feet of red sandstones and shale capped by about 1,000 feet of amygdaloidal basalt flows. These rocks were tilted and faulted, probably in the Jurassic period. The Cretaceous and Tertiary were periods of erosion in the whole Appalachian and Acadian province. The result was the production of a base-levelled surface of very low relief. Uplift took place in late Tertiary time, and since that period the rivers have entrenched themselves below this peneplained surface.

During the Glacial period, the whole region with the exception of the central part of Gaspe was overridden by ice-sheets. It is probable that the ice advanced from local centres. Since the withdrawal of ice masses, there has been a general elevation of the region, as is shown by the presence of post-Glacial beaches and the occurrence of marine shells several hundred feet above the present level of the sea.

The chief mineral resources of the Appalachian and Acadian regions consist of coal, asbestos, and gypsum, but certain other materials such as clay products, building stone, sand, and gravel are also important. The Carboniferous strata produce the coal and gypsum, and in addition a number of other mineral deposits such as salt, barite, manganese, petroleum and natural gas, and oil-shale. The asbestos occurs in the peridotite rocks of the Eastern Townships of Quebec. These were intruded in Ordovician time in the form of inclined sheets whose outcrops have widths of from 1,000 to 2,000 feet and whose lengths vary up to several miles. In other places they form oval, stock-like masses, and in still other instances they appear to form thick, lenticular, laccolithic bodies. The asbestos occurs in narrow bodies traversing the altered peridotite. These intrusions of peridotite also locally contain deposits of chromite. The mineral occurs as scattered grains throughout the rock and in places is sufficiently concentrated in irregularly shaped masses to produce ore-bodies.

This period of basic intrusions forms one important metallogenetic epoch in the Appalachian region. A second occurred in middle Devonian time, the period in which the batholithic intrusions of granite took place. The intrusions of these two epochs were responsible for metallic deposits of a considerable variety including gold, iron, copper, lead, zinc, antimony, and tungsten ores.

The chief gold region is the mainland of Nova Scotia where gold-bearing quartz occurs along anticlinal openings and in crosscutting veins in the Gold-bearing series. Gold-bearing quartz veins also occur in Cape Breton Island and placer gold has been found in gravels in Chaudière River district, 50 miles southeast of Quebec city.

Copper ores have been mined in southeastern Quebec. At the Acton mine the ore consists of bornite and chalcopyrite in a brecciated limestone. At the Harvey Hill mine schistose rocks were traversed by narrow veins of quartz, calcite, and dolomite, some of which held bornite, chalcopyrite, and chalcocite. At the Eustis mine the deposits are replacements consisting of lenses of ore, in some cases paralleling or overlapping one another. The Huntington ore-body lay in chloritic schist along the edge of a sill of serpentine.

Iron deposits occur at numerous localities in the Appalachian and Acadian province. Magnetite deposits formed by the replacement of schistose quartz porphyry rocks occur near Bathurst, N.B. Ores of sedimentary origin were mined in the Nictaux-Torbrook iron-ore field of Nova Scotia. At Londonderry, Nova Scotia, limonite and carbonate ores occur in a zone of fissuring, along the south slope of Cobequid hills. The deposits owe their origin to the igneous intrusions which form the central part of this range.

In the central part of Gaspe peninsula, veins carrying zinc and lead traverse shales and limestones of Lower Devonian age. They are related to Devonian intrusive rocks of the region. Near Stirling zinc deposits occur as replacements in volcanic rocks of early Palæozoic age. They too are related to the deep-seated intrusions.

Tungsten deposits, consisting of scheelite-bearing veins, occur in the Gold-bearing sedimentary rocks of Nova Scotia. Auriferous stibnite occurs at West Gore, Hants county, in the same series. Stibnite with some native antimony also occurs in New Brunswick at Prince William, 25 miles west of Fredericton. All these occurrences are related to the Devonian igneous intrusives.

Table IV

Appalachian and Acadian Region

Formations	Mineral deposits	Geological habit
Recent and Pleistocene	Diatomite	In beds
Tertiary gravels of the Chaudière	Gold	Placers
Triassic of Nova Scotia	Native copper	In veins
Carboniferous		
Sandstones, shales	Coal	In beds
Limestones	Salt	In beds
	Gypsum	In beds
	Manganese	In beds and pockets
	Barite	In veins
	Petroleum, natural gas, and oil-shale	
Devonian		
Granite batholithic intrusives		
Sandstone conglomerate		
Limestones and shales, volcanics	Lead, zinc	In veins
	Iron	In beds
Silurian		
Limestones, shales, sandstones, volcanics	Iron	In beds
Ordovician		
Limestones, shales	Iron near Bathurst, N.B.	Replacement
Peridotite intrusions	Asbestos, chromite	In intrusive rock
Quartzite, volcanics	Copper	Impregnations
Cambrian		
Limestones, shales, etc.		
Precambrian		
Meguma series of Nova Scotia Quartzites and slates	Gold, arsenic, tungsten, antimony	In veins related to the Devonian batholithic intrusives
Metamorphosed sediments and volcanics of Cape Breton Island and southern New Brunswick	Zinc, copper	Veins and replacements

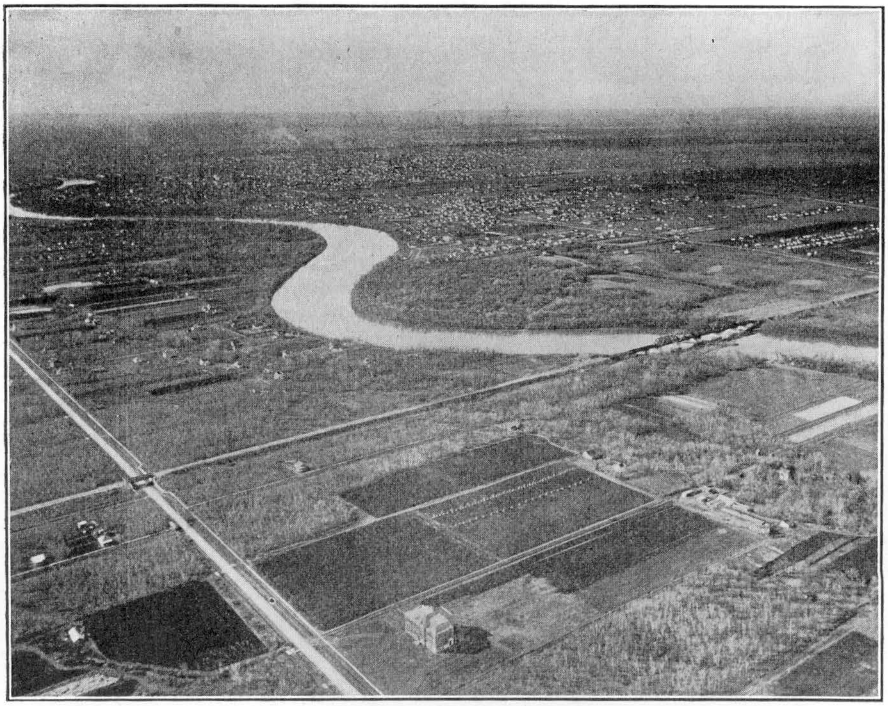
THE GREAT PLAINS

The Great Plains of Canada form part of a vast region in the interior of the continent stretching from the gulf of Mexico to the Arctic ocean. In Canada it extends from the Canadian Shield on the east to the mountains on the west. At the American boundary it has a width of 800 miles, but 1,500 miles to the northwest, at the mouth of Mackenzie river, the width is less than 100 miles. Within the northwestern part of the region, between Great Bear lake and Mackenzie river, lies the Franklin range, made up of folded strata. Elsewhere, however, the underlying rocks consist of nearly flat-lying sediments of Palæozoic, Mesozoic, and Tertiary age.

The southern part of the Plains region is well traversed by roads and railways. In the northern portion the prospector's chief method of transportation is by canoe and airplane.

The region may be divided geologically into three zones. A narrow plain on the east, known as the Manitoba lowland, is developed on flat-lying Palæozoic strata ranging in age from Ordovician to Devonian. These rocks lap over the Canadian Shield and commonly present a low escarpment at their border. In the north this zone broadens to form the great Mackenzie lowland. The second division is a wide belt underlain by

PLATE XII



Winnipeg from the air. A typical view of the Great Plains.
(Photograph by the Air Board of Canada.)

Cretaceous rocks. Its eastern border, where these rocks overlap the Palæozoic sediments, is rather an abrupt rise known as the Manitoba escarpment. From elevations of 1,000 to 2,000 feet on this flank the surface rises gradually westward until, at the border of the mountains, the elevations are between 4,000 and 5,000 feet. The third division consists of plateaux of flat-lying Tertiary rocks at Wood mountain and Cypress hills rising to elevations up to 1,000 feet above the level of the surrounding region.

The whole region is a flat to rolling country dissected by river valleys. The southern part is a treeless prairie. North of latitude 35 degrees, the country is wooded, densely to approximately latitude 60 and from there to the delta of the Mackenzie more sparsely. The drainage, except for a small portion in the south, is northward to the Mackenzie or northeastward to Hudson bay. In places in the southwest evaporation equals precipitation, giving rise to an interior drainage basin type.

The chief mineral wealth consists of coal and lignite which form extensive deposits in the Cretaceous and Eocene rocks of Saskatchewan and Alberta. Natural gas has also been produced in great quantities from various horizons of the Cretaceous in Alberta. Petroleum has been found in the Devonian beds of the lower Mackenzie valley, in Cretaceous strata at several localities in Alberta, and in Palæozoic rocks in Turner valley. Along Athabaska river, the basal member of the Lower Cretaceous, known as the McMurray or the Tar sands, is heavily impregnated with bitumen, in places to as much as 20 per cent. The only metalliferous deposits of the region consist of galena and sphalerite in Devonian limestones at certain points south of Great Slave lake.

Table V

—	Mineral deposits and formations	Geological habit
Recent and Pleistocene	Sodium sulphate, magnesium sulphate	In beds
Tertiary		
Oligocene		
Eocene	Coal (Turtle mountain, Manitoba)	In beds
	Building stone (Paskapoo formation, Alberta)	In beds
Mesozoic		
Upper Cretaceous Montana	Coal (Ravenscrag formation, Alberta)	In beds
	Refractory clay (Ravenscrag and Whitemud formations, S. Sask.)	In beds
	Coal (Belly River and Edmonton formations, Alberta)	In beds
	Gas (Milk River sandstone, S.E. Alberta)	
	Volcanic ash (Belly River formation, S. Sask.)	In beds
Colorado	Oil and gas (Colorado shale, Alberta)	
Lower Cretaceous	Bituminous sand (McMurray formations Alberta)	In beds
	Coal (Grand Rapids and Kootenay formations, Alberta)	In beds
	Quartz sand, semi-refractory clay ("Dakota", Man.)	In beds
Jurassic	Oil and gas (Fernie and Ellis formations, Alberta)	
Palæozoic		
Carboniferous	Oil and gas (Alberta)	
Devonian	Oil (Mackenzie River region)	
	Lead and zinc (Great Slave Lake)	Gash veins, etc.
Silurian	Gypsum, salt	In beds
Ordovician	Building stone	In beds

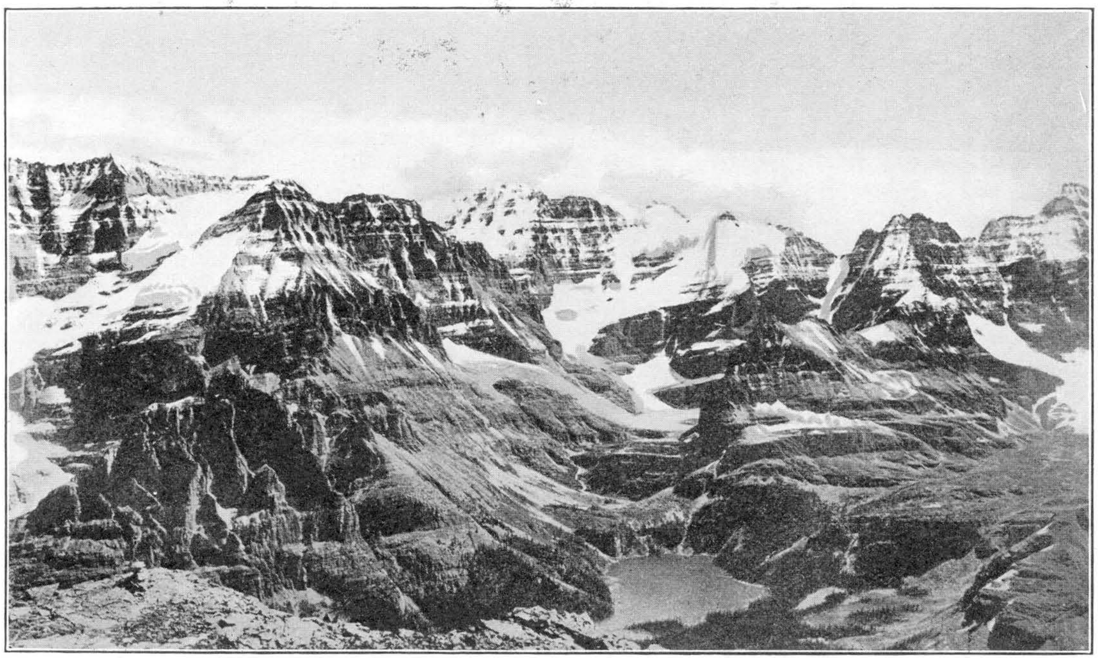
THE CORDILLERAN REGION

The Cordilleran region, comprising the mountainous country bordering the Pacific ocean, has in Canada an average width of 400 miles, a length in a northwest and southeast direction of 1,500 miles, and an area of 600,000 square miles. It is a region of mountain ranges and plateaux trending in a northwest direction. It is for the most part forested, except in the southern interior where there are wide stretches of grass-covered or sparsely wooded hills and valleys. In the south the fertile valleys are settled with a population that is continually increasing. Fruit-growing, mining, lumbering, fishing, and manufacturing are important industries. In this southern section, railway connexions, steamer service along the coast and on the inland lakes, and motor roads offer good means of communication. In northern British Columbia travel is more difficult, being confined to streams and trails, and there are large districts about which information is most meagre.

The Cordilleran region may be subdivided into three main zones. On the east the Rocky Mountain range is separated from the mountainous country to the west by a depression known as the Rocky Mountain trench, occupied by the Kootenay, the headwaters of the Columbia and Fraser, and by Parsnip and Finlay rivers, which unite to form the Peace. The Rockies have a maximum width of 100 miles and extend from the International Boundary northward for a distance of 850 miles to Liard river. They have many peaks ranging from 10,000 to 12,000 feet in height. North of Liard river, the mountains lie 100 miles farther east and are known as Mackenzie mountains. These form a range about which little is known, lying between the Yukon plateau on the west and Mackenzie river on the east. Their elevation probably does not exceed 7,000 feet.

The western border of the Cordilleran region is marked by another broad belt of mountains known as the Coast range. It stretches from the American border northward for 1,000 miles into the Yukon. It has a width of from 50 to 100 miles, and with it are commonly included the outlying mountains of Vancouver and Queen Charlotte islands. The rise from the coast is abrupt to an elevated region which, along the axis of the range, reaches elevations of from 7,000 to 10,000 feet. The coast is very irregular, being bordered by islands and indented with fiords.

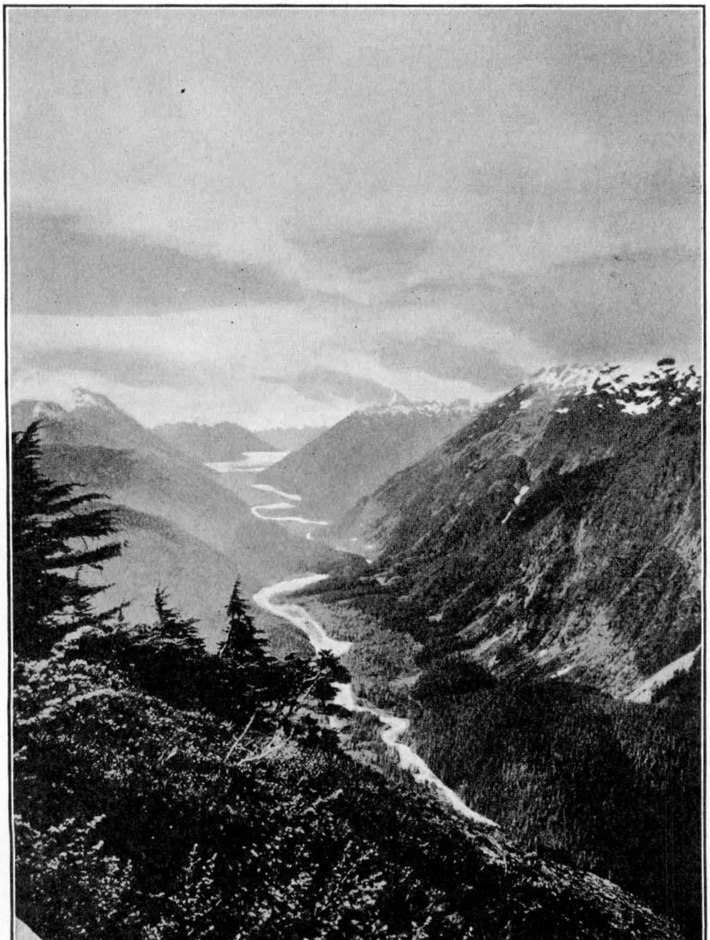
Between the Rocky and Mackenzie mountains on the east and the Coast range and St. Elias range of Yukon on the west lies the third subdivision, a broad region of plateaux and mountain ranges. The northern part is the Yukon plateau, consisting of a gently rolling upland broken up into a series of flat-topped ridges by valleys several thousand feet deep. South of the Yukon plateau is a mountainous area in northern British Columbia, about which little is known. In southern British Columbia, the interior region is a plateau with elevations of from 3,000 to 4,000 feet, cut by valleys whose floors are 1,000 feet or more below the upland surface. On the western side the plateau either joins the Coast range directly or is separated from it by mountain ranges such as the Cascade of southern British Columbia. On the east are a series of ranges separated by longitudinal, northwest-trending trenches. Of these, the Selkirk range is the most important, reaching elevations up to over 11,000 feet.



Lake O'Hara, Rocky mountains. *(Photograph by A. O. Wheeler, Department of the Interior.)*

The mountainous character of much of the region restricts the prospector's activities. The valley bottoms and lower slopes are commonly hidden under an overburden of alluvium, drift or talus. The best general view and the best exposures are obtained above tree-line. It is for this reason that most prospects are located at considerable elevations. In his work an invaluable aid to the prospector is the pack-horse.

PLATE XIV



Coast Range topography, Portland canal, B.C.

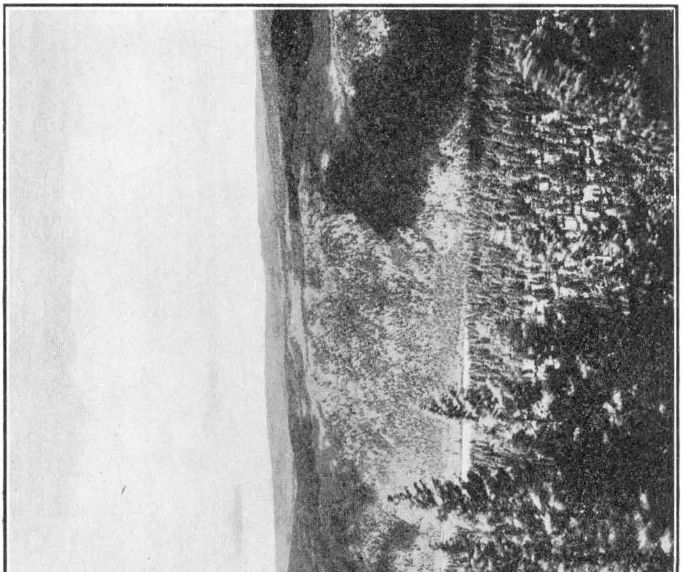
The rocks of the Cordilleran province range in age from Precambrian to Recent. The Rocky and Mackenzie mountains and the Ogilvie range of northern Yukon are made up of great thicknesses of sediments of Precambrian, Palæozoic, and Mesozoic age. The Coast range is largely a complex batholith of late Jurassic or early Cretaceous age intruded into sediments and volcanic rocks of earlier Mesozoic age. The plateaux and ranges of the interior are underlain largely by late Palæozoic, Mesozoic, and Tertiary sediments and volcanics. The pre-Tertiary beds are cut by numerous igneous rocks of deep-seated origin and in various districts Precambrian strata are exposed.

The Cordilleran region was affected by two great mountain-building revolutions since the Palæozoic. The first took place in late Jurassic or early Cretaceous time and affected the whole region from Selkirk mountains westward. It was accompanied by igneous intrusions on a vast scale and subsequent erosion has uncovered these batholiths, exposing a broad band which extends down the Pacific coast, curving eastward near the International Boundary. This period of intrusion formed the most important metallogenetic epoch of British Columbia.

The second great mountain-building revolution was the Laramide of Eocene time. In this period the great thickness of sediments that had accumulated in the geosyncline along the site of the present Rocky mountains was folded up to form that range. Igneous intrusions probably accompanied the revolution. It is probable that the lead-zinc ores of the Monarch and Kicking Horse properties at Field are to be related to them. A period of mineralization also occurred in the Oligocene, when copper ores were deposited on the Sunloch property on Vancouver island in a shear zone in gabbro of that age. Mercury deposits in several localities throughout British Columbia are associated with lavas of late Miocene or Pliocene age which otherwise are unmineralized.

The period of the intrusion of the Coast Range batholith was the most important event in the history of the Cordilleran region from the point of view of mineral deposits, and by far the majority of the metalliferous deposits of the province are to be related to this metallogenetic epoch. As already mentioned, the early Mesozoic granite batholiths form a band down the Pacific coast which, in the southern part of British Columbia, curves off to the east. Mineral deposits occur in two general zones, one on either side of this belt of granite. That on the west, following the Pacific coast, and including the island fringe, may be described as the Pacific mineral belt, and the one on the eastern side of the batholith may be referred to as the Interior belt. In the southern part of British Columbia where the batholith trends to the east, the southern zone has been called the Boundary belt, and the northern mineralized side of the batholiths is termed the Kootenay belt. The Pacific and Boundary belts are characterized chiefly by copper deposits. The former includes such camps as Anyox, Marble Bay, Quatsino Sound, and Britannia, and the latter includes Copper Mountain, Phœnix, Deadwood, Rossland, and others. The eastern and northern borders of the batholith comprising the Interior and Kootenay mineral belts are noted particularly for their gold, silver, lead, and zinc ores. The Interior contains such deposits as the Premier, the B.C. Silver, and other deposits of Salmon River region, those of the Bear River country, and Alice Arm, Dolly Varden mine, and occurrences at Hazelton, Smithers, Ootsa lake, and Whitesail lake. The Kootenay belt includes the silver-lead-zinc deposits of Ainsworth, Slocan, and Lardeau districts and the zinc-lead ores of the Sullivan, North Star, and St. Eugene mines near Kimberley.

PLATE XV



Looking west across North Thompson valley, near Vinsulla, B.C., typical of the Interior Plateau of the Cordilleran region.

These camps and others in British Columbia are a source of great mineral wealth. In 1924 that province produced 96 per cent of the lead, 97 per cent of the zinc, 63 per cent of the copper, 41 per cent of the silver, and 16 per cent of the gold produced in the whole of Canada. Coal is also abundant in the Rocky mountains and on Vancouver island. The greater part occurs in beds of Cretaceous age, though coals of Tertiary age have wide distribution also. Deposits of iron occur also at many localities in the Cordilleran region, as, for example, on Vancouver and Queen Charlotte islands; they consist of magnetite with pyrite and chalcopyrite developed along the contacts of granite, granodiorite or diorite with limestone, and were apparently formed under conditions of contact metamorphism.

Placer deposits occur at various places in the Cordilleran region. The gold of Klondike region, Yukon, the gold of the Cariboo country, and the platinum of Tulameen district are notable examples.

Table VI

Cordilleran Region

Formations	Mineral deposits	Geological habit
Recent and Pleistocene Fluviatile, lacustrine, glacial	Magnesum sulphate Gold, platinum	In beds Placers
Pliocene, gravels	Gold, platinum	Placers
Oligocene, volcanics Conglomerates, sandstones, shales	Mercury Coals	In veins In beds
Eocene, conglomerates, sandstones, volcanics	Refractory clay	In beds
Upper Cretaceous Sandstones, shales	Coal	In beds
Batholithic intrusives (Post-Triassic, Mesozoic, and Tertiary)	Gold, silver, copper, lead, zinc	In veins
Lower Cretaceous Sandstones, shales, conglomerates Kootenay coal measures. Volcanics	Coal	In beds
Jurassic Fernie shales of Rocky mountains Volcanics of interior and coast	Gold, silver, lead, zinc, copper, iron	In veins, impregnations in shear zones, replacements, and contact deposits related to the Coast Range batholith
Triassic, basic volcanics with limestone	" "	
Permian, shale, slate		In veins
Pennsylvanian Quartzite, limestone volcanics	Silver, lead, copper	
Mississippian Shale, limestone		
Devonian Limestone, slate		
Silurian Limestone		
Ordovician Shales, slate, limestone		
Cambrian Limestone, shales, quartzites	Zinc, lead	Replacements related to Post-Triassic intrusives
Precambrian Windermere / Purcell } series, schist, slate Quartzite, metargillites, limestone	Zinc, lead, pyrite	Replacements related to batholithic intrusives
Shuswap series Limestone, schist, gneiss volcanics	Silver, lead, zinc	In veins and replacements

CHAPTER V

PHYSICAL PHENOMENA OF ORE DEPOSITS

MAGNETIC AND ELECTRICAL METHODS OF PROSPECTING

(J. B. Mawdsley and T. L. Tanton[1])

INTRODUCTION

Magnetic and electrical methods of prospecting have received considerable attention in Canada and other parts of the world. Most of the magnetic methods have been in successful use for many years. Although the electrical methods are based on principles known for decades, it is only in the last ten or fifteen years that any of them have been used on a commercial scale, and it is only within the last three or four years that any of them have been used in Canada.

To any one whose duty it is to look into the whole subject or to decide which of the present methods is most suitable for his particular problem, the present literature on the subject is singularly unsatisfactory. The average reader, because of his lack of training, is unable to get a clear idea of the status of the whole subject or of any particular method. Further, for business reasons, there is much secrecy about the details of the various methods, conditions met with, and results obtained. Complete data on the electrical and magnetic properties of soils, rock, and ore minerals are lacking, to the hindrance of the proper interpretation of results of such surveys.

The literature on the subject has been freely drawn upon as well as information personally received from various operators. The writer of the section on electrical methods of prospecting is especially indebted to A. H. Miller of the Dominion Observatory, Ottawa, and to Professor Eve and Doctors Keys and Bieler, of the Physics Department of McGill University, for personal discussions of the subject.

MAGNETIC METHODS OF PROSPECTING

Principles of Magnetism Involved

The term magnet usually designates a piece of steel which has the property of attracting certain substances termed magnetic bodies, such as iron, nickel, cobalt, pyrrhotite, etc.

A magnet has two poles, one at each end. The exact positions of these poles depend on the shape and dimensions of the magnet and are a short distance from the ends of the magnet. The line joining these two poles is termed the magnetic axis. If a magnet is suspended so that it is free

[1] Electrical Methods by J. B. Mawdsley; Magnetic Methods by T. L. Tanton.

to swing horizontally it is found that it sets in moderate latitudes in a general north-south direction. It is also found that a particular end of this magnet points always to the north and the other south. These two poles have, therefore, been designated the north and south seeking poles, respectively.

It is found that if a magnet is subdivided, each division of this magnet will in itself be a magnet with two poles at ends corresponding to those of the original magnet.

If two freely suspended magnets are brought close to one another, the unlike poles attract and like repel.

The space about a magnet in which it exerts its force is termed its magnetic field. The properties of this field have been studied and the principles deduced form the basis of magnetic theory.

The force of this field at any point has magnitude and direction, and if it were possible to isolate a north magnetic pole it would travel through this field along a definite path that would join the north pole of the magnet to the south pole of the magnet in a smooth arc.

Faraday brought out the useful conception that every magnetic field is traversed by magnetic lines of force.

The mapping of the field of a magnet shows that each line of force follows a path from the north pole through the surrounding field to the south pole of the magnet and then through the substance of the magnet to the north pole again. The paths of these magnetic lines of force are, therefore, closed lines. It can also be shown that the number of the lines of force passing through a unit area is greater close to the poles and is fewer by a definite ratio at greater and greater distances from them. The number of magnetic lines of force radiating from the pole of a magnet will depend on its strength. Where the magnetic field has many lines of force per unit area, it has more magnetic intensity or strength than where these lines of force are sparse.

If a small, free-swinging magnet is put at a point in the magnetic field, its axis will coincide with the direction of the lines of force, and as unlike poles attract, its south magnetic pole will point along the direction of the magnetic line of force towards the north magnetic pole of the large magnet.

When placed in a magnetic field certain substances become magnets and are then said to possess induced magnetism. The lines of force of the inducing field crowd through such substances, causing a polarity opposite in direction to that of the inducing magnetic. Soft iron is one of the substances easily magnetized in a magnetic field. Such substances and others not capable of being permanently magnetized which are media in which the lines of magnetic force travel with greater ease than in air are said to be permeable.

The Earth's Magnetic Field

As is generally known, the earth is itself a great magnet, the magnetic poles of which are found not at the geographic poles, but some distance from them.

Surrounding this giant magnet is its magnetic field. Lines of force join the south magnetic pole to the north magnetic pole. A free magnet will set itself in the direction of the lines of force. The needle of a compass which is a magnet, will have its north pole pointing magnetic north. The direction, strength, and variation of this field have been carefully studied and mapped.

At the magnetic equator the lines of force will not only point magnetic north and south, but will be horizontal. North or south of this equator the lines of force dip below the horizontal towards the respective magnetic poles. The dip of these lines becomes progressively steeper as the poles are approached and over them is vertical. The strength of the magnetic field increases as the poles are approached.

Although these variations occur in the earth's field they are not appreciable when an area of a few square miles is considered. Within this area the earth's normal field has practically parallel lines of magnetic force, whose plane of direction is magnetic north and south, with a definite dip. The angle between the astronomic north plane and the magnetic north plane at a point is known as the angle of magnetic declination for that point.

A delicately balanced magnet free to move in the vertical and horizontal planes sets itself in the direction of the lines of force and indicates the north and south magnetic direction and the dip of the magnetic field. More sensitive instruments show that in an undisturbed earth's field the intensity or strength of this field has a definite value, within a small area. The slight daily and yearly changes in the magnetic field are here neglected as are also the changes due to magnetic storms.

Principles of Prospecting

It has already been stated that if certain magnetically permeable substances are placed in a magnetic field the lines of force crowd into these substances and induce a magnetism whose poles are found near the extremities of these bodies. Soft iron is permeable to a high degree, and a few minerals such as magnetite and pyrrhotite are somewhat less permeable. These mineral substances occurring in nature, lie in the earth's magnetic field and by induction become magnets. The induced magnetism of these bodies has a field which naturally warps the normal earth magnetic field. These two fields produce a resultant field, which differs from the normal earth field. It is different at various points in: (*a*) direction; (*b*) intensity or strength. The anomalous field in the immediate vicinity of magnetic bodies may be detected by the use of suitable instruments. This locality is said, therefore, to have local attraction.

The extent to which magnetic bodies modify the distribution of the normal terrestrial field at the earth's surface depends upon their: (1) magnetic permeability; (2) volume; (3) shape; (4) position with reference to the lines of force of the normal terrestrial field; (5) their depth below the surface of the earth.

Compass

The direction of the resultant field can be detected by a compass. A compass is a magnetized steel needle constructed to rotate in the horizontal plane. The south end of the needle carries a little weight to counteract roughly the dip of the earth's natural field, in any given latitude in the northern hemisphere. Near a magnetic mineral body the compass needle in nearly all positions is deflected from the magnetic meridian. If one is traversing along a surveyed line the actual deflexion can be noted at various points. If such a line is not available a *Sun Dial compass* can be used.

The dial compass is an ordinary surveyor's compass with which is combined a small portable sun dial. On the north side of the instrument there is an upright provided with a sight slit, and at the proper height a hole through which a thread is passed and fastened at the south side of the compass. Around the outer edge of the compass is the hour circle. The graduated circle from which the needle is read is movable and the normal declination can be set off so that the local variation of the needle, which is due to magnetic bodies, will be read from the normal declination of the needle rather than from the true north.

The dial compass is used to show the direction of the horizontal component of the magnetic field at the point of observation, and, in approximate fashion, its relative horizontal intensity. A comparison of the declinations recorded at different points reveals any changes there may be in the horizontal component of the earth's field; this is information comparable in value to that obtained by the dip needle which will be described later.

