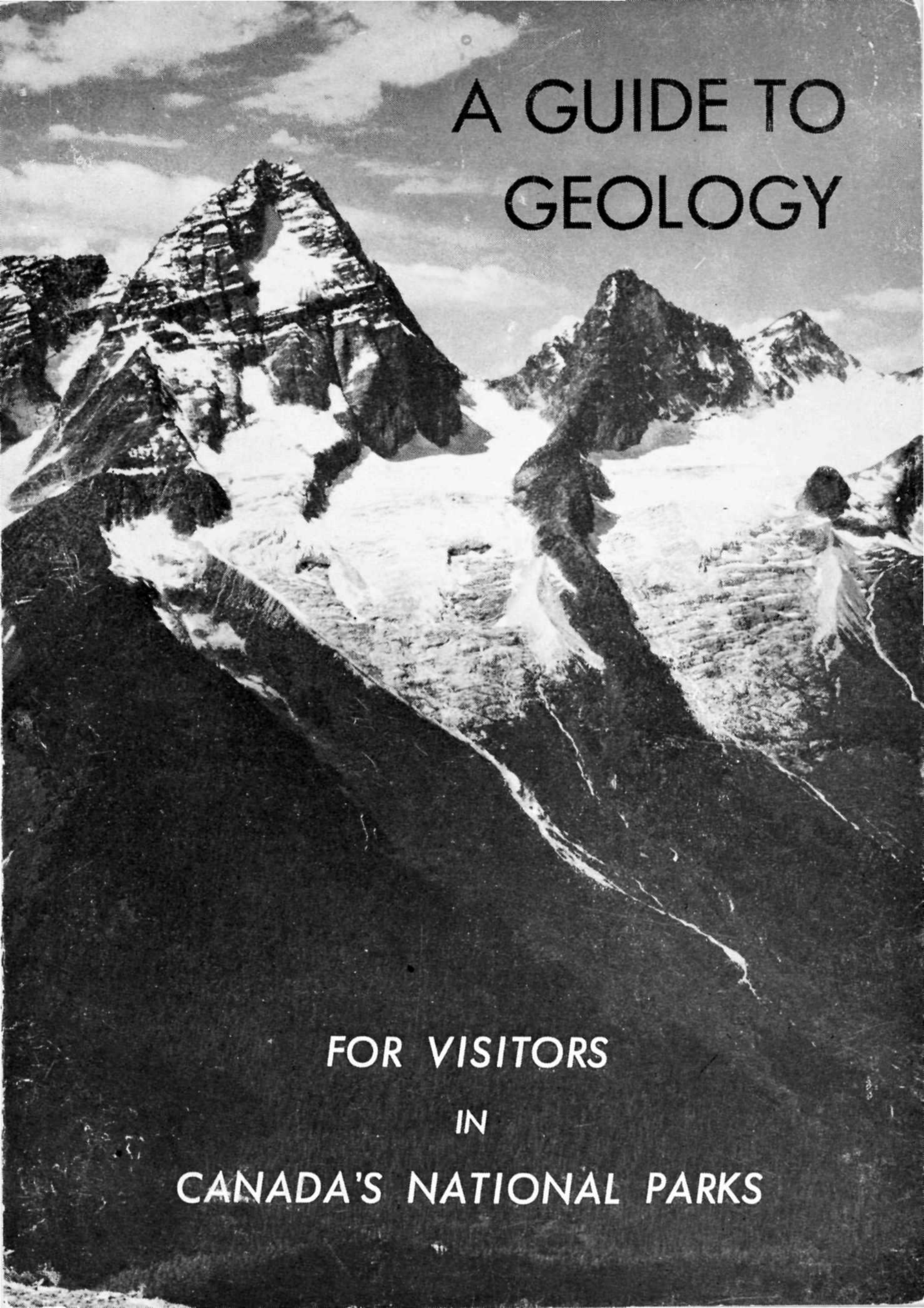

A GUIDE TO GEOLOGY

FOR VISITORS IN CANADA'S NATIONAL PARKS

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for

Visitors in Canada's National Parks

67310-3—1½

FRONT COVER

The rocky spire of Mount Sir Donald, flanked by Uto Peak to the right, dominates the view westward in Glacier National Park.

ACKNOWLEDGEMENTS

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A GUIDE TO GEOLOGY

for Visitors in Canada's National Parks

By

DAVID M. BAIRD, Ph.D., F.R.S.C.

NATIONAL PARKS BRANCH

DEPARTMENT OF NORTHERN AFFAIRS AND NATIONAL RESOURCES

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FOREWORD

The purpose of this book is to assist visitors in Canada's National Parks to get greater enjoyment from their experiences in these sanctuaries of nature. An understanding of the earth's crust and the geological processes that create majestic mountains, deep valleys, vast prairies and mighty rivers, increases the appreciation of these great forces of nature.

It has been prepared by a scientist in terms that the average person can understand and is designed to be carried in the parks for convenient reference. Pictures from the chain of eighteen national parks across the country clearly identify many geological processes.

The author, David M. Baird, Ph.D., F.R.S.C., is Chairman of the Department of Geology at the University of Ottawa. In 1958, for the CBC University of the Air, he delivered a series of radio talks on geology which created wide public interest and which were published in book form. He is the author of numerous publications concerning the geology of Newfoundland, gypsum in Canada and other topics.

The cooperation of the Geological Survey of Canada, Department of Mines and Technical Surveys, is gratefully acknowledged.

It is intended that this Guide will provide basic information on geology which will be useful for the interpretation of other more specific publications on the geological features of individual national parks.

J. R. B. COLEMAN, *Director*
National Parks Branch.

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for Visitors to Canada's National Parks

INTRODUCTION

Scenery

The scenery of Canada means different things to different people. To the fisherman on its coast it is the short stretch of shoreline where he sails frequently near his home harbour. To the tourist who visits the western mountains it is rocky peaks soaring above great valleys, clear, fast streams, and campsites set in groves of well-tended trees. To the railroader it is what he sees from the train in his section, perhaps flat prairies, deep-cut gorges filled with tumbling water, shorelines of lakes or the sea. To the city dweller in Halifax or Vancouver it is the local parks, what he sees on his week-end drives or the lake country where he spends his holidays. To the men who cut pulp and lumber in Quebec or in British Columbia it is woods and hills and rivers. They think of deep snow in winter, flies in summer, the smell of fresh cut spruce and fir, beautiful autumn colours on the hillsides.

But no matter where they are or what they do, the people who pause to look around them are looking at scenery which owes most of its peculiarities to the rocks which underlie it and the particular tools which nature has used to sculpture the land.

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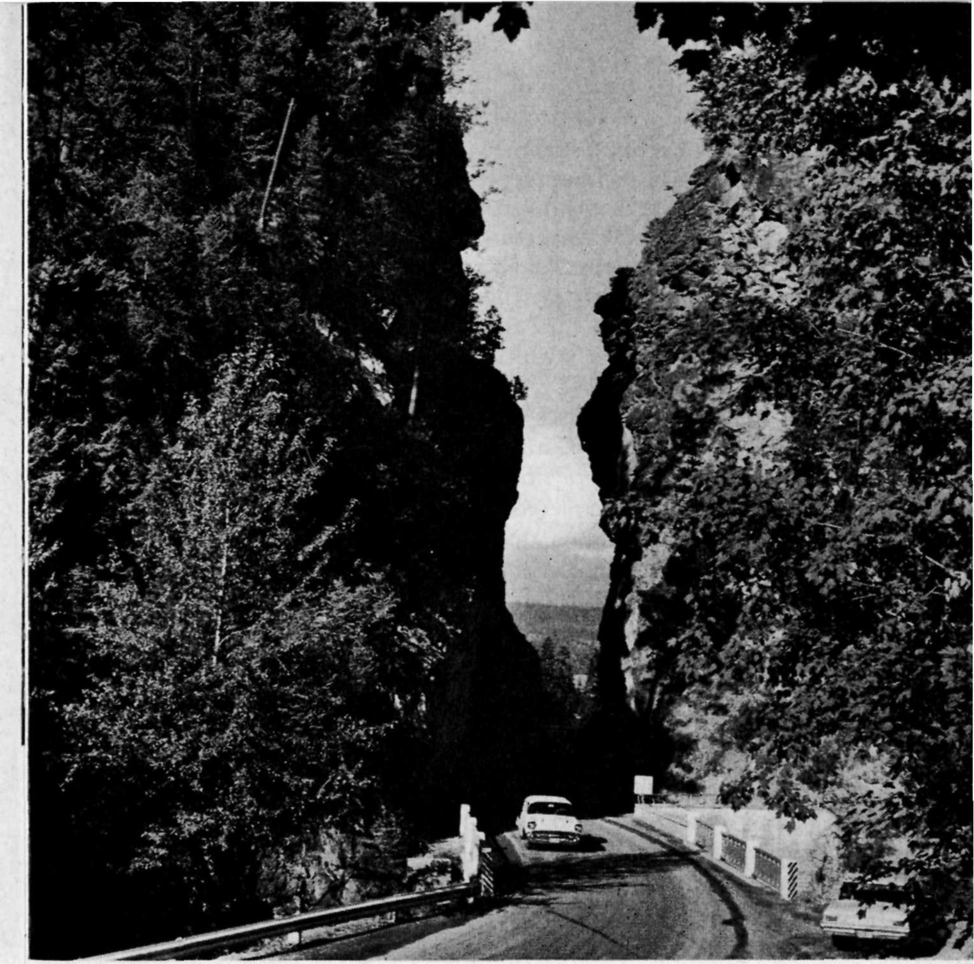
Scenery Related to Rocks

In some regions the scenery is the direct result of the kinds of rocks which underlie the country and their condition. Miles and miles of flat prairies are underlain by flat-lying, soft rocks. Then as we approach the western mountains we note that the hills seem to be made of rocks which stand on edge. In some other areas masses of hard rock stand out as hills and the softer rocks around them underlie flat country. Thus near Montreal, and on the St. Lawrence plain to the southward, hills like Mount Royal, Mount Johnson and Mount St. Hilaire rise abruptly from flat land. Sometimes, along coastlines, hard resistant rock masses form points of land and the softer rocks are worn away from the sides to form coves. Even the colours of soils and what they are made of is dependent on the rocks underneath, so that even the kind of vegetation is ultimately the result of the kind of rocks. To understand scenery we must understand rocks.

Scenery is Everywhere Changing

Everyone has seen muddy water flowing along ditches or in streams. Mud, sand grains, pebbles and boulders are common in brooks and rivers, and all seem to be moving downstream with the current. In a year even the smallest stream carries many tons of materials down to the sea or to the lake where it empties. If we think of this process going on for thousands or millions of years we begin to realize that streams must carry enormous amounts of rock waste to the oceans. Thus valleys are being cut wider and deeper by the streams which are in them.

Along seacoasts, the scenery is changing slowly as the waves wear away the land and currents carry debris from the cliffs out into deeper water. In high mountains, glaciers grind slowly over the land, tearing and plucking at the rocky walls which contain them. In deserts, the wind stirs up sand and dust and



Sinclair Creek and its ancestors, meltwaters from glaciers once occupying its valley, have slowly cut their way downward through the limestones in the southeast corner of Kootenay National Park to form Sinclair Canyon. From the roadway, built partly over the brook, the plunging waters can be seen still actively abrading and dissolving the limestone.

blows it away to dump it somewhere else. Everywhere scenery is changing, perhaps imperceptibly in a man's lifetime but in a thousand years, or a hundred thousand years, or a million years the changes we see going on around us so slowly can account for all the scenery we know. So you see that an understanding of the scenery of the world we live in requires an understanding of rocks and an understanding of the processes by which the rocks are sculptured.

Other Reasons for Knowing about Rocks

Thousands of years of human history have unfolded since rocks and minerals were first put to use by man. From the time that someone discovered that certain kinds of stones made better tools and weapons than bits of bone or wood to this day we have gradually become more and more dependent on rocks and minerals. Without them our whole material world would be different. We could build no tall buildings without steel, cement and stone. Without metals our food supply would suddenly drop off for we would have to use hand methods without machinery. Artists would have neither brushes nor pigments, our writers neither paper nor pens.

Thus to maintain our civilization we must know about rocks and minerals.

Further, to know something of the history of the earth we must examine with understanding the rocks in which the only record of that history is preserved. To know something of the interior of the earth we must examine rocks. The origins of life on earth are not recorded directly for us, but, from remains of living things preserved in rocks, we get a glimpse into many stages of the development of living things since the beginning.

Before we turn to rocks and minerals and then to scenery and its origin, let us look briefly into what the earth sciences are and how earth scientists go about their investigations.

Geology and Geologists

The study of scenery, rocks and minerals, and the structure of the earth is geology. It is really a whole group of sciences which embraces a very wide variety of fields of learning and inquiry, and, like any of the major fields of learning and inquiry, it overlaps on others. The earth's magnetism is a concern of the geologist, and of the physicist, and of a group of men who now specialize in the in-between field of geophysics. The chemistry of rocks and what constituents are to be found in them is the concern of the geologist and also the chemist. In recent years we have heard more and more of geochemistry, the area of knowledge straddling the two. Mineralogists are geologists who make a special study of how minerals, the naturally occurring chemical compounds, are put together. Their field overlaps on physics and chemistry, for both of these are concerned with the constitution of matter in all its forms.

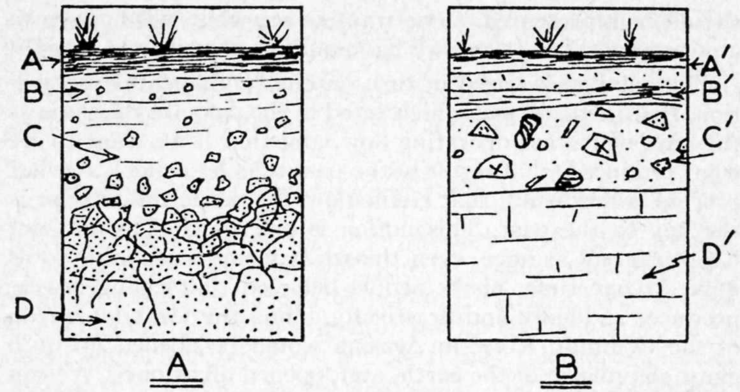
The palaeontologist specializes in the knowledge of fossils, or the remnants of ancient living things in the rocks. He can hardly be a good palaeontologist, however, without a wide knowledge of present day living things or biology. The economic geologist is the man who specializes in the finding and development of bodies of minerals in the earth from which can be extracted something useful to mankind, like copper, iron or limestone. He must know a good deal about the minerals he is looking for, their geological occurrence and something of engineering and economics. Most geologists must know something of scenic processes and how the surface of the land is changing. This area of geology overlaps on geography, for the geographer must know something of these, too, in order to appreciate how man can influence and be influenced by his environment.

Petrology is the study of the natural history of rocks of all kinds and stratigraphy is the study of layered or sedimentary rocks. Both these subjects of study overlap on other subjects. It is interesting to note that nowadays all these subdivisions require specialists who spend their whole professional lives investigating their own fields and applying their knowledge to the better being of mankind.

How do Geologists Work?