In the dial compass the indicating thread must be set at an angle parallel to the axis of the earth when the compass is set in a north-south line, i.e., the angle between the compass plate and the thread must be equal to the latitude of the place where the dial is used. The graduations of the hour circle vary with the latitude, and the instrument makers provide differently graduated circles for each half degree. The graduations on the hour circle refer to mean solar time; this is not the same as standard time and it is necessary to calculate the correction from tables giving the "equation of time" which are issued by instrument makers.

Observations are made on sunny days by levelling the instrument and turning it about a vertical axis so that the shadow of the thread, as thrown by the sun, lies on the graduation corresponding to the time of day, thus bringing the thread into the true north-south position; the reading of the compass needle on its graduated circle is then taken.

With the ordinary compass and ordinary sun dial compass, only work of a comparatively rough nature can be done. With both these instruments a function of the direction of the horizontal component of the field is noted. The general method of carrying out a survey will be discussed in a later section.

Dip Needle

With a dip needle an indication of the relative value of the field can be obtained. The ordinary dip needle is usually 4 inches long and delicately balanced, to rotate freely in the vertical plane. The dip needle case is suspended by a ring which assures that it will hang vertically. If the dip needle is placed in the vertical plane of the terrestrial field, in an area where no local attraction exists, the axis of the needle will correspond to the dip of the field. A weight is attached to the south end of the needle (in the northern hemisphere) to keep it approximately horizontal when in a normal earth field. There is another type of dip needle in which the counterweight is applied underneath the pivot at the middle of the needle. This form is usually (though not necessarily) observed in a position perpendicular to the plane of the magnetic meridian. When held thus the position of the needle depends only upon the variation in intensity of the vertical component of the magnetic field.

The horizontal component of the earth's field is thus eliminated and the attraction due to local bodies is, therefore, usually more pronounced. This type of dip needle and method of use is, therefore, the more delicate of the two for magnetic dip needle survey work. In an area containing bodies that cause local attraction, readings with the dip needle will give indications as to the position of such a body. Much valuable work has been done in mapping magnetic bodies by this method.

FIELD METHODS IN COMPASS AND DIP NEEDLE

Only a brief outline of the field methods used in carrying out magnetic survey can be given here and very little can be stated of the difficulties of interpreting such surveys. Anybody contemplating carrying out such work extensively should obtain articles such as:

Archibald, R. S.: "Magnetic Surveys of Iron Deposits"; Eng. and Min. Jour., pp. 1157-1160, June 10, 1911.

Smyth, H. L.: "Magnetic Observations in Geological and Economic Work"; Econ. Geol., pp. 367-379, 1907; pp. 200-218, 1908.

The field methods used for the ordinary compass (not the sun dial compass) or dip needle are much the same. If the strike of the magnetic body is known, traverse lines can be run at right angles to this strike and readings taken at convenient distances along these traverse lines. These lines may be 25 feet to 200 feet apart and readings at 10 feet to 100 feet apart along these lines depending on the nature of the magnetic survey required. If the strike of the magnetic body is not known or a more elaborate survey is required lines are surveyed at 25 to 100 feet apart and readings are taken at similar distances along these lines depending on the detail required.

As previously stated the readings taken with the ordinary compass are deflexions of the needle in the horizontal plane. At each point, the angle the needle deflects from the true magnetic bearing of the line is noted and recorded. This is done by sighting the compass along the surveyed line by means of the sights on the compass box and then reading the deflexion of the needle from this line. For instance, if the compass box is set along the direction of a survey line which bears 0 degrees magnetic and the north end of the needle reads 22 degrees east of north, this is the reading taken.

The readings taken with the sun dial compass are similar, but surveyed lines are not needed, the direction being given by the sun dial as previously described. This method is, of course, cheaper than the one that requires surveyed lines, but is not as accurate and requires sunny weather.

With the dip needle the same field method is used as in the case of the ordinary compass needle, except that the dip of the needle in the vertical plane is the reading noted and recorded. Care must be taken to read the same end of the needle each time. The advantage of the dip needle over the compass needle is that it is not necessary to place the dip needle accurately in the direction of the earth's normal magnetic field or at right angles to it, depending on the method used, as what is wanted is the maximum dip in one of these two general directions. This can be easily accomplished by turning the dip needle through a small arc about its vertical axis and noting its maximum dip, which is the reading required.

The readings obtained by such surveys are carefully plotted and readings of like magnitude are joined by lines. In the case of the compass the lines join points of equal angular deflexion and in the case of the dip needle points of equal dip, these last are known as isoclinal lines. These lines or curves if carefully studied can give valuable information with regard to the position of the magnetic body. It must, nevertheless, be remembered that the earth's field has an influence on the field of magnetic bodies and distorts these fields. If this factor is not fully recognized the mapped curves may be misleading and result in waste work when mining methods are used to locate the hidden magnetic body. The following general rules are of value in considering a magnetic map. Maximum dips occur approximately over the magnetic pole of the hidden magnetic body. Small ore-bodies near the surface may exert as much attraction as large ore-bodies deeply buried, but their effect extends over a smaller area. A slow, steady increase in dip limited to a small area indicates a small deposit. Lean magnetic ore at surface may give the same indications as rich magnetic ore at depth.

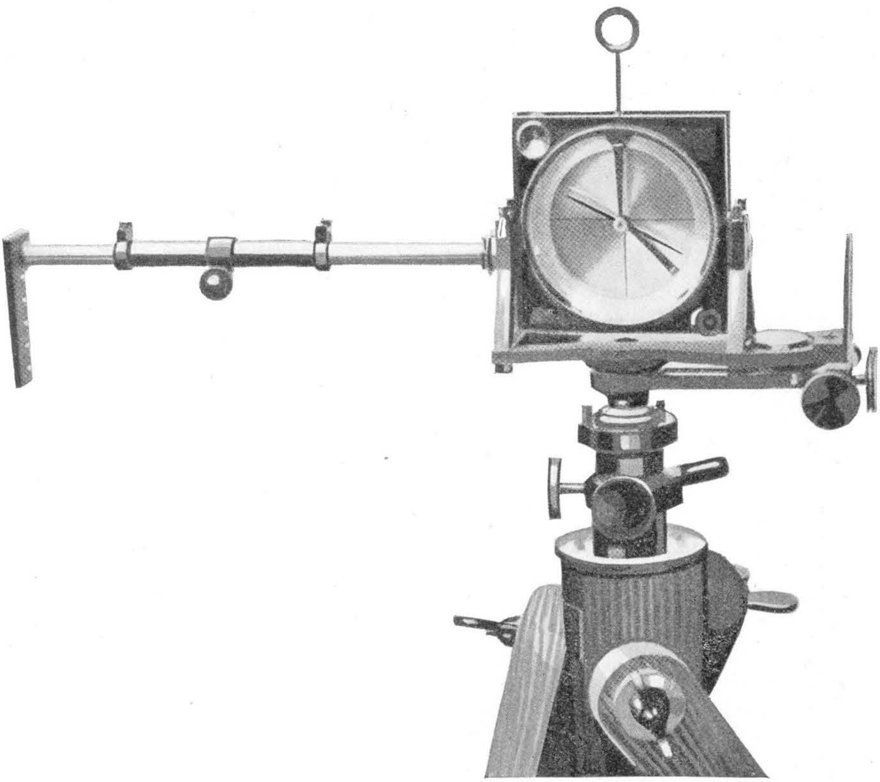
Magnetometer

The ordinary magnetometer is an instrument that is more exact than the preceding ones, in that it will indicate to a fair degree of accuracy the relative value of both the horizontal and vertical components of a magnetic field at any given point. The magnetometer is mounted on a tripod and has level-bubbles for the proper levelling of the instrument. Right above the vertical axis of the tripod is a compass case containing a delicately balanced compass about 3½ inches in length which is free to swing in a horizontal plane when the compass is horizontal, and is free to swing in a vertical plane when the compass box is vertical. The compass box is suspended in gimbals so that the compass box may be placed either in the vertical or horizontal plane. In line with these gimbals and on one side is a graduated arm about 9 inches in length. Upon this arm is a movable frame which is for the reception of a thin 4-inch magnet—the deflexion magnet. This magnet can be easily removed or attached to the frame. There are sights attached to the end of the graduated arm and to the gimbal farther from the arm, thus allowing the instrument to be sighted along a line.

The strength of the deflecting magnet is previously determined and its effect on the compass needle in the earth's normal magnetic field is noted. A magnetometer survey is then carried on in the following manner. The instrument is set up at a point and is sighted along a surveyed line. With the deflecting magnet not on the instrument and the compass box horizontal, the direction of the field at this point is indicated by the direction of the needle. The deflecting magnet is then attached to the carrier on the graduated arm. By noting the deflexion of the compass needle, the position of the deflecting magnet on the graduated arm, and by using the value of the known strength of the deflecting magnet and the normal strength of the earth's field, the relative strength of the horizontal component of the earth's field is found at this point by the sine or tangent method. This, therefore, gives the direction and strength of the horizontal component of the field, and can be expressed as a vector having length, direction, and sense. It can be at once seen that in a disturbed field a very interesting map can be made.

The vertical component can be found in a similar way, except that the compass is here used in a vertical position. As a matter of fact this is usually the only component read, as it is somewhat more rapidly obtained. It can also be seen that not only can the direction of the field, and horizontal and vertical components be obtained, but also the total relative strength of the field.

PLATE XVI



Thalen-Tiberg magnetometer.

The instrument has been used extensively in the search for magnetic ore-bodies—magnetite, pyrrhotite, etc. The Mines Branch some years ago carried on many magnetometer surveys. It is also used at present on the pyrrhotite-carrying ore-bodies of Ontario and Quebec.

The interpretation of the maps of magnetometer surveys is not as simple as it looks on the face of it and anybody interested should consult

Haanel's book[1] which, although out of print, is obtainable in all scientific libraries. The difficulties of interpretation of such a survey are similar to those discussed in the section under "Field Methods in Compass and Dip Needle Surveys."

Vertical and Horizontal Field Balance

The vertical and horizontal field balance can be obtained from various companies, for instance the Askania-Werke. These instruments measure the same quantities as magnetometers, that is the direction, the relative total strength, and the relative vertical and horizontal component of a field at any point. The instruments are extremely sensitive and very small variations in the earth's field can be recognized. For instance, the contact between geological formations, not of necessity strongly magnetic, can be indicated. The instruments are expensive and the makers include in the price a course in the use of the instrument. A trained physicist is apparently needed for their proper use. These instruments are used for the location of faults and intrusives; in some phases of prospecting for oil pools or salt domes; and the location of mineral deposits.

Earth Inductor

The earth inductor is an instrument that has theoretical possibilities. So far no reference to its having been used in ordinary practice has been noticed, although these instruments are on the market. The instrument consists essentially of a coil rotating at a fixed speed. The rotation of this coil in the earth's field causes a measurable current to flow in the coil. As has been pointed out, the concentration of lines of magnetic force in the vicinity of magnetic bodies varies and the readings of this instrument would vary as such an area is traversed.

ELECTRICAL METHODS OF PROSPECTING

Electrical methods of prospecting depend on the difference of electrical properties shown by certain minerals and ordinary rocks and drift. Many of these minerals are valuable ores when found in sufficient quantities. By suitable measurements of electrical properties over an area the position of these bodies may be located.

Those areas having distinctive electrical properties must be correlated with the known local geology. The electrical survey can only indicate the electrical nature of the area. If the geology is known it can often be inferred what is causing the electrical reactions and in this way the survey can be of the greatest benefit. If the geology is not known or studied there is the danger that there may be more than one geological explanation for the electrical phenomena observed.

Electrical methods of prospecting are merely a further aid to the geologist and mining engineer. They occupy a more or less intermediate

[1] Haanel, E.: "On the Location and Examination of Magnetic Ore Deposits by Magnetometric Measurements"; Mines Branch, Dept. of the Interior, 1904.
Smyth, H. L.: "Magnetic Observations in Geological and Economic Work"; Econ. Geol., pp. 367-379, 1907; pp. 200-218, 1908.

position between the work of thoroughly geologically mapping a property and its final proving up by the tried mining methods of stripping, trenching, diamond drilling, or other drilling, shaft sinking, and underground development. In most areas a geologist can definitely eliminate sections as not worth intensive electrical surveying or prospecting, and in a promising area his work should assure the most economical use of electrical and mining work.

The following description of the various electrical methods is of necessity a very general one. The intricate nature of some of the apparatus, the mathematics involved in the necessary deductions from observed electrical readings, or the finer points in the field and office technique used are not discussed. Much of this information is the private property of the various prospecting companies and is considered as trade secrets by them. It must be obvious that the success of electrical surveys depends on a thoroughly competent field and office staff. This staff must have a thorough grasp of the principles and technique involved and be capable of appreciating the conditions and difficulties to be met. All this calls for well-trained physicists or electrical engineers, having a due appreciation of geological phenomena.

The electrical methods may be divided into three main classes, according as they depend on:

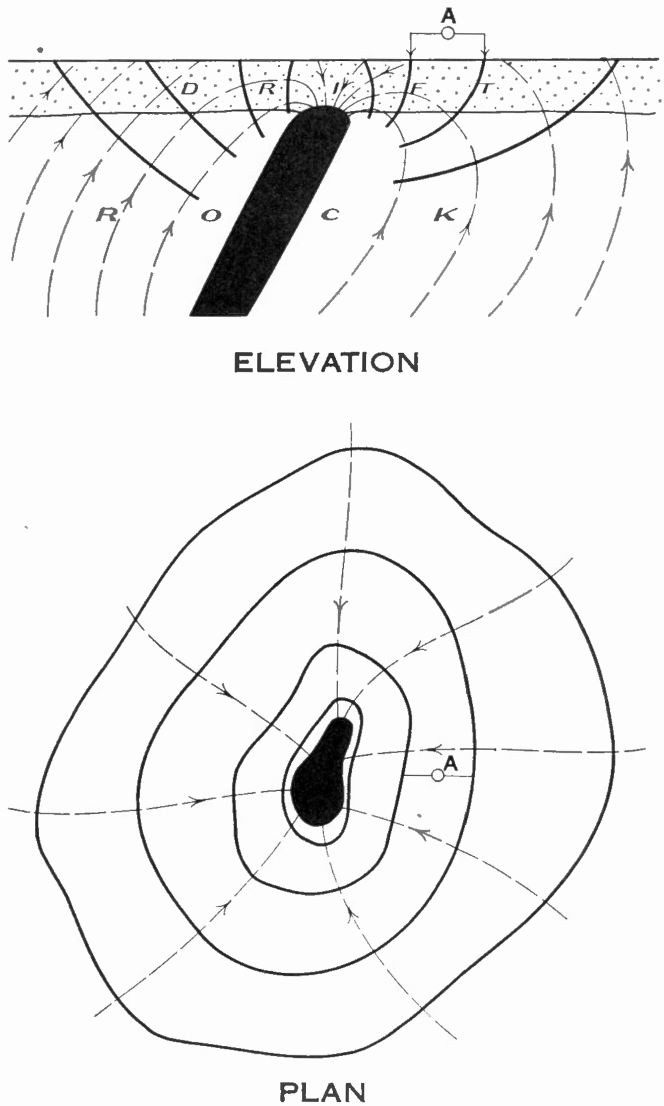
(1) The measurement of natural current effects.

(2) The measurement of the effect of direct current derived from a generator or battery and passed through the area to be studied.

(3) The measurement of the effect of alternating current derived from a generator or battery and passed through or used to induce current in the area to be studied.

Natural Current Method

The natural current methods depend on what is known as the voltaic action which exists about certain mineral bodies. The voltaic action which goes on about these natural bodies is analogous to that found in an ordinary wet or dry cell in which two electrodes of different chemical composition are placed in a solution that is an electrolyte—that is a solution that chemically acts on the electrodes and causes a flow of electrical energy from one electrode to the other; if the electrodes are joined by an electrical conductor this energy or electrical current flows along this conductor and can be measured. One electrode is said to be at a lower potential than the other and current flows in the outer circuit from the electrode of higher potential to that of lower potential. The difference of potential between these two electrodes is said to be the voltage of the cell. In nature quite a similar state of affairs exists in certain instances, even in salt and oil structures, but especially in the case of good conductors, such as metallic sulphides and native metals except sphalerite and stibnite, in a region where there is groundwater. The groundwater with salts in solution is the electrolyte of the natural cell. The character of the waters near the surface is generally of an oxidizing nature, whereas those at depth are reducing or neutral solutions. The difference in chemical action near the surface and at depth sets up a difference of potential and current flows from the lower part of the mineral body through the surrounding rock to the upper part of



Geological Survey, Canada.

Figure 11. Natural current flow about a sulphide mineral body. A, searching electrodes and potentiometer; current flow shown by fine, pecked lines; traces of equipotential surfaces shown in heavy lines.

the mineral body and then down through the mineral body itself, thus forming a complete circuit. It will be seen that the top centre of the vein or body is negative and current from all sides will flow into this centre which is known as the negative centre. The adaptation to electrical prospecting of this voltaic property of certain ore minerals was largely developed by Professor Schlumberger of the Ecole des Mines, Paris (Figure 11). The field apparatus is exceedingly simple and consists of two slender copper rods, waist high, connected by a length of wire usually 100 feet in length. On the top of one of these rods or searching electrodes is a sensitive potentiometer. This instrument measures the difference of potential between the two searching electrodes and indicates the direction of current flow. At the base of these searching electrodes are small earthenware pots containing a saturated solution of copper sulphate and into which the copper rods dip. The pots are so corked and constructed that they are easily transported. These pots

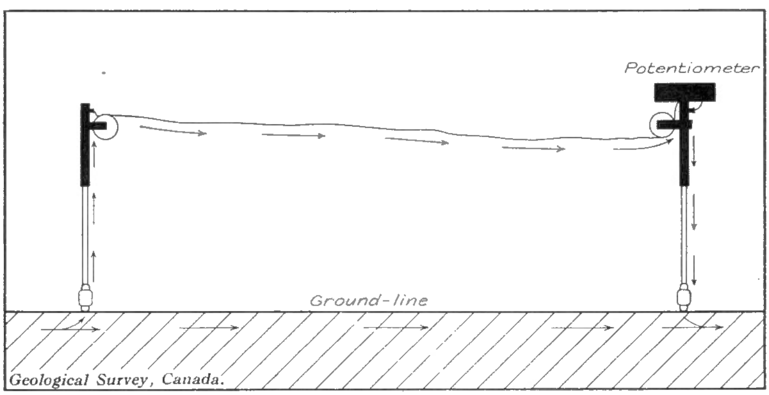


Figure 12. Path of current from ground through electrodes and potentiometer.

prevent the metal points from being in contact with the damp ground and setting up a current of their own (that is polarizing) and thus masking the natural currents to be measured (Figure 12).

The common method used is to traverse the claim in straight lines from boundary to boundary. The operator and his aide start along one of these lines. The aide with the single electrode will place it in contact with the ground and the operator with the electrode and potentiometer will move from 10 to 100 feet from him as the case warrants and place his electrode in contact with the ground. If a current is flowing through the ground between these two points, part of it will be shunted through the electrodes, connecting-wire, and potentiometer. The potentiometer will indicate the direction of the current flow and the potential difference between the two electrodes. The man with the potentiometer will now move ahead to the next station and the aide will come forward and place his electrode on the spot just left by the operator. This process is continued to the end of this line and along all the other lines.

The results are plotted in a graph, the negative potentials above the lines of traverse and the positive below. As has been previously stated, the point on the ground above the conductor or mineral body is its negative centre and on these traverse profiles proximity to the negative centre will constitute a peak. If the peak is low and narrow the conductor is weak and small, if broad and high the conductor is strong and large. Naturally the distance of this conductor below the surface will influence greatly the shape of these profiles. These profiles are run where possible across the strike of the formation. If this strike is not known a somewhat different method is used. Lines are run and readings are taken until it is seen that the current is flowing into a certain point, the negative centre, then around this centre points are searched out which all differ from the negative centre by the same difference of potential. The line joining all these points of equal potential value is an equipotential line. Such a line will be a closed loop about this negative centre. Similar lines at greater and greater distance and, therefore, greater and greater potential difference from the negative centre, are traced out in the same way. The negative centre, as previously stated, lies over the electrical centre of the conductor, and the shape of the equipotential lines will indicate the strike and size of the body.

In practice the Schlumberger method meets with difficulties. Good contacts with the ground must be made by searching electrodes, and this is not always easy. A dry, sandy surface, snow, or a wet swamp make it impossible to get the proper flow of natural currents through the potentiometer. Also readings taken just after a rain storm, which dilutes the ground water or electrolyte, will be different from those taken during a dry period. Nevertheless the speed, ease of operation, and cheapness of the method commend it. It has been used rather extensively in Canada.

Direct Current Methods

Instead of studying the natural direct currents in an area, direct current methods use currents supplied from a direct current generator or batteries and passed through the area to be prospected. The methods depend on the difference of electrical conductivity between many ore minerals such as the metallic sulphides, pyrite, chalcopyrite, pyrrhotite (excepting sphalerite and stibnite); antimonides, arsenides, such as arsenopyrite; and oxides, such as hematite and magnetite, etc., and ordinary non-conducting rocks and soil. Graphite and coal are considerably better conductors than ordinary rocks and soil. There is also a difference of conductivity between oil, salt water, and solid salt, as well as a difference between various rocks, but the conductivity of these materials is relatively slight. The more basic rocks are usually more conductive than the more acid.

The following table[1] shows the electrical resistance of some minerals and rocks.

[1] Lunberg, Hans: "Electrical and Electromagnetic Prospecting"; Trans. Am. Inst. Min. and Met. Eng., 1927, p. 4.

Minerals	Ohms per cm.³	Rocks and ores	Approximate ohms per cm.³
Calcite	$5·0\times10^{14}$	Quartzite, limestone, sandstone, granite	10^{11}
Quartz	$3·8\times10^{11}$	Leptite, schists	10^{9}
Mica	$1·5\times10^{10}$	Greenstone	10^{8}
Serpentine	$2·0\times10^{4}$	Hematite and spathic iron ore	10^{8}
Siderite	$7·1\times10^{3}$	Zinc blende ore (non-ferrous)	10^{5}
Marcasite	10·0	Specular iron ore	10–100
Chalcopyrite	1·0	Magnetite ore	10–100
Molybdenite	0·8	Schists with pyrrhotite	5–100
Magnetite	0·6	Galena ore	1
Specular iron	0·8 –0·4	Chalcopyrite ore	0·1
Graphite	0·03	Sulphur pyrite ore	·0·1
Pyrite	0·02		
Pyrrhotite	0·01		
Galena	0·003		

The three methods using this outside source of direct current, or as it is usually termed impressed direct current, differ essentially in the method in which the direct current is led into the ground. The two chief methods in which this current is applied or led into an area are the first two of the following three:

(1) The point electrode method.
(2) The parallel wire electrode method.
(3) A third one is in the experimental stage and is Dr. Eve's leap frog method.

POINT ELECTRODE, DIRECT CURRENT METHOD

In the point electrode method the current from the generator or batteries is led into the ground at two points or source electrodes. These source electrodes are usually metal plates buried in the ground. The voltage used is usually 100 to 135 volts.

A current made to flow through an area of rocks or minerals of different conductivity will follow the path of greatest conductivity. In the presence of highly conductive bodies in an area of generally low conductivity, the normal regular paths of this current will be distorted as much of the current will pass through the good conductors. A study of this distortion of the regular paths of the flow of a current gives the location of the good conductors in the area. In practice it is not the path of the current that is traced, but the drop of potential along these paths. These lines are traced out by two searching electrodes—similar to those used in the natural current method—connected to one another by 100 feet or so of copper wire through a delicate ammeter—an instrument for the measurement of the strength of a current flowing through it. If the two searching electrodes are on two current paths at points which are at the same potential, no current will flow through the ammeter and a zero reading will be given, as a difference of potential is needed for a current flow. These lines of equipotential are traced out by placing the operator's electrode at a point, the aide going forward and searching with his electrode until he is at a point of equipotential with the operator's electrode. A stake is then placed at these points and the operator moves forward over to the station occupied by the aide who goes forward and locates another point in the same manner. These points, therefore, lie on an equipotential line.

An equal drop of potential will take place in a longer distance in a good conductor and in a shorter distance in a poor conductor. These distances will be proportional to the conductivity of the rock or mineral along these paths. It will be seen if points of equal potential along adjacent current paths are joined by lines (equipotential lines) that the equipotential lines tend to crowd away from the good conductors. This feature is, therefore, used in the location of conducting bodies. In a map showing equipotential lines, an opening or scarcity of such lines is found over the conductors. In the point electrode method, the equipotential lines about the source electrodes in areas of uniform conductivity are regular curves. In an area with conductors, at the points where the good conductors are present, they diverge and are distorted (Figure 13). In rough country and

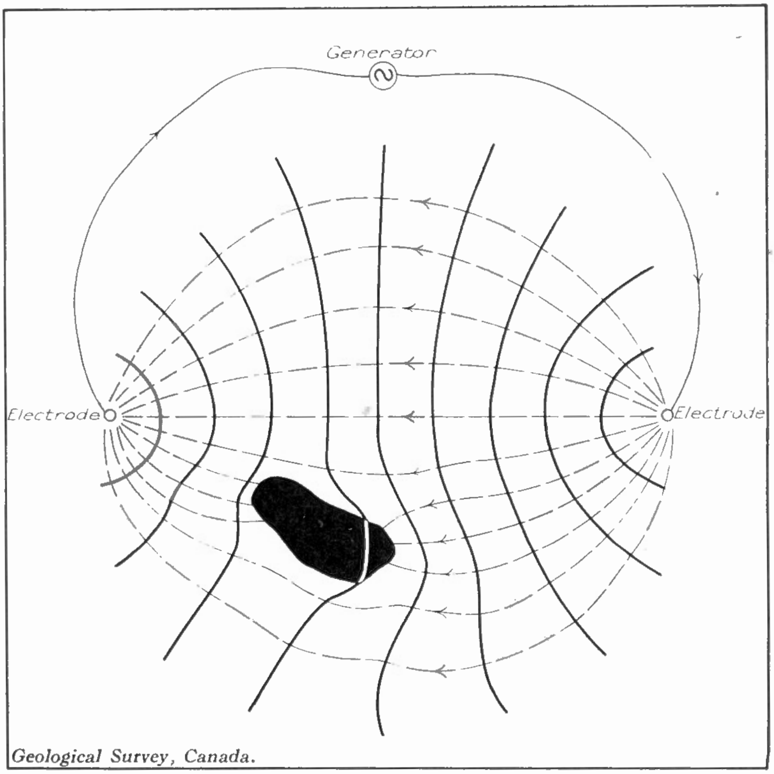


Figure 13. Area containing conducting mineral body, showing current flow and equipotential lines when point electrodes are used. Current flow shown in fine, pecked lines; equipotential lines shown in heavy lines.

where conductors are not particularly strong the distortion of these lines must be difficult to determine exactly. Although the method has certain obvious disadvantages compared with the next method to be described, it has simplicity and directness in field operation which offset somewhat the difficulty of interpreting the results. It is quite evident that a trained physicist can best operate this or any other of the electrical methods.

PARALLEL WIRE ELECTRODE METHOD

The parallel wire electrode method resembles very much in general principles the last method, except that the current flowing through the area passes not between two single electrodes but between two parallel wires which are grounded at many points along their length. These wires are

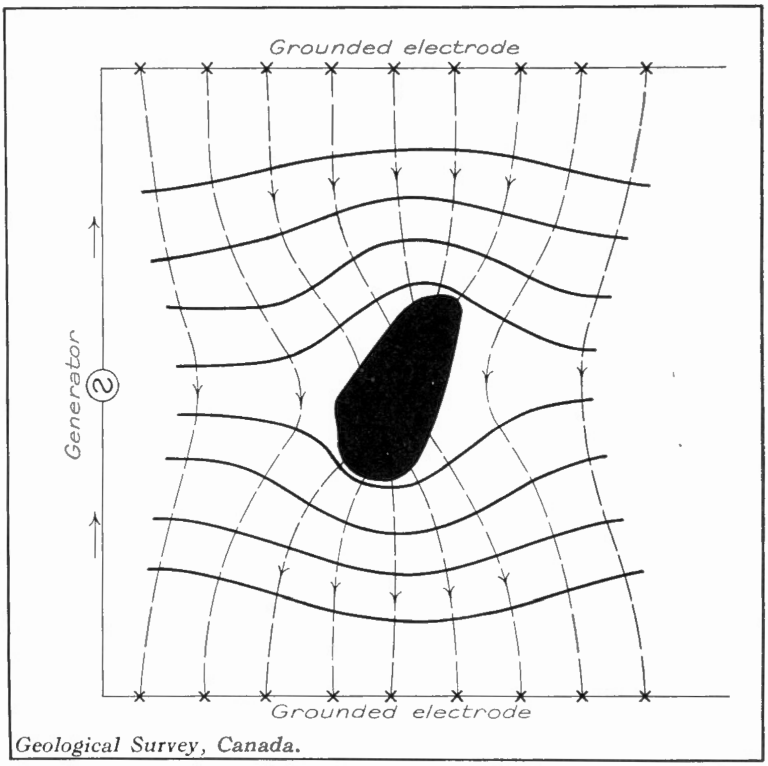


Figure 14. Area containing conducting mineral body, showing current flow and equipotential lines when parallel grounded electrodes are used. Current flow shown in fine, pecked lines; equipotential lines shown in heavy lines.

usually 2,000 feet long and 2,000 or more feet apart. The voltage used is the same as the last, 100 to 135 volts. The current from the positive wire through the ground to the negative wire flows in direct lines and not in curves as in the single pole method. In a field with no abnormal conductors present these lines are straight and the equipotential lines, which traverse them at right angles, are all parallel and an equal distance apart. If an abnormal conductor is present they will crowd away from it (Figure 14).

The method of tracing the equipotential lines is the same as that used in the previously described point electrode method. It is obvious that the location and shape of conductors will be more easily recognized by this method than by the point electrode method; but it seems obvious that the long electrodes and the grounding of them at many points present difficulties and possibilities of trouble.

LEAP FROG METHOD

The leap frog method was devised by Professor Eve during the summer of 1927 while carrying on tests of electrical methods in co-operation with the United States Bureau of Mines. Three movable metal electrodes are placed at three points at equal distances apart along a straight line. A battery of 135 volts is connected between the two outer electrodes. Through the ground between these two points a current flows which has a drop of potential of 135 volts. If the conductivity of the ground is uniform the drop of potential is uniform between the two electrodes. If a good conductor is present the drop of potential through this conductor will be much less per unit length than in the rest of the poor-conducting ground. A voltmeter is connected between the first and middle electrode and the voltage of the current flowing between these electrodes or their difference of potential is noted. The balance of the drop of 135 volts is between the middle and third electrode. It can at once be seen that of the two segments, first to second electrode and second to third, the segment having the better conductivity will show the lower drop of potential, or difference in voltage, between its two ends. In other words the conductivity of these two sections of ground is inversely proportional to the voltage drop through these sections of ground.

The next reading is taken after moving the electrodes forward another unit distance; the first electrode takes the place of the second, the second of the third, and the third a new point ahead of them. The same procedure as in the first reading is repeated. The voltage drops between the first and second and between the second and third electrodes are noted. With the conductivity of the first section of ground as the datum, the second, third, and subsequent sections are calculated by proportion, which gives a number for the conductivity of each of these sections. The whole area to be prospected can be covered in the same way in a series of squares. Each side of a square will have a number designating its conductivity. When numbers between definite ranges of value are joined, a series of curved lines result. The lines of high conductivity lie over the most conductive part of the area and those of least conductivity lie over the poorest conducting part of the area. The method is extremely simple, entailing only some direct and simple calculations. A weakness of the method is that it is always assumed that the grounded electrode contacts are in every case equally good. It can be seen that any difficulty in making a contact affects the accuracy of all later readings. Also the moisture content of the soil affects the resistance at the immediate contacts with the ground.

Alternating Current Methods

In several methods of electrical prospecting alternating current is used. Of these alternating current processes, some employ the equipotential and others the electromagnetic method and measure various properties of the resulting electromagnetic field. As previously stated the alternating current methods are the most important. They have some distinct advantages over the direct current methods. Owing to the use of alternating current polarization troubles are eliminated, weak currents can be easily detected by the use of simple amplifiers—direct current amplifiers are usually bulky and heavy—and an ordinary telephone receiver or detector can be used. The telephone detector is a cheap, rugged, and sensitive instrument, much lighter and more portable than an indicating meter. A comparison between all equipotential methods and electromagnetic methods will be made towards the end of this article. Several prospecting companies using alternating current methods have published descriptive literature, but they give no clear and detailed idea of their field practice or of the quantities they measure to obtain their results. It is true that practically all companies cross-check their results by the use of more than one method or by the measurement of more than one electromagnetic quantity.