Now how do these various people in the geological world go about gathering and systematizing knowledge of the earth? The answer is just as varied as the kinds of geological investigation. But throughout all the kinds of investigation runs what might be termed the scientific method. We hear a great deal about this and it always seems to sound as though it were some very mysterious process entirely divorced from ordinary thinking. And yet, all that scientific method really is, is a kind of systematic investigation, something that can be applied to any question. It consists, first, in the collection of evidence or data. This may come from experience, or observation. When what information is available is all collected, it is reviewed and some preliminary conclusions called hypotheses are drawn up. Some thought is now given to the hypotheses in turn, along the lines that if that is true then we should find certain other things to be true. The next step is to test the various hypotheses to find out which one best fits the observed facts and also those ideas which have been deduced. People in many branches of learning are able to use laboratory experiments to test the various hypotheses or preliminary conclusions that the first collection of evidence has led them to. The last step in the scientific method is to decide which of the hypotheses best fit the facts and to draw conclusions.

Geological processes are so slow-moving that an enormous amount of time would be needed for experimental reproduction of some of the processes at work. Others affect very large things like mountains or ocean basins which we cannot bring



Roadcuts and steep river banks often show cross-sections from the soil down to the bedrock below. In non-glaciated regions (A) *thick soils, A, grade downward through subsoils, B, and mixtures of soils and partly decayed rock, C, to the solid rock, D. The boulders above the solid rock are all derived from the bedrock below.*

In glaciated regions (B) *like most of Canada, fresh, solid rock, D', may appear at the surface, or it may be covered with a thin soil, A', a few feet of bedded sands and gravels, B', and glacial till which is a mixture of boulders of many kinds and finer materials, C'. Boulders in this region may be quite different from the bedrock below for they may have been transported many miles by moving ice.*

into a laboratory. Many different scientific methods can be employed, of course, and in geology one of the common ones is to use sequence arrangements to see how processes operate through long periods of time. For example, when we wish to study what happens in the erosion of river bends we obviously cannot stay around for a million years to see, so a different method has to be found. If we have a hundred river bends to look at, and if they are in different stages of development, it makes sense to think that if we arrange them all in a series with the most eroded one at one end and the least eroded at the other, then all stages in the development of river bends should be represented. If we want to see what will happen to any one river bend then we have only to consult our series.

This method is based in turn on one fundamental supposition, that the processes which acted in the past are the same as the ones which are operating now, and that if we want to see what produced what result in the past then let us look at what process is producing that result now. In short, the present is the key to the past. This notion is one which man did not happen on all at once, even though it seems reasonable to us now. At one time, many people believed that changes were produced suddenly and drastically. Thus the Grand Canyon of the Colorado River in Arizona would be opened up by a giant convulsion of the earth, and, opened all at once. We can see now, however, that there is no need to call on great catastrophes to explain large things. We can observe the muddy Colorado River carrying off millions of tons of rock waste every year and we know that the gradual wearing away of the land by the river, even as now, if extended for a long enough period of time, would be quite sufficient for the cutting of this enormous canyon. The same applies to the canyon of the Fraser River in British Columbia and the gorge below Niagara Falls.

Thus it appears that geologists are pretty much as you might expect in their gathering and systematizing of information and knowledge about the earth, except that they have no recourse to the experimental method of proof or disproof of some of their theories and hypotheses, and that, as a result, they use other methods. One further note—because of the nature of the subject and the unavailability of direct evidence, the geological sciences must have a great deal of speculation in certain fields. No one has been able to watch mountains rise 30,000 feet into the air or minute crystals of carbon form into diamonds deep in the interior of the earth. For some, this makes for discouragement but, for others, the keen scent of

mystery puzzles them enough to take up the challenge and try to see what happened, and why, from indirect evidence.

Now, let us turn to rocks and minerals and see how they originate and what makes so many different kinds of them.

ROCKS AND THE ORIGIN OF THE EARTH

No matter where we travel on the face of the land we will see rocks. Solid rock ramparts form our seacoasts for hundreds of miles. Over a vast area of northern Canada rocky ledges and hills alternate with gravel or sand-filled valleys. Even in places where soils cover the surface it only takes a few feet of digging to get down to the solid rock. The soils themselves are often full of boulders and pieces of rock which have come from solid ledges nearby. To see why this is, it is necessary that we review a little of the history of the earth from its earliest beginnings.

It seems that a little more than five billion years ago the earth was a blob of hot gases, which was part of a series of such masses in space. As heat was gradually lost the gases condensed to liquid and the heavier parts of the liquid settled towards the centre of the mass. Still further cooling of the earth's mass led to solidification of the outer part to form a solid crust. Finally the outside part of the earth cooled enough for rain to condense from the atmosphere and fall on the newly formed surface. Soon rivers began to form and the great ocean basins to fill with water. From that time to this the face of the land has been undergoing slow but constant changes.

Earth's Interior

We can walk over and examine the outside of the earth to see what it is like but our knowledge of the interior is not so easily acquired. From the highest mountain to the greatest depth of the sea is only about 14 miles. This not much of a scratch on the ball of the earth which is some 8,000 miles in diameter. The deepest mines are only about two miles deep and drills have penetrated only about four miles below the surface. Erosion has stripped off the outer cover in some parts of the world so that we can see rocks which at one time were perhaps as much as ten miles below the surface. All of this means that our knowledge of the interior of the earth has to come by indirect means.

Most of the information so far obtained comes from earthquake waves which penetrate right through the fabric of the earth. From a study of these and how they are affected at different depths we have come to know that the earth is made up of a number of concentric shells. A great mass of heavy material some 4,000 miles in diameter forms the central core of the earth. We cannot tell for sure whether this is actually solid or whether it is a liquid which behaves like a solid because it is under such enormous pressure due to the weight of all the outer part of the earth. This innermost core is covered by another shell of an intermediate type of rock material some 1,800 miles thick. The outermost shell or crust of the earth is about 25 miles thick, and seems to consist of two types of rock material, the one lighter by weight and lighter by colour than the other. The continents seem to be made up largely of the lighter material with a layer of the darker and heavier underneath. The great ocean basins on the other hand seem to have little or none of the lighter rock material on their floors.

Now, we have seen something of the rocky framework of the earth, and how at first the surface of the earth was made of nothing but rocks which had crystallized from the molten mass from which the earth began. We have seen, too, how erosion of these began with the first rains.

White igneous rock has invaded dark metamorphosed gray gneisses in this roadcut along the Trans-Canada Highway between Glacier and Mount Revelstoke National Parks. In some places the gneisses have been shredded by the invading rock which tends in a general way to follow the well-marked banding in the gneiss.

Igneous Rocks

At many places in the world, volcanoes are spewing out masses of melted or molten rock which spread over the country as lava flows. As they cool they gradually solidify to make solid rock. Rocks which were thus at one time molten are called igneous rocks. People can actually see the molten material cool and solidify in the case of lava flows, but other rocks, which show evidence of having once been molten, have apparently solidified at great depths below the surface of the earth and are only visible to us after long erosion has stripped off the surface rocks and uncovered them. Lava flows are called extrusive igneous rocks because they are squeezed out or extruded onto the surface of the earth where they cool. The other types are called intrusive rocks because they cool and solidify deep below the surface where they cut into or intrude other rocks. Perhaps the biggest differences in appearance between the two types result from the different ways in which they cool.

Extrusive igneous melts cool very quickly when they reach the surface and are exposed to the air and cool surface rocks. As the temperature drops rapidly many crystals are formed but few of them have a chance to grow to any size before the rock has solidified. Thus the average grain size in lava flows is about the same as that of granulated sugar and the rocks are said to be fine grained. Extremely rapid cooling sometimes produces a rock with no crystals at all. It looks like black or dark brown glass and is called obsidian. When some igneous melts, which are charged with gases in solution, come to the surface, the gases bubble out of solution and the rock melt puffs up into a spongy mass. If this should solidify in the puffed up state, a rock froth or pumice is formed. After violent explosions of volcanoes in some parts of the world the surrounding oceans have been found to be covered with floating pieces of pumice formed in this way.

Ordinary lava flows have a wide range of chemical and mineralogical composition because the original melts they come from are of various compositions. Out of a great variety of names we may find it useful to remember rhyolite for light-coloured, pink or red, lava flows and basalt for dark lavas.

Masses of molten material which cool at a depth below the surface of the earth must cool more slowly than those which cool at the surface because of the insulating effect of the rocks

overhead. Slow cooling under undisturbed conditions produces a coarser grain size. Fudge-makers know that slow cooling makes coarse, sugary fudge, whereas faster cooling with constant beating makes far finer grain and smoother texture. When talking of igneous rocks the word "texture" refers to the grain size and arrangement of grains in the rock. Thus intrusive igneous rocks have a coarse grain size or texture when crystals are the size of peas or larger.

Coarse-grained, intrusive rocks sometimes occur in enormous masses. One of these masses forms the entire Coast Range of British Columbia, a belt of mountains more than a thousand miles long and a couple of hundred miles wide. Such enormous masses are usually made of a light pink or grey rock called granite, which is composed of the three minerals, quartz, feldspar and mica. Coarse-grained rocks are sometimes very dark grey or black and are then usually called gabbro. If we were to compare chemical analyses of a granite with a rhyolite or a basalt with a gabbro, we would see that they are really the same compositions in each case, so that the differences between them are only differences in grain size and, thus, differences in their manner of cooling.

A peculiar combination of two histories may result in a combination of characteristics. Some of the most unusual rocks result from masses of molten material which begin to cool slowly at depth with the formation of some large crystals. If, at this stage of partial cooling and solidification, the mixture of some large crystals swimming in a molten mass of melted rock should be caught up and spewed out of a volcano, the remaining molten part may cool very rapidly. Thus is produced a rock which consists of a few large crystals scattered through a fine-grained background. This is called a porphyry and is usually named from the large crystals so that we might have quartz porphyry or feldspar porphyry and so on.

One last note about igneous rocks—when volcanoes erupt violently great clouds of dust or ash, fragments of broken rock and bits of liquid rock, which cool and solidify while in flight through the air, are blown over the country. This debris may collect in a blanket tens of feet thick or be mixed with muds and silts in rivers or the bottom of the sea. Dust and ash from one gigantic eruption in 1883 at Krakatoa, between Sumatra and Java, was blown into the upper reaches of the air where currents sifted it all over the earth causing brilliant sunsets around the world for many years.

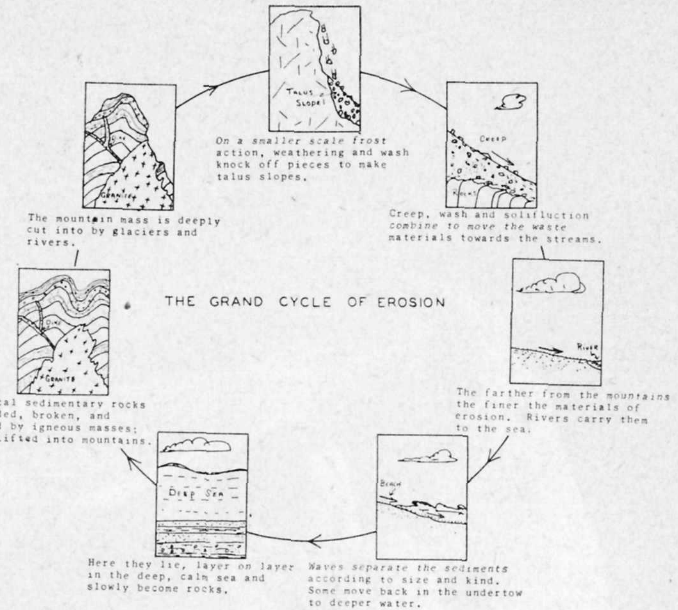
Many of our finest building stones are igneous rocks. Public buildings and commercial establishments often have polished igneous rocks as panels, pillars or facings along the sidewalk or between windows. Some of the best places to study igneous rocks are in cemeteries where polished and rough-hewn slabs are brought from all over the world.

Weathering and Erosion

A nail left on the ground very soon rusts away in the air and rain. A sandstone monument soon becomes weather-beaten and begins to crumble. Buildings built of brick soon lose their newness and have to be repaired. Rocks which are exposed to the weather similarly begin to go to pieces almost immediately. The processes of breakdown and decay of rocks on the surface of the earth are collectively called weathering.

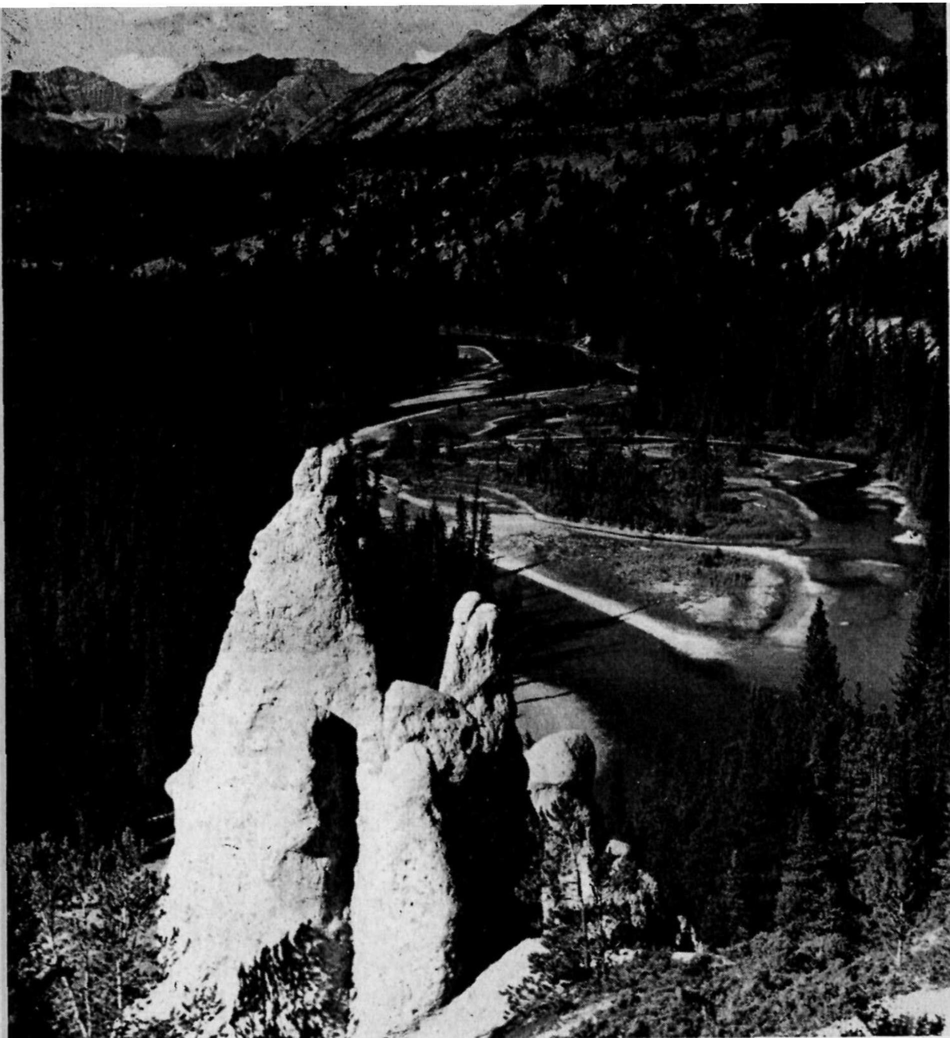
When rain falls on the surface of a rock a little may penetrate into pores and tiny cracks in the rocks. If the water freezes, its expansion may force apart the individual grains in the rock and loosen them. Some minerals which alter chemically on the surface may swell and force apart adjacent mineral grains. Plants force their roots into tiny fractures and split rocks. These processes are called disintegration because the rock goes to pieces by physical breakdown.