EQUIPOTENTIAL METHODS

The two equipotential methods that use alternating current differ from one another in the way the alternating current is conducted into the ground. One is a point source electrode method, the other a parallel wire electrode method. They are similar to the first two methods described under the direct current methods.

In the link up of the parallel wire electrode system two 2,000-3,000-foot electrodes are placed parallel, 3,000 or so feet apart, and well grounded along their length. They are connected across one end by electric cable through a small alternating current generator. The alternating current circuit is completed by the current flowing through the ground between the electrodes. As alternating current is used the current reverses itself many times a second which eliminates polarization at the points where the current is led into the ground. Thus a more constant flow of current through the ground is ensured than if direct current were used. The method of studying the flow of this alternating current through the ground is the same as that employed in the direct current equipotential method, that is, equipotential lines are traced out by two searching electrodes connected by an electric cable through a micro-ammeter or micro-voltmeter. If the two searching electrodes are at points of equipotential, no flow will pass between them and a zero reading will be given by the ammeter or voltmeter. Alternating current as well as direct current may be used, for, at the two electrode points on this equipotential line, the alternating current through the ground is flowing in the same direction at the same time and reaches the zero point at the same time. It has as well the same voltage or potential at the same instant, so that no electrical adjustment between these two points can take place by a flow between the electrodes of current which would give a reading in the ammeter or voltmeter.

In practice, instead of an alternating current generator as the source of current, a 6-volt battery connected in series with a buzzer and induction coil is commonly used. This buzzer makes and breaks the circuit, giving an intermittent direct current, that is the current voltage reaches a peak and then falls to zero. From a physicist's point of view this current has many of the properties of an alternating current and this method is usually considered with alternating current methods. In this method the searching electrodes are linked together through a head phone, with which an amplifier is sometimes used. When the two electrodes are on the same equipotential line no current flows through the phone and no sound is heard. If current flows through the phones buzzing is heard having the same vibration frequency as the buzzer attached to the source electrodes. This method is said to be more reliable and accurate than if a micro-ammeter or micro-voltmeter were used.

ELECTROMAGNETIC METHODS

General Principles

Electromagnetic methods are based on the study of electromagnetic phenomena. When a current is flowing through a conductor, for instance a wire, a field exists about this wire, and the lines of force that surround the wire link themselves about it in rings. If a magnetic needle is brought within the field of such a wire which is carrying a current the lines of force about it set the needle parallel to their direction; the properties of these lines of force are the same as those found about a magnet. They are in every sense magnetic lines of force and owing to their origin are known as electromagnetic lines of force.

If a good electrical conductor such as a wire is moved so as to cut the lines of force of a magnet or the lines of an electromagnetic field about a wire carrying a current, a current is produced in the moving conductor. The direction of this induced or secondary current is in a definite direction with relation to the lines of force cut. The field of force which is cut is known as the primary field and the current generating this field the primary current. The current in the moving conductor is called a secondary or induced current. The strength of the secondary current is directly proportional to the number of lines of force of the primary field cut in unit time, and is also proportional to the conductivity of the secondary conductor. A good conductor will allow a greater current to flow through it than a poor conductor.

If the primary current is alternating, that is if it in one instant flows in one direction and the next instant in the reverse direction, its field will also be alternating, and its field will be destroyed and built up in a reverse direction every time the current changes direction. The conductor carrying the induced secondary current will, in this case, not need to be moved to cut lines of force, for they will keep cutting this secondary conductor every time they are built up and destroyed about the primary alternating current conductor.

In the case of electromagnetic methods a primary field is broadcast much as in the case of ordinary wireless. A large or small aerial is used.

In some cases the aerial is set up in the vertical plane, in other cases in the horizontal plane. If the loop is set up in the vertical plane the primary field will be generally horizontal. If the loop is horizontal the primary field is generally vertical. The wave length or conversely the wave frequency also varies. In some methods a low frequency is used, in others a high frequency.

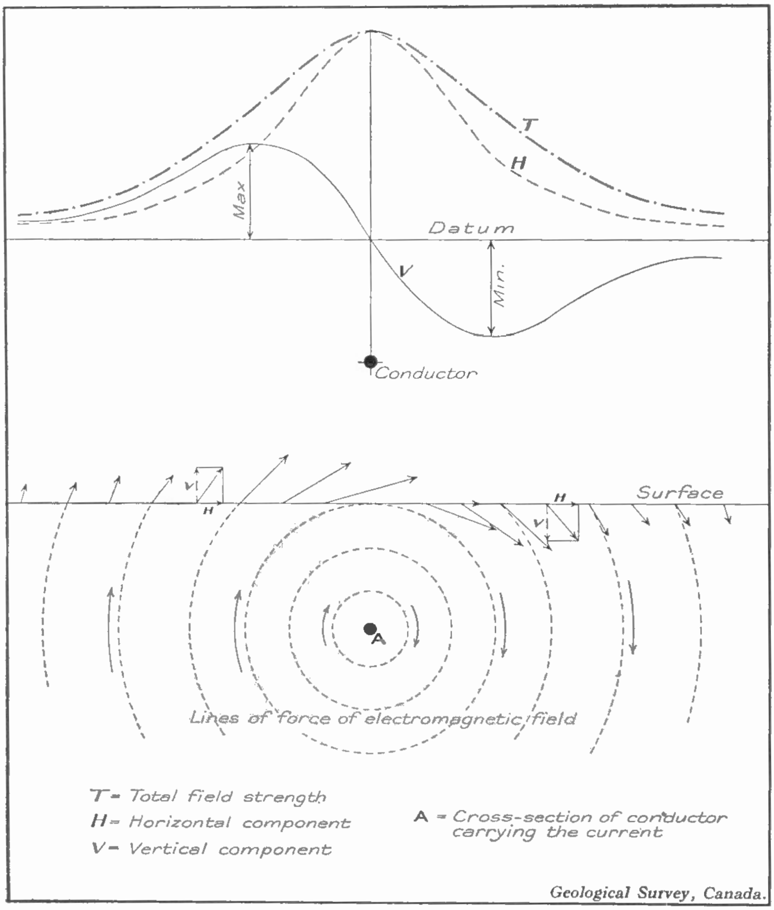


Figure 15. Electromagnetic field around a flow of current.

In the case of a conducting mineral body which is surrounded by a broadcast alternating electromagnetic field, an alternating current is induced in this mineral body. This current is believed to flow about the outer periphery of this body in a closed loop. The electromagnetic lines of force cutting this loop cause the current to flow in the loop.

The electromotive force induced around the periphery of the conducting mineral body is directly proportional to the alternating magnetic field cutting it. The ensuing current will, therefore, at low frequencies at least, be directly proportional to the conductivity of the body. This secondary electric current in the mineral body induced by an alternating primary field is much greater than in the surrounding poorly conducting rock or soil.

This secondary electric current in the mineral body has all the properties of an ordinary electric current, including an electromagnetic field of its own which is known as the secondary magnetic field (Figure 15). It is this secondary field that is mapped and studied in electromagnetic methods of prospecting, or rather the resultant of the secondary and primary fields about the conductor in an area that is being electromagnetically prospected.

Electric Magnetic Properties of the Magnetic Field Measured

The measurable properties of the induced electromagnetic field, about conductors, are:

(1) Horizontal and vertical components of the intensity of the resultant field.
(2) Total strength of the resultant field.
(3) Direction of the resultant field.
(4) Phase difference between primary and secondary fields.

Both horizontal and vertical components of the field are measured in much the same way and usually only one of these components is measured. In practice the components are measured by using a detector loop—usually a rectangular or circular loop of 2 or 3 feet in diameter. This may be connected to a calibrated amplifier and vacuum tube voltmeter, which can measure the electromotive force induced in this loop by the field passing through it. Readings are taken at regular intervals all over the area which is to be prospected and which is subjected to the primary current.

If the vertical component is to be measured, the following is the practice: the broadcasting loop is placed in a horizontal position near the surface of the ground. The electromagnetic field threads this loop at right angles to it and, therefore, perpendicular to the earth's surface. The detector loop is placed in a horizontal position. In a disturbed field, lines of force will generally cut this horizontal detector loop at an angle. It can be seen that the vertical component of this field will thread the loop and will induce a current in the loop. A micro-ammeter or voltmeter in series with this loop will record the strength of this vertical component. The strength of the primary field being known, the vertical component due to the disturbing conductor can be calculated. In a similar way the horizontal component can be calculated.

Total Strength of the Resultant Field. If the detector loop is placed normal to the direction of the lines of force, the greatest possible number of lines of force thread this loop and the total strength of the field can be measured by measuring the current induced in the loop.

Direction of the Resultant Field. If the plane of the detecting loop is placed in the plane of the resultant field, it will have no lines of force cutting it and, therefore, a zero reading will be obtained. If a buzzer is used in this circuit, no sound will be given out by it. The loop will show by its direction and inclination the direction and dip of the resultant field. A line at right angles to the plane of the loop will point in the general direction of the conducting body causing the disturbance. It will be seen that the position of the detecting loop when the total strength of the resultant field is measured also points in the general direction of the conductor.

The Radiore Company uses this method to locate the axis of conductors, by taking readings on the two sides of a conductor and compensating for the primary field. This method does not indicate the boundaries of the conducting body, but only the electrical axis of this body. In fact it is apparently the position of the upper part of the closed current circuit flowing within this body, that this method attempts to indicate.

Phase Difference between Primary and Secondary Field. An alternating electromagnetic wave is similar in some respects to an ordinary sound wave, and both are analogous to an ordinary wave on the surface of water. These waves have a crest and a trough, and a complete wave is considered to be a complete crest and trough. If two waves are said to be in phase, they will travel parallel to one another and their troughs and crests will occur at the same instant. If they do not synchronize at these points they are not in phase.

It is found that the secondary field about a mineral body is usually not in phase with the primary field. This is due to the fact that the electromotive force induced in the secondary conductor always lags behind the primary field. The difference in phase can be measured. Apparently the greatest phase difference is at the margins of the conductors, so this is a delicate method for locating these margins. Little is published regarding the exact methods used.

HIGH AND LOW FREQUENCY ELECTROMAGNETIC METHODS

The electromagnetic methods vary not only as regards the quantities measured, but also as regards the frequency of the current used in the primary loop. In some methods a high frequency is used, in others a low. The use of a high or low frequency is important as there is a difference in the results to be expected. It is known from electrical theory that if low frequency is used in the primary circuit the current induced in a conductor present in the field will be proportional to the conductivity of this conductor. If a high frequency field is used the current in the conductor will be largely controlled by its inductance, which depends on the outline and size of the conductor and not on its relative conductivity. With high frequency, a large disseminated conducting mineral body may give as large a reaction as a massive conductor with much greater conductivity. The use of high frequency does not allow discrimination between good and weak conductors to the same extent as low frequency.

A limiting factor in the use of high frequency is that absorption by soil and rock of the radiated waves increases rapidly with the frequency used.[1] The experimental evidence on this point is not very abundant, but absorption does not seem to be serious until the frequency is increased a good way

[1] Eve, A. S., Keys, D. A., and Denny, E. H.; "Penetration of Radio Waves"; Nature, Sept. 17, 1927, p. 406.

beyond the frequencies used by the companies that operate with radio-frequency waves. Conducting bodies some distance below the surface will tend to be masked if too high a frequency is used.

The field advantage of the high frequency methods is that the apparatus used is more compact than that used in low frequency methods. The primary and detecting loops are small in high frequency equipment, whereas in low frequency equipment the primary loop is large. The primary or sending loop in low frequency apparatus at times surrounds the area to be prospected. The large, low frequency loop has the additional disadvantage that it is difficult to make it exactly horizontal or vertical and the resulting field will, therefore, be affected. The sending loop of a high frequency method is only a few feet in diameter and can easily be placed in any required plane. Though the high frequency loop can be moved easily, it must nevertheless be moved often as compared with the one set up of the low frequency primary loop.

COMPARISON BETWEEN SURFACE POTENTIAL METHODS AND ELECTROMAGNETIC METHODS

A comparison of surface potential methods, using both direct and indirect current, and electromagnetic methods, brings out some important points regarding their direct application in locating conductors. The following discussion is largely suggested by Dr. Mason's article.[1]

Surface potential methods require properly grounded electrodes, which electromagnetic induction methods do not require. This makes surface potential methods unsuitable for snow- or ice-covered ground.

Using surface potential methods where a non-conducting layer exists between the relatively conductive surface soils and a mineral body, the current flowing between the electrodes will tend to travel through the surface soil. The mineral body will, therefore, be masked. In an inductive method the electromagnetic field penetrates the non-conducting layer.

In the case of surface potential methods no absolute scale for the measurement of conductivity exists. The currents will tend to crowd more into the better conductors than into the poorer; but if one conductor is very much better than the poorer, the current does not crowd into this conductor in direct proportion to its conductivity, as there is a saturation effect which produces only a slightly greater difference in the ratio. Dr. Mason states that when the conductivity ratio is 10 or 20, about 90 per cent of the possible influence is realized and higher ratios will not be discernible. In practice it is found that ratios of conductivity between neighbouring soils are often in the ratio of 10 or more, therefore, a swamp will and does react much like an ore-body which often has many thousand times greater conductivity than either soil or swamp. On the other hand the indications of inductive methods that depend primarily on the conductivity of the conductors and not on their inductance, are approximately proportional to the conductivities of neighbouring bodies.

[1] Mason, Max: "Geophysical Exploration of Ore"; Eng. and Min. Jour., Nov. 12, 1927, pp. 766-771; Nov. 19, 1927, pp. 806-811.

DEPTH TO WHICH MAGNETIC AND ELECTRICAL METHODS CAN LOCATE BODIES OF MINERAL

The factors that limit the depth to which the various magnetic and electrical methods are effective, are all more or less the same. The signal that will be received at the surface is of a strength which will decrease with depth, probably in every case according to a power higher than the second. It will, therefore, be recognized that average-sized reacting mineral bodies can not be located when at a depth of 500 feet or even much less.

All these methods will apparently indicate only bodies close below the earth's surface and will not locate anything at average or deep mining depths.

Where rock exposures are plentiful an ore-body close to the surface will with few exceptions give some indication of its presence. In such areas magnetic and electrical methods would probably give little extra information that could be used to guide deep exploration by diamond drilling or shaft sinking. But in areas where drift cover is extensive they will no doubt give much information of value regarding the sub-drift conditions.

COST OF MAGNETIC AND ELECTRICAL PROSPECTING METHODS

No detailed information is available on costs of the various magnetic and electrical prospecting methods, but some general information is obtainable from the literature.

Irrespective of the method used it is obvious that the investigation by one of these methods of a large block will be cheaper per acre than that of a few claims. The general figures stated below are considered as applying to blocks of approximatly 1,000 acres or so.

The cost of transporting the equipment and personnel to the area to be prospected is not considered in the following figures. Difference in the cost due to difference in the difficulty of the country prospected is believed to be allowed for in the ranges quoted. Cost of hire, cutting, and transit surveys in average Precambrian country range from $25 to $40 a lineal mile. If parallel lines were run at distances of 200 feet apart, as is the usual practice, it would mean a cost per acre for this work of $1 to $1.75.

Not counting cost of transit survey and lines, magnetic balance or natural current surveys would cost probably from $1 to $3.50 an acre. With transit surveys this would amount to a cost of $2 to $5.25 an acre. Dip needle and magnetometer surveys would cost even less.

Electrical methods require more equipment and personnel and are, therefore, expensive, and would cost without transit surveys probably from $2.50 to $7 an acre, depending on the method and the difficulties of the country surveyed. Including transit surveys the cost an acre would be from $3.50 to $8.75.

If in any instance extra lines are run over specially promising areas, the average price will naturally increase accordingly.

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CONCLUSIONS

Evidence of subsurface bodies of magnetic minerals is given by a compass needle, dip needle, and magnetometer. Such magnetic minerals include magnetite, ilmenite, and pyrrhotite. The above methods are sensitive in varying degrees, but are useful in preliminary exploration and in certain instances are as valuable as the more elaborate geophysical methods.

The magnetic balance is a delicate instrument that will indicate even weakly magnetic bodies and such minute variations in the earth's magnetic field as are locally due to geological formations or structures.

The natural current method of electrical prospecting depends on the voltaic action set up in certain mineral bodies, especially most of the metallic sulphides, in the presence of ground waters.

The electrical equipotential methods depend essentially on the relatively high electrical conductivity of most of the metallic minerals as compared with that of most rocks and soils.

The electromagnetic methods depend on the high electrical conductivity of most of the metallic ore minerals as compared with the low value of this property in most rocks and soils.

Magnetic methods of prospecting may be successfully carried on by relatively inexperienced, though careful, operators, but well-trained operators are essential for the successful use of electrical methods. None of the methods discussed can do more than indicate bodies, relatively close to the surface, having characteristics detectable and measurable by electrical and magnetic instruments.

The results of these methods do not provide definite information on the nature of the minerals present. An intimate knowledge of the geology of the area surveyed and of adjacent mineral deposits may give a clue to the nature and possible value of these deposits, but these prospecting methods alone will not distinguish worthless areas from valuable ore-bodies. These methods are only a further aid to the location of hidden mineral bodies of certain special compositions.

All the magnetic and electrical prospecting companies now operating in Canada have amassed valuable field experience and data and have supplemented this by laboratory work. There is, nevertheless, a great deal of work to be done in the determination of various constants and the perfecting of methods and apparatus. These methods of prospecting are still largely in the experimental stage. In large sections of Canada areas of potential economic importance are hidden by comparatively thin layers of glacial drift. Such areas are ideal for any reliable shallow subsurface method.

The magnetic and electrical methods of prospecting have already proved of value and it is felt that with the improvements that are bound to be made in these methods in the future that some at least of the methods will become a part of the standard prospecting practice of Canada.

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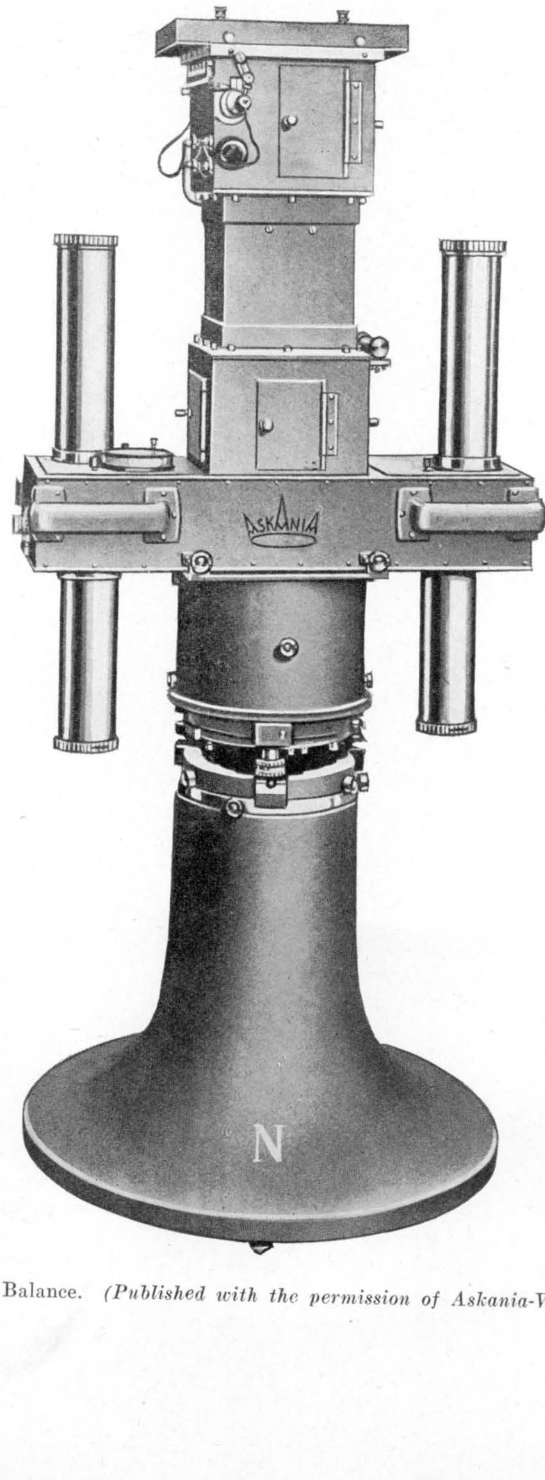
GRAVITATION

(G. S. Hume)

All particles of matter attract one another. The attraction exerted by the earth on any mass is, therefore, the resultant of the attraction exerted by all the component particles of both the earth and the outside mass. Besides this attraction there is the centrifugal force due to the rotation of the earth. This has a maximum intensity at the equator and is non-existent at the poles. The attraction of the earth and the centrifugal force combined is the force of gravity. According to Newton's law the force of attraction between two particles is directly proportional to their masses and inversely proportional to the square of the distance between them. Thus, if two equal masses are so situated that one is twice as far as the other from a third mass, the force exerted on the third mass by the more distant of the two equal masses will be only one-quarter of that exerted by the nearer of the two equal masses. It follows, therefore, that the attractive power of an underground mass of greater density than the surrounding rocks, will be different at different distances. The attraction between any two masses is always in a straight line. The attractive force exerted by an underground mass will act vertically above the centre of the mass, but elsewhere will act along lines making varying angles with the vertical and can be resolved into two forces, one vertical and the other horizontal. The value of the horizontal force will vary from place to place, depending on the varying degree of inclination of the lines of force and the variations in the strength of the force. This principle is used in making relative measurements of gravity by an instrument called the Torsion Balance. A light, movable beam is suspended by a fine wire and to the ends of the beam are attached weights, one directly attached to the beam and the other suspended from it. The suspended, that is the lower, weight being nearer the underground mass is more strongly attracted by it and hence the horizontal component of the attractive force due to this mass is

PLATE XVII



Torsion Balance. *(Published with the permission of Askania-Werke.)*

greater than it is in the case of the mass attached directly to the beam. Apart from the restraining torsion produced in the wire, the beam is free to turn and, therefore, tends to set itself in the direction of the greatest horizontal pull. This phenomenon is used in making readings with the instrument which is sensitive to one-billionth part of a gram weight. The turning of the beam causes a torsion or twisting of the wire suspending it and the amount of this is determined by measuring the deflexion of a ray of light reflected from a mirror attached to the wire. From such measurements differences between the force of gravity at a number of points can be calculated.

The original Torsion Balance as constructed by Eötvös was the single arm·type described. Its use necessitated making readings with the arm pointing in five different directions, whereas a later type of double-armed balance constructed by Eötvös in 1902 required readings in three positions only. Recent models of the Torsion Balance are equipped with automatic photographic recording apparatus and the instruments are encased in metal tubings which eliminate, as far as possible, the effect of outside disturbances.

The Torsion Balance has been successfully used to discover structures suitable for oil accumulation: (1) where in a dome or anticline a core of material lighter or heavier than the surrounding sediments occupies the central part of the structure; (2) where the sediments on opposite sides of a fault are of unequal densities. Examples of structures with cores of relatively light material are the salt domes of the gulf coast of Louisiana and Texas and of Mexico and certain parts of Europe. These salt masses have been upthrust into the sediments in which they occur and have caused an arching of the enclosing sediments. Where petroliferous rocks occur in the vicinity of such upthrust masses, the oil and gas tend to accumulate on the flanks of the salt domes and in certain cases in a dolomitic cap rock associated only with these salt domes. The discovery of oil, therefore, is incidental to the finding of the salt mass by the Torsion Balance method. So far as known there are no salt domes in Canada, so that occurrences of oil-bearing structures of the salt dome type probably do not exist. Examples of folds having cores of heavier material than the enclosing sediments occur in folds over buried ridges or mountains, such as the buried Nehama mountains of Kansas. The core has a greater density than the enclosing sediments and the folding is apparently due to differential settling of the sediments overlying the core. The minimum compaction occurs over the core and the maximum in the thicker sediments away from it, the amount of settling being proportional to the weight of the overlying sediments. Blackwelder has calculated, by assuming certain values for the consolidation of shales, limestones, and sands, that a hill 700 feet high would produce such a structure as the Eldorado dome of Kansas "which has a surface structural relief of about 160 feet." In eastern Manitoba and northeastern Saskatchewan it is not unreasonable to suspect that there may be knobs and ridges of Precambrian rocks buried under the Palæozoic and later sediments, but how effective these may have been in producing folds as a result of differential settling of the overlying sediments is unknown. If such folds occur in areas of petroliferous rocks it seems possible that oil and gas accumulated in them. Such structures could be located by the Torsion Balance, since the Precambrian rocks of the core would be markedly heavier than the overlying younger sediments.

There are limits to the application of the Torsion Balance. The instrument is very sensitive, since it must measure very small variations in gravity. As the measurements are affected by topographic features, corrections must be made for all departures from a horizontal surface within a certain radius of the point of measurement. The making of these corrections is a complicated matter and can be made and properly interpreted only by a trained man, usually a geophysicist. Thus the Torsion Balance is best adapted to level country, such as the plains of Canada, where the geological structure is difficult or impossible to work out because the rocks are largely concealed by a cover of glacial material. This glacial material is of a non-homogeneous character and of variable thickness and there is little doubt that such a condition would tend to confuse the interpretation of the results obtained by the Torsion Balance. According to the exponents of the Torsion Balance, however, these difficulties can be overcome by making necessary corrections.

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SEISMIC WAVES

(G. S. Hume)

An instrument called a seismograph has been used for many years to record earth tremors, called seismic waves, caused by earthquake disturbances. Quite recently this instrument has been adapted for oil prospecting. An explosive charge is set off and the resulting tremors are recorded by the seismograph at a convenient distance from their point of origin. The tremors caused by such an explosion travel with different velocities along various paths. These are through the air, along the surface through the looser deposits, along the limits of the latter with the denser rock from which deflected waves originate and are recorded, and through the deeper rocks, although these are difficult of observation. By determining from the seismograph record the rates of transmission along the different paths traversed by the tremors, it is possible under certain conditions to interpret the results in relation to the geological structure. The rate of transmission through dense limestones on account of their greater elasticity is high compared with that through sands and shales, and where, for instance, shales and sands are underlain by dense limestones it is possible from the seismograph record to determine to some extent the configuration of the limestone surface and thus calculate to what extent it has been thrown into folds suitable for the possible occurrence of oil.

Very little information has been made public regarding the use of the seismograph as a means of determining geological structure. The instrument is said to have been used with marked success, both alone and in conjunction with the Torsion Balance, in locating salt domes in the gulf coast region of United States and in Mexico. It is understood that the tremors travel through the salt of the salt dome with about three times the velocity that they do through surrounding sediments. This fact is used to locate the salt domes, for it is obvious that such a speeding up of the rate of transmission can be easily detected.

In Canada as far as known there are no salt domes, so that it would seem that investigations of the waves deflected at depth from a high velocity medium like limestone offer the most promise of yielding results of value with this instrument. Underlying the Cretaceous shales and sands of the Plains area is a thick series of Palæozoic limestones in which it would be assumed that the rate of transmission of the waves would be greater than in the overlying sediments. Since, however, the top of the limestones is an erosional surface, it is not known to what extent it conforms to the folds within the limestones. Also it is understood that the seismic method of prospecting for oil structures is expensive, a feature that greatly restricts its use.

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RADIOACTIVITY

(H. V. Ellsworth)

Radioactivity is a term applied to the property, possessed only by a few elements, of spontaneously giving off radiation of an extraordinary character. It has nothing to do with wireless communication—"Radio" so-called, with which it is sometimes popularly supposed to be connected. The rays comprising radioactive radiation are in part entirely different from others common to human experience such as light, heat, sound, wireless, or radio waves, etc. One or more of three distinct kinds of rays are emitted by radioactive substances, the alpha, beta, and gamma rays. The alpha rays[1] are made up of atoms of the gas helium charged with positive electricity and travelling at an initial velocity of about 10,000 miles a second. The beta rays consist of electrons, which are nothing more than minute particles of negative electricity having a mass of only about $\frac{1}{7000}$ of that of a helium atom, ejected at a velocity approaching that of light, i.e., 186,000 miles a second. Thus the alpha rays consist of minute positively electrified particles of an actual material substance, the gas helium which has weight and is identical with ordinary helium gas obtained in other ways, whereas the beta rays are identical with the electrons emitted by the red-hot filament of a radio vacuum tube, except that in the latter case the electrons are thrown off at a much lower velocity. Both alpha and beta particles have size and weight and are actually minute fragments of the original atom thrown off like projectiles at tremendous velocity by the radioactive substances. The initial velocity of alpha and beta rays varies considerably with different radioactive substances, the figures cited being approximate maxima. The gamma rays, on the other hand, are ether vibrations of the same nature as light, wireless waves, and ordinary X-rays, but of much shorter wave length than even X-rays. It has been estimated that it would be necessary to use 2,000,000 volts on an X-ray tube in order to produce X-rays as short as gamma rays.

The three types of rays differing so fundamentally in character, naturally have very different properties and effects. The alpha rays, because they consist of comparatively large and heavy atoms of helium and travel at a much lower velocity than the beta and gamma rays, have the least penetrating power and are stopped even by a sheet of paper or tinfoil. The beta rays composed of the much more minute electrons which have a mass only about $\frac{1}{7000}$ of that of the helium atoms and travel nearly as fast as light, are more penetrating and can pass through as much as 3 millimetres thickness of aluminium. The gamma rays, being no more than a wave motion propagated through the ether at the speed of light, have very great power of penetration, exceeding ordinary X-rays in this respect. It has been found that the gamma rays will penetrate a foot of iron. The penetration is less the greater the density of the substance bombarded, hence lead being a cheap element of high density is commonly used as a protective material to shield workers from X-rays and radioactive radiations.

The range of the various rays in air, as might be expected, corresponds to their penetrating power. Alpha rays travel not more than about 8 centimetres, being soon stopped by collisions with the oxygen and nitrogen atoms of the air. Electrons of the beta rays may travel as much as 250 centimetres in air, whereas gamma rays from radium are only half absorbed after passing through 115 metres of air and their intensity is reduced to $\frac{1}{100}$ only after traversing 760 metres.

[1] Strictly speaking, an alpha particle is the positive nucleus of a helium atom carrying two positive units of electricity and when these two positive charges of electricity are neutralized by the addition of two negative units, i.e., electrons, the alpha particle becomes an atom of ordinary electrically neutral helium. It is now known that the atoms of all elements consist of a relatively heavy central nucleus carrying positive electricity around which are distributed electrons corresponding in number to the number of positive units of electricity associated with the nucleus. The nucleus charge and corresponding number of electrons varies from one in the case of hydrogen to 92 for uranium. Helium with two electrons is next to hydrogen in the series and like hydrogen is a very light gas but differs in forming no chemical compounds.

All three rays affect a photographic plate, the beta rays much more strongly than the alpha or gamma rays. They excite luminescence in various chemicals and minerals, hence radioactive substances are mixed with a specially prepared impure zinc sulphide, for example, to make luminous paint. The alpha particles are chiefly concerned in producing luminescence, the action of the beta and gamma rays being relatively feeble. The luminescence of a zinc sulphide screen acted on by alpha particles appears to the unaided eye as a steady glow, but if observed under a microscope it is seen to consist of countless individual flashes each caused by the impact of a single alpha particle. By a suitable arrangement it is possible in this way to count the number of alpha particles thrown off by a known weight of substance in a given time and thus determine the rate of disintegration of the substance. Highly active substances such as salts of radium and mesothorium themselves glow in the dark, and excite luminescence in the glass containers.

The radiations produce marked colour changes in glasses and gem-minerals, and may either decolorize, cause a colour to appear in a previous colourless substance, or change the colour of a naturally coloured material. One of the most interesting natural examples of such action is the occurrence of pleochroic haloes in the micas of igneous rocks. These haloes are seen occasionally in thin rock sections under the microscope as darker coloured circular areas or rings surrounding minute inclusions, most often in mica, but sometimes in other minerals, and represent a cross-section of a spherical mass of the mica which has been coloured by the action of alpha rays from radioactive substances contained in the inclusion. The dark, " smoky " quartz, which is often found associated with radioactive minerals in pegmatites is believed to owe its colour to the action of radiation from radioactive substances, and pink or red feldspar in contact with radioactive minerals is usually a darker red than it is elsewhere. The dark purple fluorite sometimes found in pegmatites and veins of igneous origin also probably owes its colour to radioactive radiations. Lind states that the colour of materials such as glass and minerals which have been artificially coloured by exposure to radium radiation, can be discharged by heating to a fairly high temperature. This is also true of the naturally coloured minerals just mentioned. Smoky quartz and purple fluorite heated to about 500 degrees C. become colourless and the dark red feldspar loses the greater part if not quite all of its colour by similar treatment.

All the radiations have the power of ionizing gases, that is, they cause gases to become conductors of electricity, the alpha rays being much more effective than the others in producing this effect, hence all three rays will discharge an electroscope. This property constitutes an extremely sensitive method of detecting even the most minute quantities of radioactive matter and is much used for the detection and quantitative estimation of such substances.

The internal bombardment of radioactive substances by their own radiations, especially by the alpha particles which possess great energy, must be at least partly responsible for the continuous generation of heat by these elements. One gramme of radium continuously produces about 130 calories an hour, which is enough heat to melt one and one-half times its own weight of ice in that time.

The presence of radioactive elements in the rocks of the earth's crust is believed to account for the fact that the temperature increases with depth, but the amount of heat generated by radioactive minerals occurring in rocks near the surface would not ordinarily be sufficient to cause snow to melt at a greater rate over such deposits than it does elsewhere, as has been sometimes supposed.

The radiations from appreciable amounts of very active substances such as radium, mesothorium, and their emanations will cause severe burns or even kill living tissue. Certain types of cells appear to be more affected than others. Thus radium is much used in the treatment of cancer and other abnormal tissue growths, also in certain skin diseases. Water containing minute traces of radioactive substances is supposed to be beneficial when used for drinking and bathing. The gamma rays more particularly are utilized for therapeutic purposes, the active preparation being usually contained in metal applicators sufficiently thick to stop all alpha rays and much of the beta radiation.

RADIOACTIVE ELEMENTS

Radioactivity is a property which appears to be definitely connected with high atomic weight. There are some forty radio-elements having atomic weights between 206 and 238·17 and all elements with atomic weight greater than 209 are radioactive. Of the elements having atomic weights less than 206 only two—potassium and rubidium—are definitely known to be radioactive, and these only to a very slight degree, their activity, which is confined to the emission of beta-rays, being not more than $\frac{1}{1000}$ that of the beta-ray activity of uranium.

All the radio-elements, with the exception of potassium and rubidium, are found only in minerals containing uranium and thorium. Uranium has the highest atomic weight (238·17) of all known elements, thorium the next highest (232·15) and these two elements are the parents of all other radio-elements, except potassium and rubidium. The way in which uranium and thorium break down to form other elements was explained by Rutherford and Soddy in 1903 and is one of the most fundamental and far-reaching discoveries of all time, since it led to entirely new conceptions of the constitution and properties of matter, and formed the foundation for many of the great advances in pure and applied science which have been so noteworthy in recent years.

Rutherford and Soddy showed that radioactivity is due to spontaneous violent explosions or disruptions of the atoms, accompanied by the expulsion at tremendous velocities of actual fragments of the atom—the alpha and beta particles. In any radioactive substance only a certain fraction of the total number of atoms explode in a given interval of time, this fraction being characteristic and unalterable for that particular element. In other words, nothing can cause a greater or less percentage of the atoms to explode. What causes the atoms to disintegrate or why some do so sooner than others is unknown. After an atom has exploded it has lost some of its former constituent parts—i.e.—alpha or beta particles, or both, and consequently it becomes an atom of a totally different substance with a lower atomic weight and different chemical properties. The element thus formed may be itself radioactive, in which case its atoms also will explode and form atoms of another different element and so on until the stepping down process is finally brought to an end by the formation of an element—lead—which does not undergo further transformation. Thus uranium atoms explode—on the average about one in every 10^{18} per second—and expel an alpha-particle, a helium atom of atomic weight 4. What is left of the original uranium atom now has in round numbers the atomic weight 238—4=234 and is a new element known as uranium X_1, with totally different properties from the original uranium atom. Of the uranium X_1 atoms present one in 10^7 explodes per second and expels a beta-particle only. As the beta-particle is of such small mass as to be inappreciable the atomic weight of the remainder of the atom, now called uranium X_2, remains 234 the same as its parent, but nevertheless the loss of the beta-particle has changed the electrical constitution of the remainder of the atom, so that it is definitely a new element with different properties from either its parent or grand-parent. Uranium X_2 also emits a beta-particle and becomes uranium II, a new element with atomic weight still 234, but strange to say, having chemical properties identical with the original uranium. Gamma rays accompany the expulsion of beta particles but have no part in the production of new atoms, being probably merely a secondary effect somewhat analogous to the ripple wave motion produced by dropping a stone into still water. Continuing with the uranium disintegration series, uranium II loses an alpha-particle and becomes ionium with atomic weight 234 — 4 = 230. Ionium expels alpha-particles and becomes radium with atomic weight 230—4=226. Radium expels both alpha and beta particles and becomes a highly radioactive but chemically inert gas known as radium emanation or radon with atomic weight 222. This in turn loses an alpha-particle and changes to a solid element radium A of atomic weight 218. Disintegration continues in successive steps until finally inactive uranium lead, atomic weight 206, is produced.

Thorium goes through a somewhat similar series of changes, one stage being a highly active product, mesothorium, corresponding to radium, and another stage is a highly radioactive but chemically inert gas, thorium emanation or thoron, corresponding to radium emanation. The final end product of thorium is also inactive lead, but with atomic weight 208, instead of 206 as for uranium lead and 207·22 for ordinary lead. Uranium lead, thorium lead, and ordinary lead are identical in all chemical respects. Atomic weight, density, and solubility are the only properties in which they differ. Thus thorium lead is slightly heavier than common lead, which in turn is heavier than uranium lead, and saturated solutions of salts of heavier lead contain more grammes per litre of lead salt than do saturated solutions of a lighter lead salt, at the same temperature. The three leads once mixed cannot be separated. Elements such as these three leads having identical chemical properties but slightly different atomic weights are said to be isotopes. It is now known that the greater number of so-called elements, formerly supposed to consist of one substance only, are really mixtures of isotopes.

In addition to the series of radioactive elements just mentioned resulting directly from the disintegration of uranium and thorium, there is a more or less similar series known as the actinium series which includes a gaseous stage, actinium emanation, and which ends in inert actinium lead with atomic weight 206. Actinium and its products are only found associated with uranium, but it is not known whether they are derived from uranium or uranium II or from an isotope of uranium. The actinium series contributes a constant proportion of about 3 per cent of the total activity of the uranium in minerals. At certain points in all three series so-called branching occurs, by which one of the radio-elements breaks up into two different products, both of which eventually end as lead.

The final result of all the changes of uranium and thorium is that:

One atom of uranium changes to one atom of uranium lead and eight atoms of helium.

One atom of thorium changes to one atom of thorium lead and six atoms of helium.

Consequently, 238·17 grammes of uranium if completely disintegrated would produce 206 grammes of uranium lead and 32 grammes of helium, and 232·15 grammes of thorium similarly would yield 208 grammes of thorium lead and 24 grammes of helium.

The rate at which the various radio-elements disintegrate has been determined, so that the rate at which lead and helium are produced from uranium and thorium is known and consquently if the amount of uranium, thorium, and lead contained in a primary unaltered radioactive mineral is known the age of the mineral can be calculated. The exact calculation of the age is somewhat complicated, but approximate results are obtained by substituting the percentages of lead, uranium, and thorium in the formula:

$$\frac{Pb}{U + 0\cdot38Th} \times 7900 = \text{age of mineral in millions of years.}$$

In this way the age of the Precambrian granites intruding the Grenville series of Ontario and Quebec has been found to be about 1,100 million years.

The helium content of a mineral could be used in a similar way in conjunction with the uranium and thorium content, to determine the age, if it were not for the fact that much of the helium escapes, so that low results are obtained by this method.

As all the other radio-elements (except rubidium and potassium as previously mentioned) result from the disintegration of uranium and thorium and as millions of years are required for the accumulation of appreciable quantities of the disintegration products, these can be obtained only from uranium and thorium minerals. Of the various disintegration products radium and mesothorium are the only ones extracted commercially at present.

RADIUM

Radium element has been prepared in small quantities and is a heavy pure white metal melting at about 700 degrees C. Radium is not marketed in the metallic form, however, but as chloride, bromide, or sulphate which, when fresh, are white salts resembling ordinary table salt. In its chemical properties radium resembles barium. The sulphates of both are very insoluble and this common property is used to separate radium from associated elements. Soluble uranium minerals may be brought into solution as nitrates or chlorides, a little soluble barium salt is added, and then both barium and radium are precipitated together as sulphates by the addition of sulphuric acid or a soluble sulphate. An alternative method is to treat the minerals at once with sulphuric acid or if minerals insoluble in acids are to be treated they may be fused with sodium bisulphate. In any case the radium is initially separated as insoluble sulphate along with barium sulphate and some lead sulphate. The barium sulphate carries with it the radium sulphate and furnishes sufficient bulk to permit efficient handling of the precipitate without much loss. Up to this point the separation of radium from ores is comparatively simple, but the final separation of radium from barium can only be effected by thousands of recrystallizations of the barium sodium mixture after conversion to soluble salts.

Mesothorium is similar to radium in its chemical reactions and cannot be separated from it. Hence both are unavoidably obtained as a chemically inseparable mixture when minerals containing both uranium and thorium are treated. Mesothorium, however, has a much shorter life than radium, half of any given quantity will disintegrate in a little over six years, whereas half of any amount of radium is transformed in 1,690 years. For this reason mesothorium is less valuable than radium.

The amount of radium relative to uranium contained in old, unaltered uranium minerals is a constant, and is in the ratio of 3·4 parts of radium element by weight to 10,000,000 parts of uranium element. Thus one gramme of radium is associated with about 6,484 pounds of uranium element or 7,645 pounds of U_3O_8 contained by minerals. In commercial practice the value of radium ores is based on the U_3U_8 content as determined by chemical analysis.

GEOLOGICAL OCCURRENCE OF URANIUM AND THORIUM MINERALS

All rocks contain exceedingly minute traces of uranium and thorium and their decomposition products, but commercially important concentrations of these elements are found only in certain minerals of uranium and thorium, which occur, so far as known, chiefly in four types of deposits:

(1) Pegmatites

These consist of the coarsely crystallized residual mother liquor of intrusive granite magmas in which rare element minerals tend to be concentrated, and are familiar to most prospectors as the source of commercial feldspar and white mica (*See* Pegmatites, page 78 this volume). Uraninite, thorite, allanite, monazite, and a considerable number of minerals such as euxenite, containing uranium, thorium, rare earth elements, titanium, tantalum, and columbium are not uncommonly found in the Precambrian pegmatites of Ontario and Quebec, and in one or two instances[1] quantities of half a ton or a ton of such minerals could have been recovered from feldspar workings, but so far there has been no commercial production of these minerals from pegmatite, in Canada.

[1] Typical occurrences of radioactive minerals in Canadian pegmatites are described in Geol. Surv., Canada, Sum. Repts. 1921, pt. D, pp. 51-73 and pt. C 1, pp. 6-20. These reports may be obtained on application to the Bureau of Economic Geology, Ottawa.

The majority of the occurrences of uranium and thorium minerals in Canada have been in the so-called Grenville area comprising the southern tip of the Precambrian shield, southeast of a line from Killarney to lake Timiskaming in Ontario and in the region tributary to Lièvre and Gatineau rivers in Quebec, where the pegmatites on the whole seem to be larger and more abundant than elsewhere and have been most thoroughly explored and worked for commercial feldspar and muscovite. Whether the apparent concentration of such minerals in this area has a special geological significance or is merely due to the fact that the pegmatites have been more intensively explored and worked in this region than elsewhere, remains to be seen. Radioactive minerals have also been found at Mamainse on lake Superior and in Quebec as far east as Saguenay river, Lake St. John region. Only one or two occurrences are known in British Columbia.

(2) Quartz or Calcite Veins Originating from Igneous Intrusions

Such veins are closely related to pegmatites proper, being formed by the same agencies and under much the same conditions, but as a rule at a lower temperature, so that they may be considered to represent the very last material intruded by a cooling magma, after the pegmatities have for the most part crystallized out. There is no record of thorium minerals occurring in this type of deposit. The radioactive mineral most likely to be found in such veins is pitchblende, the amorphous oxide of uranium. It may occur along with gold, silver, tinstone, and metallic sulphides and arsenides. Veins of this nature have yielded commercial quantities of pitchblende in Saxony, Cornwall, and Colorado. The extremely rich deposits of the Belgian Congo which now dominate the radium industry of the world may also be of this type. No deposits of this sort have been discovered in Canada so far, with the possible exception of an occurrence of what appears to have been a highly altered pitchblende in a now lost locality near Mamainse, Ont. This mineral is said[1] to have formed a vein 2 inches wide at the junction of trap and syenite.

(3) Disseminations of Carnotite in Sandstone

In some of the western states, chiefly Colorado and Utah, certain rather soft, friable sandstones of Jurassic age are more or less impregnated with the yellow uranium mineral carnotite. Trunks, stumps, and fragments of ancient trees occurring in the sandstone in some cases are so strongly impregnated with carnotite as to form the richest part of the ore. This carnotite sandstone ore rarely ran over 5 per cent and probably most of it only betwen 1 and 2 per cent of U_3O_8; nevertheless this ore supplied by far the greater part of the world's total production of radium up to 1922, when the opening of the rich pitchblende deposits of the Belgian Congo resulted in almost complete cessation of the United States production.

[1] "Geology of Canada, 1863," p. 504.

Placer or Beach Sand Deposits

In unglaciated tropical or subtropical regions commercially valuable deposits of the thorium-bearing minerals monazite, thorite, and thorianite have been formed by the weathering out of these minerals from the igneous rocks in which they originated and their subsequent concentration in stream or beach sands and gravels by the action of water. Such deposits are not likely to be found in Canada because the glaciers of the last ice age would have scoured them away even had they existed previously.

GENERAL PROPERTIES OF THE COMMONER RADIOACTIVE MINERALS

Radioactive minerals are mostly black, or brownish black, non-magnetic, and heavy. A few are yellow, reddish, or green. They are very complex in chemical composition and in many cases complete chemical analysis is necessary for exact identification. All have the property of discharging an electroscope and of affecting photographic plates.

Uraninite. The richest uranium mineral may contain up to 80 per cent uranium oxide with 1 to 12 per cent thorium oxide, 10 to 11 per cent lead oxide, oxides of the rare earths, and small amounts of the common elements. Uraninite occurs in pegmatite as cubic or octahedral black crystals which are very nearly as heavy as lead. Nine occurrences of this mineral are known in Ontario and Quebec; extending from lake Superior to Murray Bay, Quebec.

Pitchblende is very similar to uraninite, except that it contains no thorium and does not form crystals. It occurs in mineralized veins as mentioned above.

Allanite is a silicate of the rare earths, with aluminium and iron chiefly, containing in some cases up to 2 per cent of thorium and traces of uranium. It is black and lustrous when fresh, in many cases altered to brown on the outside. Allanite is a rather common mineral in pegmatites and coarse granites in Ontario and Quebec.

Complex Titano-tantalo-columbates. May contain up to 20 per cent U_3O_8 with thorium and the rare earths, titanium, tantalum, and columbium as the chief constituents. These minerals are black or brownish and about as heavy as magnetite. Such minerals as euxenite, samarskite, fergusonite, hatchettolite, etc., are of this type. Minerals of this class are the most widely distributed and abundant radioactive minerals in the pegmatites of Ontario and Quebec.

Monazite. Monazite is a phosphate of the rare earths with up to 10 per cent thorium oxide. It is usually yellowish, brownish, or cinnamon coloured and may form wedge-shaped crystals in pegmatite. Smaller grains may sometimes occur in granites, syenites, or even in more basic rocks. Several occurrences of monazite in the pegmatites of Ontario and Quebec are known.

Thorite is a silicate of thorium chiefly, with some uranium, rare earths, and common elements. It occurs usually as square prisms which are black and lustrous where fresh, yellow or orange when altered. This mineral has been found in the pegmatite of the MacDonald mine at Hybla, Ont.

Thorianite is thorium oxide chiefly with some uranium oxide and small amounts of other elements. It occurs as heavy black cubic crystals in pegmatites and placers in Ceylon, but has not yet been found in Canada.

FIELD INDICATIONS OF RADIOACTIVE MINERALS

Radioactive minerals in pegmatite may be recognized with almost absolute certainty after some experience by the fact that they give rise to fractures in the rock which radiate out in all directions from the radioactive mineral. The common inactive minerals found in pegmatites, such as black tourmaline, ilmenite, magnetite, garnet, hornblende, pyroxene, titanite, etc., do not produce this effect, which appears to be confined entirely to radioactive minerals. Zircon produces the same fracturing and might be cited as an exception to this rule, but as a matter of fact it usually contains small amounts of uranium and thorium.

The feldspar surrounding radioactive minerals is usually a deeper red than elsewhere—another good indication, but as feldspar is sometimes superficially reddened by iron rust from oxidizing pyrite or other sources of iron, care should be taken in applying this observation.

Uraninite which is considerably altered may show stains of canary yellow or bright orange, but certain iron stains may be easily mistaken for these uranium decomposition products.

TESTS FOR RADIOACTIVE MINERALS

The alpha-ray electroscope furnishes the best test for radioactive minerals. This is in principle a very simple instrument which could be easily improvised by any mechanically inclined person, but unfortunately it is practically not of much use unless a microscope with graduated scale is provided to read the deflexion of the leaf and the instrument thus completely equipped is rather expensive.

Another little instrument that can be used to detect radioactive substances is the scintilloscope, sometimes also called the spintharoscope or radioscope. This is simply a small glass plate coated on one side with sensitive zinc sulphide and a low power microscope for observing the plate. When a radioactive mineral is brought near the sensitive side of the plate flashes of light caused by alpha-particles striking the zinc sulphide may be seen by means of the microscope. Care should be taken that the zinc sulphide coating does not become contaminated with radioactive matter, such as dust or powder from radioactive minerals. The screen may be tested for contamination by simply viewing it in the dark for some time, when if not contaminated no flashes should be seen.

A simple alpha-ray electroscope with a reading microscope may be obtained for $27 from the Central Scientific Company, Toronto. The same firm lists the U.S. Bureau of Mines type alpha-ray electroscope for more precise measurements, at $85, and a radioscope at $13.50[1]. So far as the

[1] These prices are only approximate.

writer has been able to ascertain these instruments are not listed in the catalogues of other Canadian dealers in scientific apparatus, but no doubt any such dealer would supply them if so requested. Instructions for using the electroscope are supplied with the instrument.

One of the simplest ways of testing for radioactivity is to expose a photographic plate or film to the action of the mineral. The unexposed plate or film may be wrapped in black paper and enclosed in an envelope. The mineral should not be laid on the envelope, but should be kept an inch or so away and a metal object such as a silver coin should be interposed between the plate and the mineral. After being left in position for several days, if the mineral is radioactive, the plate on development should become more or less dark except for a light spot where the coin has shielded it. This test is more sensitive and quicker results are obtained if the unexposed plate without any covering is exposed to the action of the radioactive mineral, both being contained in a light proof box.

Tests for radioactivity are made on Canadian minerals free of charge by the Geological Survey. Mineral samples up to 12 ounces in weight addressed to the Bureau of Economic Geology, Ottawa, may be sent post free, and should be marked "Mineral Samples, O.H.M.S." As nearly as possible the exact locality from which the samples are obtained should be indicated in the letter accompanying samples.

BIBLIOGRAPHY

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CHAPTER VI

FIELD PRACTICE

PROSPECTING EQUIPMENT

(C. E. Cairnes and W. F. James)

Prospecting equipment should be such as to permit both freedom of movement and comfort. Individual taste is a factor in selecting equipment, but it is generally unwise to depart much from what long usage in the various sections of the country has proved to be the best. Prospectors entering an unfamiliar district will find it profitable, as a rule, to engage some person native to the district and to be guided mainly by his ideas in choosing equipment and planning movements. The Geological Survey also has available a fund of information on conditions in almost every region in Canada and those planning trips in districts to which they are strangers may take advantage of such information. Maps of the district in which it is proposed to work are desirable guides and a geological map will save the prospector much unnecessary work. Maps are provided free or at small cost by the Federal and Provincial Governments.

From the point of view of working conditions, Canada may be divided into three sections which coincide fairly closely with the physiographic divisions of the country:

(*a*) The more settled or otherwise easily accessible regions.
- (1) Maritime Provinces.
- (2) Areas in southern Quebec and Ontario near the St. Lawrence.
- (3) Southern parts of the Prairie Provinces.
- (4) Coastal regions.

(*b*) Canadian Shield, Northwest Territories, and more remote parts of the Prairie Provinces.

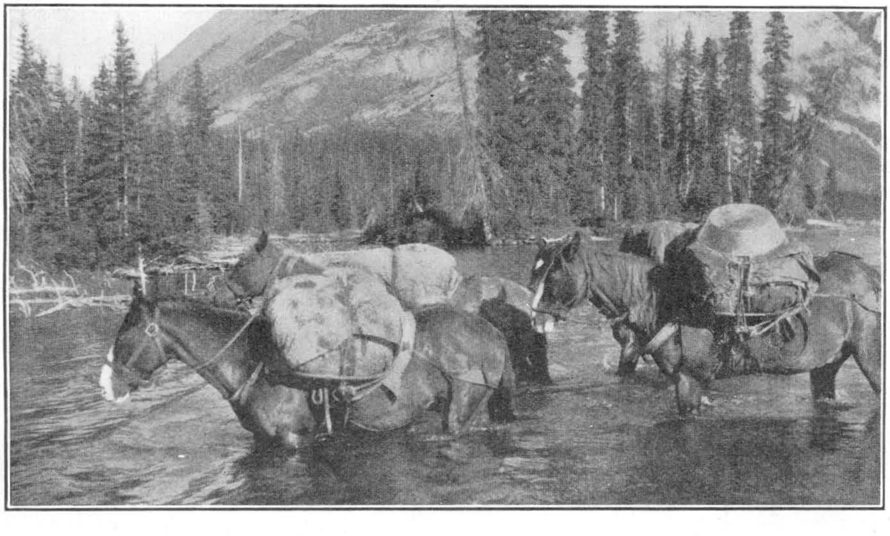
(*c*) Cordilleran region.

The Maritime Provinces are quite well settled and accessible by highways and railways, so that the prospector has little trouble in the way of transportation. Lumbering has been carried on in almost all parts of the provinces and there are very few areas that can not be reached by old lumber roads. Canoe and packing methods are employed in some of the more remote areas of these provinces and in Gaspe peninsula, which is a difficult and wild region in the midst of settled territory. The coastal lowlands of this peninsula are, however, partly settled and easy of access either by roads or by boat.

The St. Lawrence lowlands and the southern part of Ontario are extremely easy of access, but have in general less of interest to the prospector than more remote areas. Roads reach almost all parts of this well-settled region and food and accommodation may be obtained with little difficulty.

Plate XVIII

A. Method of carrying a canoe.



B. Pack-horses fording a river.

In the southern parts of the Prairie Provinces prospecting is mostly for gas, oil, and coal, which are explored by drilling and consequently require a large and expensive outfit. Automobiles, or light horse-drawn vehicles, may be used in these sections to advantage and communication is easily maintained with settlements where supplies may be obtained. It may be mentioned that duck tents are here preferable to the so-called silk tents on account of the high winds and lack of shelter on the open plains.

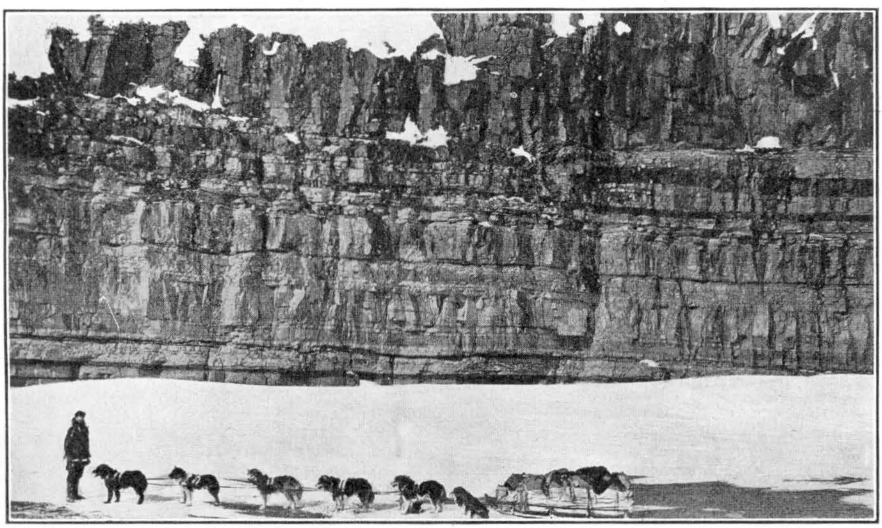
The northern and eastern coastal regions of Canada may be prospected from a supply base provisioned by suitable sail or power boats. Power boats are preferable and are best obtained by charter and should be in charge of a capable and experienced pilot. A considerable outlay for equipment is required for work in these regions and should be undertaken only under direction of experienced persons, as the difficulties encountered are considerable. Proximity to the magnetic north pole in the extreme northern waters necessitates careful handling of the compass.

Travel in the Canadian Shield, Northwest Territories, and remote parts of the Prairie Provinces, requires a specialized type of equipment, in the evolution of which much has been learned from the Indians. Except in the few developed areas, travel is commonly by means of canoes on waterways which are not continuous. The boats used must consequently be light enough to be carried easily from one water route to another. The Canadian Shield is particularly remarkable for the character of its drainage. A large percentage of its surface is covered by a network of lakes both large and small, many of which are connected by navigable streams which form the main water routes. The close spacing of these streams permits the prospector to reach almost every section. The season during which canoe travel is possible varies as one goes north. In the sections to the south of the Canadian National railways the ice may be expected to leave the rivers and streams some time in May, according to the season. Freeze-up may occur about the middle of October, though canoeing is generally possible until late in that month. Travel in early spring or late autumn is difficult and disagreeable and is to be avoided if possible. During such seasons travel on lakes and streams is dangerous because of the weak condition of the ice which may nevertheless prevent the use of canoes. Recently war developments have extended flying from an adventurous experience enjoyed by a few daring spirits to an every day method of transportation that knows no limits as regards routes. The large number of lakes and rivers and the relatively flat topography make it possible for an airplane to travel almost anywhere in northern Canada. The desirability of using a plane is a matter to be decided by the individual. Where speed is essential there is no question of its efficiency, but its cost is quite high and depots of supply must be established in areas where work is proposed. Planes have already been used by mining interests and have proved satisfactory. Their use in the mapping of northern Canada during the past few years has demonstrated their utility.

Timber enough for firewood grows far northward into Labrador and the Northwest Territories. In the timbered areas game is more or less plentiful and farther north specialized species like caribou are found. Wild fowl are plentiful and fish abound in most of the lakes and streams. For

Plate XIX

A. Illustrating: (1) Method of carrying a pack. (2) Use of dogs in carrying packs. (3) Protection from mosquitoes.



B. Transportation by dog-team.

more or less permanent dwellings, cabins may be constructed of timber secured close at hand. Where tents are used these should ensure the maximum of comfort and the minimum of weight and bulk. It should not be forgotten that protection against insects is very important. Bedding and clothing are to be selected with regard to durability and comfort. Food should be of high nutritive value relative to its weight and in view of infrequent opportunities for replenishment and the difficulties of transport should not be easily perishable.

The Cordilleran region in Canada is included mostly in the province of British Columbia and Yukon territory and embraces an area of over 600,000 square miles. This great region is a veritable sea of mountains marshalled into a solid phalanx of chains or ranges which sweep on in substantial unity northwestward through British Columbia into Yukon, and into Alaska. The general trend of intermontane valleys is unfortunately about parallel with the coast-line, a feature that makes the interior sections difficult of access and renders their exploration a very special problem. The region is but meagrely equipped with railway lines and along these the population of the province, averaging less than 1 person to the square mile, is mostly segregated. Only a small part of this vast area is, therefore, really known and of this only a small part has been carefully prospected.

In the brief period of its mining history, during which the mineral resources of this region have been so signally proved, the prospector has played an important rôle and, in the light of the past and possibilities for the future, his program of usefulness seems hardly to have begun. His life in this mountainous country is of necessity a strenuous one, in which a strong back and familiarity with the conditions under which he labours are the prime requisites. These conditions are remarkable for their variety and consequently require great adaptability on the part of the prospector. Even within an easy radius of railway communication he may, for example, find it convenient to drive a car in the early stages of his journey, to transfer his outfit to pack-horses where the trail begins, and to find his back his sole resource at the higher elevations.

Probably the commonest means of transportation in this region is the pack-horse. The animal in general favour for this purpose is the hardy, half-wild pony familiarly known as the cayuse or bronco. The cayuse is intelligent, sure-footed, and in most places quite able to forage for itself. It can carry 150 pounds with ease, and on short trips, or where travelling is good, up to 250 pounds. In the southern interior of British Columbia these animals may be purchased "off the range" for from $5 to $10 each. When "broken" or trained to the saddle, however, the charge may run up to $50 or more for select stock. For purposes of transport these animals are equipped with specially constructed pack-saddles, on either side of which are slung boxes or bundles of about equal weight, which are spoken of as the "side-packs." Other goods piled between these and on top of the horse constitute the "top-pack." A considerable amount of skill is required in balancing the load and in lashing it tightly in place by one of several well-known hitches. For side-packs, specially made canvas, fibre-board, or wooden alforjas may be used. The latter two types have the lower outer edge bevelled to avoid catching on trees, rocks, etc., where trails are narrow or absent.

In northern British Columbia and the Yukon the upkeep of stock is expensive. Pack animals are, therefore, scarce, and travel in consequence is chiefly by canoe in summer or dog-team in winter.

On the many lakes of British Columbia and the Yukon shallow draught steamers, small power boats, skiffs, and canoes may all be employed to advantage and even the multitudinous streams, though on the whole rough, tortuous, and unnavigable, are made frequent use of along stretches of quieter water. The chief difficulty attendant upon the use of such craft is generally the expense of transportation. Boats are, of course, the one means of transport in all explorations conducted along the coast and coastal islands of British Columbia, but a trained pilot and navigator should be carried unless some member of the party is experienced in handling the type of boat used and is also familiar with the local waters.

There is very little prospecting in the Cordillera in the winter months, as the region is mostly covered deeply with snow. In testing Yukon placer deposits, however, particularly where these are rather deeply buried, the frozen ground makes it possible to prospect the surface of the underlying bedrock. The snow, too, furnishes a ready means of transportation of supplies on sleighs hauled by dog-teams, allowing "caches" of provisions to be established for the following prospecting season. Ore that has been stacked up during the green months of the year is commonly rawhided down the mountain slopes on the snow with efficiency and economy.

OUTFITS

The following list of equipment includes articles used by field parties of the Geological Survey. These have all been found to be useful and practical and can be purchased from, or made to order by, any good supply house. Some of the items are suited only for the specialized requirements of certain districts, but others form a necessary part of any well-equipped expedition. It does not follow that all the articles listed are essential or that individual taste and circumstances may not result in the substitution of other articles. The list is merely intended to draw attention to what can be had in the way of adequate equipment.

Alforjas or Panniers. Cases especially constructed for use as side-packs on pack animals and made of fibre-board, wood, or canvas. The fibre-board type, though more costly than the others, has the advantage of light weight combined with great durability. These can be purchased for from $10 a pair upward.

Axes. To suit individual taste or special requirements.

Axestone and Files.

Bags. Paraffined waterproof duck bags of a size suitable to enclose sacks of flour, sugar, etc.—very useful in protecting contents against dampness and rain.

Bags. Cotton or silk provision bags fitted with tape for tying. These can be purchased in sizes holding from 5 to 20 pounds, and are very useful for carrying small amounts of such articles as sugar, salt, and flour

Beds. Folding camp cots are a great convenience where their transportation can be arranged. They are made of canvas with collapsible metal or wooden frames.

Blankets. Sleeping blankets should be of good quality wool. They are made in different sizes and weights and either singly or in pairs. Blankets are also necessary for use under saddles, one double blanket being generally necessary for each animal.

Canoes. The most useful types are of cedar, covered with a good quality of canvas. A 15-foot canoe is the smallest useful size. It weighs 50 pounds or slightly more, and carries 500 pounds without being too heavily loaded. A 16-foot canoe weighs 65 pounds and is very convenient for two men and will carry enough supplies for a 4-weeks trip. A 17-foot canoe weighs from 75 to 100 pounds and will carry from 600 to 1,200 pounds. An 18-foot freighter type weighs from 90 to 130 pounds and will carry from 900 to 1,700 pounds. A 20-foot canoe can be had to carry up to 2 tons.

Canoes of the types mentioned are furnished, if desired, with square sterns to which outboard motors may be attached. An 18-foot freighter canoe driven by a 55-pound 2½ horsepower motor will travel about 7 miles an hour. Such motors are very convenient on lakes and rivers where there are long stretches of quiet water and few portages. Gasoline consumption is small, about 20 miles being attained to the gallon.

An extra paddle should as a rule be provided on long trips. Marine glue, bitumen, or shellac and cotton, are useful for canoe repairs.