Chemical decay of minerals, mentioned above as contributing to the physical breakdown of rocks, is going on all around us. Certain kinds of rock are soluble in rain water and,



THE GRAND CYCLE OF EROSION

as the years pass, the surface of the rock is gradually dissolved away. Water, which passes down cracks and fissures, may dissolve the rock and make the openings larger thus allowing even more water to pass through. Rotting wood and vegetable debris produce complicated chemical compounds which are added to the water and assist in the breakdown of the rocks which it passes through. Oxygen, carbon dioxide and water vapour in the air react with some rocks to produce new mineral substances. These chemical changes in rocks at the surface are together called decomposition. Thus weathering of rocks is the sum total of all processes of physical and chemical changes in rocks at the surface.



Tall remnants left by erosion in loosely consolidated, clayey gravels overlook islands of sand and gravel in the Bow River, Banff National Park. The mountains in the background are slowly wasting away to make these river sediments which are now in transit to the sea.

Erosion on the other hand is the transportation of materials which come from weathering of rocks. Rivers carry muds and silts to the sea. Glaciers push and scrape piles of rock waste down their valleys. Wind carries fine dust and sand from some areas and spreads them over others. Waves along the shoreline cut into cliffs and carry the resulting sands and gravels along the shore or out into deep water. In later chapters we will examine each of these agents of erosion in detail to understand what kind of scenery they produce, but at this point, we wish only to see enough of them to understand that the sedimentary materials which they carry are eventually dumped into the sea, or into lakes or remote corners of the desert. Here they may become solidified into sedimentary rocks.

Sedimentary Rocks

Sedimentary rocks are rocks which at one time were sediments like sands, gravels, muds and silts. The original materials, which came from the physical and chemical breakdown of rocks, were transported by rivers, glaciers, wind, or waves and eventually were deposited in deep, quiet water offshore in the ocean, in river deltas, or in certain parts of deserts. After these sediments were buried by other sediments, sometimes to depths of hundreds or even thousands of feet, they hardened or were cemented together to form solid rocks. It is by these processes that sands have become sandstone, gravels have become conglomerate, and muds have become shale.

In certain, very special parts of the sea, marine muds are made mostly of calcium carbonate which has been precipitated from sea water by organisms or by chemical means. In some places millions of tiny creatures, which have skeletons of calcium carbonate, accumulate on the sea bottom to form very fine-grained muds or oozes. When these deposits of calcium carbonate become solidified they form limestone.

The remains of living things are sometimes entombed in sediments as they accumulate on the bottom of the sea. If the remains, or their imprints, survive the changes which make rocks out of soft muds and sands they may be preserved indefinitely and are called fossils. Here we see imprints of trilobites, creatures which have been entirely extinct for 200 million years, in shales from a famous fossil locality in Yoho National Park. The two large trilobites catch the eye at first but you may see several smaller ones of different species between them and in the upper left corner.

Fossils

As some of these sedimentary materials were accumulating, the remains of living things, plants and animals of the day, were buried in them. As the enclosing sediments gradually turned to solid rocks, the plant and animal remains were preserved. The remains of these ancient creatures in the rocks are called fossils. In some rocks, fossils are so abundant that the main part of the rock is made up of shells and bones. In others no fossils are found at all. This is just what you would expect because some parts of the sea bottom are even now covered with pieces of shells and bones and others are clean sands and muds.

Preservation of ancient living things is sometimes very nearly perfect. Thus in Western Canada we find dinosaurs, that roamed the country which is now Alberta, in such perfect preservation that the contents of their stomachs tell us what they ate for their last meal about 100 million years ago. Fossil trees and leaves tell us accurately of the forests of 250 million years ago in the Cape Breton area in Nova Scotia. In shales and limestones, in Yoho National Park, imprints of animals, which have long been extinct, tell us what lived on the bottom of the sea 480 million years ago when the landscape of North America was very different from that of today.

Almost all fossils are found in sedimentary rocks for this is about the only place where they could be preserved.

Metamorphic Rocks

Almost everyone is familiar with the manufacture of bricks. Wet clay or special muds are pressed into moulds and made into brick shapes. These are then allowed to dry a little and placed in kilns or furnaces where they are heated until they are red hot. When they cool, a strong rock-like material makes up the brick. The same kind of thing sometimes happens in nature, Where lava flows or intrusive igneous masses come

Ancient rocks on Beausoleil Island in Georgian Bay Islands National Park have been profoundly altered by elevated temperature, and enormous pressures to form the metamorphic rocks shown here. The light diagonal streak is a vein of quartz which invaded the older rocks as a fluid mass at very high temperature and then froze.

into contact with muds or shales the latter are baked and altered into entirely new kinds of rocks. New kinds of rocks which result from the alteration or changing of other rocks are called metamorphic rocks.

Now, to change rocks the conditions do not have to be as severe as they are in a brick kiln. Small changes may take place if rocks are heated only a little. If they are subjected to high pressures, such as would happen if a sedimentary rock were to be buried deeply by other sedimentary materials, then certain changes may take place. Thus the sedimentary rock, shale, becomes slate under high pressure and elevated temperature. Limestone becomes marble because of a coarsening of grain under high pressure and temperature. Sandstone may be recrystallized to form quartzite which is a strong rock made of interlocking grains of quartz instead of simply cemented sand grains.

Under extreme conditions the rocks which result from the change of sedimentary or even igneous rocks bear little or no resemblance to the original. New minerals appear by reaction of the old minerals with one another and a new appearance altogether may result from the development of flat mineral grains, or needle-like minerals. In some cases the minerals tend to clump together in bands and new families of rocks, the schists (finely banded) and gneisses (more coarsely banded, say ¼ inch or more thick) appear.

One would expect that metamorphic rocks would be more commonly found in some places than in others. One would expect that new rocks would be formed by heat and the addition of hot gases and liquids where large masses of igneous rocks butt up against other rocks. Great pressures and sometimes heat are generated during the building of mountains so metamorphic rocks would be expected in mountain belts.

Many millions of years ago a mass of limestone boulders became embedded in a matrix of silt on the bottom of the sea. Thin layers of mud and limy mud were laid down on top of this when conditions became more calm and stable. Now we see these ancient sediments as solid rocks. The boulder-filled mass is now conglomerate and the mud and limy mud have become shale and impure limestone. Note how very even the bedding or layering is in the upper zone.

MINERALS

Anyone who has looked closely at rocks or sand knows that they are made up of individual grains of different looking materials. These we call minerals and say that rocks are aggregates of grains of different minerals. When we consider carefully what a mineral is we find it necessary to make a fairly accurate definition. First of all, they are naturally

TABLE OF MINERALS

Name	Common Colour	Lustre	Hardness *1	Specific Gravity	Cleavage *2	Where it is commonly found	Special Features
1. Quartz	Colourless or white	Glassy	+ knife	Average	None	Sand grains; sandstone; veins; grains in igneous rocks.	Often occurs in six-sided, pointed crystals. Most common of all sand grains.
2. Feldspar	White, pink or grey	Shiny to dull	+ knife	Average	Good (2)	Major part of igneous rocks; occasional sand grains; in some veins.	Light coloured minerals with shiny faces in igneous rocks are largely feldspars.
3. Biotite (black mica)	Black	Shiny	– fingernail	Average	Excellent (1)	Igneous rocks; veins; flakes in sands and sandstone; schists and gneisses.	Black flakes in sand; tight books of cleavage flakes in other rocks.
4. Muscovite (white mica)	White to transparent	Pearly to shiny	– fingernail	Average	Excellent (1)	As above for biotite.	Often as flakes in sands where they are sometimes golden.
5. Hornblende	Black or dark green	Dull to submetallic	– knife	Average	Fair (2)	Igneous rocks; gneisses and schists; occasional grains in dark sands.	Needles and grains in igneous rocks or fragments in sands.
6. Pyrite	Pale yellow	Metallic	+ knife	Twice the average	None	Almost everywhere, sometimes in perfect cubes.	"Fool's Gold"; unlike real gold because hard, brittle and often in cubes.
7. Calcite	White or light colours	Glassy	+ nail	Average	Good (3)	Limestone; veins, pockets.	White and fairly soft with three cleavages not at right angles.
8. Magnetite	Black	Metallic to submetallic	+ knife	Twice the average	Poor in several directions	Common in sand grains and sandstone; some igneous rocks.	Magnetic so can be picked up with point of magnetized knife blade or magnet.
9. Limonite	Yellow or brown	Dull	—	A little more than average	None	Rusty stain on almost any rock.	Really iron rust and looks like it.
10. Garnet	Red, pink, brown	Glassy	+ knife	A little more than average	None	Common in sand; some igneous and metamorphic rocks.	Pink, glassy grains in sand and metamorphic rocks.
11. Olivine	Olive green	Glassy	+ knife	Average +	None	Grains in sand; certain igneous rocks.	Green, glassy grains in sands or lava flows.
12. Chlorite	Grey to dark green	Shiny to dull	– nail	Average –	Good (1)	Foliated or scaly masses.	Common in schists and as an alteration of dark minerals.

*1 + means harder than; – means softer than; knife is ordinary jackknife blade.
*2 Good (2), means good cleavage in two directions.

occurring substances. This distinguishes them from man-made or synthetic materials. Secondly, they have some sort of definite internal arrangement of the elemental materials of which they are made. Thus coal, water and organic materials are eliminated. Thirdly, they have distinctive chemical and physical properties by means of which they can be recognized.

Very few naturally occurring compounds in nature are without some impurities of foreign matter so that there is usually a narrow range of chemical and physical properties for any one mineral. Sphalerite or zinc sulphide, the mineral from which most commercial zinc is obtained, is nearly colourless or pale honey-yellow when pure. But in nature there is almost always a small quantity of iron with it. The result is that the colour is nearly always brown or even black. It is because of the range in characteristics like this that the definition is elastic.

How Minerals are Recognized

One can see from the definition, which says that minerals have distinctive chemical and physical properties, that one should be able to tell minerals apart on the basis of either chemical or physical tests. Chemical analyses of minerals are usually expensive and take a lot of time. Physical tests, on the other hand, can be made very quickly and easily in most cases. In fact, geologists and mineralogists can usually tell what a mineral is by its general appearance. This is not so unusual when we come to think of it, for we recognize our friends that way and we know which house is our own by its look, its shape, its size, its colour, where it is located and so on. With minerals we use colour, lustre, hardness, cleavage, crystal form and specific gravity. Not all these are familiar so they will be explained briefly one by one.

Colour

Minerals can be almost any colour you can think of. At St. Lawrence, in Newfoundland, where over 100,000 tons of the mineral fluorite (or fluorspar) were mined in 1955, you can see purple, yellow, green, pink and white fluorite. The fluorite has different colours because of tiny amounts of different impurities in it or very small structural differences. This variation in colour is found in lots of minerals. We can say, however, that certain colours are usual for a particular mineral, even though we know that sometimes that mineral might have other colours because of impurities.

Lustre

Lustre is the appearance of the surface of the mineral. Is it sparkly or is it dull? Is it greasy looking or hard and bright looking? Lustre is talked about in no special scientific words but in tems of things everyone knows about. Glassy lustre means that the mineral looks like glass. Pearly lustre means that it has the same sheen that pearls do. Salmon scales, for example, have pearly lustre. Dull lustre or bright lustre is another way of describing it so that you might talk of bright, pearly lustre or dull, greasy lustre. The lustre of diamonds is brilliant.

Hardness

Everyone knows that some things are hard and others are soft. Glass is quite hard but lead is quite soft. The scientific definition of this property of minerals and other substances says that hardness is the resistance to abrasion. This is just a way of saying that hardness is a measure of how difficult it is to scratch. It is very easy to scratch lead with your fingernail. But on glass your fingernail makes no impression at all. However, with a good quality razor blade or a file you can scratch the glass. This means that your fingernail is harder than the lead, the glass is harder than your fingernail, and the file or razor blade is the hardest of the lot.

A long time ago, a man by the name of Mohs picked ten minerals and arranged them so that each one farther along

the row was harder than the one before it. He then said that mineral number one had a hardness of 1, mineral number two had a hardness of 2, and so on up to 10. This has been used ever since and is called Moh's scale. Lead is about 2, the fingernail is about $2\frac{1}{2}$, the glass is about $5\frac{1}{2}$ and the file is about 6 on Moh's scale. Now we can describe the hardness of a mineral by simply giving it a number.

Specific Gravity

Some things are heavier than others. We know that this is so sometimes because they are larger. But some things are heavier than others of the same size. This is what we mean by having a greater specific gravity. A cork float on the top of a net is certainly a lot lighter than a lead weight of the same size on the bottom. To make it easier to talk of this matter of how heavy things are, the scientist has decided that the weight of water makes a good thing to compare with the weight of other materials, and has given it a value of 1.

Now, if we take three portions of material of exactly the same size we can figure out how heavy they are in relation to one another. Suppose we take sand, sawdust, and lead shot. Now, if we measure out cupsful of each and weigh them we find that the sawdust weighs less than the same cupful of water, so it is said to have a specific gravity of less than 1. The sand will weigh about twice what the water weighed so it has a specific gravity of about 2, and the lead shot, correspondingly, will have a specific gravity of about 8, because it weighs eight times as much as the same volume of water.

Most rocks are made up of minerals which are about $2\frac{1}{2}$ times as heavy as the same volume of water so that most rocks have a specific gravity of about $2\frac{1}{2}$. Some of the minerals of such heavy metals as lead, zinc and copper are much heavier than that.