Fibre Case or Box. These boxes are designed like a telescope valise and may be had in suitable sizes and are convenient to load in canoes and carry on portages. They are light, extremely durable, and fairly resistant to water and are a useful protection for articles of food and equipment which might otherwise be damaged by crushing.

Fire Arms. These are of use when the season or locality permits shooting of game for food.

Fishing Tackle. An assortment of lines, hooks, flies, and trolls can generally find profitable use on any extended trip in Canada.

Hammers, Etc. Personal preference usually determines the choice from a great variety of geological hammers and prospecting picks.

Haversacks. These are made of duck and are convenient for daily work in the bush. They are preferred by some to a rucksack which is carried over the back.

Insecticides. Protection against various insect pests is generally necessary. Insecticide solutions are now on the market, which, when sprayed inside a tent, will effectively kill all insects within. Where such a solution is not at hand a smudge may be used to drive the insects out of the tent.

For use during the day, fly repellants of various sorts may be made up or purchased. A solution of Epsom salts has some such virtue when rubbed on the face and hands and also aids in reducing the swellings due to insect bites. An effective repellant against both flies and mosquitoes is made by mixing two to three parts of sweet or cotton-seed oil with one part of oil of tar and adding oil of citronella in the proportion of 1½ ounces or more to the gallon.

Of late years the sandfly is becoming an increasing nuisance in the clay belt of Ontario, and elsewhere it is accounted among the worst of the insect pests. This fly is of diminutive proportions and is extremely active and annoying due to its poisonous sting. Those around a camp ground may be destroyed in some measure by the lighting of a large fire of some material that will blaze well, such as dry evergreen brush. Their light bodies are drawn into such a fire. Within the tent they may be destroyed by rubbing the walls and roof of the tent with a wet towel. Their vulnerability lies in their extreme fragility and lightness.

Instruments. Compass, aneroid, etc.—*See* sections on Practical Surveying and Surveying Instruments.

Kits—First Aid. It is desirable to have some provision against accident or sickness. The minimum outfit should include at least some bandages, iodine, adhesive tape, and some of the simpler medicines put up in convenient form. A great variety of kits are offered by medical supply houses. Some are very elaborate, containing thermometer, lancet, sutures, and needles for stitching, antiseptic bandages of various shapes and sizes, and a comprehensive assortment of medicines. Such kits may cost $20 or more. Others less expensive, and generally quite adequate, may be had for less than $10. Small pamphlets on first aid should be included with each kit.

Mattocks. These are useful in stripping moss and light vegetation from the underlying bedrock.

Packsacks. Packsacks of waterproof duck, fitted with head and shoulder straps, are as a rule indispensable. The straps should be riveted as well as sewn to the sack.

Pack Saddles (for horses or mules). Either single or double-cinch types may be had, according to individual preference. Experience shows that certain pack saddles are best suited for certain animals and the prospector learns to select the types which give most comfort to the particular animals he is using.

Pails. The collapsible varieties made of reinforced duck are convenient to carry and quite serviceable.

Reflectors. Reflectors of aluminium or tin are useful in lieu of a stove. The type that folds up flat is most convenient. It requires some experience to bake with them before a small, open fire.

Sleeping Robes. These are preferred by many to blankets, but are somewhat more costly. They are light, comfortable, and convenient.

Stoves. Four-hole collapsible stoves are available, weighing slightly over fifty pounds. Two-hole stoves weigh somewhat less. These stoves are fitted with ovens. Stoves are a great convenience during wet weather and are almost indispensable for use inside a tent when the weather is uncomfortably cold. As a substitute for a stove an oven may be quickly built of large, flat stones cemented with mud and provided with a door and a top draft. A good fire left in such an oven for almost an hour leaves the rock sufficiently hot to bake bread, meats, etc., after the embers have been drawn out. Baking may also be done in covered pots placed beneath sand which has previously been well heated.

Tarpaulins. These are made of waterproof canvas in various sizes, weights, and colours. They are very useful for protecting supplies and make suitable floor cloths for tents.

Tents. The material used in making tents should be determined partly by the weather conditions expected, ease of transport, etc. Where moves are frequent and bulk and weight are important factors, sail silk is the most desirable material. Where high winds, cold weather, and heavy rain and snow are prevalent, duck is more suitable. A very useful tent is also made with duck roof and silk walls. A silk tent costs about 30 per cent more than a duck tent of equal size.

Tents are made in various shapes according to conditions under which they are used. A useful type is the wall tent, with a door in one end and a ventilator or window in the back. It is well to have the wall slightly higher than those generally made because of the greatly increased space thus provided. A 7 by 9 wall tent, for example, should be fitted with a vertical wall 3½ to 4 feet high. Such tents are usually made with a sod cloth up to 1 foot wide, but in regions where mosquitoes and flies are a nuisance it is sometimes better to have a sewed-in floor of light, waterproof duck.

Pyramid tents of various types are coming into increasing use. They have the advantage of lightness and require only one pole. A 7½-foot square pyramid tent provides rather cramped quarters for two men if much personal baggage is kept inside.

"A" tents with no vertical walls are inconvenient, but are sometimes used where moves are frequent and bulk and weight must be reduced to a minimum. Bell tents are seldom used in travelling in remote areas as they have many disadvantages.

Where it is desired to use a stove inside a tent asbestos pipe rings are sewn into the tent roofs and flies to prevent burning of the fabric by the stove-pipe. Sail silk burns very easily and tents of this material are frequently destroyed by sparks from stoves.

Several kinds of waterproofing solution are now manufactured for tent fabrics. It is preferable to have even new tents treated with a solution of this sort and in the case of tents that have begun to leak after a year or so of service, the waterproofing treatment is to be highly recommended.

In early summer, when flies are most numerous, it will be found necessary to have a cheesecloth fly bar sewed into the opening of the tent. The fly bar should be cut sufficiently large to allow it to lie well over the edge of the floor of the tent so as to be held down by such articles as boots, boxes, etc., to prevent entrance of insects once the tent has been cleared of them by smudging or other means. The ventilator requires a covering of fine net, well sewed in, and may be covered on the outside by a flap of silk or duck which may be raised or lowered from inside as the weather demands.

A silk fly tightly stretched over a tent aids greatly in keeping it cool during the hot part of the day and keeps the interior dry during heavy rains which may otherwise beat through the roof.

Tool-kit. Small, light pocket kits provide a selection of useful tools.

Tump-lines. Leather tump-lines are useful in back-packing heavy sacks and boxes. It is best to have one tump-line for each member of the party. Some prospectors leave a tump-line permanently attached to the thwarts of their canoes to facilitate carrying on portages.

Utensils. Cooking knives and forks are best made of nickel-plated steel. Other dishes, such as cups, plates, bowls, etc., may be of tinplate, aluminium, or enamel. Convenient aluminium sets are provided complete for parties of four or more. Aluminium frying-pans with removable handle are very serviceable.

The following ration list will serve as a guide when ordering provisions. Personal taste may suggest an increase in some articles and a decrease in others. The amounts given allow for no safety factor, a feature well to keep in mind. A trip often requires more time than proposed. Waste or spoiling of food may cut down the available amount, and provision may have to be made for probable guests. It may be advisable, therefore, to add slightly to the amounts given.

Revised Ration List

Pounds per Man per Day

	Lbs.
Flour or hardtack	0·900
Baking powder	0·025
Cereal (oatmeal)	0·150
Beans	0·20
Rice	0·075
Evaporated potatoes	0·161
Split peas	0·025
Evaporated soup vegetables	0·022
Bacon and ham	0·750
Lard or crisco	0·06
Cheese	0·05
Crystallized eggs	0·03
Beef tea capsules	If desired
Sugar	0·35
Tea	0·06
Coffee	0·03
Chocolate	1 bar (small)
Onions desiccated	0·005
Barley	0·02
Milk (powdered)	0·15 can
Salt	0·04
Evaporated fruit	0·22
Pepper	0·002
Spices	0·002
Soap	0·02
Butter	0·15
	3·5

Mustard, matches, candles, jam, yeast cakes, soda, spices, essences, syrup, macaroni, cornmeal, pickles, molasses, corned beef, and ketchup may also be added according to taste and conditions.

A few suggestions may be offered concerning some of these items. Bacon and hams are now provided packed in pitch casings which protect the meat against dampness, make it more convenient to handle, and will preserve it for several months. Sides of dry salted pork keep well, are cheap, and are very welcome food in cold weather. For very long trips, pemmican is useful as it will keep indefinitely and is a highly concentrated food, although not suited to all tastes. Canned meat of various sorts is palatable and convenient where no difficulties are experienced in transportation. Among the cereals, oatmeal is thought superior to rolled oats, but requires longer cooking. Desiccated vegetables are light to carry and are very good food. Dried potatoes are most convenient when shredded or sliced. Soup vegetables are a valuable addition. Pea meal thickens soup and is nourishing and tasteful. Tea of good quality is economy in a diet where it is such an important article. Sweetened chocolate in small bars is convenient to carry and an excellent food, particularly when lunch is eaten away from camp. For carrying, powdered milk is much superior to the ordinary liquid condensed varieties. Both skimmed and whole milk are available in powdered form and are mixed with water as required, thus eliminating waste and economizing on weight. On canoe work it is a good plan to carry matches in a waterproof container.

Storage of surplus food is sometimes required. If a large amount is to be stored it pays to build a platform about 10 feet high, set up on convenient tree stumps. The boxes, etc., may be placed on this, covered with a tarpaulin, and tightly lashed in place. The stumps should be peeled smooth to keep animals from climbing to the cache.

Stock Ration

Pack animals are generally capable of finding their own food, but where this must be provided the following unit ration a day will serve as a guide:

	Oats Lbs.	Hay Lbs.
Heavy horses	12	18
Light horses	10	14
Mules	8	12

BUSINESS ARRANGEMENTS

The business arrangements under which prospectors work are of all sorts. Many men prospect in pairs, sharing the expenses, doing their own development work, and, when possible, selling promising claims and dividing the profits. There is today a large class of prospectors at work on behalf of companies or syndicates, who pay the prospector's wages and expenses and agree to give him an interest in whatever claims he may stake on their behalf. The interest naturally is of no value to the prospector unless he is assured that his syndicate will carry forward development work and endeavour to secure production. Provisions are sometimes made in prospector's contracts to protect his interests in this respect and to guarantee that all potentially valuable land located by the prospector during his contract shall become the property of the syndicate paying him. Such provisions are designed to preclude later appropriation for his own benefit of a discovery made by an agent under contract. The term "grubstake" arose from the arrangement very commonly made between the prospector and some backer whereby the prospector contributed his time and experience and the backer a sum of money or the supplies necessary for the prospector's subsistence during a trip. The understanding generally was that all profits should be evenly divided.

PRACTICAL SURVEYING

(G. Hanson)

INTRODUCTION

Mining engineers and geologists when examining mineral prospects make plans showing the workings, veins, etc., in order to have a map or miniature representation of what they see. Prospectors as a rule do not make maps of their properties, yet it is a simple task full of pleasurable interest and one from which much profit is in many cases derived. A map can give an abundance of information, as a result of which possibilities and lines of development not otherwise evident become apparent. Everything may not be clear on first inspection, but time can be spent profitably in studying the maps, which in the end will convey more information than a long, written report. Further, a property can be described more effectively to prospective buyers with the aid of a map, which has this advantage, too, that it is always available, whereas it may not be always convenient or even possible to see the property. Maps are consequently of value as records for prospector's associations, chambers of mines, mining bureaus, and provincial and federal departments of mines.

When prospectors make long trips over unmapped country very little delay is occasioned by keeping a record of distances travelled, the location of prominent points, the sizes and depths of valleys and streams, glaciation, and geological phenomena. A map showing these data would later be found very useful, either to the prospectors or to others who might wish to conduct further explorations in the area thus traversed. Claims could, for example, be recorded with greater precision than if no map had been made. Great accuracy can not be expected and is not essential in such a reconnaissance map.

SURVEYING METHODS

The methods of surveying discussed in the following pages are chiefly those pertaining to map-making and include special reference to some of the problems that may be encountered by the prospector. Before, however, taking up the principles of surveying and their practical application it seems advisable to refer those interested in, or contemplating the making of, a map to another part of this book (page 267) in which the nature and uses of maps, and in particular geological maps, are treated in some detail.

In mapping an area locations are made, or the position of certain points is determined, and the map is built up around these locations. One known position may form the starting point and all other locations fixed by measuring the distance and direction from this point. Or, all locations may be made with reference to each other, and their position on the earth's surface determined either in relation to some known point or by calculations for latitude and longitude. The accuracy of the completed map will depend upon the precision of the instruments and the skill with which they are used in making the necessary locations. The principles are the same, whatever instruments are used.

Distance and direction are measured in two general ways: (1) by traverse; (2) by triangulation.

In flat areas locations are generally made by traverse. In traversing, distance and direction are measured successively from station to station. The accuracy of the traverse depends on the accuracy of these measurements of the distance and the angle between all stations occupied. Various instruments may be used depending upon the accuracy required, but the prospector will as a rule find it most convenient to employ only the simpler methods in which the direction is obtained by compass and the distance by tape, the counting of paddle strokes or paces, timing, or by estimation. A straight line can be established by lining up three pickets and this line may be projected in either direction by removing the rear picket and placing it in front in line, and so on. Several methods of traversing are mentioned in the following discussion of Figure 16, diagram 1.

A is a point whose position is known, a claim post, the junction of two streams, or some such point shown on a map. From A the direction to another point B is taken with a compass and the distance A-B is measured or estimated. From B a backsight can be taken with the compass to A, and the average of the two readings will be the direction. In the same way the bearing is taken from B to C and back from C to B. If several readings are taken with a compass to a single point it will be found that the readings differ slightly from one another. This difference is due to errors in reading the instrument. The average reading will represent approximately the correct direction. Backsights as well as foresights are taken, therefore, in order that errors due to the reading of the instrument be eliminated as far as practicable and also that areas of local magnetic attraction may be recognized and corrected. By taking backsights the compass is read twice at every station. If no backsights are taken the compass can be read from the first station to the next, and from the second to the third, and so on. The compass in this case is read only once at each station. A more rapid method can be adopted. Take bearing from A to B. Then move to some convenient point C and from there take the bearings to B and also to the next point D. Next go to E and take bearings to D and F (a known point), measuring the distance between stations as the traverse progresses. By this method the compass is read at only half of the stations. In order to make a traverse of reasonable accuracy it is advisable to tie in the end points of the traverse to points of known position. The traverse can then be adjusted between the known points. If the traverse is long it should be tied in to fixed points at several places along the traverse. In places where local magnetic attraction influences the compass the ordinary methods of compass traverse discussed above are not satisfactory. A traverse can, however, be carried through a place of local magnetic attraction in the following manner. Take foresight from A to B and backsight from B to A and so on (Figure 16, diagram 1). If the foresight from A to B and the backsight from B to A agree approximately neither of these stations is under the influence of local magnetic attraction. If, however, the backsight from C to B differs; for example, by 10 degrees from the foresight, from B to C, the latter station must be affected by a local magnetic pull to the extent of approximately 10 degrees. In reading the foresight from C to D this 10-degree magnetic pull must be taken into

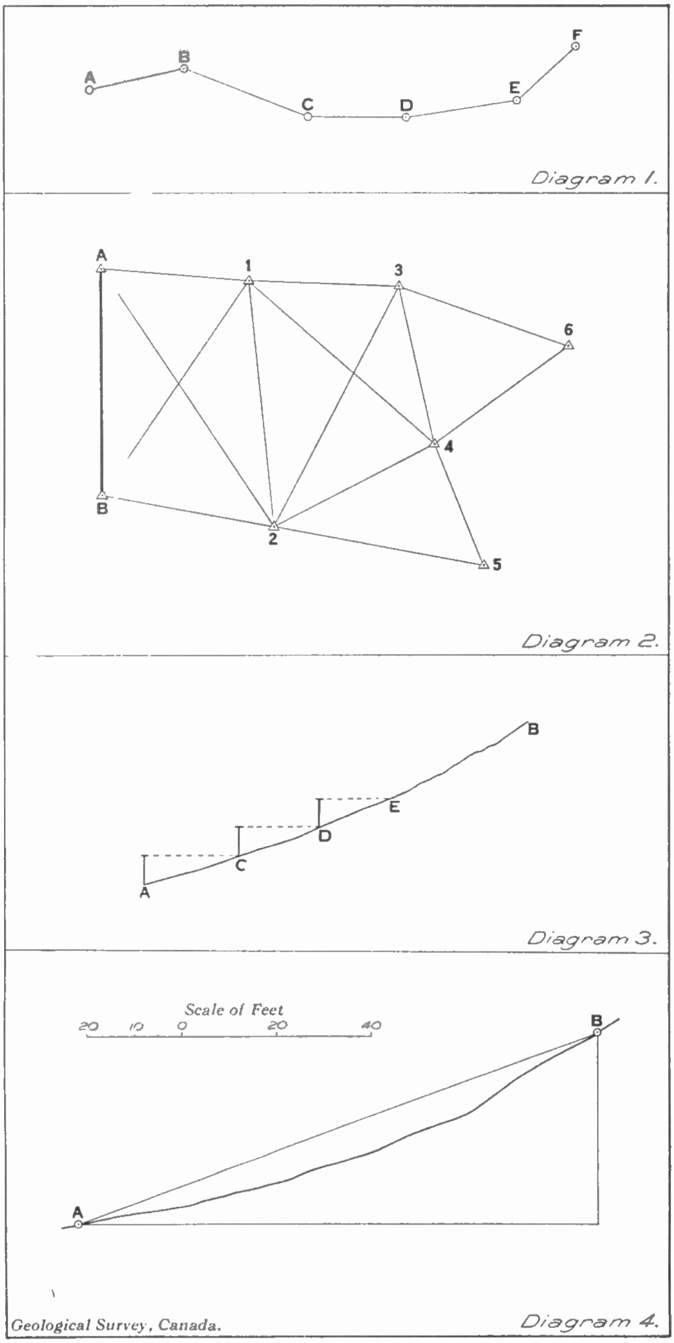

A
B
C
D
E
F
Diagram 1.
A
1
3
6
4
B
2
5
Diagram 2.
B
E
D
C
A
Diagram 3.
Scale of Feet
20 10 0 20 40
B
A
Geological Survey, Canada.
Diagram 4.

Figure 16.

consideration. In reading the backsight from D to C it may be found that it differs from the foresight from C to D by 10 degrees, but corresponds approximately with it when allowance is made for the 10-degree magnetic pull at C. It will, therefore, be evident that D is not under the influence of local magnetic attraction, and the traverse can be continued in the usual way until other areas of local attraction are encountered. Traverse is simpler than triangulation, but the latter is preferred for certain kinds of work. Distances are not measured between stations in triangulation, so where stations are far apart a network of points can be fixed far more rapidly than by traverse.

In areas of relief triangulation is usually adopted to fix the main points. A base-line is measured and the direction determined. From the ends of the base-line angles are read to prominent points. These points are then occupied by the instrument and the triangulation is extended to other points, and in this way a triangulation net is spread over an area. The accuracy of the locations depends on the accuracy of the measurement of the length and direction of the base-line, and the accuracy in reading the angles to the various points. The distances between stations are not measured, but are calculated from the length of the base-line and the angles. Figure 16, diagram 2, illustrates triangulation.

A-B is the base-line of known direction and distance. From A angles are read to points 1 and 2 represented by lines A-1 and A-2. From B angles are read and points 1 and 2 represented by lines B-1 and B-2. Stations 1 and 2 are then occupied by the instrument and the angles to the other three points, A, B, 2, and A, B, 1, of the first quadrilateral are read to have checks on all the angles. For rough work all check readings can be omitted. The positions of 1 and 2 can now be calculated as the angles and the distance A-B is known. The positions of 1 and 2 are then fixed, as well as A and B, and any two of these four locations can be used as the ends of a new base-line for extending the triangulation.

From 1 angles are read to points 3 and 4.

From 2 angles are read to points 3, 4, and 5. Stations 3 and 4 are then occupied and check readings are taken to the other points of the quadrilateral 1-3-4-2. These check readings may be omitted for rough surveying.

From 3 the angle is read to 6.

From 4 angles are read to 5 and 6. In this way all stations become very accurately located. The positions of all these points are then known in relation to each other and to the base-line which is the starting point. It will be evident, perhaps, that as the horizontal distance A-B is known, all the other distances, for examples B to 6 on Figure 16, are the true horizontal distances. Any differences of elevation between the various stations have no bearing on the accuracy of the location.

It is not likely that the prospector will use triangulation alone for mapping any area. The method is given here, so that any individual can have a fair idea what triangulation means and how it is done. The prospector will in general use traverse and will locate points outside of this by intersection of bearings taken from known points of this traverse. His traverse will be the base-line, and his bearing intersections will locate points just as stations 5 and 6 are located in Figure 16.

LEVELS

In surveying it is generally necessary or desirable to measure or calculate vertical as well as horizontal distances. With an aneroid, elevations can be read directly and for reconnaissance work this instrument can be used to advantage. Even when used in the best manner and under ideal conditions, however, an aneroid may be 10 feet in error for every rise of 100 feet, so for detailed and accurate information the vertical distance should actually be measured. This can be done with a surveyor's level, a compass which can be used as a level, or even with a carpenter's level. A compass or hand level can be read conveniently at the height of a man's eyes. A carpenter's level can be used best on a tripod.

It is desirable to have two men to run levels, one man to use the instrument and the other to place the rod. Figure 16, diagram 3, illustrates the method of running levels up an incline represented by A-C-D-E-B.

The instrument is set up at A and levelled. The level sight intersects the hillside at C which is marked by the rodman. The instrument is then set up at C and levelled to D, and so on. If the instrument is 5 feet high, then C is 5 feet, D is 10 feet, and E is 15 feet, higher than A. The horizontal distance can be measured with a tape by holding the tape taut between the top of the instrument and the next station up the hill, and so on. To get the difference of elevation between any two points it is not necessary to run the levels directly from one point to the other. A zigzag course can be followed, but if horizontal distances are to be measured the levels must be run directly from one point to the other.

It may not be convenient to measure the horizontal distance and this can be calculated between any two points if the difference of elevation is known, by reading the vertical angle or angle of slope from one point to the other. In Figure 16, A and B are two points on a hillside, which differ in elevation by 40 feet. The vertical angle from A to B is read and is 20 degrees. From Table I (page 250) a vertical angle of 20 degrees is the same as 36·4 per cent grade or 36·4 feet rise for every 100 feet horizontal. In a 40-foot rise then, the horizontal distance is 100 by $\frac{40}{36 \cdot 4}$ or 110 feet. If the vertical angle and the horizontal distance are known the difference of elevation is calculated in the same way. The angle and distances known can be plotted to a certain scale as in Figure 16, diagram 4. It will be obvious that when the vertical angle is known, if the vertical, horizontal, or slope distance is measured and plotted any other desired distance can be measured on the diagram.

Minor irregularities on the ground can easily be measured with a level as shown by Figure 17, diagram 1. In the figure the level is 5 feet high; the rod 10 feet long, marked in feet; and A-B is the irregular surface. Station C is 5 feet less 1 foot, or 4 feet higher than A. Station D is 3 feet lower than A. Station E is 2 feet higher than A, and F is at the same height as A.

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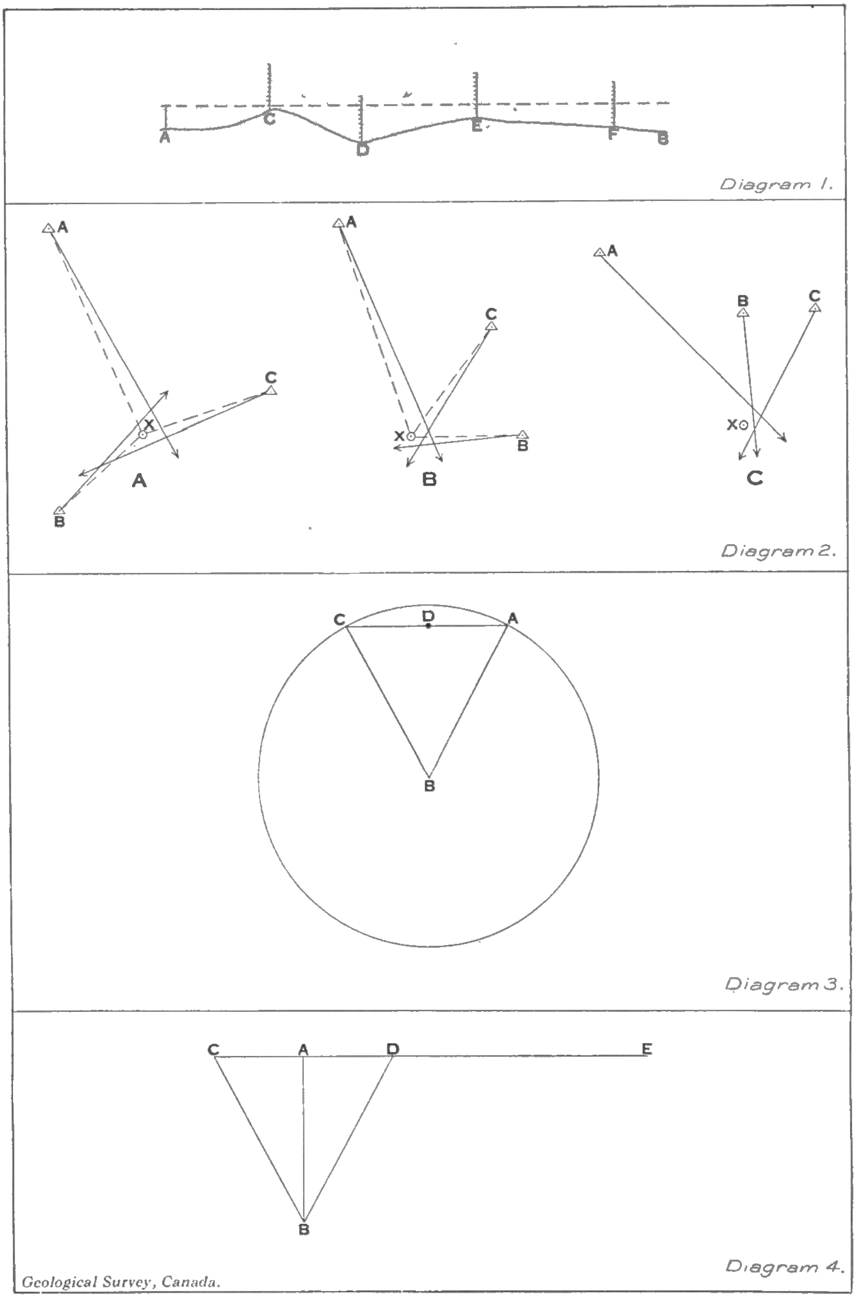
A
C
D
E
F
B
Diagram 1.
A
B
C
X
A
A
C
X
B
B
A
B
C
X
C
Diagram 2.
C
D
A
B
Diagram 3.
C
A
D
E
B
Diagram 4.
Geological Survey, Canada.

Figure 17.

To Locate Position by Reading Angles When Only Three Known Points Are Visible

Take bearings to the three locations and draw lines representing these bearings on the map which shows the locations. The lines in each case are drawn from the three locations at the proper angle, towards the observer's supposed position. If the lines meet in a point, that is the position of the observer. If the lines do not meet in a point, but form a triangle, known as the Triangle of Error, the observer's position is on the same side of each of the three lines drawn from the locations, and the distance of the position from these lines is in the same ratio as the actual distance of the three locations from the observer. The following explanation will make this rule clear. The error in bearing due to local magnetic attraction or some such cause is of the same magnitude and also in the same direction for all three readings as all the bearings are taken from the same point. This explains why the position is on the same side of each of the lines. Further, the line representing an erroneous bearing will depart more and more from the line representing the true bearing the more distant the object sighted on. If the line is 50 feet out in half a mile it will be 100 feet out in a mile. The distance of the observer's position from the lines then is in the same ratio as the actual distances of the three locations from the observer. Three examples are given in Figure 17, diagram 2. The lines from A in all cases are twice as long as the ones from B, and those from C are of intermediate length. The position X is then twice as close to the lines from B as it is to the lines from A. It is also closer to the line from B than to the line from C. As these proportions must be correct and as the position X must be on the same side of each of the lines from the three points, it is evident that in Figure 17, diagram 2 A, the position is within the triangle of error. In Figure 17, diagram 2 B, the position cannot be within the triangle, as it must be on the same side of all the lines. It cannot be on the left side of the lines drawn from the points as the distances to the lines must be proportional to the distance to the fixed points. Therefore, it must be on the right side of the lines in the place indicated. The same reasoning applies to Figure 17, diagram 2 C.

If the desired position as located above is now joined to the three fixed points by lines (the broken lines in Figure 17, diagram 2 A and B) it will be noted that the angle between the lines representing the actual direction and that obtained by reading the instrument is the same for all of the three points. Had there been no local magnetic attraction or any such cause of incorrect reading of direction, the directions read would have been those indicated by AX, BX, and CX, that is the lines would all have met in one point which would be the observer's position.

To Find True North by Means of a Watch

Point hour hand to the sun. Half-way between hour hand and twelve o'clock is south. This holds for the northern hemisphere.

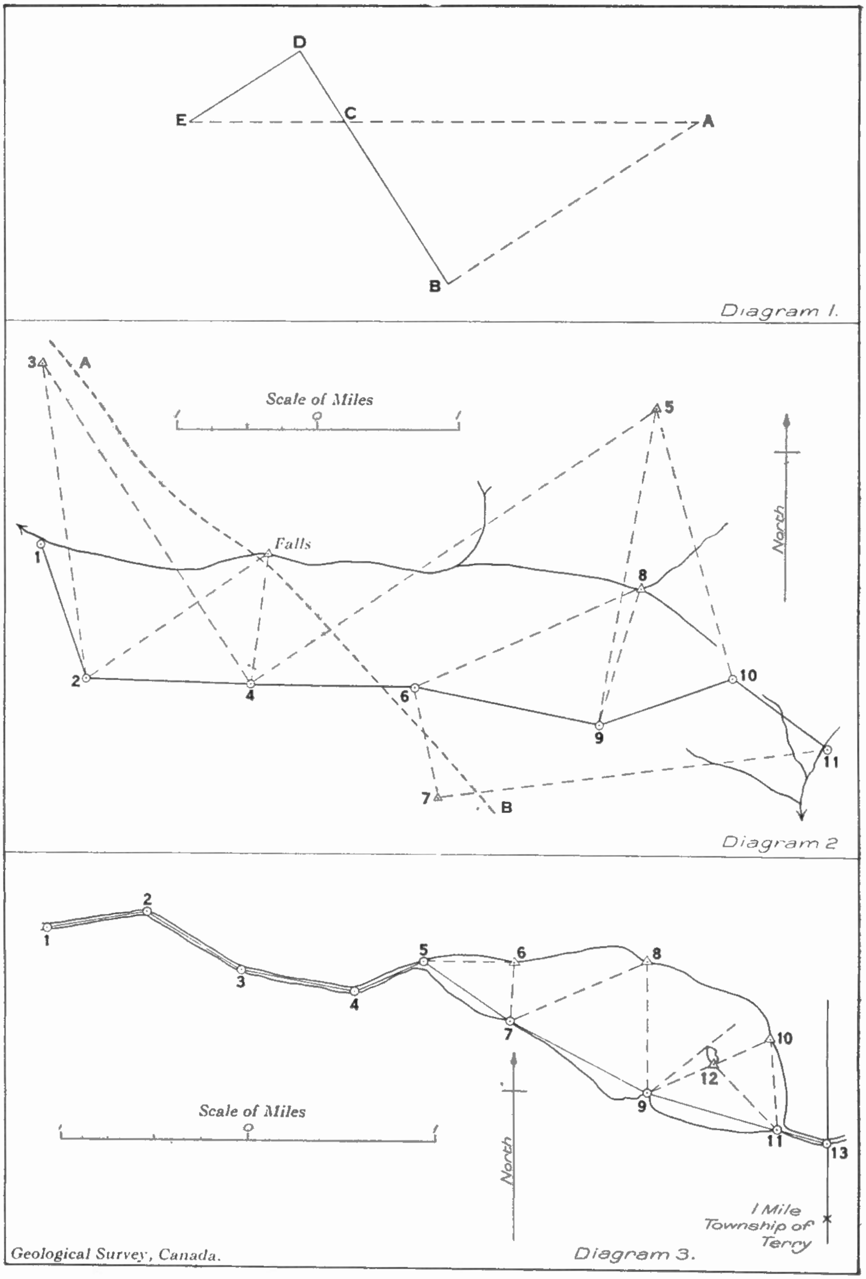
D
E
C
A
B
Diagram I.
3
A
Scale of Miles
5
North
Falls
1
8
2
4
6
10
9
11
7
B
Diagram 2
2
1
5
6
8
3
4
7
10
12
9
11
13
Scale of Miles
North
1 Mile
Township of
Terry
Geological Survey, Canada.
Diagram 3.