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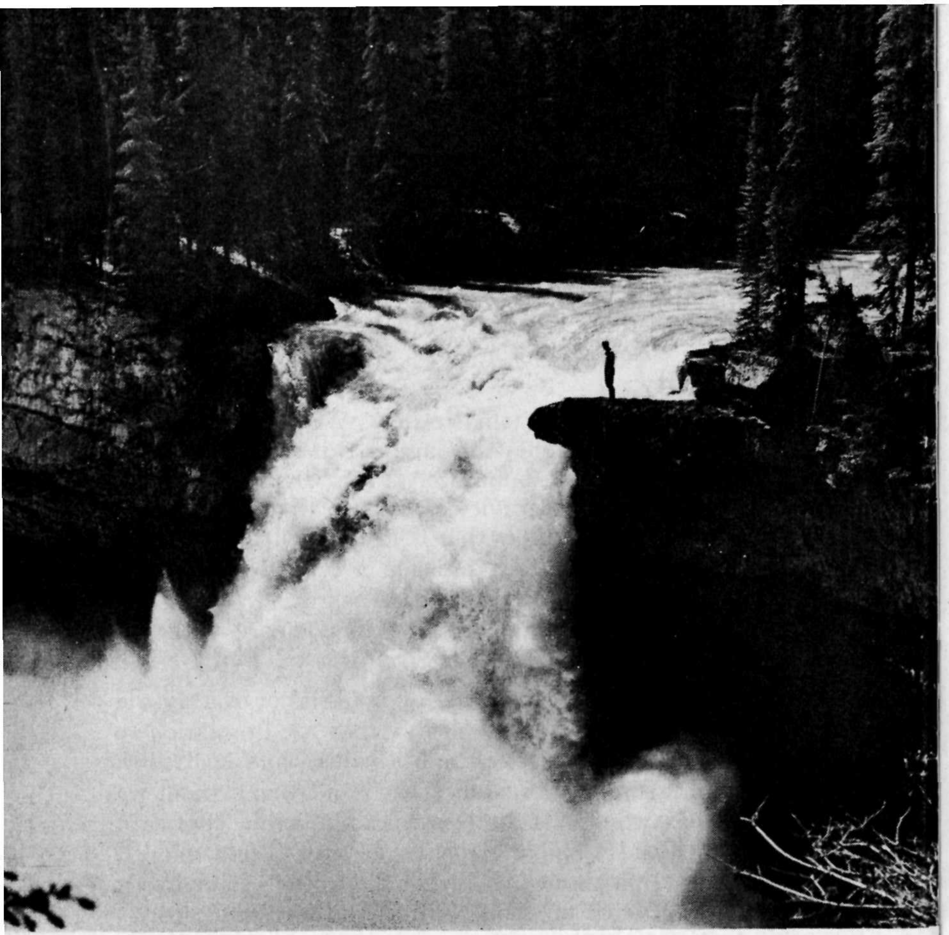

A hard resistant layer of limestone forms the lip of Snake Indian Falls in Jasper National Park. The turbulent waters have cut a considerable canyon below the present location of the falls where undermining of the limestone ledge is constantly going on.

Streak

When we scratch a coloured mineral and churn up a little of its powder we sometimes find that it is a different colour

from the mineral itself. Perhaps you have already noticed that scratches on the rocks, made by a bulldozer blade scraping over them or by the nails in someone's boots, are nearly always white or grey and are, at any rate, much lighter coloured than the rock itself.

Although it is found that minerals are of different colours because of small amounts of impurities in them, like the St. Lawrence fluorite we mentioned before, their streaks or scratches always stay the same. The different colours of fluorite, for example—the red, purple, blue or white—all have the same white streak. Hematite, a common ore of iron, may be red, brown, black or of a shiny metallic colour, but its streak is always dark red. Streak, then, is a useful way of identifying minerals.

What is a Crystal?

Almost everything in nature, aside from living things and their remains, comes in crystals. If you look at the white sugar you use at mealtime you will see that each little grain is a rectangular block of clear material. Look at the salt you sprinkle on your food and the same is true. The salt used for icy streets is the same, except that the crystals are much larger, and you can see clearly the same rectangular blocks of salt, or pieces of rectangular blocks if they have been broken.

Minerals occur in crystals which have a great variety of shapes and sizes. Some minerals occur in nature with neat crystals while others are very rarely found in crystals big enough to see with the naked eye. Some minerals come in rectangular blocks like the salt, but others come in six-sided spikes, with six-sided points on top, and still others in more peculiar shapes. Thus it is that we can recognize certain minerals by looking at their crystal shapes. It has been recognized now that the hundreds of different crystal forms can be referred to only six crystal systems with a great variety of forms in each.

The best crystals are usually found in openings or cracks in rocks into which natural solutions have circulated. In these the crystals have grown out from the walls into open spaces, and were free to develop their own symmetrical forms. In all the natural world there is nothing more spectacularly beautiful than clusters of natural crystals.

Cleavage

If we break a piece of wood it usually breaks in a splintery way. If we smash a piece of glass it breaks into sharp, curved pieces. If we take a piece of coarse salt, however, and break it we will find that it will break into neat little rectangular blocks, very much like the crystal it comes from. A piece of mica, which is a commonly known mineral, can be split again and again along smooth flat surfaces. This odd property of minerals, of breaking along smooth surfaces in certain directions, is called cleavage. It is due to an orderly internal arrangement of the chemical constituents of the mineral. Some minerals have well developed cleavage and others do not. Some minerals have more than one direction of cleavage which meet at different angles from others. Thus it is that we can tell minerals apart by whether or not they have this breaking property and its nature if they do.

Chemical Composition

Chemists and physicists, men who study such things, tell us that all the materials on the earth are made up of only 92 naturally occurring, different substances called elements, and various combinations of these elements. The iron in a piece of pipe or a shovel is one of these elements in almost pure state. When it rusts, all that happens is that the iron combines with oxygen, an element in the air, to form a combination of iron and oxygen, which we know as rust.

Some rare minerals are elements, but most minerals are made of combinations of elements. So we talk of pyrite or

fool's gold as being iron and sulphur in combination, or iron sulphide. The common minerals from which we obtain lead and zinc are lead and zinc sulphides and refineries for these metals are places where the combinations are broken apart and the pure metals extracted.

Some minerals such as those we have already mentioned are very simple combinations of two elements but others are very complicated both in the numbers of different elements in them and in the ways they are combined. A table which lists some of the properties of minerals you might encounter in your ordinary travels is included and also a little key or guide to help in their identification.

To identify minerals which you may find as constituents in rocks, in veins or as grains in sand start with the key, then compare what you have with the properties in the table. It lists only 12 minerals but these are the ones which make up most of the common rocks, fill almost all veins and form nearly all the grains in sands.

What colour is the mineral?

If it is	Try
White or glassy	1, 2, 4, or 7
Green	5, 11, or 12
Pink or red	2 or 10
Black	3, 5, or 8
Grey	2, 4 or 7
Brown or yellow	6, 9 or 10

EROSION AND SCULPTURING OF THE LAND

The actual erosion or carrying away of materials produced by the breakdown of rocks is carried on by many different agencies in nature. Rivers carry vast amounts of sand, mud, and silt to the sea, beginning in the tiniest rivulets, and gaining force as the volume increases. Glaciers carry rock rubble and waste to the sea, or into lower valleys. Wind picks up dust and sand and blows it somewhere else. Water trickling underground dissolves limestone, salt, or gypsum and carries it off towards the rivers of the area. Waves and currents in the sea cut into cliffs and carry off rock waste to dump it along the beaches or into deep water offshore. Landslides and mudflows carry very large amounts of materials quickly in what sometimes are spectacular displays of nature's power. It is the last of these that we will think of in some detail now—that is, those forms of erosion or transportation of materials on the surface of the earth where gravity affects directly large masses of material. By some this is called mass-wasting.

When we look at kinds of mass-wasting we find that they can be divided at once into two principal types—those of rapid movement and those of slow movement. Landslides and rock-falls are obviously accomplished by rapid motion, while those we call creep and some types of mudflows are accomplished by slow, long-continued movement. Let us examine the rapid ones first.

Landslides and Rock-falls

On a quiet evening in a mountain valley it is not at all uncommon to hear an occasional rock-fall from the cliffs. Sometimes these falls are almost continuous, particularly in the spring when thawing loosens rocks and everything is wet and well lubricated. If you stand near the cliffs along the shore of the Bay of Fundy, or in the Arctic islands, or steep places in the mountains, and watch carefully you can see rock fragments

continuously trickling down. Occasionally, after a rain, great masses of rock are let loose and fall downward to a stopping point. The sloping piles of such debris, which lie under the cliffs from which they come, may be called talus or scree. In some places the blocks of material may be as large as a house, in others we find very finely divided particles the size of sand or even dust.

A spectacular fall of rock occurred at Frank, Alberta, in 1903. Here a mass of limestone, in Turtle Mountain above the town, was criss-crossed by joints or small breaks. Softer rocks supporting the mass were apparently gradually giving way, weakening the whole structure. Heavy rains undoubtedly supplied a little extra lubrication along breaks in the limestone. Finally all these led to a tremendous rock-fall, wherein a mass of stone half a mile long and 150 feet thick, fell from the upper part of the mountain, crashed on down the slope, overrode part of the town, and slid up the other side of the valley some 400 feet. Such was the fury of the internal banging about in the mass of rubble that the rock was completely shattered so that the largest fragments remaining were scarcely ten feet in diameter. Man's feeble structures which happened to be in the way of the colossal mass of moving rock were crushed completely with the loss of many lives.

In 1958 a rain-saturated slope near Prince Rupert, British Columbia, suddenly let go, and an enormous slide went down the hillside. Along the banks of certain rivers in the St. Lawrence lowlands great slides of water-soaked clays and sand have taken place, off and on, as long as the area has been settled. One at Nicolet, Quebec, did considerable damage in November, 1955.

In Saint John, New Brunswick, a few years ago a more gentle type of landslide took place. It happened just back of a residential area, quite close to the famous Reversing Falls. Steep banks of glacial debris were weakened by extra heavy rains. A new roadway had just been built across the lower part

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of the slope into the Saint John River, probably cutting off the natural drainage lines under the gravels and clays and, certainly, adding to the load on the slope. When the whole mass had been lubricated with extra water it began to give way. Residents noticed small cracks in the fresh but thin blanket of snow one morning. Within a few hours the back gardens and garages of some of the houses were carried tens of feet straight down an almost vertical wall, as a great mass of material sheared away from the bank. Near the water's edge, below all this, a bulging mass marked the classically-shaped lower end or toe of the landslide. This much slower movement over several days contrasts with the catastrophic swiftness of the Frank and Prince Rupert landslides.

A still slower variety of mass movement of surface materials is found in many parts of the world where large masses of clay and rock become more and more heavily saturated with water until they begin to behave like large, slow-moving rivers. In fact, there is a complete gradation, from the clear waters of northern rivers, through silt-laden streams, through thick muddy streams, to watery muds and eventually to solid-appearing muds and clays with no tendency to flow at all.

To get back to the watery muds on slopes, these begin to flow very slowly downhill, perhaps at the rate of a few inches or even a few feet a year. They are rarely spectacular, as are quick-moving landslides or rock-falls, yet in some places enormous quantities of surface materials are moved from place to place. Once in a while these slow-moving mud and rock streams will suddenly let loose in a great messy gush of mud, clay, rocks, and slurp, in a gigantic sort of way, down and into a valley. In the mountain areas of the National Parks spring thaws and sudden rainstorms occasionally loosen slides onto some of the roadways.

This transfer of large masses of materials sometimes has startling effects on the scenery. Half of a mountain suddenly is no more, while in the valley below a great chaos of broken

rock, fractured forests, and perhaps a dammed-up stream appears suddenly. One large lake in Labrador near the village of Hebron, far north of the timberline, can be seen on aerial photographs to be the result of a landslide-created dam at one end, with the scarred hillside clearly visible. Sometimes rivers are pushed out of their courses by these masses of material shoving out into them from one side.

In 1957, Grand Lake, near Goose airport in Labrador, suddenly turned from its usual blue to muddy brown over 30 miles of its length. The cause was not hard to see from the air, for there on its shore was a giant slide of mud and clay which had exposed a great gash of raw earth and had pushed a large bulge out into the western shore of the lake. In the western Canadian mountains this kind of thing is commonplace, particularly in the banks of large rivers.

Slow Slides and Creep

The really slow mass-motion of surface materials can be called creep. It usually affects only a few feet next to the surface and may be due to a variety of causes. In northern and cold regions the gound may be permanently frozen. In the short summers, however, a few inches or even a few feet at the very surface will thaw. This upper few feet is quite likely to be pretty wet. If it should be on a slope, even though slight, it will probably begin to ease very gently downhill over the solid, frozen mass underneath. Along comes the winter again and things come to a halt as everything is frozen tight. Then in the warmer season, thawing and a gentle downhill motion may once again set in. This variety of movement is given the name solifluction.

In other places creep may be of a different character. Masses of rocks in talus slopes, or even rocks standing by themselves, may gradually creep downhill by an alternation of freezing and thawing of the water between rocks or between boulders

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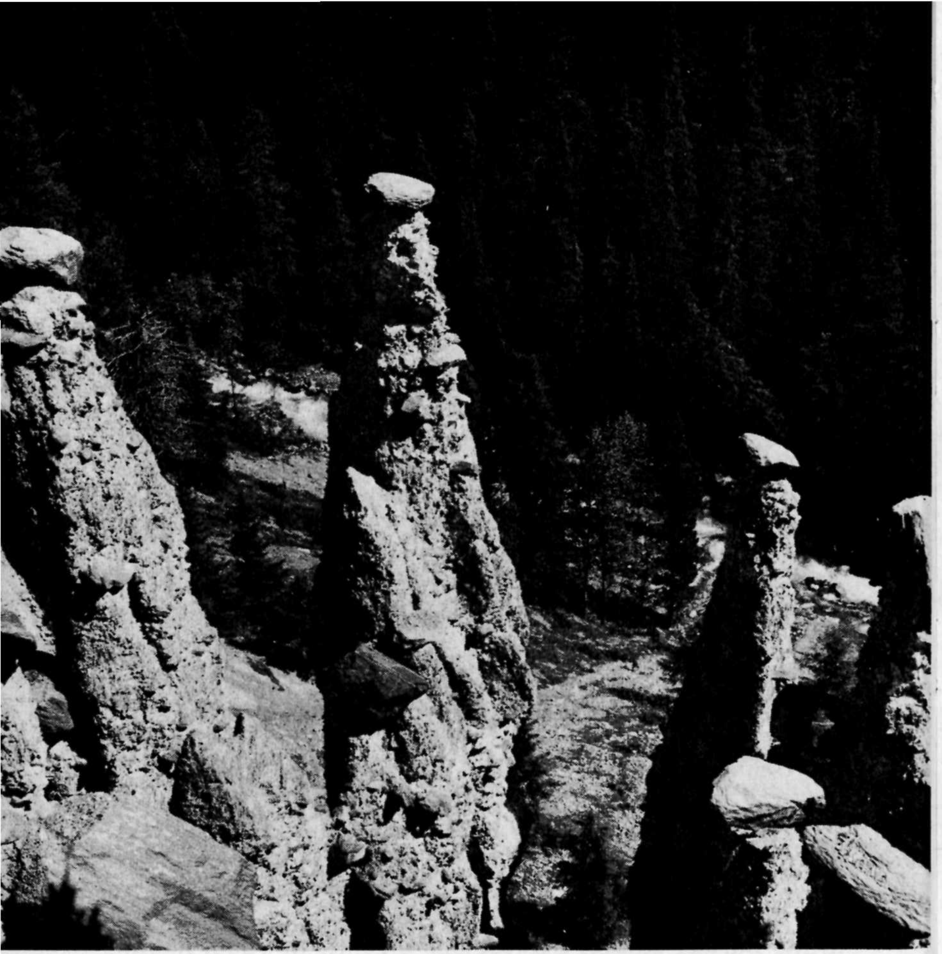


Unusual erosional forms like these "Hoodoos" near Leanchoil, in Yoho National Park, result from the wasting away of loosely consolidated masses of boulder-filled sands and clays. The boulder "caps" protect the underlying material from erosion and as the surroundings gradually wear away they get taller.

and the ground. If a thin film of moisture or water lies between a boulder and a rock surface, freezing will lift the boulder outward from the surface. This is not straight up in the air but outward from the sloping surface. When the ice melts the boulder is let down again—not in the opposite direction, but in a vertically downward direction. This means that every time the boulder is frozen under, it is pushed outward and away from the surface it is lying on, and then, on thawing, is let down again but at a slight distance downhill. Each cycle may move the boulder only a fraction of an inch, but if the cycle of freezing and thawing is repeated thousands of times, the boulder will gradually creep downhill. If all the boulders in a talus slope or a rocky surface are doing the same, the whole surface sheet will be in slow motion. This is, however, only one of the causes of motion. On other slopes we find that a very slow creeping is the same flowage of wet muds that we would call a mudflow if it were moving faster.