Figure 18.

To Find True North by Means of Shadows

Set up a vertical rod on level ground in the morning between 10 and 11 o'clock, and mark the end of the shadow C (Figure 17, diagram 3). Then with the rod B as centre and BC as radius describe a circle on the ground. The shadow will shorten until noon and then lengthen and eventually will be long enough to touch the circle at A. The point D midway between C and A is then true north of B.

To Make a Right Angle On the Ground By Means of a Rope

On the line C-E (Figure 17, diagram 4) measure equal distances CA and AD, each distance being approximately one-quarter of the length of the rope. Fasten the ends of the rope at C and D and taking the centre of the rope draw it out sideways to B so that the rope is tight. The angle EAB is then a right angle.

To Find the Distance to an Inaccessible Object

Let A be the inaccessible object (Figure 18, diagram 1). Lay out line BC at right angles to the line AB and continue the line BC to D any convenient distance beyond C. From D lay out line DE at right angles to DB, so that E, C, and A are in line. Then $\frac{AB}{DE} = \frac{BC}{DC}$ or $AB = \frac{DE \times BC}{DC}$. All these distances except AB can be measured, so by substituting the lengths in the equation above, the length AB is found.

EXAMPLES OF TRAVERSE AND TRIANGULATION RECONNAISSANCE IN UNMAPPED AREAS

MOUNTAINOUS REGION

Prospector leaves camp at station 1, elevation 1,900 feet (by aneroid), beside stream 30 feet by 2 feet swift, clear water flowing west, and climbs side hill to station 2 at timber-line, elevation 4,030 feet. *See* Figure 18, diagram 2.

From station 2 he reads bearing north 18 degrees west, and vertical angle —22 degrees to his night camp at station 1. Having the difference of elevation and the angle of slope he calculates distance as 1 mile. In this way he locates position of station 2. Station 1 was located by the previous day's traverse. From station 2 he takes bearings north 8 degrees west to peak 3 and north 56 degrees east to falls. Vertical angles are read in each case as well. He travels eastward $1\frac{1}{6}$ miles to a convenient point, station 4, notes elevation, and reads bearings north 89 degrees west to station 2, north $33\frac{1}{2}$ degrees west to peak 3, north 8 degrees east to falls, and north $55\frac{1}{2}$ degrees to peak 5. The intersection of the lines from stations 2 and 4 locates peak 3 and the falls. The horizontal distance to these points can be scaled off the skeleton map and, as the vertical angles have been taken, the differences of elevation or the height of peak 3 can be calculated. He now travels due east for $1\frac{1}{6}$ miles to station 6. He notes elevation and reads angles south 12 degrees east to peak 7, north 66 degrees east to forks in stream 8, and south 79 degrees east to station 9. He travels to station 9, a distance of 1⅓ miles, reads aneroid, and takes bearings north 10 degrees east to peak 5, north 17 degrees east to forks 8, and north 70 degrees east to divide station 10, estimated to be 1 mile away. He goes to station 10, notes elevation, and reads angles north 17 degrees west, to peak 5, and south 55 degrees east to station 11 where he intends to camp. He finds the distance from station 10 to station 11 to be ⅚ mile, and at station 11 he reads aneroid and takes a bearing south 82 degrees west to peak 7.

All of the points are roughly located, but with the information he has obtained he can calculate the elevations of all peaks, stations, and so on, and can plot all his information to scale. The more accurate the measurements the better the map. In this way he may sketch in roughly his angles, stations, streams, and topography in general and plot his information accurately when he has more leisure, or he may plot his information accurately when he does the surveying.

He notes that at stations 1, 2, and 4 the rock is granite. Rocks at the falls are probably not granite and those at station 6 are volcanic. The rocks at stations 9, 10, and 11 are volcanic. Peaks 3 and 7 look like granite, but peak 5 is probably volcanic. He now has enough information to draw in the granite contact as shown by the broken line A-B. Very useful reconnaissance maps can be built up in this manner. In the figure the points 3, 5, 7, 8, and the falls are located by triangulation, and 1, 2, 4, 6, 9, 10, and 11 by traverse. For reasonable accuracy the survey should be tied to known points at least at its beginning and end.

FLAT-LYING AREAS COVERED WITH BUSH

In the east a prospector may use a canoe for travel. For rough surveying he can place his compass in the bow of the canoe in front of the bowman and set it so that when the canoe is pointed towards any point the compass will register the direction. He can measure distance by counting paddle strokes, by timing, or by estimation. In streams he will perhaps estimate the distance as accurately as he can measure it by timing or by counting paddle strokes. In lakes or still water, timing or the counting of paddle strokes is rather accurate. The bowman can record direction and distance to each station in a few seconds while the stern man keeps the canoe in motion, so that very little time is lost. In streams of small to moderate size, bends that are as far apart as vision is unobstructed can be selected as stations. If the stream is crossed by any lines of known position, such as township lines, they can be put on the map under construction, and with such checks a fairly good map of the stream can be made. If no such lines are present the traverse must begin at a known point and end at a known point.

In lakes travel may be from point to point along one side. Distance and direction are taken from station to station and bays sketched between. If the lake is not too large cliffs or peninsulas on the opposite side can be located by triangulation from the traversed side. In traversing lakes it is advisable to get out of the canoe onto the shore to take compass readings.

Figure 18, diagram 3, illustrates traverse and triangulation of a stream and lake. Stations Nos. 1, 2, 3, 4, 5, 7, 9, 11, and 13 are located by traverse and 6, 8, 10, and 12 by triangulation. A township-line crosses at station 13. A mile-post on the township-line is shown a short distance south of the stream and this known point can be used for tying in the survey by pacing in to the mile-post.

A prospector wishes to traverse away from his camp on a stream. He can find just as much mineral by walking straight lines as by meandering, and he can keep a record of his approximate position much more easily. He travels east from camp (Figure 19, diagram 1) getting the distance by pacing or by timing, and the direction by compass or by sun. He crosses a stream flowing southwest at 1,500 paces or 1½ hours, or at 1½ miles from camp. At 3,000 paces he finds outcrops of granites, whereas he has been travelling on greenstone up to this point. At 3,500 paces he is still on granite, so he turns north entering greenstone again at 500 paces. At 1,000 paces north he turns west. At 1,000 paces west he encounters a small lake. Here he offsets 100 paces south and again turns west, crossing a stream flowing out of the lake at 75 paces. At 2,500 paces he reaches the stream on which his camp is located. He follows the river back to camp, a distance of approximately one mile. From the information given he can map the stream, lake, and geological boundaries as shown in the figure. If he can tie in the eastern part of the traverse to any known point he will be able to map his traverse fairly accurately.

SURVEYING CLAIM LINES

In flat-lying areas the lines can be run with a compass and the distance can be measured by pacing. The distance can be measured accurately and very quickly with a long tape rope, fish-line, clothes-line, or some such way. A good, strong, metal tape is very satisfactory, but some metal tapes are easily kinked and broken. In areas of considerable relief, where claims are located on a mountain side, lines running up hill can not be measured directly. Vertical angles can be read, however, and elevation taken with an aneroid. The data can be plotted to scale and the elevation required for an horizontal length of 1,500 feet can be measured, or with the information obtained the required height or distance can be calculated from Table I. Levels could be run along the claim-lines, but this would take a good deal of time.

In Figure 19, diagram 2, vertical angles have been plotted to scale. The figure was constructed in the following manner. The horizontal line AC is drawn representing a length of 1,500 feet, which is the required length of claim-line. Slope of hillside from A to D is 40 degrees. This is plotted with a protractor, the line AD representing the sloping hillside. By aneroid, D is 425 feet above A, so the line DE is drawn according to scale 425 feet long and at right angles to AC. The point D on the diagram now represents the point D on the ground. The slope of the hillside above D is 18 degrees and is represented in figure by line DB. A line is now drawn from C at right angles to AC, intersecting line DB at G. As AC represents the correct length of claim-line the point G represents the upper end of the claim-line on the ground. By measurement on the diagram the line CG is 750 feet long, so

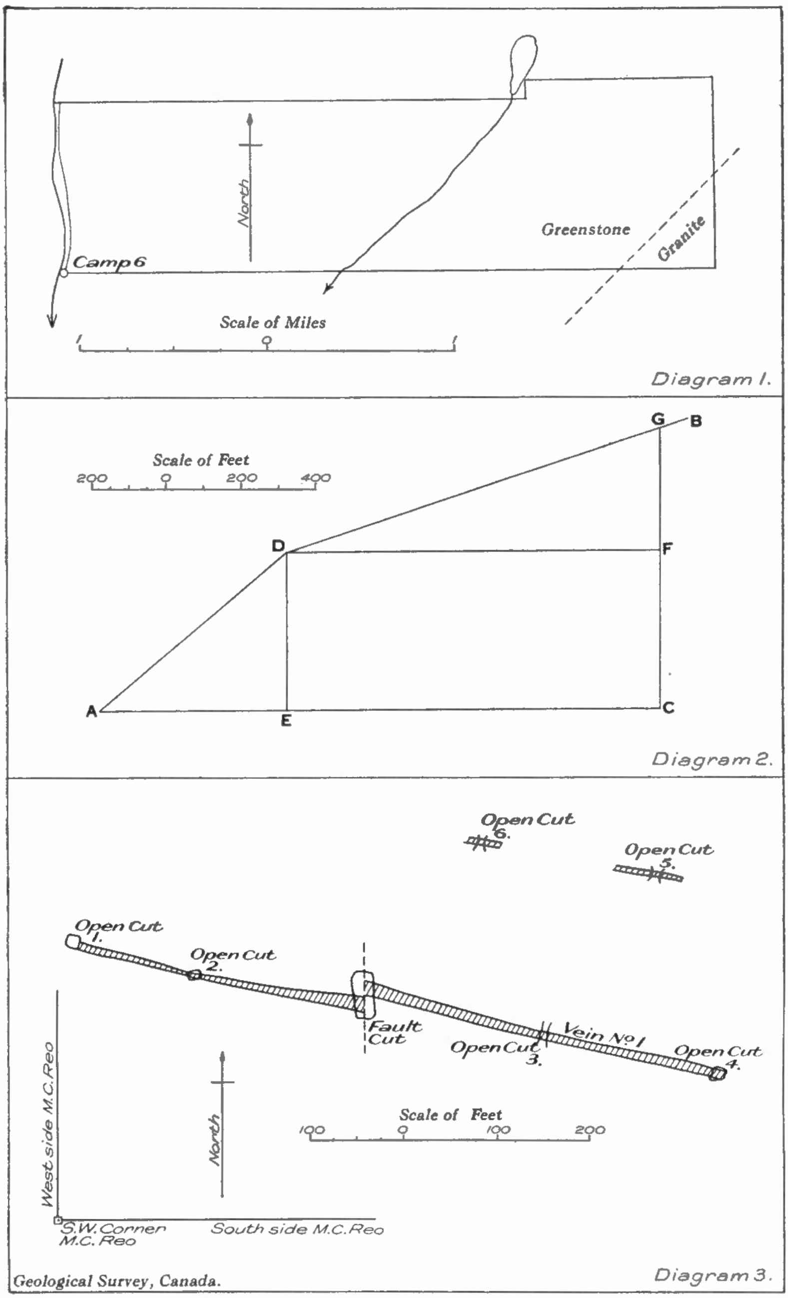
North
Greenstone
Granite
Camp 6
Scale of Miles
1
0
1
Diagram 1.
G
B
Scale of Feet
200
0
200
400
D
F
A
E
C
Diagram 2.
Open Cut 6.
Open Cut 5.
Open Cut 1.
Open Cut 2.
Fault Cut
Vein No 1
Open Cut 3.
Open Cut 4.
West side M.C.Reo
North
Scale of Feet
100
0
100
200
S.W.Corner M.C.Reo
South side M.C.Reo
Geological Survey, Canada.
Diagram 3.

Figure 19.

the upper end of the claim-line is 750 feet higher than the lower end at A. The point G on the ground can then be located by using the aneroid.

Instead of measuring from a diagram calculations can be made by using Table I as the elevations and slope distances are known.

SURVEYING SURFACE DEVELOPMENTS

This can be done by traverse from one open-cut to another, and so on, and the whole tied in if desired by traverse or triangulation to a claim-post. A base-line can be measured and all open-cuts located by triangulation. If the open-cuts, trenches, etc., are all visible from one point they can be located by taking bearings to each one from this point and measuring the distance in each case. Figure 19, diagram 3, shows an example of traverse and triangulation. Two veins are exposed on a hillside. The exposures of vein No. 1 are all at approximately the same elevation. Figure 19, diagram 3, was drawn from the following notes. The lines used in the construction of the diagram have been removed.

Stations	Direction	Distance Feet	Remarks
1 to 2.......	S. 3°W.	....	Sta. 1 is south side of open-cut 1 on quartz vein 10 ft. wide. Strike S. 80°E. Vertical dip. Sta. 2 is SW. corner M.C. Reo.
1 to 3.......	S. 76°E.	142	Sta. 3 is same vein, 5 ft. wide, same strike and dip, open-cut 2
3 to 4.......	S. 78°E.	180	At sta. 4 vein is 15 ft. wide, offset by vertical fault striking north. East side of fault offset 20 ft. north along fault-plane. Well exposed in fault cut at sta.
4 to 5.......	N. 35°E.	....	Angle to open-cut 6 on upper vein, 5 ft. wide
4 to 6.......	N. 66°E.	....	Angle to open-cut 5 on upper vein, 5 ft. wide
4 to 7.......	S. 81°E.	198	To open-cut 3, vein 8 ft. wide, same strike and dip
7 to 8.......	S. 78°E.	194	To open-cut 4, vein 10 ft. wide, same strike and dip
8 to 5.......	N. 46°W.	....	Angle to open-cut 6
8 to 6.......	N. 17°W.	....	" " 5
8 to 2.......	S. 78°W.	....	SW. corner M.C. Reo.

In this example vein No. 1 is traversed, distances are measured, and the traverse is located by triangulation to the corner post of the mineral claim. The upper vein is located by triangulation from the traversed vein. Vertical angles should be read so that elevations can be shown or contour-lines drawn. Usually a good deal of geological information can also be placed on the diagram.

To Find Length of Tunnel Required to Reach Vein or Shaft

In Figure 20, diagram 1, the portal of the proposed tunnel is at A, and the outcrop of the vein or collar of the shaft is at B. A vertical vein or shaft is represented by BC, a vein dipping 80 degrees toward portal or incline shaft of same dip is represented by BD, and a vein or incline dipping 70 degrees away from the portal is represented by BE. The tunnel is to be driven at right angles to the strike of the veins. A figure of this type is really a vertical section from the surface down to the proposed tunnel level.

Levels are run up the hillside, represented by the curving line AB, from portal of tunnel to the vein outcrop at B. If the levels are run directly from portal to outcrop the horizontal distance can be measured. It is advisable to actually measure the horizontal distance, as accuracy is desired in a case of this kind. If the horizontal distance is not measured a vertical angle can be read from A to B, and the horizontal distance calculated, or measured from the diagram. B is found to be 157 feet above A, the horizontal distance by measurement or calculation is 275 feet, and the vertical angle is 30 degrees. If the vein is vertical the length of tunnel required is 275 feet. The line BD represents a vein dipping 80 degrees toward the

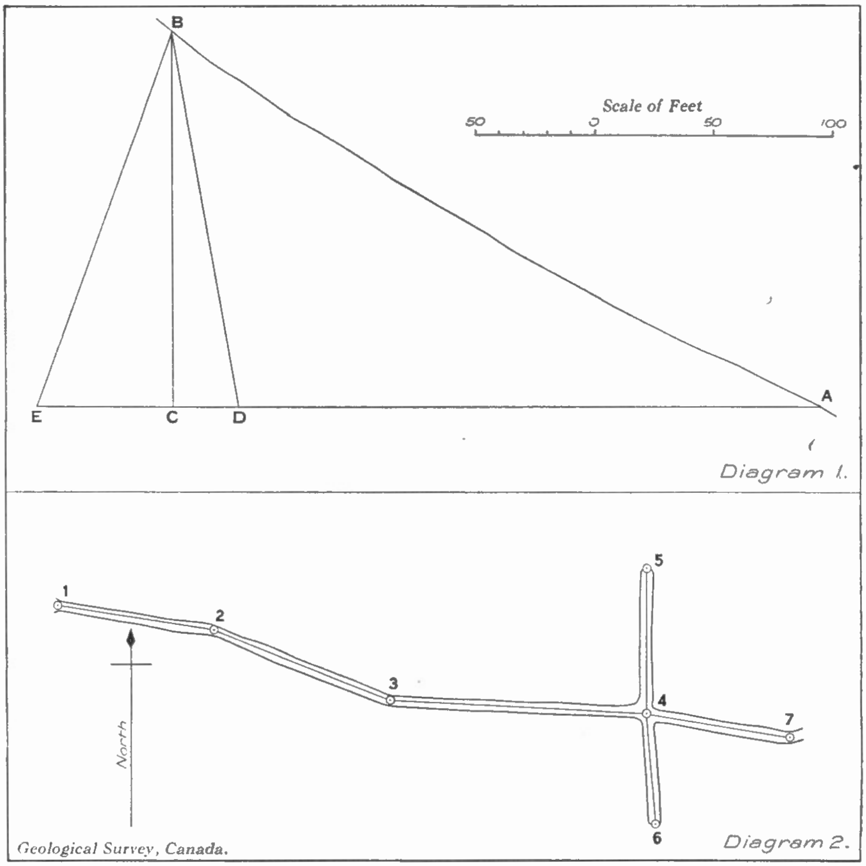

Figure 20.

portal of the tunnel. The line is simply drawn from the outcrop location B in the diagram with a protractor. The distance AD is then the length of tunnel required to reach this vein. By measurement on the diagram this distance is 246 feet. BE represents a vein dipping 70 degrees away from the portal. It is laid down with a protractor and the length AE measured on the diagram. This distance is 332 feet. As the necessary angles are known the horizontal distance could also be calculated from data given in Table I.

UNDERGROUND SURVEYING

Underground work should always be laid out by plan and should always be surveyed, and the plans obtained from such surveys studied in connexion with surface plans. It may seem strange, but more than one tunnel has been driven into a hillside, only to emerge again at another point on the same hillside.

In surveying tunnels in which steel rails, air-lines, etc., have been laid, a compass can not be relied on for correct direction.

In plane-table surveying (*See* page 257) bearings are not read and as a consequence magnetic attraction has no effect. This instrument is then very useful for any work where local magnetic attraction exists. An ordinary scale or ruler can be used as an alidade. Sights preferably like peep sights for rifles can be fixed on the scale for sighting, but even two pins can be used for sights. Set up and level the plane-table in the tunnel in such a position that the portal can be seen. On the plane-table paper make a mark, station 1, to designate the portal. Place edge of scale at this mark. If a sharp pencil is held upright with point on the mark, the scale can be quickly placed to touch the pencil. Turn scale so that the portal is seen through the sights. Now, having measured the distance from the portal to the instrument, draw a line on the plane-table paper from station 1 along the edge of the scale of the required length to station 2 which is the position of the plane-table. Set up a light farther in the tunnel and without moving the plane-table take a similar sight on the light or station 3, with the edge of the scale at station 2. Measure distance and draw the line from station 2 to station 3 of the corresponding length.

Move plane-table to station 3, set up and level, place the edge of the scale on the line between station 2 and station 3 and turn the plane-table until station 2 is visible in the sights. Now the plane-table is oriented in the same way as it was at station 2. The sighting back to the previous station along the line is done at every station in order to have the plane-table always in the same orientation. With the edge of the scale at station 3 sight to station 4 farther in the tunnel, and draw line of required length to station 4. Move plane-table to station 4 and orient as before by placing edge of scale on the line between stations 3 and 4 and sighting to station 3. At station 4 are two crosscuts. Place edge of scale at station 4 and sight into the crosscuts stations 5 and 6, and ahead to station 7 in the main tunnel. Proceed in the same way until tunnel survey is completed. In this way the tunnel plan is drawn directly on the plane-table paper. The actual direction is not determined, but the direction in some part of the tunnel away from the influence of steel rails can be taken with a compass and the whole plan oriented in the proper direction. Figure 20, diagram 2, illustrates above description. No steel was present in crosscut 4-5, so the direction was read from 5 to 4 as south and the plan was orientated from this. The construction lines joining the stations in the figure are left on the diagram in this instance simply to show clearly how the diagram was constructed.

PLOTTING THE SURVEY

In practically all surveying the end in view is the production of a map or miniature representation of the area covered. It is, therefore, necessary to plot the survey notes obtained to a determined scale. This plotting may either be done at the time the observations are made, or at a subsequent time when facilities permit, but in any event a rough representation should be made at the time of observation to ensure that all the necessary data have been recorded. The choice of scale is dependent upon the use to which the map is to be put, the extent of the area covered, and the amount of detail that must be shown. In general, as small a scale as is consistent with a clear delineation of the smallest features to be shown is chosen, but at the same time ease of plotting or of scaling distances from the finished map should be considered. The choice is in many cases restricted to some scale so small that the whole map will fall within a given rectangle, i.e., the size of paper available or convenient to handle. Consequently for maps of small areas such as a mineral claim or underground workings scales as large as 1 inch=10, 20, 30, 40, 50, or 80 feet, or more, are at times chosen, as on maps of this character considerable detail is shown in many cases. For somewhat larger areas or areas where less detail is required, scales of 1 inch=100, 200, 400, 1,000, or even more feet are used. Using a scale of 100 feet to the inch, for example, a sheet of paper at least 14 inches square would be required to a mining claim of 40 acres; but a vein 400 feet long can be plotted on a scale of 40 feet to the inch on an ordinary sheet of foolscap. For maps of still larger areas scales of 1 inch=1, 2, 4, or 8 miles are chosen. The degree of precision in both field work and plotting should correspond to the scale chosen. Thus an error of 10 feet in locating a point would be an error of great magnitude on a scale of 1 inch=20 feet; serious on a scale of 1 inch=100 feet; but negligible on a scale of 1 inch=1 mile.

The choice of paper is also important. For accurate maps and for maps that will receive rough usage, mounted paper is preferable. Pencil drawings preparatory to tracing may be made on any good grade of drawing paper. For field traverses cross-section paper is preferable as it gives lines of reference from which angles may be plotted with ease. Tracings may be made of any drawing on tracing cloth or tracing paper with drawing ink, and from these tracings any desired number of blue print copies may be made.

Only the simplest method of plotting can be touched on in this article. For more accurate methods, which usually require a knowledge of trigonometry, the reader is referred to standard works on surveying. In general the prospector will survey by traverse, using a compass for direction and some simple method for measuring distances. The plotting thus resolves itself into two operations—laying off the course in relation to some definite direction, usually magnetic north, and laying off the distance along this course to some suitable scale. Traverse lines may be plotted by a number of different methods, but of these the most suitable is by means of a protractor (*See* page 258). The compass directions will be recorded in the notes either as bearings, or as azimuths, depending upon the compass used. Bearings are always measured from the north or the south point, so many degrees east or west of these points. A bearing thus cannot exceed 90 degrees. Azimuths are measured from the north point in a clockwise direction from 0 degrees to 360 degrees. Thus a line of which the azimuth is between 0 degrees and 90 degrees lies in the northeast quadrant; between 90 degrees and 180 degrees in the southeast quadrant; between 180 degrees and 270 degrees in the southwest quadrant; and between 270 degrees and 360 degrees in the northwest quadrant. Thus an azimuth of 65 degrees is the same as a bearing north 65 degrees east, an azimuth of 140 degrees lies beyond the east point and as a bearing is measured from the south towards the east, i.e. 180 degrees to 140 degrees, namely south 40 degrees east, and so forth.

The prospector will find it an advantage when plotting to use azimuths or bearings, depending on which is actually recorded by his compass. A line is drawn in any convenient direction through the initial station. This is taken as the reference meridian, usually corresponding, in a compass survey, to magnetic north. The centre of a protractor is laid on the station and the zero graduation of the protractor on the meridian, and the azimuth,

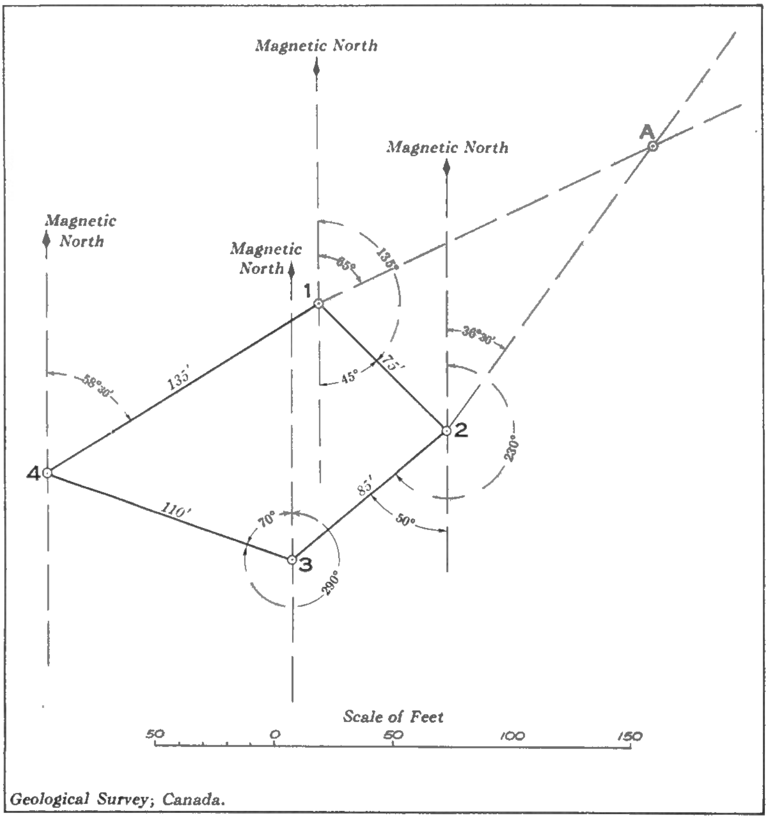

Figure 21.

or number of degrees by which the initial course departs from this north line, or the bearing, or number of degrees east or west by which the initial course departs from the north or south, can then readily be marked against the edge of the protractor. A line is then drawn joining this point to the initial station, and the distance between the initial station and second station is scaled off along this line, starting from the initial station. A meridian parallel to the first meridian is drawn through the second station, and the azimuth or bearing of the third station laid off from this meridian in the same manner. In this way the traverse, which in reality is the control of the map, is built up. Bearings to a point lying off the traverse are plotted in the same way, and intersections of bearings to the same point give the location of this point.

The following are the notes of a survey platted in Figure 21.

Stations	Azimuth	Bearing	Distance	Remarks
			Feet	
1-2	135°	S. 45°E.	75	
1-A	65°	N. 65°E.	....	A is northeast corner of claim
2-3	230°	S. 50°W.	85	
2-A	36° 30′	N. 36° 30′	....	
3-4	290°	N. 70°W.	110	
4-1	58° 30′	N. 58° 30′ E.	135	

Thus at station 1 an azimuth of 135 degrees to station 2 was read. This is 135 degrees from the north point. Had the bearing been read the angle would be 45 degrees from the south point towards the east. The direction of the line 1-2 is thus fixed and by scaling the distance from station 1, 2 becomes fixed. At station 2 the azimuth to station 3 is 230 degrees from the north, measured in a clockwise direction. This is equivalent to a bearing of 50 degrees towards the west from the south or south 50 degrees west. In plotting azimuths it is useful to have a protractor in the form of a complete circle graduated from 0 degrees to 360 degrees. In plotting bearings a semicircular protractor is best, the protractor lying east or west of the meridian according as the bearing is east or west of the north or south points. As most semicircular protractors are graduated to read both ways from 0 degrees to 180 degrees little difficulty is presented in laying off the correct angle.

Table I

Angle of slope, or vertical angle	Percentage grade	Angle of slope, or vertical angle	Percentage grade
Degrees		Degrees	
1	1·7	24	44·5
2	3·5	25	46·6
3	5·2	26	48·8
4	7·0	27	50·9
5	8·8	28	53·2
6	10·5	29	55·4
7	12·3	30	57·7
8	14·1	31	60·0
9	15·8	32	62·5
10	17·6	33	65·0
11	19·4	34	67·4
12	21·3	35	70·0
13	23·0	36	72·6
14	24·9	37	75·4
15	26·8	38	78·0
16	28·7	39	81·0
17	30·6	40	84·0
18	32·5	41	87·0
19	34·4	42	90·0
20	36·4	43	93·0
21	38·4	44	96·5
22	40·4	45	100·0
23	42·5		

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SURVEYING INSTRUMENTS

(J. R. Marshall)

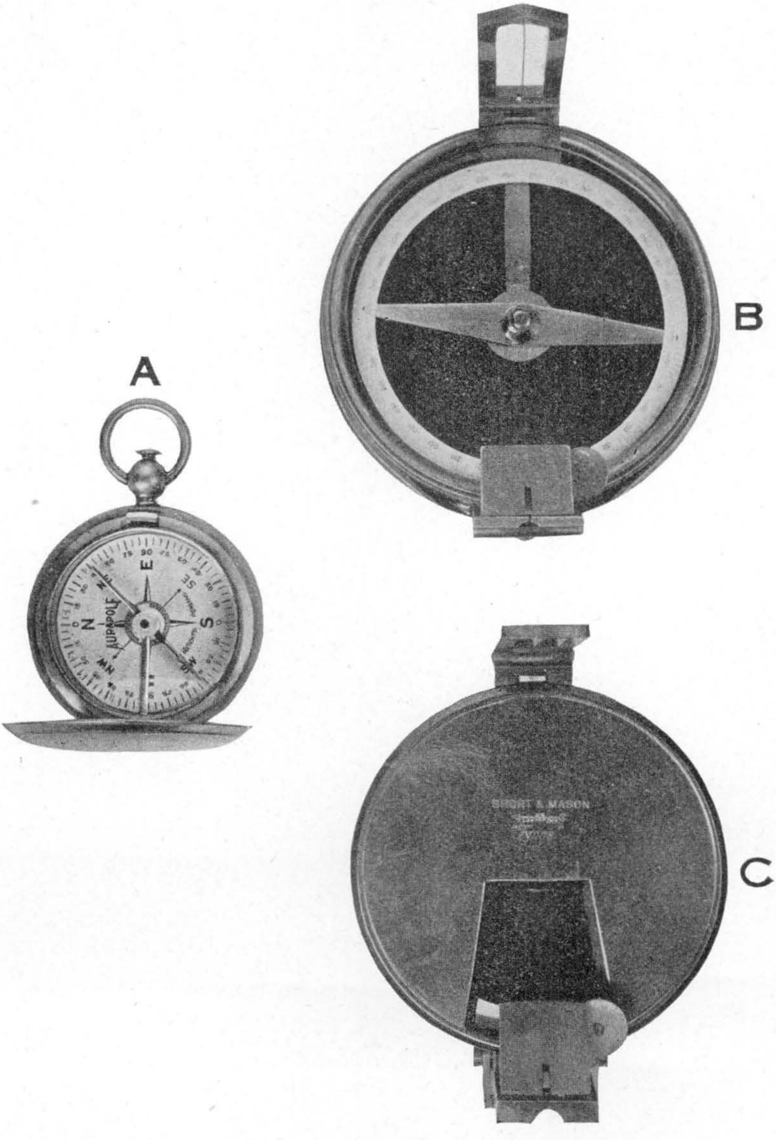
The prospector's needs, so far as instruments are concerned, are few. A good compass is indispensable. Some knowledge of the simplest surveying instruments will in many cases prove a decided advantage to the prospector. Herein are set forth the details of various types of compasses, together with a brief description of the plane-table, aneroid barometer, hand-level, tape, protractor, scales, and camera.

COMPASS

When travelling through thick timber, whether in mountainous or flat country, a good compass is essential to every prospector, and to learn the use of it is one of his first duties. The ordinary pocket or hand compass is simple and is known to all. The illustration (Plate XX) shows the dial compass enclosed in hunting case.

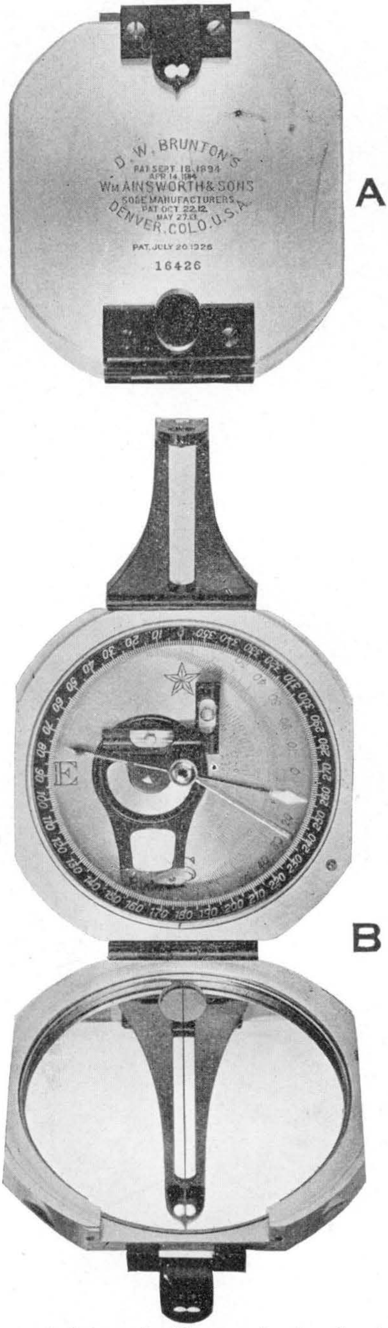
The principal parts of all compasses are the same. In the more elaborate instruments certain refinements are added to produce the accuracy demanded in the particular piece of work. The parts of any compass are: (*a*) magnetic needle commonly pointed or coloured at the north end. This is mounted on a metal pivot about which it revolves; (*b*) graduated circle or dial, marked off in degrees and half degrees and on which the points N, S, E, and W are marked. The simplest type of compass should be used only for a rough idea of direction while travelling, or for very rough locations. For more accurate work either the Brunton or Prismatic compass should be used. The common pocket or hand compass may be obtained from any hardware or sporting goods store for as low as $1.

PLATE XX



A. Dial compass enclosed in hunting case.
B. Prismatic compass, open face.
C. Prismatic compass, closed face.

PLATE XXI



A. Brunton pocket transit (Compass), closed. Actual size.
B. Brunton pocket transit (Compass), open. Actual size.

92326—17½

BRUNTON POCKET TRANSIT (Compass)

A very light pocket instrument designed by Mr. D. W. Brunton and very useful for those intending to make prospecting their life work may be obtained from Wm. Ainsworth and Sons, Denver, Col., U.S.A., price $25 to $30.

Cover is provided on inside with a mirror with black hair-line centre. Attached to compass is sight bar A 4. Magnetic needle *B* mounted on pivot in compass box, in which is metal ring graduated from 0 degrees to 360 degrees. Compass box is provided with a graduated vernier arm for measuring vertical angles. Vernier arm is provided with a level bubble or bubbles.

The E.W. and N.S. letters are the reverse of those in the ordinary compass, so that the readings may be taken directly from the face of the instrument. In order to avoid confusion the north end of the needle is pointed.

Some of the uses of the Brunton compass are:

(a) *For Reading Horizontal Angles.* Set the bubble tube at right angles to the line of sight and incline the mirror-lined lid to give a perfect view of object sighted. The instrument is correctly sighted on object, when the eye, looking into the mirror, sees the black centre-line bisecting both the opening in the reflected sight and the object sighted at, after which the reading of the needle may be taken.

(b) *As a Prismatic Compass.* For horizontal angles or corners. While looking through the two sight apertures the position of the needle and reading can be accurately observed in the mirror.

(c) *Reading Vertical Angles.* In taking vertical angles the sighting bar is thrown out parallel with the face of the instrument with sighting end folded at right angles to the bar. Then the mirror-lined lid is held at approximately an angle of 45 degrees with the face of the instrument, in which position the eye can see through the opening in the end of the sighting bar, the cylindrical opening in the lid, and at the same time view the reflection of the bubble tube in the mirror. Care should be taken that the sides of the instrument are held perpendicular when the sight is taken. The mirror is used merely to show the operator when the bubble is central, after which the lid is opened and the vernier arm read direct.

(d) *As a Level, Clinometer, and Plumb.* By opening out the cover parallel with the face of the instrument, it produces a long, parallel edge, permitting its use as a level, clinometer, and plumb.

Although the Brunton is designed to be used principally as a hand instrument, it may be mounted on a light tripod, and used as a level, for vertical angles, for sighting long tangents, and for tracing the outcrop of a dipping vein on irregular ground.

PRISMATIC COMPASS

These instruments are made in sizes from 2 to 6 inches in diameter. The compass needle is a floating metal or cord dial graduated to ½ degree and enclosed in a metal case. The reading of the compass is effected by means of a glass prism which both magnifies (*See* Plate XX) and reflects the figures of the dial. As the reading is made on the side of the dial nearest the observer the figures on the dial are engraved right to left. On the compass box opposite the glass prism is a hinged sight arm with central hair. This arm folds over the box lifting the dial off its centre.

May be obtained from W. and L. E. Gurley, Troy, N.Y. Price $15 to $27.

The object to which it is desired to obtain the course is lined up on the cross hair of the hinged sight arm through a slit in the prism. At the same instant the reading of the dial reflected in the prism is taken. In practice there is a lever projecting just back of the sight arm for lifting the compass dial off its pivot. By use of this the vibrations of the compass may be deadened and the dial more quickly brought to rest in its proper position.

USEFUL HINTS ON THE USE OF THE COMPASS

Compasses are graduated either in quadrants or from 0 degrees to 360 degrees. In effect this means they are graduated to read either bearings or azimuths. The prospector will find it to his advantage to read his instrument directly, i.e., he will read either bearings or azimuths according to the manner in which his instrument is graduated.

The prospector should find out which end of the needle to read and always read that end of the needle. In general compasses are designed so that the reading is taken from the north end of the needle. In the Brunton compass, however, when used as a prismatic, i.e. with the north point towards the observer, the true course is given by the south end of the needle. A little practice in a locality where directions are known will enable the observer to ensure that he is reading the true courses.

In taking backsights, the course of bearing will differ from the foresight by 180 degrees. Thus, if the bearing from station 1 to station 2 be north 45 degrees east (45 degrees) the bearing from station 2 to station 1 will be south 45 degrees west (225 degrees). Where a difference is obtained there is local attraction at one or both of the stations.

HAND LEVELS

LOCKE HAND LEVEL

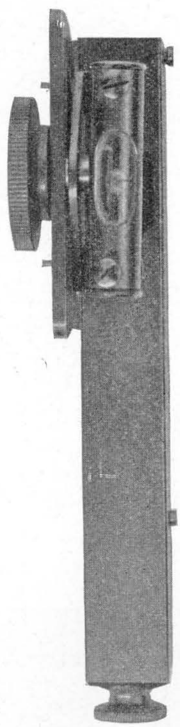
This instrument consists of a brass tube about 6 inches long, having a level bubble on top near the object end. There is an opening in the tube beneath through which the bubble can be seen, as reflected by a prism immediately under the level bubble. Both ends of the tube are closed by disks of plain glass. At the eye piece, a semicircular convex lens serves to magnify the level bubble and the cross wire beneath, while it allows the object to be clearly seen through the open half of the tube. When the level bubble is bisected by the cross hair any object on the cross hair as seen through the telescope is at the same level as the eye. In practice the reading may be taken to the foot of a picket or mark. The difference in elevation between the ground-level at which the observer stood and the ground-level at the mark or picket is equal to the height of the observer's eve above the ground where he stood.

ABNEY HAND LEVEL AND CLINOMETER

The main tube is square and can be applied to any surface, the inclination of which is ascertained by bringing the level bubble into the middle and reading off the angle on the vernier. When sighted at an object and the bubble brought into the middle, the vertical angle from the height of the eye is indicated. When at zero it indicates a level line.

Supplied by W. and L. E. Gurley, Troy, N.Y.: Locke Hand Level $8; Abney Hand Level $13.50.

PLATE XXII



Abney hand level.

PLANE-TABLE

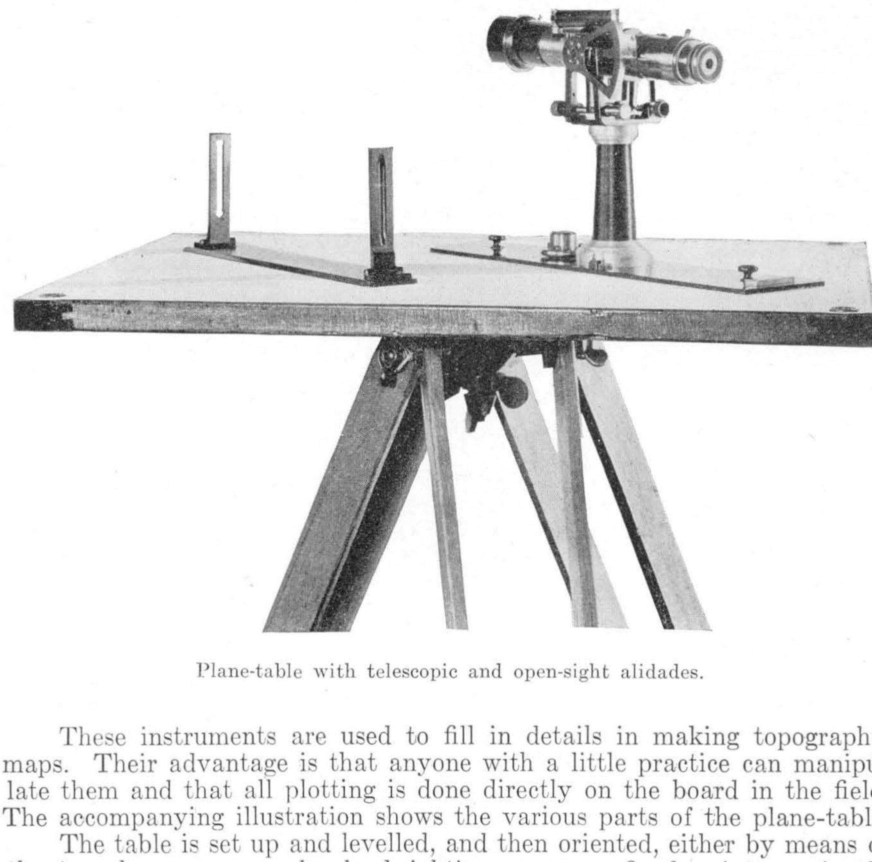
The plane-table is merely a portable table mounted on a tripod or legs. The tables are made in various sizes, the more convenient sizes being 15 by 15 inches, 16 by 20 inches, and 18 by 24 inches. The accessories to the table are the sight-vane, also called sight rule or alidade, and the box or trough compass.

ALIDADE

Has a straight bevelled edge and is provided with sights at either end. By means of the alidade the direction of any object from a given point on the sheet may be determined and plotted. Where great refinement of observation is required a telescope is mounted on the alidade, and the direction and distance plotted directly on the sheet.

Trough Compass. A magnetic needle set in box about 6 inches long. This may be attached either to the table or the alidade.

PLATE XXIII



Plane-table with telescopic and open-sight alidades.

These instruments are used to fill in details in making topographic maps. Their advantage is that anyone with a little practice can manipulate them and that all plotting is done directly on the board in the field. The accompanying illustration shows the various parts of the plane-table.

The table is set up and levelled, and then oriented, either by means of the trough compass or by backsighting on some fixed point previously platted. In commencing a survey the position of the initial station may be assumed at any convenient point on the board. The survey then proceeds by traverse or by graphical triangulation. In the former method the procedure is similar to that explained in the preceding article. The courses are platted as taken with the alidade. Orientation of the table at each station occupied may be done by the compass or by backsighting on the last station occupied.

In graphical triangulation a measured base is necessary, this being platted on the plane-table paper. The table is then set up at one end of the base and oriented by laying the alidade along the base, and turning the table until the other end of the base is sighted through the alidade. Lines are then drawn sighting the points it is desired to locate. The table is then moved to the other end of the base and the procedure repeated. Intersection of lines to the same point gives the location of that point platted to the same scale as the base. Any point thus located may be occupied as a station for extending the survey. A graphical solution of the position of an unknown point by sighting three fixed points is also possible (*See* page 239). In the use of the plane-table care must be exercised when orienting the table by backsight that the sight be taken with the alidade pointing on the map from the station occupied to the station sighted, otherwise the table will be 180 degrees out of orientation. Thus in occupying station 2 and sighting station 1 the alidade must be laid on the map pointing from station 2 to station 1.

TAPES

These are made of heavy steel ribbon, with etched graduations, and in lengths of from 50 feet to 500 feet. They may be obtained graduated in feet or chains, or feet on one side and links on the other.

A very serviceable tape for a prospector is the metallic tape, 100 feet in length, in leather case. This is made of linen thread interwoven with fine brass wire. The graduations, which are etched, are in 10ths or 12ths of a foot, as desired, on one side, and in links on the reverse side.

Supplied by W. and L. E. Gurley, Troy, N.Y. Price $4.20.

ANEROID BAROMETER

The aneroid barometer is an instrument for measuring atmospheric pressure. It contains a metallic box from which the air has been exhausted. The variations in the pressure of the atmosphere, acting upon the thin cover of this vacuum chamber, cause the cover to move in or out, and this motion is transferred, by levers, chains, and springs, to a pointer moving around a graduated dial, recording air pressure usually in terms of inches of mercury of a mercurial barometer. A second dial gives altitudes in feet. The aneroid is open to a number of objections, but for rough work it is an extremely useful instrument. Absolute elevations above sea-level cannot be obtained with it with any degree of accuracy, but differences of elevation, particularly where these are large, and the time elapsed between observations is not great, may be obtained within reasonable limits of accuracy. The instrument reads directly in feet and requires no skill for reading, but as it is extremely sensitive it should be handled with care. May be obtained at stores handling surveying instruments and from most jewellers.

PROTRACTOR

The protractor is an instrument for laying off angles on a drawing. It is made of wood, celluloid, paper, or cardboard and consists usually of a circle or semicircle, the edge of which is graduated in degrees and fractions of a degree from 0 degrees to 180 degrees or from 0 degrees to 360 degrees as the case may be. The centre of the circle or arc of the circle is marked. To lay off an angle the centre of the protractor is placed at the apex of the desired angle, so that the line from the centre to the zero graduation will fall on one side of the required angle. To get the other side of the required angle follow around the circular edge the required number of degrees from the zero point and make a dot. Draw a line joining this dot to the apex. May be purchased at small cost at any store handling draughting instruments or one can be made from a piece of cardboard.

SCALES

The scales most commonly in use are those in which the number of feet represented by one inch is some multiple of ten. Thus scales may be purchased divided so that an inch has 10, 20, 30, 40, 50, 60, 80, or 100 divisions. The scale suitable to the work is chosen. Thus in platting on a scale of 40 feet to the inch, a 40 scale is chosen, on which each small division represents a foot. Platting on a scale of 400 feet to the inch the same scale would be chosen, each small division representing 10 feet. On 4,000 feet to the inch the same scale would be chosen, each small division representing 100 feet. Scales may also be purchased having divisions representing decimals of a mile. For field use a flat boxwood scale with bevelled edges with graduations on a celluloid strip along both edges will be found convenient. These may be purchased at any store handling draughting instruments.

CAMERA

The camera is an instrument that may prove of great value to the prospector. Not only are photographs of great value as a record and in indicating the type of country to be travelled, but pictures of vein outcrops, open-pits, trenches, etc., afford definite evidence of what may be seen on a mineral property and may well be a factor in influencing prospective purchasers to visit it. The camera is so well known that no description is necessary, and personal taste will be the determining factor in its purchase. The camera should be equipped with the best lens the purchaser feels he can afford and should be as compact as possible, and yet make photographs of sufficient size to be of value. For most purposes a roll film camera taking pictures $3\frac{1}{4}$ by $5\frac{1}{2}$ inches will be found suitable. In all photographs showing details of rock or vein exposures an object such as a pick, hammer, or coin should be included to give an idea of the relative size of the details of the exposure.

DEVELOPMENT OF PROPERTIES

(E. R. Faribault and J. F. Walker)

Only small, high-grade deposits can be developed to the stage of production by the discoverer. Large deposits require organized capital for their exploitation, and these the discoverer can only hope to explore to the point where capital can be interested. Work should be done with the object of meeting the requirements of the purchaser. Essential things to consider are: present and future demand for the mineral; type and size of deposit and grade and complexity of ore; location, transportation, and power; distance to smelter where ore or concentrates must be shipped; mill requirements; experience of neighbouring properties, if any. The prospector will do well to consider these factors at all stages of his work and to remember that there are few big mines that have not had good surface showings. Before locating and recording claims it is advisable, whenever possible, to make a preliminary examination of the discovery noting all the information gained, so that it can be put together in a map which will prove to be invaluable in showing the location of the claims, planning further work, and in negotiating for the disposal of the property.

Most mineral deposits are largely covered with overburden and vegetation, hence the discovery and adjacent ground should be examined with the object of determining, not only the minerals present and the type of deposit, but the extent and direction of outcrop. A base-line, with points marked at 100-foot intervals, should be located along the direction of the outcrop, the adjacent ground examined, and the information gained recorded, and located with reference to the fixed points. This work should be carried both ways from the discovery as far as any pertinent evidence can be formed relating to the discovery. The next step is to search the ground at greater distance on either side of the direction of outcrop and, in flat or gently rolling country, it can be done by running lines one-quarter of a mile long at right angles to the base-line at intervals of 200 feet. The ground between these lines can be searched and features such as outcrops, drift-covered areas, swamps, etc., accurately located from fixed points at 100-foot intervals on these side lines. Example:

The discovery was made at D, Figure 22, and the direction determined resulting in the base-line A-G being located. Prospecting on either side of the base line showed a swing of the mineralized contact between greenstone and schist to both north and south. The side-lines were then run and the ground between them thoroughly searched. The contact is found to be offset, suggesting a fault, and another greenstone-schist contact also discovered toward the south. Further search should be continued east and west of the area covered as the contact appears to be well mineralized. With this information in hand, claims can be located and a campaign of stripping and trenching planned to expose as much as possible of the mineralized zone along the contact and also to determine if the southerly contact is mineralized.

Stripping and trenching are the cheapest and most effective methods of showing up the possibilities of a prospect and expensive underground work should never be started until all possible surface work has been completed. In ordinary ground, stripping and trenching can be carried out to depths of 2 to 3 feet. Compare this with underground work. In the time that it would take a man to drift 10 feet on a 2-foot vein, another man could strip 250 feet of vein with an average cover of 3 feet. In the first case, 120 cubic feet of ore has been recovered and the vein exposed for a length of 10 feet and a depth of 6 feet. Assuming that ore in sight extends but 1 foot beyond the surface exposed, there is in the first case 56 cubic feet of ore in sight along top, bottom, and face of drift, whereas in the second case there is 500 cubic feet of ore in sight on the surface. As the recovery of ore is not likely to pay at this stage of development, it is obvious that the stripping has

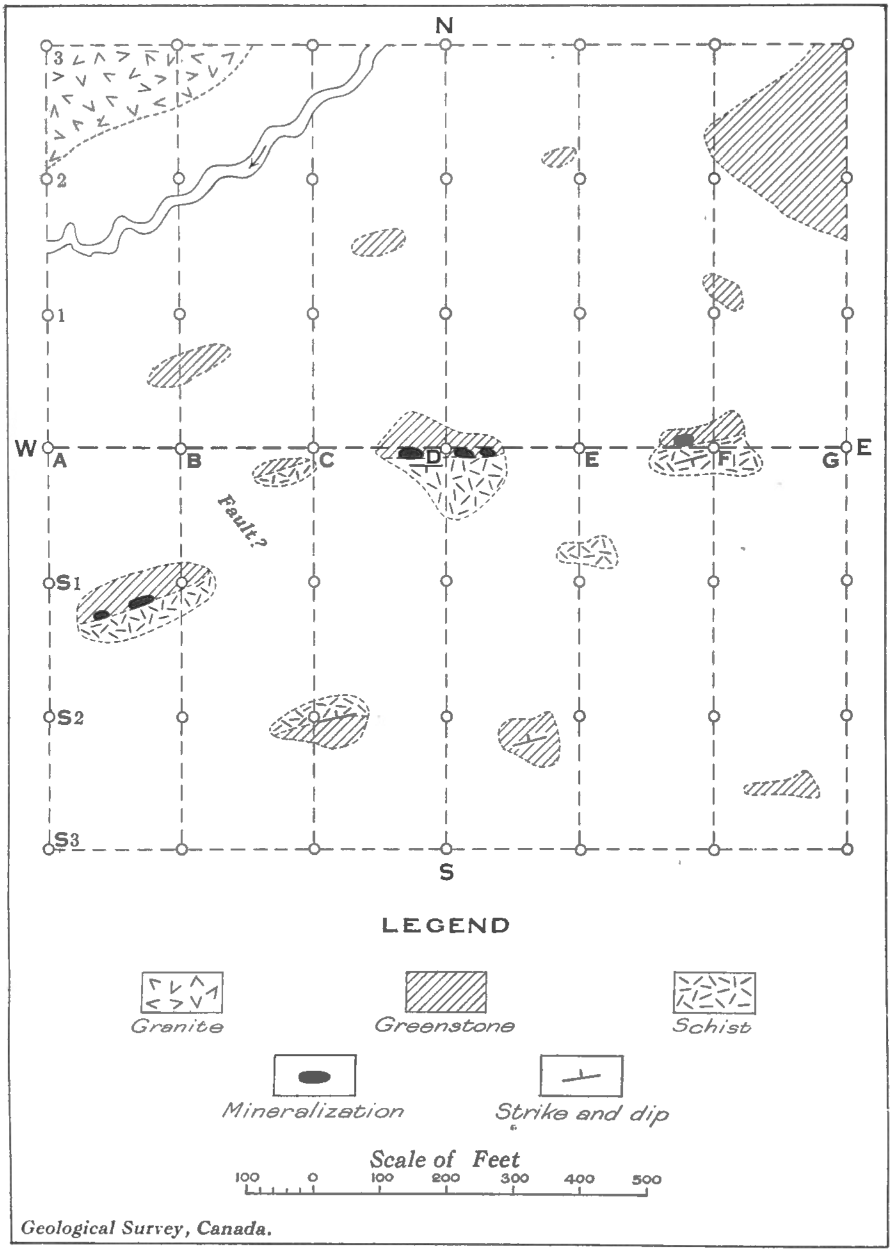

N
3
2
1
W
A
B
C
D
E
F
G
E
Fault?
S1
S2
S3
S
LEGEND
Granite
Greenstone
Schist
Mineralization
Strike and dip
Scale of Feet
100 0 100 200 300 400 500
Geological Survey, Canada.

Figure 22.

proved more ground at less cost than the 10-foot drift. Shaft sinking will prove still less ground, as sinking is slower than drifting. Trenching may be done to depths of 6 to 7 feet in the case of wide deposits in good ground. Water and boulders are the chief impediments. When the overburden is too thick for trenching, test pits may be sunk under favourable conditions. Shallow pits in good, dry ground are cheaper than borings and give more satisfactory results. They should be carefully located, for time and cost mount rapidly with depth and a 30-foot pit represents much stripping or trenching elsewhere. By probing with an iron rod, drive pipe, or hand auger, advance information on the depth of cover may be gained which will guide stripping, trenching, or test pitting. In soft ground a light iron rod can be used to shallow depths to determine cover and a hand auger for greater depths where deep trenching or test pitting may be used. A drive pipe can be used to obtain information as to the nature of soil and overburden within limits of about 15 feet for soft soil if small pipes are used.

In mountainous country the prospecting of a discovery calls for somewhat different application of the methods used in flat ground. Traverses cannot ordinarily be run and frequently there is little need, as the ground surrounding the discovery may be well exposed on an open hillside. The outcrop should be traced and located, as described under the section on surveying, with the object of being able to put the information on paper. Consideration must be given to the topography and the strike and dip of a vein in tracing it in hilly ground. For example a vein striking north with westerly dip across an east and west ridge will have on the south slope an apparent northeast strike, or outcrop, and on the north slope an apparent northwest strike, or outcrop (*See* Figure 23). A vein lying flat on the hillside may have a very large outcrop but no depth and no great extent, due to erosion everywhere else on the ridge. Bedded veins following the structures may vary greatly in strike and require careful tracing on the surface, the rock structures being a guide to their location. In many cases excellent sections of veins or other types of deposits can be seen exposed on a hillside. For example, a vein is traceable up a hillside with a difference in elevation of 500 feet and the horizontal distance between top and bottom of exposure is 800 feet. What does this mean to the prospector in the mountains? It means that on the surface there is exposed a section of the vein to a depth of 500 feet and that there is about the same amount of information available that would be obtained by sinking a 500-foot shaft on an 800-foot vein outcrop in flat ground. He has depth on his outcrop without putting a pick into it and a fair idea of what the showing is going to look like if he goes underground on it. As in flat ground, stripping and trenching are the quickest method of proving up a prospect and more so in country of marked relief, as depth on the showing is seen on the surface. There are cases when the overburden is too great to handle and the prospector can work more efficiently underground. An adit or tunnel, when required should be made at a favourable point on the outcrop and the mineral followed, no matter how irregular the workings may be, for if the prospect shapes up workings will in most cases be planned to fit the ground as seen in the light of the preliminary underground work. Underground work is advisable only, as stated above, when cover is heavy, surface outcrops limited, and where the only way to find out the nature of the deposit is to work in it. It is useless to tunnel, as so often is done, far below the outcrop, when the location and nature of the deposit at that level are unknown. Underground work is slow and costly and the time necessary to prove but a small area of ground should be seriously considered, when in the same length of time there are possibilities of making new discoveries and exploring them by surface work elsewhere.

Before starting, and as surface work proceeds, sufficient samples should be taken and assayed to determine the advisability of continuing the work.

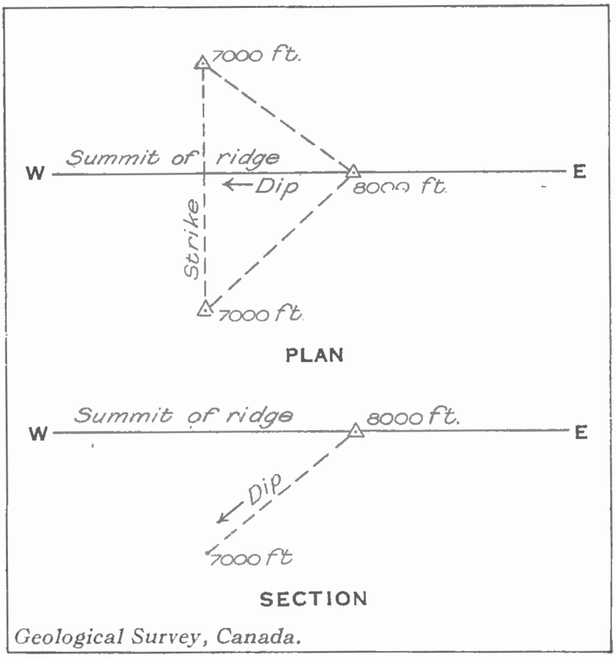


Figure 23.

In the case of free gold ores, panning may replace assaying during preliminary exploration. The results though not as accurate are cheaply and quickly obtained. Sampling should proceed with the surface work. The number and size of samples depend on the uniformity and grade of the ore. Fresh surfaces should always be provided for sampling. If an appreciable tonnage of oxidized material is apparent it should also be sampled. The lower the grade and more uniform the deposit the smaller the sample necessary to give an accurate estimate. Large samples should be taken from spotty, high-grade deposits, as in a spotty gold ore a small sample with visible gold will give a high assay, whereas a sample of similar size taken a few inches away may show no assay value. Therefore, the larger the sample the more closely will the assay represent the actual contents. The following are minimum sample weights for low, medium, and high-grade ores.

	Lbs.
Low-grade uniform ore crushed to 20 mesh	1
Medium-grade uniform ore crushed to 20 mesh	2
High-grade spotty ore crushed to 20 mesh	15

Larger samples are required for coarser material than for fine. These weights will serve as a guide in making channel samples, for the prospector can hardly be expected to cut channels 5 inches wide and 2 inches deep at intervals of 5 to 10 feet, as should be done for a thorough valuation of a property. A wide low-grade uniform showing requires only a narrow and shallow channel. A narrow high-grade and spotty showing requires a much larger channel or a combined sample from several small channels. When the ore is very hard a series of chips can be taken in place of a channel sample. When the deposit is over 4 feet in width samples should be taken from each 4 feet of width, or else taken so as to show rich and lean parts of the deposit. A moil is used in sampling and care must be taken to secure every particle cut. A box, bag, or canvas sheet held close to the moil can be used to collect the sample. The material is next crushed with a mortar and pestle, or broken down with hammer and is then split into two or more parts. This is difficult for the prospector to do accurately, for a small sample can only be split accurately by some such contrivance as a Jones riffle. Conning and quartering is not an accurate method, but is perhaps the only way a sample can be split in most cases in the field. The crushed material is placed on a piece of canvas and the canvas rocked by raising one corner and then another until the material is thoroughly mixed. It is then split into two equal parts and the halves carefully split again. This may be done several times in the case of large samples until the whole is cut down to three or four samples of suitable size. These are then put in sacks and carefully marked. One sample is sent to the assayer and two should be kept by the prospector so that check assays may be made.

With the assay values shown on the map it is possible to estimate the value of the mineral exposed. The following table shows the weights in pounds per cubic foot and the number of cubic feet to the ton for some of the common minerals and rocks.

Table I

—	Wt. lbs. per cu. ft.	Cu. ft. per ton
Arsenopyrite	374	5·3
Cerussite	405	4·9
Chalcopyrite	262	7·6
Galena	455	4·4
Magnetite	312	6·4
Pyrite	318	7·6
Pyrrhotite	287	7·0
Sandstone and rhyolite	150	13·4
Shale, quartz, and schist	162	12·3
Limestone and granite	168	11·9
Andesite and basalt	181	11·1
Diabase and diorite	187	10·6

To estimate the mineral content of a deposit calculate the tonnage to a depth of one foot at surface area and multiply this by a reasonably estimated depth in feet and the product represents the estimated tonnage. As depth is really unknown the result is only an approximation of the value of the deposit.

Example:

A galena vein 300 feet long and averaging 2 feet in width.
Assay returns of 50 per cent lead and 20 ounces silver to the ton.
Value of lead at 0·07 cents is $\frac{50}{100}$ by 2,000 by 0·07 or \$70.
Value of silver at 0·50 cents per ounce is \$10; gross value of ore is \$80 per ton.
Tonnage: Cubic content to depth of one foot is 300 by 2 by 1 or 600 cu. ft.
Galena content estimated at 60 per cent or $\frac{60}{100}$ of 600 cu. ft. = 360 cu. ft.
Galena tonnage is 360 cu. ft. divided by 4·4 cu. ft. (*See* Table I) or 82 tons even numbers.
Gangue content is 40 per cent or $\frac{40}{100}$ of 600 cu. ft. = 240 cu. ft.
Gangue tonnage is 240 cu. ft. divided by 12 cu. ft. or 20 tons.
Gross tonnage is 102 tons.
The smelter will pay about 3½ cents for lead ore when lead sells at 7 cents. Allowing full value for silver the value of the ore is then \$45 a ton.
Value to depth of one foot of surface showing is 102 (tonnage) by \$45 (value per ton) or \$4,590.

The probable depth of the vein cannot be assumed as greater than ⅓ its length, or 100 feet. Should surface values hold, the value to a depth of 100 feet is 4,590 by 100 or \$459,000. Recovery is seldom as high as assay returns and 10 per cent is deducted to cover loss in treatment. The value is now \$459,000 less 10 per cent or \$413,100. Consider the charges against mining and recovery of the minerals.

The vein is but 2 feet wide, therefore, some waste rock must be mined. It will average about 1 foot.

Waste tonnage is 300 by 1 by 1, divided by 12 (*See* Table I), or 25 tons per foot of depth.
Total tonnage mined per foot of depth is 102 + 25 or 127 tons.
At a mining cost of \$4 per ton the cost per foot of depth is 127 by 4 or \$508. To a depth of 100 feet it is \$50,800.
Transportation is paid on 102 tons of ore per foot of depth at \$4 (assumed) per ton. Cost is, therefore, \$408 per foot depth.
Assume an initial outlay on buildings, equipment, and transportation facilities of \$40,000. Interest charges on investment will be neglected. Total cost of recovery is then..........................\$ 50,800
40,800
40.000
\$ 131,600

Deduct from gross estimated value of property and \$281,500 is found to be the net estimated value to a depth of 100 feet, calculated from surface work only. Actual values can only be obtained by extensive underground development. Surface work is sufficient, however, to give the prospector some idea of the value of a property. What can the prospector expect to get for a property as described? Actually there is about \$4,590 worth of ore in sight with possibilities of proving up a quarter million dollar property. To do this will require the outlay of several thousand dollars of capital and investors demand a return proportionate to the risks taken. The prospector has perhaps spent several years of effort and considerable money to discover and prove the prospect. Consider his time and expense to amount to \$20,000 which is half the estimated outlay to develop the property. He is then entitled to a third interest in the property, which on the estimated possible value is $90,000. This he cannot hope to receive until depth and values have been proved. He may, however, bond the property, retaining his interest in it, or, for a percentage interest and the balance in cash as the property is developed, or, for a number of cash payments arranged over the period of development.