Some interesting practical results come from creep. Since it is likely to be faster at the surface than down below, in a given time the surface part will have moved a little farther than the substrate or lower part. A tree which has its roots extending downward through the faster-moving top layers into the slower-moving or stationary substrate will find itself gradually pushed over. Most trees try to straighten up again and this of course results in curved trees. In Newfoundland, Nova Scotia, and some other coastal regions where boat-building demands curved pieces of wood, it is common for men to go out into the woods and carefully pick out the trees with just the right natural curve for the bow, ribs or other parts of the boat. These sometimes come from badly rooted trees in swamps but they also come from bent trees in areas where creep is constantly pushing the trees over. Man-made affairs like telephone poles, fence posts, and foundation piers are sometimes affected in the same way. Engineers are wary indeed of building in areas of creep, but on the other hand are sometimes called in to try to halt creep and stop damage to various structures. Thus we see that gravity directly affects large masses of material and may produce sudden movements like landslides or slow movements like creep. The former leave gaping scars on the steeper parts of the scenery and piles of debris below. The latter sometimes do the same but are more apt to be integrated into the generally changing scenery without obvious discontinuity.

WIND AS AN AGENT OF EROSION

In Canada we cannot say that wind is an important agent of erosion except locally where it might actually be the most important one. We certainly know that it is active when we travel some beaches in windy weather and see wind spraying sand along the ground, or building dunes which inundate and bury the marginal forests. We can see it again in some of the very dry areas of Western Canada in swirling clouds of dust and fine soil. And in any city street we may be reminded of the carrying power of the wind when we find ourselves with a speck in the eye.

If wind is thought of as moving air then its importance in erosion is very great indeed. Without the winds to blow moisture from ocean areas over the continents there would be no rain and snow and so no erosion by rivers and glaciers. Without the winds of the world to blow to and fro and mix cold air and warm air the climates of the world would be far different from those we know now. Climates affect weathering profoundly and largely control erosion. Without the wind, there would be no waves on the face of the sea to cut into the land and erode the cliffs, for most waves are the result of wind moving over the water.

The waves which gnaw away at the shore of Great Britain may be born of the wintry winds far out in the North Atlantic, off Newfoundland and south of Greenland. Surf on the Pacific

Coast of the United States may be offspring of the great air-currents far south of the equator in the distant reaches of the Pacific. Erosion of Australian coasts may be done by rollers from thousands of miles away, generated in the storms of the 'roaring forties' far below the southern continents. These are indirect ways in which wind is an agent of erosion.

When we examine the ways in which wind is directly active in erosion we must recall that all modifiers of scenery have two different aspects—those which tear down something already there, which we can call the destructional effects, and those which build something not there before and which we can call the constructional effects. With wind we can see at once that where sand and dust are picked up by the wind, something must be in the process of being torn down. When the wind subsides the sand and dust it was carrying are deposited. Where this takes place something will be added or constructed. Part of nature's energies are devoted to tearing down and part to the building of something new. What happens at any one place will be the result of the balance between the two.

Where is Wind Active?

Now, you may ask, what would be the conditions under which wind would be an effective agent of erosion? In regions where sufficient rain and snow fall to keep the ground moist, wind is but a minor factor in the erosion of rocks and soils. Water is not a very strong binding material yet it is strong enough to defeat the best efforts of wind, for the air is of very low density. Plants bind soils together with their roots in addition to fending off the wind with their above-ground parts. Plants also serve to hold and maintain moisture in some areas where, without them, there would be times during the year when the soils would dry up and be vulnerable to wind attack. For wind to be effective, there must be some material to be blown about. One would hardly expect the wind to be an active eroding agent in a region where there are no soils or loose materials. Wind will lift loose, dry materials and carry them off somewhere else, so for wind to continue to be effective in a region, one would require that rocks, that will go to pieces to produce more fine-grained materials for the wind, must also be present.

So obvious as to be easy to miss among the requisites for effective wind erosion is wind itself. Strong, prevailing winds would be best. Thus, to find places where wind would be most effective we would look for dry places, with no vegetation, with strong winds, with loose sands and rocks underneath which would give rise to more loose material when the surface bit is gone. One of the places on the earth best fitting all these is the Libyan Desert, and to a lesser degree it is also true of an estimated one-fifth of the land surface of the earth where neither moisture nor vegetation can effectively deter wind erosion. These places are more or less what we can call the desert regions of the world.

There are some other places in which we may find wind effective because of the extra strength of one of the factors we have listed. Along some river banks, for example, large quantities of sand and silt may be left high above spring water-mark to dry out during the summer. Along some lakeshores, and commonly along ocean beaches, great quantities of sand may be pushed up by waves. The sand is so porous that it dries rapidly and thus becomes available to the passing winds. Retreating glaciers leave vast areas of loose debris open to wind erosion as soon as it dries. Parts of southern Canada and the northern United States show evidence of having been in this condition at the end of the great continental ice-age. Occasionally seacoasts are cold and barren of vegetation and yet have sand. Many parts of the Labrador Coast show

strongly the action of wind because of this peculiar combination of circumstances. The tops of mountains are often subjected to very high winds which, combined with the absence of vegetation, result in cleanly scoured rock surfaces.

Deflation and Abrasion

Wind effects are of two kinds. The simple picking up of a grain of sand in a gust of wind and dropping it somewhere else is called deflation. Vast areas in the Libyan Desert and in parts of Mongolia have been deflated to the point of developing considerable relief directly from this activity of the wind. Deflation was very obvious in the thirties for those who lived in the Dust Bowl country of the southwestern United States or the western Canadian prairies. Giant dust clouds darkened the sky and swept across the country. Great areas of topsoil were completely stripped and blown away. The mere presence of these dust clouds proves deflationary powers of the wind, for where they deposit their millions of tons of dust and sand they show conclusively that 'what comes down must go up', if we may be permitted to twist an old one.

The second way that wind is an effective agent of erosion is by abrasion. Lighthouse-keepers of Sable Island off Nova Scotia find the glass in their windows being pitted and frosted. In some of the desert regions, railways find the natural sand-blast cuts into and thins the steel rails and cuts off wooden telegraph poles. Millions of little particles of hard rock or mineral, pounding the surface of the rocks, wear and tear the surface away, and add to the sand in the wind, in the process.

Sand Dunes

When the wind dies out or the land obstructs the motion of the air, deposition of what it is carrying will take place. Sometimes the sands are piled irregularly into drifts, even as snow is. When the drifts get larger they eventually become

Here, at Cavendish Beach in Prince Edward Island National Park, waves have scalloped the edge of the beach into cusps and winds have blown the dry sand above high tide level into hummocky dunes. The reddish sandstones, which supply the sand when they disintegrate, are just visible in the left foreground.

dunes. Occasionally where the wind blows from the same direction over long periods the piles of sand may develop perfect crescentic forms, although in most regions of drifting sands such forms are rare. When wind blows in one direction, sand from the front of the dune may be blown up and over the crest to fall at the back. This removal at the front and addition at the back will mean that the dune will appear to move downwind. Such moving dunes are common in deserts and in any coastal regions.

Migrating sands are often very destructive. In Africa and in central Asia old cities have been overwhelmed in shifting sand. In the southwestern United States, along the shores of some of the Great Lakes, in coastal regions of France, and along the Baltic, creeping dunes have covered roads, forests, and even villages. Sometimes they inundate and cover buildings only to release them again, years later, as the sand mass moves on.

Other Effects

Grains of sand in wind-blown deposits are different from grains of sand developed in other places such as streams and beaches, for the abrasion of particles by other particles leaves their surfaces pitted on a minute scale which makes them look frosted. Rock surfaces in such areas are commonly fluted, pitted, or even faceted. Boulders sometimes have flat faces ground on them by the abrasion of the moving sand and become known as ventifacts. They are characteristic of windy areas and when they are found in regions of heavy vegetation and abundant rainfall they are indicators of formerly drier times.

Dust-size particles of wind-blown material sometimes travel great distances and accumulate in great deposits called loess. Because loess is derived from desert regions where leaching by water is almost non-existent, it usually forms soils of wonderful fertility. Thus it is that the extensive loess deposits of China have been able to support millions of Chinese for many centuries. The Yellow River and the Yellow Sea get their names from the loess suspended in their waters. In Northern Argentina, in New Zealand, along the Rhine and the Mississippi River systems, other deposits of this wind-blown material are to be found.

Volcanic Dust

When volcanoes explode into activity and after that belch large amounts of fine dust into the air, the winds of the earth may carry the dust over the whole world. This settles out gradually as a thin film everywhere and contributes something to all deposits. Since it is in the air everywhere it means that we are breathing it all the time. Theoretically we are taking into our lungs, every time we breathe, a tiny amount of dust from the volcanoes of the world, a tiny amount of dust from each or all of the deserts of the world, and a tiny amount of dust from all the other contributors. People used to look askance when geologists talked of this but the atomic bomb blasts have put into the atmosphere tiny amounts of dust which because of their radioactivity, can be traced. Now when the snow or the rain falls on Vancouver or Winnipeg or Halifax we can show certainly that it contains small fragments of coral atolls in the Pacific Ocean, which were blown to bits by atomic explosions and then wafted over the surface of the earth by winds.

Summary

To summarize, then, we have seen that wind is vital to most processes of erosion because it moves water from the oceans over the land and drops it there to begin rivers and glaciers; that wind generates the eroding waves and currents in the oceans; that it blows dust around the earth so that all of us breathe the Sahara, southern Saskatchewan and the volcanic explosions of past times. We have seen that wind moves great masses of shifting sand and that rocks in dry areas may be polished and abraded by natural sand-blast. In deserts, however, we must note that most of the scenery is the result of erosion by the rare rains that fall, rather than by wind.

UNDERGROUND WATER

Where it Comes From

Have you ever thought of what happens to the rain or snow after it has fallen? Most people know that ditches are

filled and rivers rise higher in their valleys after rains but seldom think directly of the fate of falling rain or melting snow. There are five places it may go. Some of it evaporates, perhaps as it is falling or later when it is on the ground. Engineers who are estimating the power potential from the rainfall of an area allow for evaporation. Some of the water becomes part of the vegetation, either as water or bound up chemically in organic substances. Some of the water becomes permanently taken out of circulation in the hydration of minerals. In most parts of the world a very large portion passes into the runoff—the rivers and streams, and lakes. The fraction we are interested in now has still another fate—it sinks into the ground to become part of the underground water or ground-water system.

Just what proportion of the rainfall of any area becomes ground water depends on several things. The amount of rainfall affects it for in regions of heavy and steady rainfall the ground becomes saturated so that most of what falls goes into the runoff system. The climate of the region will affect evaporation and whether the precipitation of the region is rain or snow and, thus again, how much water goes into the underground system. A variety of characteristics of the ground that the rain or snow falls on will affect underground water supplies too. The steeper the country the quicker will be the runoff. The penetrability of the ground will be important, for a waterproof clay or an impenetrable, dense rock will allow little or no water through. Man's activities affect greatly the underground water system and how much water comes into it. By removal of forests and overcultivation he increases the runoff fraction and decreases the underground water fraction. The situation is reversed where he builds great dams, irrigates his fields, or practises reforestation. Now, what happens to the water that does sink into the ground?

Almost all rocks and the superficial cover of sand, clay, mud and soil have some pore space between the particles which make them. This may vary from close to none at all in some dense igneous rocks to as much as 35 percent in some very porous materials. If the pores connect with one another then water will be able to trickle through them and the rock is said to be permeable. If we go down a deep mine, in a region where there is lots of water in the surface rocks, we will find that as we travel deeper into the mine the amount of water gradually drops off. This is probably because pore spaces cannot stay open because of the great pressures on the rock at depth. So ground water is a feature of the rocks in the region of the surface and down for only a few thousand feet.

Springs and Wells

In any region where the rocks are porous and permeable the water from rain or melting snow moves downward. Eventually it comes to a surface or a zone below which the pores are filled with water. This surface is called the ground water table and a hole or a well drilled below this level will fill with the water from surrounding pores. Most wells near the surface are exactly like this. This explains too why wells drilled or dug will encounter water almost anywhere.

Springs are a little different, but may originate in a variety of ways. If water penetrates downward from the surface and encounters a non-porous or non-permeable layer it may be forced to run along the top of that layer. If the layer comes to the surface of the ground somewhere the water may come gushing out as a spring. Many springs originate in clays and gravels where the gravels are water-bearing and the clays are non-permeable. In other places springs originate in fracture systems in rocks. If breaks or fractures in a rocky hillside receive water from rainfall, the water may flow downward along the cracks and issue where there is a connection to the surface somewhere down the hill.

In some places such waters, which penetrate deep below the surface, come into contact with hot rocks and themselves get heated. When these waters issue from the ground hot springs are the result. You can swim in naturally warmed water with this kind of history at Banff, Jasper, and Kootenay National Parks.

In regions where sedimentary rocks are tilted up on edge unusual underground water conditions prevail and are sometimes very useful to man. Suppose sandstone and shale, the former porous and permeable and the latter impermeable, are interlayered and lie in a basin-shaped structure with upturned edges. The upturned sandstones would receive water which would percolate downward along the beds where it would be held in by the waterproof shales. Water in the centre of the basin would actually be under pressure and, if a hole were to be bored through the waterproof shales which hold it in, the water would push up towards and perhaps beyond the surface. This type of well is the true artesian well and any such water-bearing layer is called an aquifer.

Many parts of the world would be desolate, semi-deserts were it not for supplies of water which man has been able to tap with drilled wells. Very large areas of northern Queensland in Australia are fed by artesian water, as are vast areas in the western part of Canada and the United States, where upturned sandstones gather water in the mountains and conduct it out under the flat plains where it appears in wells.

Caves and Sinks

When water travels through a rock in pores or in fractures it will dissolve anything which is soluble. Limestone or calcium carbonate, gypsum or calcium sulphate, rock salt or sodium chloride are all highly soluble. If the water becomes channeled in cracks or fissures in such rocks it is common for the percolating waters to gradually enlarge the openings. This tends to

Underground water may dissolve large openings in soluble rocks like limestone during its travels. Nakimu Caves in Glacier National Park consist of several thousand feet of underground caves and connecting passageways. Here, at the end of Cave 4, you can see the dimpled solution surfaces on the rock and the layering or stratification which dips down to the right.

increase the amount of water which travels through them. Large openings made this way eventually become caves. In some limestone regions vast caverns with connecting passageways form great mazes underground. This is how the Nakimu Caves in Glacier National Park were formed.

Water which penetrates the rocks above such caverns may pick up material in solution from the rocks it is passing through. When it emerges on the ceiling of an open cavern it may begin to evaporate and deposit some of its dissolved load. When a little lump of this stuff is deposited on the ceiling of the cave, it makes a projection which is a little lower than the surroundings so that the next drop of water will naturally run down on it. In evaporating before it drops to the floor of the cave the water may deposit some more of the lime or whatever it has in solution. Thus, stone "icicles" are built from the roofs of caverns and are called stalactites. The drops of water hitting the floor may build up small masses of stony material there, and these are called stalagmites. They would do this because as they are dropping through the air from ceiling to floor they would be evaporating and would be instantly ready to precipitate on hitting any object. Stalactites and stalagmites are sometimes of great beauty, for small amounts of impurities colour the tall icicles and graceful fluted columns so commonly formed.

When underground water circulation is long continued caves get dissolved out larger and larger. It often happens that large caves near the surface get so large that their roofs collapse and great conical holes filled with rocky rubble are thus formed. In some areas the surface of the ground is pitted with these "sinks" and travel becomes very difficult with closely spaced, steep-walled holes. In gypsum areas the solution is very fast and sinks are filled with twisted and tangled forest undergrowth. In 1959, a farmer and his team of horses were plowing a field in Cape Breton when the ground fell away under them as a hidden gypsum cave suddenly collapsed and a new sink formed. Gypsum areas with sink holes occur at Dingwall, Cheticamp, Pleasant Bay and Ingonish all of which are on the edges of Cape Breton Highlands National Park.

Summary

We have seen, then, that part of the precipitation which falls on the surface of the land evaporates, part becomes immobilized in vegetation and in minerals, part goes into the runoff system, and some of it percolates through pores and openings in the rocks to form an underground water system. We have traced the path of the underground water to find out how springs and wells are formed, how caves and sinks are made and how various conditions affect the distribution of underground water.

RIVERS

Rivers have played an important part in man's history from its very beginnings. His early villages were placed on river banks and he found it most convenient to use them as highways from place to place. He still places his cities on or near rivers and he still uses them extensively as routes of transportation. The history of exploration of most countries begins with stories of penetration of the interior along rivers.

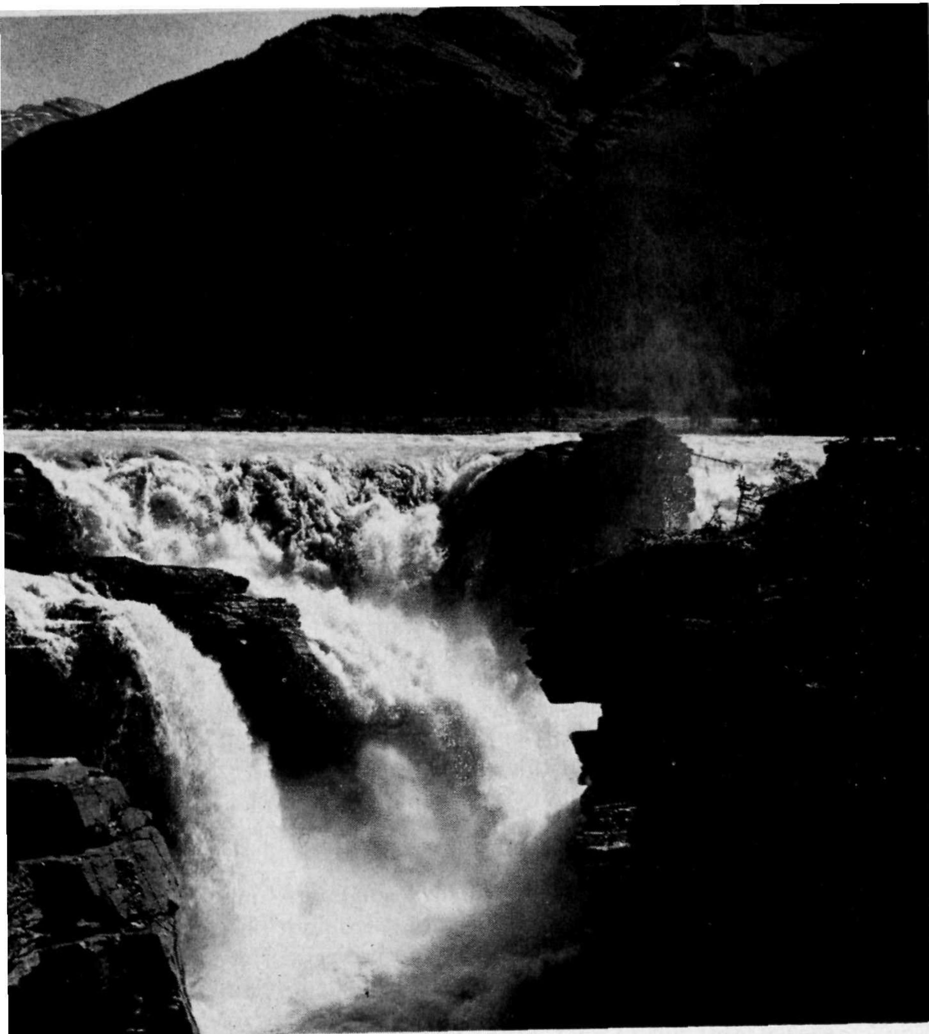
Canadian history is dominated as much as that of any country by its rivers. The great St. Lawrence River system has been a main highway since the earliest quest for a northwest passage to China, and still is today, with the development of the new seaway into the heartland of North America. The names of early heroes come down to us in romantic succession as we think of the rivers of our country—Jacques Cartier in the St. Lawrence; Champlain at the mouths of the St. Croix, the Saint John, and the Annapolis before 1610; La Verendrye

westward from Superior to the Assiniboine and Souris; Henday to the Saskatchewans; Samuel Hearne west and north to the Coppermine; Peter Pond and Alexander Mackenzie northward to the Arctic on the Mackenzie River, and later Mackenzie to the sea on the Peace and its tributaries.

Rivers and Valleys

We have been looking at and using rivers for a very long time. Yet it is only since about the end of the 18th century that we have enquired into their origin and their development. It was about then that people began to realize that river valleys are the result of the slow but steady cutting of the land by the rivers which occupy those valleys. The spread of this understanding started with an obscure book written and published by James Hutton, a scientific pioneer who developed his ideas while walking the shores and moorlands of Scotland. His admirer and friend, John Playfair, rewrote in a more readable form the monumental but dull work that Hutton had left, and published it in 1802. From that time to this we have looked to the processes which are operating now for the explanation of features of the landscape which we see around us. Here is an extract on the subject of rivers from Playfair's exposition of the Huttonian view. While we read it let us listen to the lovely old language which is now so rare in scientific writing.

> "If indeed a river consisted of a single stream, without branches, running in a straight valley, it might be supposed that some great concussion, or some powerful torrent, had opened at once the channel by which its waters are conducted to the ocean; but when the usual form of a river is considered, the trunk divided into many branches which rise a great distance from one another, and these again subdivided into an infinity of smaller ramifications, it becomes strongly impressed upon the mind that all



Mount Kerkeslin looms darkly in the background as the waters plunge wildly over Athabasca Falls into the steep-walled gorge below. Waterfalls like this one in Jasper National Park are typical of either youthful streams or of regions in which the normal drainage has been disrupted by glacial erosion and deposition.

these channels have been cut by the waters themselves; that they have been slowly dug out by the washing and erosion of the land; and that it is by the repeated touches of the same instrument that this curious assemblage of lines has been engraved so deeply on the surface of the globe."

Once this idea became accepted it meant that rivers could be investigated in the sense that they are orderly and that they have a system of development.

Amount of Water in Rivers

We have already seen that the water which falls on the surface of the earth may evaporate, become immobile in plants and minerals, sink into the earth to become part of the underground water system, or form part of the runoff in rivers and lakes. Water destined for the runoff system may fall directly into a river or a lake and begin at one its journey back to the sea, or it may fall on other surfaces and take a short time to get into the flow of things.

Some of the water which sinks underground comes out at the surface again and becomes part of the runoff. In some areas, in fact, it is only this supply of water which keeps rivers and streams going in times of drought. Since the pores and openings in rocks and soils are very small the water moves very slowly through them. This means that rainwater may reach the rivers a long time after it first arrives on the ground. This lag is what evens out the flow of rivers in many areas.

The matter of the volume of water in any one river and its distribution during the year is an important one. In most parts of Canada our rivers fall low during the summer, rise in late summer or autumn rains, slacken off again in winter when the precipitation stays immobilized on the ground as snow and ice, then rise sharply to their seasonal high in a springtime of rapidly melting snow. In our western mountain streams this rhythm may be altered when the snow on lower levels makes for a spring rise and then, all summer long, the snowfields, higher and higher and farther and farther back in the mountains, continue to keep the streams well supplied with water.

Visitors to the mountain parks in Western Canada in summer may note that the early morning sees a low water level in streams and that they will have to wait until past noon for the rise which comes from the increasing melt water from the morning sun. Correspondingly the tapering off of the daily increase may not take place until well after nightfall.

An interesting river in respect to its volume is the Rhine, for it rises in several different kinds of places. One set of headwaters is dominated by glacier meltwaters. These pour forth their maximum in the heat of summer. Another contributor rises in lower mountains which give their snowy melt waters in the spring, and reach a low in summer. Still a third part of its reservoir comes from a warmer lowland area where winters are marked principally by heavy rains, thus adding a load to the Rhine at exactly the minimum season of other parts of the system. The result is that the Rhine, in its lower reaches, is remarkably constant in its volume of water which comes from different places at different times.

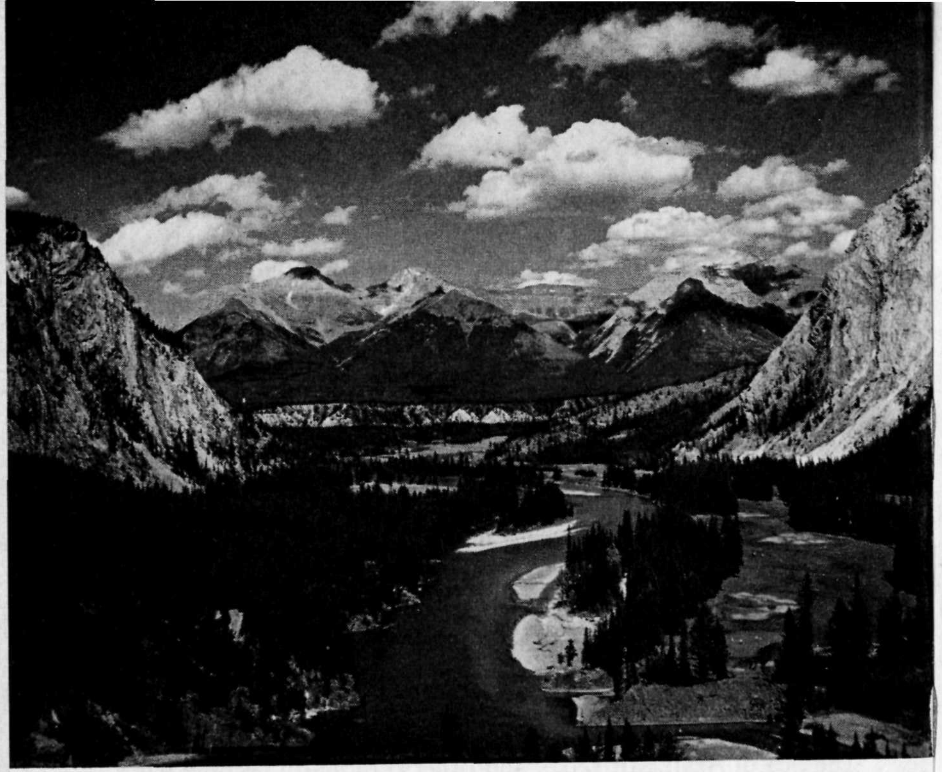
Lakes in the courses of rivers make natural regulators of the flow by absorbing sudden increases in volume of flow and feeding it more slowly and evenly to the lower river again. Thus in almost all Canadian waterways lakes even out the spring freshets or floods. Man has emphasized the role of the lakes in many places by adding dams, with which he can further even out the flow, so that he will have a steady supply for his hydro-electric stations or for his irrigation and other projects. In some places the dams are put up for the specific purpose of preventing sudden runoffs which we call floods.

The Mississippi River is getting gradually more and more under control in this respect as more and more dams hold back the sudden rush of water, particularly in tributary basins. The South Saskatchewan Dam will similarly even out the flow in that great river, as will storage dams on the Columbia.

In some areas of the world the runoff is much affected by evaporation. Evaporation takes place wherever water is exposed to the air. Surfaces of lakes and rivers, and of the sea, are always providing water-vapour to the atmosphere. In basins where evaporation is less than the precipitation some water must run off or sink into the ground, and thus may make rivers. In a few areas, however, the amount of evaporation exceeds the precipitation. Thus some parts of the world are characterized by streams which are temporary because of this. Perhaps rain falling in the mountains starts streams flowing down into dry valleys where eventually evaporation removes all the water. Perhaps a lake is formed in a valley and the water evaporates from the lake surface as fast as the rivers bring it in. Such is the Dead Sea, an inland lake where water from the Jordan River collects and evaporates at about the same rate as it comes in. Lakes like the Dead Sea, the Caspian, the Sea of Aral, Salt Lake, and others gradually become more salty as the rivers keep bringing in small amounts of dissolved materials, which are left behind as the water evaporates. Many lakes in southern Saskatchewan are rich in salts because they have no outlets and evaporation concentrates what is washed into them.

How Rivers Cut and Carry

The salts which are left behind when river water evaporates, deltas where the rivers enter the sea, the cutting into and the falling away of river banks, and muddy waters themselves, all tell us of the cutting and carrying power of rivers. Now let's see how they do it.



This view of the Bow River, looking toward the Fairholme Range, is in Banff National Park. The rocks of the distant mountains seem to be nearly horizontal but these in the foreground seem to be dipping steeply. The river is making islands and gravel bars out of the materials of weathering of the mountains all around. The flat terrace in the middle distance must have been made when erosion was controlled at a higher level than now, for the present river is cutting into it. Where park visitors pass restful days the glaciers once slowly ground their way.

When rain falls on the surface it is usually nearly pure water. If the rock or soil the rain falls on contains anything that is soluble, the pure rain water will dissolve it, and when the water reaches the river the dissolved material will be carried on downstream. River waters all carry some dissolved materials.

When mud is stirred up in the water the fine grains will stay suspended in the water for long periods. Thus rivers carry, by suspension, large quantities of materials to the sea. The third method might be called hydraulic action. By this is meant the push of a moving stream of water, the same thing that makes dirt on the street fly when a hose is turned on it. On the river bottom small grains of sand and pebbles are pushed and rolled along by the force of the water itself. In rivers which flow very fast the hydraulic action is powerful enough to move great boulders as can be seen in many of the mountain streams in Canada's Parks.

These same processes help add to the river's load of material being carried to the sea by wearing into the bank or dissolving soluble materials from it. They are joined, however, by another process called abrasion. As it bumps along the bottom, a large boulder cannot help but loosen and knock off other fragments which then become part of the river's load. Even small sand grains knocking against rocks may grind them down and the ground-up rock then joins the river's load on its way to the sea.