Examples

A quartz vein 300 feet long and averaging 2 feet in width
Assay returns of $12 per ton in gold
Tonnage to depth of one foot is 300 by 2 by 1, or 600 cu. ft. divided by 12 cu. ft. (*See* Table I), or 50 tons
Value to depth of one foot is 50 (tons) by $12, or $600
The depth cannot be estimated at over ⅓ the length or 100 feet
The possible value of the ore is then $600 by 100, or $60,000 less 10 per cent, or $59,400

As a vein is only 2 feet wide an average of 1 foot of country rock must be mined. Waste tonnage is, therefore, half the ore tonnage. Total tonnage is then 75 tons per foot depth. To depth of 100 feet is 7,500 tons. Mining cost assumed at $4 per ton is $30,000. The balance of $29,400 from the possible value of the ore to 100 feet in depth must cover initial outlay, treatment, payment for property, and interest on investment. Apparently it is almost impossible, and the prospect of little or no value on the surface exposures. A widening of the vein or increase in values, to offset the cost of mining waste rock, would change the aspect of the property. If the vein is exposed on a hillside where depth as well as length can be seen, the chances of improvement underground are small. If the exposure is in a flat country there are chances that it may improve and it is worth investigating. Underground development is the only means of proving the property and it is too slow and costly work for the prospector. Diamond drilling offers a ready means, but is also too costly to the prospector. Capital will, however, explore such a property in consideration of a substantial interest in it and should it prove up the prospector will have no difficulty in disposing of his interest in the property. The prospector should see that any interest he retains in a property is non-assessable.

The conditions under which a prospective purchaser examines a property in many cases influences his decision. The prospector should try to land him on the property with as little discomfort and fatigue as possible, so that he is fresh and ready for the examination.

TOOLS

Tools required for development vary according to the nature of the country and type of work. The following list covers some of the tools commonly used: prospecting pick, miner's pick, mattock, long and short-handled shovels, sledge hammer, blacksmiths' hammer, claw hammer, single jack hammer, handsaw, crosscut saw, ax, saw and ax files, blacksmith's files, portable forge or bellows, anvil, tongs, hot and cold cutters, drill steel, moils, cleaning spoon, pail, gold pan, light iron rod, earth auger, drive pipe, framing chisel, grindstone, wheelbarrow.

SOURCES OF INFORMATION

The Federal and Provincial Departments of Mines will give to the prospector, upon request, such information as they have at their command. Rock and mineral identifications not requiring chemical analysis are made free of charge. Analysis and assays are charged for at tariffs which can be obtained upon request. In submitting specimens for identification full information as to their occurrence and locality should be supplied and a corresponding amount of information will be given in return.

ADDRESSES

The Bureau of Economic Geology, Ottawa, Canada.
The Director, Mines Branch, Dept. of Mines, Ottawa.
The Provincial Mineralogist, Victoria, B.C.
Scientific and Industrial Research Council of Alberta, Edmonton.
Bureau of Labour and Industries, Regina, Sask.
Commissioner of Mines, Winnipeg, Man.
Ontario Department of Mines, Toronto, Ontario.
Bureau of Mines, Dept. of Colonization, Mines, and Fisheries, Quebec, Que.
Provincial Mineralogist, Department of Lands and Mines, Fredericton, N.B.
Department of Public Works and Mines, Halifax, N.S.

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GEOLOGICAL MAPS AND REPORTS

(C. E. Cairnes)

WHAT CONSTITUTES A GEOLOGICAL MAP

A geological map of any given area shows what different kinds of rocks occur, where they occur, what they are like, and, as well as possible, how they extend underground. The rock formations must be shown on a *base map,* that is, a geographical or topographical map, so that they can be located in relation to lakes, streams, hills, roads, and other features. Since these features and the geological information appear together, the geological formations are as a rule shown in light transparent colours through which the lines of the base map as well as any other geological signs or symbols can be seen. Black and white patterns of dots, dashes, crosses, or other figures may be used in the place of colours to give the geological information. Such patterns are used instead of colours for the reason that a map employing them can be printed in much less time and at much less cost than a coloured map. Geological maps employing colours are in general easier to read than those in which black and white patterns only are used, and in the latter case the person using the map may find it advantageous to colour over the patterns with crayons or other suitable material using, of course, corresponding colours on legend and cross-sections.

As a great deal of information is gathered for a geological map which has to be condensed by using such colours, patterns, and symbols, a *legend* is always supplied to explain their special significance. The legend printed with each map furnishes a key without which the map itself is unintelligible. It explains what colour or pattern is used to represent each rock formation and also what the character of each formation is. The formations are arranged in order of age and their relative sequence is given in terms of eras and periods of geological time. The legend also explains the different line patterns or other symbols on the map, such as those used for geological boundaries, faults, veins, dip and strike symbols, glacial striæ, and physical and cultural features.

A *scale* is printed on each map to give an exact idea of the size of the area covered. A scale of 1 inch to 4 miles, for example, means that 1 inch on the map represents 4 miles or $4 \times 5{,}280 \times 12 = 253{,}440$ inches on the ground. Another way of expressing the scale of 1 inch to 4 miles would be by the representative fraction or natural ratio $\frac{1}{253440}$, which means that any distance on the map represents 253,440 times that distance on the ground. Commonly bar scales are shown on the map and can be used instead of measuring scales or rulers when the latter are not handy.

Most maps are *oriented* with respect to astronomic or "true" north either by an arrow or by lines of latitude and longitude. In either case the "declination" or angle between true and magnetic north will generally be given. A compass needle always points towards magnetic north and the declination will be to the west or east of true north according as to whether the magnetic pole lies to the west or east of true north from the position occupied by the observer. Where, for example, the declination is 20 degrees east and a compass bearing on a certain point reads north 35 degrees east, the true bearing on this point would be north 55 degrees east. If, on the other hand, the declination were 20 degrees west, the true bearing on the same point would be north 15 degrees east.

In addition to legend, scale, and orientation, a geological map will show the authority under which the map is issued and the name or names of the person or persons responsible for the topographical and geological work. Reference will also be given to a report, if any, that the map is intended to accompany.

Structural features are indicated on the map by symbols representing dip and strike, faults, structural contours, etc., and by cross-sections. The *attitude* of a formation or of a vein or fault is commonly represented by dip and strike symbols in which the strike or trend is always at right angles to the dip and in which the angle of dip, measured in degrees from the horizontal, is generally given. *Faults* are generally represented by

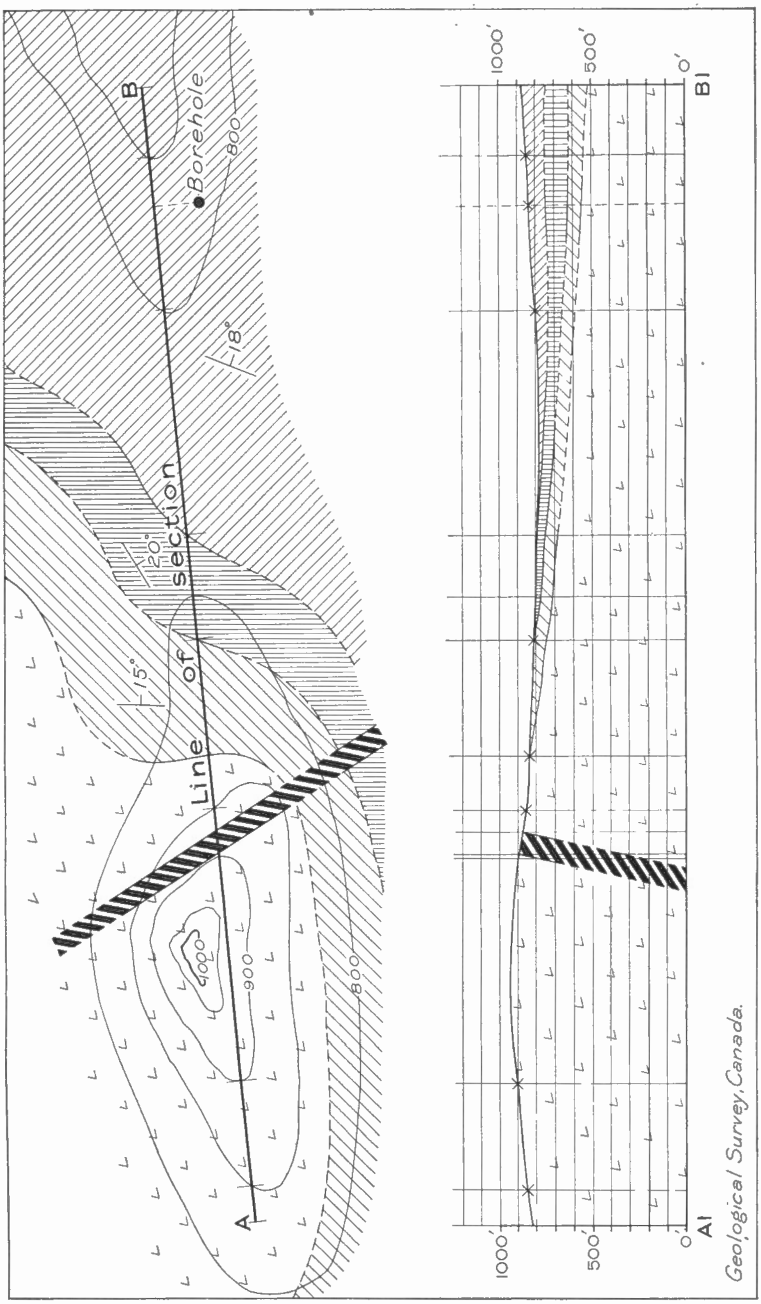
B
Borehole
800
18°
Line of section
20°
15°
1000
900
800
A
1000'
500'
0'
B1
A1
Geological Survey, Canada.

Figure 24.

heavy black lines either drawn in full or broken, depending upon the accuracy with which their position has been located. Only the more important faults can be shown on a map covering any considerable area. One or more *cross-sections,* illustrating the extension of the rock formations beneath the surface, are commonly shown on the margins of a geological map. The information is depicted against planes cutting vertically across portions of the area mapped, the positions of the planes along which the sections are taken being indicated by lines drawn on the map. In the following sketch a cross-section has been made along the line AB. The dip of the formations below the surface has been obtained from attitudes taken on outcrops and from the record of one bore-hole. The accuracy of this cross-section, as of all others, depends in part on the number of observations made at the surface or otherwise obtained from drill holes, mine workings, etc., and upon the regularity of the structure between such points where definite information has been obtained.

The structure of geological formations beneath the surface may be indicated by *structural contours* which take the place of dip and strike symbols. Such structure contour maps are made, as a rule, only where the sources of information, as obtained from observation of outcrops, drill and mine records, etc., are especially abundant and reliable. In every case, however, such structural interpretations must be regarded merely as diagrammatic inferences based as closely as possible on such scattered facts as can be assembled. These structural contours are essentially analogous to topographic contours in that they depict the configuration of a surface by lines of equal elevation generally referred to mean sea-level as the datum plane. Whereas, however, the surface, in the case of topographic maps, is the exposed land surface, in a structure contour map it is a bed or horizon that is easily recognized and widely extended in the area under consideration. This bed furnishes the *key horizon* to which the structure of the overlying and underlying beds is referred. The elevation of this key horizon is obtained at as many points as possible, either from outcrops or drill records, etc., and these elevations are plotted on the map and connected up by lines a contour interval apart, each line joining points of equal elevation. In this way the contour map of this key horizon is made. In the compilation of data for these maps more than one key horizon may be used where the thickness of rocks separating them from each other has been closely determined. This method is, of course, subject to additional errors arising from possible variations in thickness of the intervening strata. Structure contour maps are particularly valuable in oil geology where interest is not only centred on a particular horizon or horizons which have produced oil or gas, and where, consequently, it is desirable to know their position below the surface, but where it is also important to determine the character of particular structures such as anticlines, domes, etc., which are favourable for the accumulation of these mineral products. The Geological Survey has published maps of this character covering certain oil and gas fields of southern Ontario and Alberta.

RELATION OF MAPS TO REPORTS

Geological maps commonly accompany reports. In such cases map and report should be studied together to obtain a clearer knowledge of the different formations and their economic possibilities, and also to learn the author's reservations which cannot be expressed within the limited scope of a map. The reader may, for example, discover that a certain formation which, as shown on the map, is apparently barren of mineral deposits, is not for that reason to be ignored as the report may state that in adjoining areas this formation contains some highly productive deposits. Or, vice versa, he may learn that although a formation may include abundant mineral wealth within a certain area, this condition is of purely local significance and may not obtain elsewhere. Again the map may not be on a scale large enough to show the location of mining properties or mineral veins and deposits. The report will enable the reader to become more familiar with the different geological formations, their origin, composition, and structure, and learn which, in the writer's opinion, are most favourable to ore occurrences. He may, in this way, discover, for example, that whereas the mineral deposits of the area favour a certain formation or series of formations it does not follow that the entire area so occupied is of equal prospective value, but that important mineralization occurs only within a comparatively narrow zone adjacent to a contact with another formation. Or he may learn that even within this zone the mineral deposits are mostly restricted to beds or intrusions of a certain composition, and that he need only explore this contact zone where such rocks have been traced into it. Where the positions of such favourable horizons have been mapped the operations of the prospector should be confined to certain localities, but where the character of the map does not permit of their representation it may be that only through consulting the report will he be guided as to what conditions to look for and might otherwise waste much valuable time in an exploration of unprofitable country.

FACTORS INVOLVING ACCURACY OR DETAIL SHOWN BY MAPS AND REPORTS

The accuracy or amount of detail shown by geological maps varies in relation to a number of important factors essentially analogous to those involved in any other representation of the surface features of the earth. It is based on the number of fixed points between which the features to be mapped are sketched in. In exactly the same way that the course of a stream, the shoreline of a lake, or the slope or contour of a hill is sketched in between known points, so the course of a geological boundary is interpolated between stations whose positions have been determined. The value of the completed map, either topographic or geologic, will, therefore, depend in part upon the number of fixed points that the conditions of each particular survey have provided and in part upon the skill with which the intervening sketches or interpolations have been made.

In the matter of reports as well as maps, authors, who for many years have been contributing information of acknowledged worth, will receive greater attention than their less heralded brethren. The conclusions of those, too, who for some time have been engaged in a particular field or who have specialized on certain problems peculiar to that field will be accorded a greater weight than those emanating from a less authoritative source.

Aside, however, from the personal factor the information conveyed by such maps is very largely dependent upon such important considerations as the time spent, the physical characteristics of the country investigated, and the scale upon which the maps are published. Other factors being at all equal, the time spent in a certain area should bear direct relation to the information obtained on the character, relations, economic possibilities, and boundaries of the component formations. A mountainous district or one otherwise difficult of access or hard to traverse, may be expected to require more time to explore than another more conveniently situated or easier to examine. In another respect, too, the accuracy with which the geology of an area can be mapped may depend very largely on the extent to which bedrock can be seen. A heavily drift covered area which affords only few rock exposures, cannot be mapped as accurately as one of equal complexity in which outcrops are abundant. In this connexion it might be pointed out that Geological Survey maps employ different devices for representing drift and rock exposures. The drift may be shown by a black stipple (a pattern consisting of dots) beneath which the character of the bedrock is indicated by the colours assigned to the various formations only so far as the extent of these formations beneath the drift seems reasonably certain. Such a method is commonly employed in mapping areas of the Canadian Shield. Or, in areas such as those situated in the Great Plains, where the bedrock is represented by only occasional outcrops these may be marked on the map by crosses or some other symbol and the whole area left uncoloured as being mostly obscured by drift. Again, and particularly in the Cordilleran region, it has been common practice to map as drift only those heavy deposits that occupy the more prominent valley bottoms where it is often difficult or impossible to venture an opinion as to the character of the underlying bedrock. In such maps these drift deposits are usually given a distinctive colour after the fashion of any other geological formation. Elsewhere in these areas the superficial deposits are not regarded as sufficiently thick to seriously interfere with prospecting, and except in rare instances their presence is not even indicated by stippling. Exposures may, however, be abundant and yet the geological relations so intricate as to more than offset the disadvantages of a heavily drift-covered area which is underlain by geological structures so simple as to be readily interpreted from comparatively few outcrops. A few rock exposures in the Great Plains of Canada, for example, afford more complete information than a great many outcrops in an area of equal size in the Cordilleran region to the west.

Finally, the scale of the map bears an important relation both to the character of the field work and the nature of the information which the map proposes to express. Or, viewed in another light, the scale of a map for a given area determines the amount of information that can be shown on it. Where the geology is relatively simple a small scale map may express all the necessary information as well as a map on a much larger scale. But where detail is essential this can be shown to better advantage on a large scale map, and any attempt to reduce this scale will of necessity result in

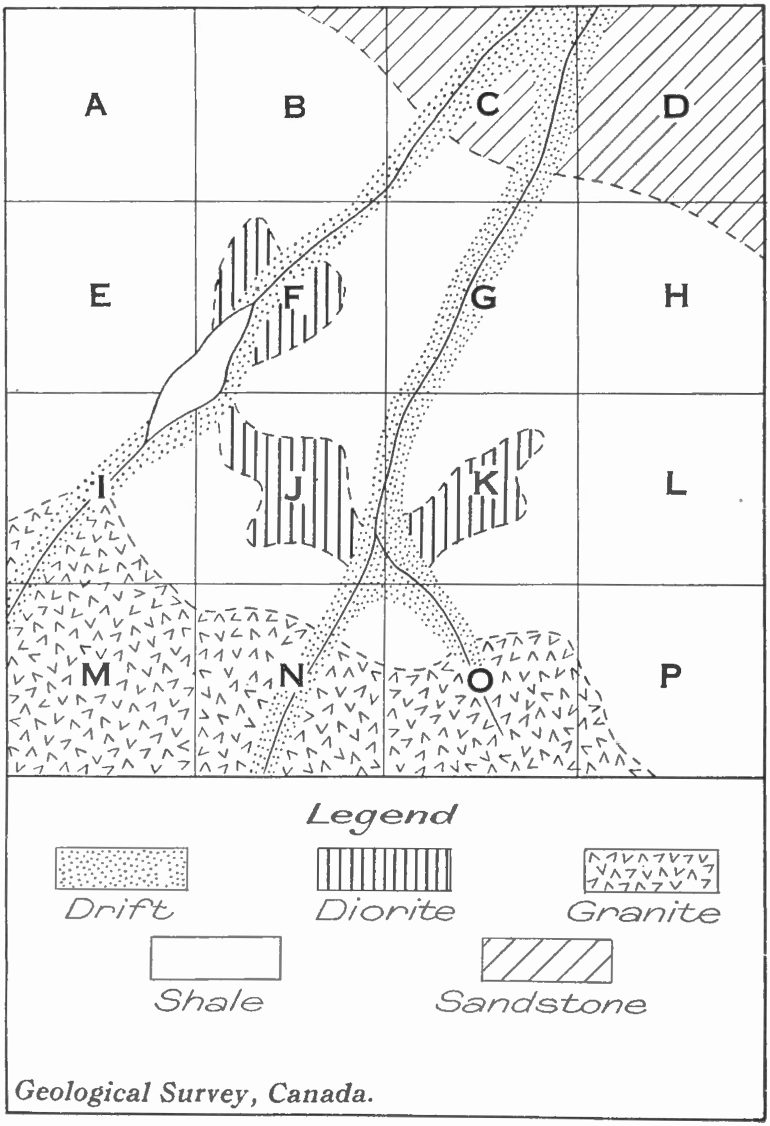
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Legend
Drift
Diorite
Granite
Shale
Sandstone
Geological Survey, Canada.

Figure 25.

the omission of more or less of this detail, and, as a consequence, of the information afforded thereby. Where it is advisable to explore a large tract of country in a limited time only the broader geological relations can be studied, and in consequence only such relations can be shown on a map of the area. Such a map may be referred to as an exploratory or reconnaissance map and cannot be expected to furnish detailed information on portions of the area that happen to be of special interest to certain people or may subsequently prove of great importance. Only on larger scale maps of these portions can such complete information be given. A large part of southwestern British Columbia was, for example, covered years ago by a series of reconnaissance maps on a scale of 8 miles to the inch. These maps, the work of Dr. G. M. Dawson, give a general idea of the geology of the areas traversed and cover many thousands of square miles each. Since that time many smaller areas covering only a few hundred square miles at most have been selected from this part of the province for special study and as a consequence the maps covering these smaller areas are published on a much larger scale in order to convey the additional information that the more detailed study provided. A rather extreme case of detail is illustrated by the map of Hedley area, B.C., which covers only 16 square miles and is published on a scale of 1,000 feet to the inch. Still larger scale maps are often necessary in attempting to portray the geological structures about a particular mining property where the greatest detail is often necessary. Such maps are commonly published on a scale of only a few feet to the inch.

Very often the character of a geological map or report is dependent upon the consideration of a special problem, in the interests of which all other matters are subservient. It may be, for example, that a map is concerned only with a certain formation which has been found to carry coal seams and that in comparison with this formation all others in the vicinity are regarded as equally unimportant. As a consequence this map may illustrate only the extent and character of this coal-bearing formation and cannot be considered as an accurate geological representation of the area as a whole.

It is necessary, therefore, that the limitations of a map be understood, so that apparent inaccuracies may not destroy the confidence of those using the map. Rarely will the rocks of an area of any size be everywhere exposed to view or the exposures themselves be all examined. Generally a very considerable proportion of the area is covered with drift, grown over by forests, hidden by lakes, swamps, and streams, or even, in very limited areas, obscured by buildings, mine dumps, etc. Consequently, no matter how carefully an area may be explored it is only at those points where rocks have been examined that precise information is obtained. Figure 25 gives a rather exaggerated idea of what might be overlooked in an area that had been systematically traversed.

In this sketch the entire belt between the sandstone and the granite might be mapped in as shale, for none of the traverses across the belt has shown outcrops of the comparatively large body of diorite lying within its boundaries. If, however, any one of sections F, J, or K, should subsequently be selected for more detailed study the presence of this diorite would then be revealed and its discovery would not necessarily bring discredit on the original map or the work of the first investigator.

USE OF GEOLOGICAL MAPS AND REPORTS

If geological maps are to be of practical use to the prospector he must be able to employ them in the field. He should be able to locate himself with reference to the topographic features. Very often he can do this by inspection. Stream junctions, peculiar-shaped meanders, islands, high cliffs, buildings, bridges, or any other features shown on the map and easily recognized in the field may afford this information. Failing this assistance, however, the prospector must resort to other means. In mountainous areas or regions of considerable relief the base maps commonly show contour lines. These represent the imaginary intersections of horizontal planes with the surface of the country at regular intervals above an assumed datum or zero plane which is commonly mean sea-level. The contour interval, or distance between contours, will vary with different maps, depending in part on the relief of the area in question and in part on the scale on which it is mapped. A large scale detailed map depicting the surface features about a particular mining property may, for example, show contour lines for each 10 feet of increase in elevation, whereas in areas mapped on small scales and covering many hundreds and possibly thousands of square miles the contour interval may be 500 feet or more. A study of a contoured map will serve to give the prospector a very good idea of the surface configuration of the country he is about to explore and in his exploration will afford much assistance in locating himself. Very frequently and particularly where his view is unhampered by timber, fog, or smoke, he may be able to determine his position with considerable accuracy by inspection alone by observing his position in relation to nearby peaks, knolls, prominent cliffs, valley intersections, buildings, mine workings, etc. Failing this visual assistance, however, or wishing more precise or confirmatory information he may use an aneroid barometer to determine his elevation and employ some form of compass to obtain directions on recognizable topographic or cultural features recorded on his map. When, however, no contour lines are shown, the prospector may be able to fix his position with relation to drainage or cultural features shown on the map either by inspection or by actual measurements and bearings to or from such recognizable features. The latter operations are seldom necessary, but can be employed to advantage when, for example, it is desired to locate a mineral discovery accurately on a map.

In searching for or following any particular contact the prospector should remember, first, that this contact is not everywhere exposed, and, second, that except at certain fixed points where it has been precisely located its position on the map will be more or less accurate depending upon its regularity and the distance between the fixed points. The prospector may, therefore, either pass over this contact without seeing it or may find it at a somewhat different position from that shown on the map. Very often a map indicates the accuracy with which a geological contact has been located by means of different line patterns, whose significance is explained in the legend. Commonly, for example, where the contact is exposed and, therefore, closely located on the map, its position will be marked by a full line. Where this position is known within comparatively narrow limits it may be indicated by a series of dashes. Where, finally, the course of this contact is only assumed this condition may be represented by a line of dots.

The prospector on receipt of a geological map or report examines it in the hope of securing information that will direct him to such section or sections where there is the most likelihood of discovering mineral wealth. He may already be aware that deposits of an encouraging character have been found in a certain formation or along the contact of two formations and he is anxious to learn the extent of this formation in the area or the course of the particular contact in question so that he may thereby limit his field of investigations. In the event, however, that the area is entirely unknown to him, the report accompanying the map will tell him how to get there, what mineral deposits have been discovered, in what formation and under what conditions they occur, and, probably also, what the possibilities of the area are. Should he then be sufficiently interested to visit the area the map will guide him to those parts of the area he wishes to explore.

The interest that a geological map or report holds for a prospector varies in relation to a number of considerations based on personal circumstances and the object of his proposed investigations. He may not be able to afford the expense of a visit to the area in question or it may be so remote as to afford him little chance of immediate profit from the development of its mineral deposits. Rather extreme illustrations may be afforded in the discovery on the one hand of a coal seam and on the other of a gold placer deposit. The coal seam may be unusually large and of excellent quality, but the cost of haulage may easily be so great as to afford no profit to the operator. In the case of the placer gold, however, the prospector may carry out on his back in a single trip sufficient to yield him a good return. Geological maps, too, will limit the areas of investigation. The prospector will realize that it is useless to prospect for lode deposits in sections shown to be covered with drift. Nor would he look for coal seams in a body of granite or other intrusive rocks, and in his search for metallic minerals he will be more likely to explore the contacts of such intrusive rocks with older formations than confine his efforts to the more central and, usually, more barren portions of these granitic masses. Some types of ore deposits are commonly associated with certain kinds of rock, as, for example, nickel ores with norite or gabbro, platinum and asbestos with ultrabasic intrusive rocks, and tin with granite. Geological maps will indicate where such rocks occur and the report, if any, which the map illustrates, will guide the prospector in his search for such minerals. The report will in this way facilitate examination of an area; will lead the prospector to a better appreciation of the nature of its mineral deposits; and will enable him in consequence to recognize the possibilities of his discovery from the character of the outcrop and arrive, thereby, at the most efficient plan for its development.

An illustration of the successful use of a geological map in the search for ore deposits is furnished at Sudbury, Ontario, the centre of the most important nickel mines in the world. The nickel-copper ores are associated with an intrusive, basin-shaped sheet which has been referred to as the "nickel eruptive." This sheet is 36 miles long, 17 miles broad, and has an average thickness of $1\frac{1}{4}$ miles. It varies in composition from top to bottom, its lower and more basic portions having the composition of hypersthene gabbro or "norite." Coleman[1] found that the ore-bodies are located along or close to the lower margin of the sheet, and this rule has closely guided the search for them. An extraordinary example of the usefulness

[1] Coleman, A. P.: "The Nickel Industry: with Special Reference to the Sudbury Region, Ontario"; Ont. Dept. of Mines, No. 170.

of this rule was given in 1916 when the E. J. Longyear Company of Minneapolis prospected by drilling a section of the outer edge of the nickel eruptive in Falconbridge and Garson townships where the rock is covered by as much as 130 feet of gravel and sand. The first three drill-holes located the contact and further drilling along it revealed nearly 2,000,000 tons of ore. Few maps are so serviceable in this respect as the Sudbury map; nevertheless, almost all maps serve the same purpose to a varying degree.

HOW AND WHERE TO APPLY FOR GEOLOGICAL MAPS AND REPORTS

In applying for information on any particular region or area it is generally advisable to state the use for which this information is intended and to leave to the discretion of the authority to whom the application is made the selection of such maps and reports as may bear most directly on the particular problem in mind. Where the applicant specifies a particular map or report without further comment he allows no such opportunity for selection and may thereby forfeit the chance of securing other maps and reports, of whose existence he is unaware, which might afford him greater assistance than those he has applied for.

The Geological Survey, Canada, a branch of the Federal Department of Mines with head offices at Ottawa, is an important source of information on all matters relating to the geology and ore deposits of Canada. A branch office of the Geological Survey is also maintained at Vancouver, B.C., for the special convenience of those located in the west, and concerned particularly with the mineral wealth of that province. The Mines Branch of the Department of Mines, Ottawa, constitutes another valuable source of reference on matters relating more particularly to the occurrence, treatment, marketing facilities, and uses of different minerals and mineral substances.

Aside from the Federal Department of Mines there are several provincial departments and organizations in Canada which publish information relating to their mineral resources. Among the more important of these may be mentioned: Department of Mines, Halifax, N.S.; Department of Lands and Mines, Fredericton, N.B.; Bureau of Mines, Quebec, Que.; Ontario Department of Mines, Toronto, Ont.; Mines Branch, Edmonton, Alberta, and Scientific and Research Council, Edmonton, Alberta; Industrial Development Board of Manitoba, Winnipeg, Man.; Minister of Labour and Industries, Regina, Sask.; and Minister of Mines, Victoria, B.C.

MINING LAWS

(W. Malcolm)

There is no uniform mining law for the Dominion of Canada. This statement cannot be made too emphatic. The mining laws and regulations for the provinces of Manitoba, Saskatchewan, Alberta, Yukon, and the Northwest Territories, and to a certain extent those relating to the Railway Belt in British Columbia and the Peace River Block, are administered by the Dominion Government, and the mining laws for the other provinces are administered by the Provincial Governments. Prospectors, therefore, should not ask for the Dominion Mining Laws, and no comprehensive digest of the various mining laws should be trusted to contain all that a prospector needs to know. He should know where he intends prospecting and familiarize himself with the mining laws that apply to that particular province. If his field of operations lies near another province, it might be advisable to familiarize himself also with the laws of that province. The report of a mineral discovery may lead him into new fields and these may lie beyond the boundaries of the province in which he is working.

Application for copies of the mining laws should be made as follows:

(1) Yukon and Northwest Territories: Deputy Minister, Department of the Interior, Ottawa.

(2) Alberta: Chief Inspector of Mines, Mines Branch, Edmonton, Alta.

(3) Manitoba: Director, Mines Branch, Department of Mines and Natural Resources, Winnipeg, Man.

(4) Saskatchewan: Deputy Minister, Department of Railways, Labour, and Industries, Regina, Sask.

(5) British Columbia: King's Printer, Victoria, B.C.

(6) Ontario: The Deputy Minister, Department of Mines, Toronto, Ontario.

(7) Quebec: The Director, Bureau of Mines, Quebec, Que.

(8) New Brunswick: The Deputy Minister, Department of Lands and Mines, Fredericton, N.B.

(9) Nova Scotia: The Deputy Minister, Department of Public Works and Mines, Halifax, N.S.

No attempt will be made here to give a synopsis of the laws, but suggestions will be made as to matters with which the prospector may find it advisable to be familiar. Among the more important things that he should know are:

(1) The advisability of having agreements with principals and partners in writing. This may prevent dissatisfaction and law suits if a valuable discovery is made.

(2) What lands may be entered upon for the purpose of prospecting. Mineral rights on public lands are vested in the Crown; mineral rights on lands that have passed under private control may remain under Government control or may have passed in whole or in part under the control of those who have acquired the surface rights; rights may be granted to prospect areas of limited extent; the interests of the holder of surface rights

are safeguarded; special regulations may apply to forest reserves, national parks, Indian lands, or lands held under timber licence.

(3) Whether it is necessary to procure, on the payment of a fee, a certificate or licence to prospect, and where such may be obtained.

(4) Limitation as to age or nationality.

(5) The number of claims that may be staked on the one licence; the number of claims that the prospector may stake by proxy for other licence holders.

(6) The size and shape of the claim (*a*) in surveyed territory, (*b*) in unsurveyed territory. It may vary with the province and with the kind of mineral discovered.

(7) The method of marking the claim so that it may be recognized on the ground. It may be necessary to place a post on the mineral discovery and place posts bearing certain information at each corner of the claim.

(8) How and where to record a claim; the period that may elapse between the time of staking and the time of recording; the penalty for staking and not recording.

(9) How to relinquish a claim.

(10) Conditions under which a prospector may continue to hold a claim. The regulations may be such as to require that a certain amount of work be performed annually, or a rental may be demanded.

(11) The rights to the use of timber or waterpower on the claim.

(12) Any special privileges, such as free assays or free claims when discoveries are made in localities where mineral deposits were not previously known to exist.

(13) Regulations governing the transportation, storage, and use of explosives.

(14) When in doubt consult the department administering the mining laws or the local mining recorder.

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