These several processes together contribute the load to the moving water. Whether or not they will be effective and thus whether or not a stream has a large load will depend on a variety of things. The faster a stream flows the greater will be its cutting and carrying power. The more turbulent a stream is, the greater its cutting and carrying power. The bigger the amount of the water in the river, the greater the potential load will be. Differences in shape of the channel will affect it, too. The character of the materials being fed to the river will affect the load as will the kind of rocks the river is flowing over. Thus in regions underlain by sandstone, a sandy load would be expected and in regions of soluble limestones the load would be largely in solution.

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Deltas

Regardless of how and why the load of the river is carried, the place where it empties into the ocean is bound to see it largely precipitated. There the current of the river is stopped so that most particles in suspension or carried by hydraulic action are deposited. There the salts in the sea precipitate most chemically precipitable materials. And, thus, deltas are born.

Deltas may be of almost any size or shape. The Mississippi River delta is estimated to be at least 30,000 feet thick, and two million tons of solid matter are carried down every day to be added to it. It is scores of miles long and very wide, and really begins miles upstream from the sea-front, for it is by deposition along the channel that the uppermost area of the delta is built up. At the lower end the river has split up into many distributaries which seem to extend themselves out into the sea, building their own little deltas.

Other classic deltas are those of the Nile at the southeast corner of the Mediterranean Sea, the Mahakam on the east coast of Borneo, and the Niger flowing into the Gulf of Guinea. Canada's largest river system, the Mackenzie, has a large delta where it empties into the Arctic Ocean. Unusual "inland deltas" are formed where some of its large tributaries enter the great northern lakes. One of these is being built on the southwest end of Lake Athabasca by the Athabasca River and another on the south shore of Great Slave Lake by the Slave River.

Some rivers have no deltas at all because of emptying into very deep water or into a part of the sea which is swept by such powerful currents that all the river's load is carried off and dispersed, away from the river-mouth. Still others have their deltas in estuaries so that one doesn't notice them. This last kind of river and delta arrangement is common on coastlines

which have been submerged in the oceans so that the river valley is flooded part way. Many of the rivers in eastern and western Canada are like this.

Youthful Rivers and Waterfalls

Now we have looked at the origin of rivers in the runoff of precipitation and have seen how they cut and carry materials and what happens when rivers dump their loads. From here let us turn to see what happens to rivers themselves after they begin. New rivers and new parts of rivers, which we call youthful, tend to be fast-flowing and to flow in more or less straight lines. The areas between adjacent rivers tend to be high and wide. The dominant action of such new or youthful rivers is to cut rapidly downwards into the rocks below. This results in steep-sided valleys and streams which fill the width of the valley bottoms. Because rivers in this early stage of development are cutting rapidly downwards into their rocky beds, it is very common to find waterfalls and rapids in them, marking places where especially resistant rocklayers protrude. These interruptions in down-cutting generally mean that the rivers are slowed above them, then run rapidly or even fall over them, to be slowed again below them. The Lachine Rapids in the mighty St. Lawrence mark the head of unassisted navigation because resistant dike rocks cut into and support the limestones of the district. What a profound effect on Canadian history this interruption in the down-cutting of the St. Lawrence River has had, for without it, it is unlikely that Montreal would have grown where it did.

Western rivers are full of rapids and waterfalls. Some of these are spectacular, sheer drops and others, like the canyon of the Fraser, are stretches of wild rapids. Niagara Falls, on the other hand, is where a comparatively new river crosses layers of rock of different hardnesses which lie athwart its path and dip gently upstream, rather the same as water

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flowing down a shingled roof. One of these layers is especially massive and resistant but is underlain by another which is much less resistant. The softer layer gets rapidly worn away by the water, thus undercutting the hard one, resulting in the great falls with the canyon below. Not all waterfalls and rapids are the result of interruption in the downward cutting activities in youthful streams for a great many of them originate when rivers are pushed out of their courses by glaciers and flow wherever they can. If they should flow over the side of an old valley, or find their courses blocked with masses of great boulders then falls and rapids may be produced. But this aspect of erosion we will leave for the section on glaciers and their effects.

To get back to the youthful, fast-flowing streams. As rivers cut downward, their slopes or gradients are reduced. As we saw earlier the slope is one of the things that affects the cutting and carrying power of streams. Thus the river is slowed and weakened in its cutting power as it approaches some lower level. What is this level? Ultimately it is sea level, but temporarily it may be a lake level. The river obviously cannot cut below this and it is thus given the term base level. The new stream cuts rapidly downward towards its base level, and when it approaches it, its down-cutting is reduced. Small tributaries and the wash of rain and snow on the valley sides begin to eat away at the shoulders of the valley. This results in the broadening or opening up of the valley. In the valley bottom itself the river begins to wander sideways, back and forth, and gradually begins to cut a level area which it may partially fill with its own deposits.

Mature and Old Age Streams

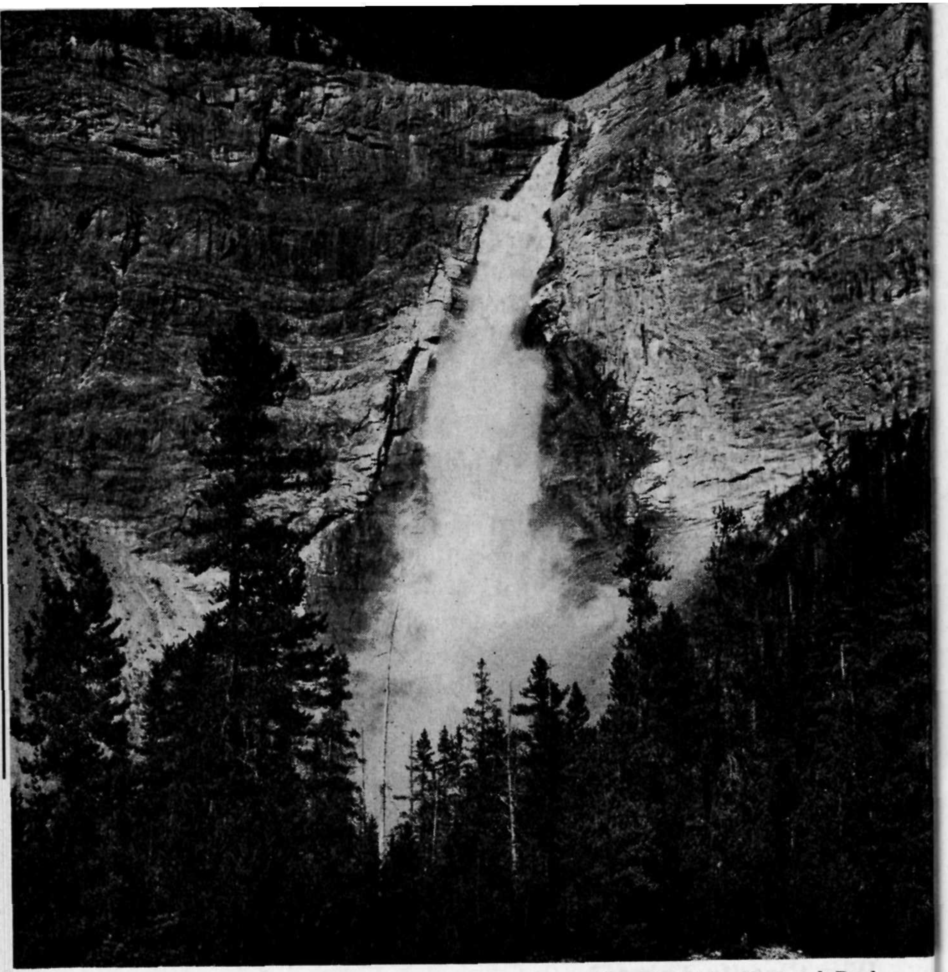
The beginning of the valley flat marks a new stage in the life of the river which is given the name maturity. As the stream further matures, its tributary system gets more and

more well developed until the whole country is covered with a branching network of streams, which are tributary to the one we have our eye on and the similar ones adjacent to it. The whole country by this time is cut up by the stream valleys and shows a marked diversity of relief or ups and downs. Streams have had time to remove most obstructions from their paths so that waterfalls and rapids are no longer common. Such mature rivers are to be found in many parts of the country.

If we follow the idea of the developing stream another step, we find our river getting more and more tired and sluggish. Sweeping bends and looping meanders develop. Enormous amounts of sediment are handed the river by its great network of tributary streams so that deposition of some of it becomes necessary and wider valley flats are covered with mud and silt. Some of the meanders may actually get so bent that the river may cut through the narrow neck of land separating two parts of a single bend, thus cutting it off, and leaving it as a stagnant lake or oxbow lake. The country around has now been completely reduced by the river and all its tributaries so that no more than a great valley flat is visible. Gone are the days of active cutting and waterfalls and narrow valleys. Old age has come. Thus the great Mississippi River is an old age river, so that the man who first sang about 'ol' man river' was as scientifically sound as he was sentimental.

Why Classify Things?

Now, you might ask, what is the good of carefully classifying rivers on their development and erecting all this fancy set of stages? The answer is the same as for the systematizing of any knowledge—it helps us to think neatly instead of in large miscellaneous masses of information, and it helps us to predict



Tongues of glacial ice occupied many of the valleys in Yoho National Park where swift-flowing mountain streams now run between gravelly banks and dark forests. In many places they have steepened the walls of the main valleys and left small tributary valleys "hanging" on their sides. In this lovely place the meltwaters of Daly glacier come tumbling over a glacially steepened wall to form this beautiful plume.

what will happen in any one place if we can understand that a particular sequence is to be expected. Furthermore it establishes an ease of language in river descriptions, so that there is no more need to describe in detail all the little aspects of an old age stream than there is to describe all the details of an old age person.

Patterns of Rivers

People who can see great tracts of country at one time are often impressed by the patterns which rivers make on the face of the land. Map makers or riders of high-flying airplanes can look at them directly but they can equally well be understood by studying maps of a country. One can readily see that if the rivers of an area are cutting into completely homogenous or even rocks, then the patterns should be predictable, on some sort of purely mathematical basis. But rocks are rarely without some differences in hardness or resistance to erosion from place to place. Thus as rivers cut down into the underlying rocks of a country softer rocks will be more rapidly worn away than harder rocks. The result is that larger valleys are usually cut into areas of softer rocks and the water is concentrated in them to increase the faster cutting. If there is a pattern to the different kinds of rocks, hard and soft, then a pattern should appear in the drainage of an area. Parallel zones of rocks of different resistances should produce parallel drainage patterns. Western Canada has many places where mountains and valleys, which are the results of rivers cutting into uplifted areas, are like parallel windrows with hard rock layers underlying the mountains and softer layers underlying the valleys.

In some areas, rocks of differing hardness are folded into complicated patterns. Drainage soon etches out the soft areas and before long the pattern of the streams will directly reflect the rock pattern beneath. On some parts of the earth's surface

Seven Sisters Falls at Lake O'Hara, Yoho National Park, tumble over horizontal sedimentary rocks. The accumulation of sharp, angular boulders above and beside the falls on the left is typical of regions which are undergoing physical breakdown with very little chemical decay of the rocks.

the rocks are jointed or broken along rectangular or parallelogram patterns. Streams in the Adirondack Mountains of New York, in several parts of the Northwest Territories, and in Quebec-Labrador, show this systematic pattern as a result of the rock pattern below.

Volcanoes are usually conical mountains and the drainage from them is usually off the slope in all directions. On a map the drainage will thus be radial. We are apt to forget, however,

while looking at these unusual types of drainage patterns, that the average pattern is dendritic or branching like a tree. The main river branches, or splits, and each of the branches in turn splits as we travel upstream. When we start up a river looking for the origin we very commonly have to choose between two more or less equal branches to call one of them the main stream and the other one a tributary. It is customary to call the one which is most nearly straight-flowing at the junction the main stream if there is a reasonable closeness of size, otherwise it is the larger.

Rivers that Cross Mountains

When we survey rivers in different parts of North America we find a number of rivers that have unusual relations to highland and mountain areas. The Humber River in western Newfoundland rises in an interior basin area and then plunges through the mountains to the sea at Corner Brook. The rivers of the north side of the St. Lawrence below Quebec City seem to rise in the inner part of a saucer-shaped plateau, then cut through the uplifted saucer-like rim and thence to the sea. In the northeastern United States, the Delaware and the Susquehanna Rivers rise in interior valleys and then cut directly across the mountains. In Western Canada, and adjacent parts of the United States, rivers like the Fraser and the Columbia rise on the landward side of the coastal mountains, run partly parallel to them, and then cut across them to the sea. How can rivers cut their valleys across the mountains? The answer is that the rivers were there before the mountains were made.

Mountains rise very slowly by a gradual upheaval of the earth's outer layers. If a well-established river with a deeply incised valley is flowing across the trend of a rising ridge two things may happen. If the mountain rises faster then the river can cut down through it, there must come a time when the

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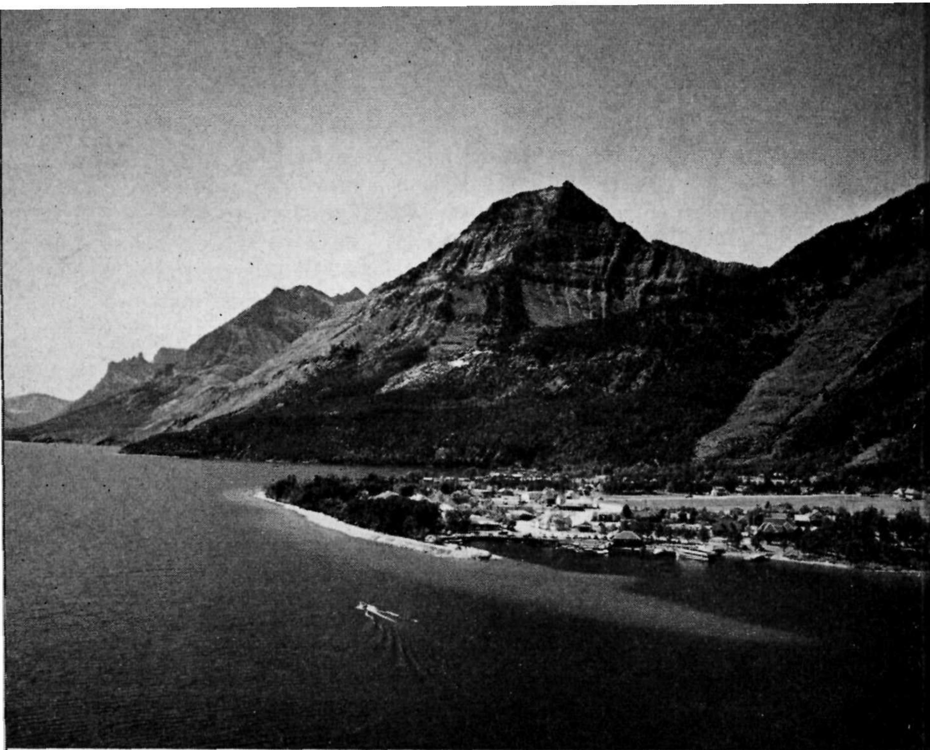

Waterton and the National Park Headquarters are built on the delta of Cameron Creek which has been smoothed out and reshaped by the waves of Waterton Lake. All around, the wasting mountains are making talus slopes and feeding the streams of the area with sedimentary material. Note how clearly the shallow water shows in the right foreground.

river is dammed off by the mountain and must seek a way around it. If, on the other hand, the river is able to gnaw its way down through the rocks as fast as they rise underneath it, then eventually we may get the situation we have described, a river cutting across a mountain.

There is another way this can happen. Most people are familiar with the idea of a stencil where particular shapes,

perhaps letters or designs, are cut out of something. Using this stencil as a guide, the shape can be cut into whatever it is held against. Thus a stencil, made of something soft like wood or plastic, can be held up against something hard like a polished stone and a design etched onto the hard stone with the stencil holding the instrument of cutting. It appears that sometimes in nature a layer of softer rocks overlies a series of hard and soft rocks. If a stream were to cut into the overlying soft rock and down through it into the hard rock, the shape of the valley would be held in the hard rock with the overlying soft rock acting as a stencil. The stream cuts deeply into the hard rocks below, perhaps across their grain, held in by the stencil of soft rocks above. Eventually erosion may remove all of the soft rock. Streams which are tributary to the main river now may etch out softer layers in the basement rocks and gradually form hills, which trend at steep angles to the main stream. Thus we end up with a river appearing to cut straight across the mountains. What has happened again is that the river was there before the mountains. It was stencilled across the grain of the rocks which were later to be etched out into mountain ridges. Needless to say these are not events which take place very quickly, nor are the circumstances common which allow such events to take place. Yet the rivers we have mentioned all have histories something like this.

Summary

In summation, rivers are the fraction of the precipitation which runs off the surface of the land towards the sea. They begin as swift-flowing streams full of rapids and waterfalls and go through a long but systematic cycle of development which ends with them in old age, sluggish, full of sediment, filling in their lower valleys and building large delta deposits. Some of them have unusual patterns because of the kinds of

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Flooding of the land by water takes place wherever the drainage is blocked. St. Lawrence Islands National Park is a flooded country with old hills sticking out of the water as islands and the lower parts now making a lovely network of waterways.

rocks they are cutting into. Some cut across mountains because they were there before the mountains came into being and others have been altered profoundly when glaciers covered the land and disrupted their old courses.

Even now as we talk of them, rivers are cutting their valleys deeper and wider. Waterfalls are being undercut, rapids being worn down. Sand and silt are being deposited in some places and being scoured out from others. Slowly by

human standards of time the rivers of the world are undergoing constant changes as Nature moves on in her cycle. We can witness but a small fragment of the changes taking place but now we can understand what is happening at any one spot and its relation to the whole pattern.

OCEANS AND SHORELINES

For people who grow up near the coast no scenery is quite complete without the ocean. Here, great cliffs stand firm against the onslaught of rollers which have come across hundreds of miles of open sea to smash against them. Icebergs may drift slowly into view and then pass southward to their fate in warmer waters but in their transit of our shores show us beauty in their whiteness on the dark water. In times of calm, a beautiful sunset may be doubly enhanced by reflection from the mirror of the sea. For hundreds of generations men have been fascinated by the ocean, in its savagery of storm and wind, or in its peaceful and reflective calm.

For the scientist or for him who understands something of the processes at work there, the oceans are not only very beautiful but are also storehouses of fascinating phenomena. The geologist looks at the oceans and sees them as great basins in the crust of the earth which are filled to overflowing with salt water, the rugged landscapes of their bottoms being scoured by currents in some places and being covered in others with a great variety of oozes and muds. He sees the shoreline as the scene of a great struggle between the processes of erosion and deposition, of destruction and building. The geologist also wonders about the manner of distribution and deposition of the land which are brought to the sea by countless rivers and by the waves themselves. He is interested in the chemical and biological makeup of oceans for they are the parents of most sedimentary rocks.

Other scientists are apt to see other parts of the oceans. Biologists may see the oceans as the cradle of life and the place where more living things in greater diversity of kinds are to be found than in any other environment on the face of the earth. Physicists may see the oceans in terms of earth magnetism, gravity or heat transfer. The chemist sees a solution of salts of various kinds complicated in their interaction by a vast mass of living material. Mathematicians and astronomers are concerned with the oceans as they modify the shape of the earth or change its rotation because of the drag of marine tides.

Oceans Generally

A close look at a globe or a world map will show that about two-thirds of the surface of the earth is covered with oceans. We have already mentioned that continents seem to be discrete blocks which stand up above the ocean basins along fairly sharply marked boundaries. It seems, furthermore, that the ocean basins are a little more than full because some of the water encroaches on the edges of the continental masses. The areas that are thus covered with water are called continental shelves and aggregate something like 10 million square miles or about $2\frac{1}{2}$ times the land area of Canada. The width of them varies considerably, from a narrow rim along the Pacific coasts of the Americas to 250 miles, east and south of Newfoundland in the famous Grand Banks, and even 400 miles along the Siberian Arctic coast.

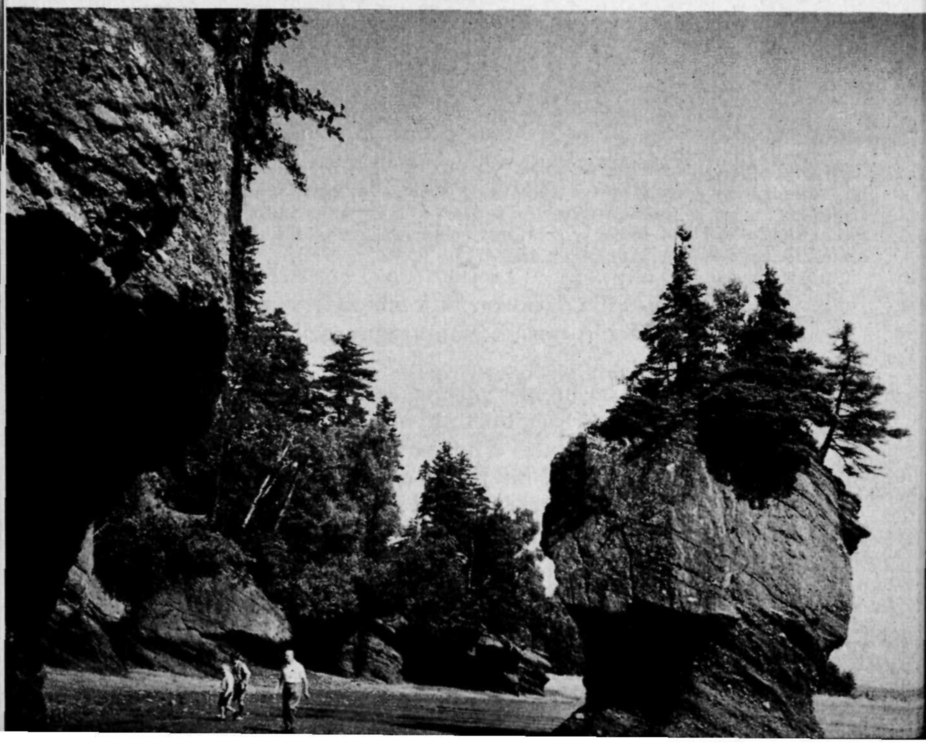
The slope on the shelf areas descends gently seaward under the water at the rate of only 10 to 20 feet a mile. Then at the outer edge the slope steepens and drops off into the ocean depths. Thus the real shape of the continent of North America would look rather different from the present shoreline map of North America that we are accustomed to, for

Men have always been awed by storms on the sea. Here a granite shore resists the onslaught of great breakers which may have come many miles across the surface of the sea to crash against it. The force of the moving water may remove blocks bodily, bits and pieces of rock may be hurled against the shore, solution and chemical decomposition go on apace.

many of the features like Hudson Bay which lies on top of the continental block would not show and things like the Grand Banks would be land areas.

Ocean depths are as highly various as the places at which they are measured, for the bottom of the sea is about as irregular as any land surface. The maximum depth is nearly 40,000 feet, which means that the deepest part of the sea is much deeper than the highest part of the land is high. Parts of the ocean bottoms which lie below about 18,000 feet are called deeps. The deepest of the deeps are elongate trenches or troughs which are often near continental margins, where folded mountains are found or arcs of islands, like the Aleutians. They are thus thought to be of structural origin, that is, down-wrinkles on the bottom of the sea. The average depth of the sea is much less than its greatest deeps, of course. The Pacific Ocean is about 14,000 feet, the Indian Ocean is about 13,000 and the Atlantic about 12,900 feet. While these figures cannot be accurate to the nearest foot they do show us in a general way how thick the watery blanket of the oceans is on the surface of the earth.

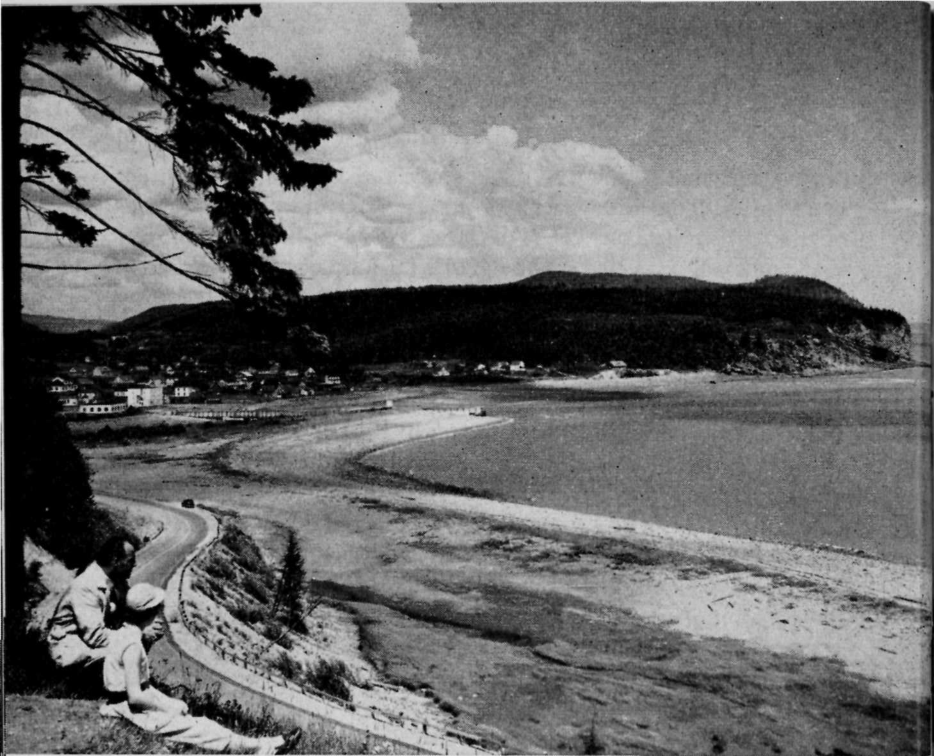
Conglomerate and sandstone dip gently toward the sea at Hopewell Rocks, N.B. on the road which leads to Fundy National Park from Moncton. These curious shapes result when softer parts are worn away leaving harder parts standing isolated or as points jutting out from the bank. Note the boulders and pebbles in the dipping sedimentary rocks.



It is interesting to note that with the earth some 8,000 miles in diameter and the oceans about 13,000 to 14,000 feet or $2\frac{1}{2}$ miles deep, the water is a pretty thin film on the outside of the ball we live on. We are apt to gather a different impression from our travels on the earth's surface.

The Bottom of the Sea

What is the bottom of the sea like? In earlier times the only way to find out the depth of the water at any one spot was to stop a ship and lower a weight on the end of a rope or wire. Because of this slow and difficult method, observations of depth were very sparsely scattered over the oceans. As a consequence, ocean bottoms were pictured as very smooth, gently sloping affairs with only minor undulations over enormous areas. Only a few of the great deeps, a few of the major submarine ridges, and a few of the canyons were known. In recent years, however, a device has been invented which measures the depth by sending out a sound wave and timing its trip down to the bottom and back. Since the speed of such sound in water is known, then the depth can be accurately measured. With this device the captain of a ship needs only to push a button and read on a dial the depth of water beneath his keel. These instruments have been refined to produce an accurate, continuous record of depths over which a ship is passing so that a map of the bottom is possible by making a number of evenly spaced, parallel trips. This technique has suddenly made clear to us that the sea bottom is not the flat monotonous landscape we used to think but instead presents a great diversity of relief and topographic types. Naturally enough, the absence of streams, and wind, and desert types of erosion makes it impossible to have certain of the finer details of sculpturing of the landscape, but this is compensated for by some forms which are peculiar to the ocean bottoms.



Part of this curving beach is in Fundy National Park, near the village of Alma and Owl's Head. Waves and currents carry the materials of erosion from the crumbling cliffs and build these beaches. Notice how the waves have piled up a beach ridge at highest water level.

In very recent years man has found ways to go into the great depths of the sea himself and look at the bottom. Some penetration of the upper parts of the ocean was made before this by men who sealed themselves into a strong, water-proof sphere with windows in it and then dangled at the end of a long rope from the decks of a surface vessel. Since World War II penetrations to depths as much as seven miles have been made by suspending the gondolas below bags which are filled with liquids which are lighter than water. The whole apparatus

is then manipulated like a balloon with ballast adjustments to make it rise or sink. A whole new world of discovery has been suddenly opened up. Now what do we find?

The sea bottom is covered with great mountain ranges like the Mid-Atlantic Ridge which runs up and down the Atlantic Ocean from end to end; valleys of great depth; rugged volcanic mountains tens of thousands of feet high, and perhaps poking a bit out of the water as islands such as Hawaii and Bermuda. Thus some island areas of the world prove to be but the tips of giant mountain masses, as large in relation to their surroundings as any we know on the surface of the land.

Seacoasts are constantly undergoing change as waves and currents cut into the rocky cliffs and strew the debris from them along the shore. This island, on the west shore of Cape Breton Highlands National Park, has been joined to the main shore by the spit in the foreground as waves and currents carried the debris from the eroding cliffs across the gap.

By far the most complicated relief on the sea floor is to be found around modern island chains where volcanic and earthquake activity is apparently a part of a mountain-building process in action. Such places are the Indonesian Archipelago and the West Indies. Here, basins and trenches alternate with prominent ridges, some of which stick out above the sea as the islands we know. Isolated volcanic cones, some of which protrude above the surface, appear scattered over the sea. In addition, plateaus and flat areas are found, some of them with drowned river-valley systems superimposed on them. So now we think of the bottom of the sea as an area of relief something like that we know on land, with flat areas, mountains and valleys, submerged plateaus and isolated hills.

It has been known for a very long time that the bottom of the sea is covered with different kinds of things in different places. The charts made by Captain Cook in Eastern and Western Canada in the late 18th century show where individual soundings were made and whether the bottom was sand, mud or rock. This is still important to sailors for it makes a difference where one might drop an anchor.

One would expect that near the land and in shallow waters sedimentary materials derived from the land would be most common. These would be mud and silt, sand, and, very close to shore, gravel. Once off the continental margins and into the great ocean depths, however, the sedimentary materials are very different. Bluish-grey muds of fine grain cover the sea bottoms close to the continents. They are probably derived from the lands and carried on out very slowly in fine suspension. Very fine, clay particles may take years to settle through the depths of sea water in these zones, so can stray out from shore a long distance.

In the very deep, sea regions the most widespread stuff of the bottom is red clay. It covers a quarter of the floor of the

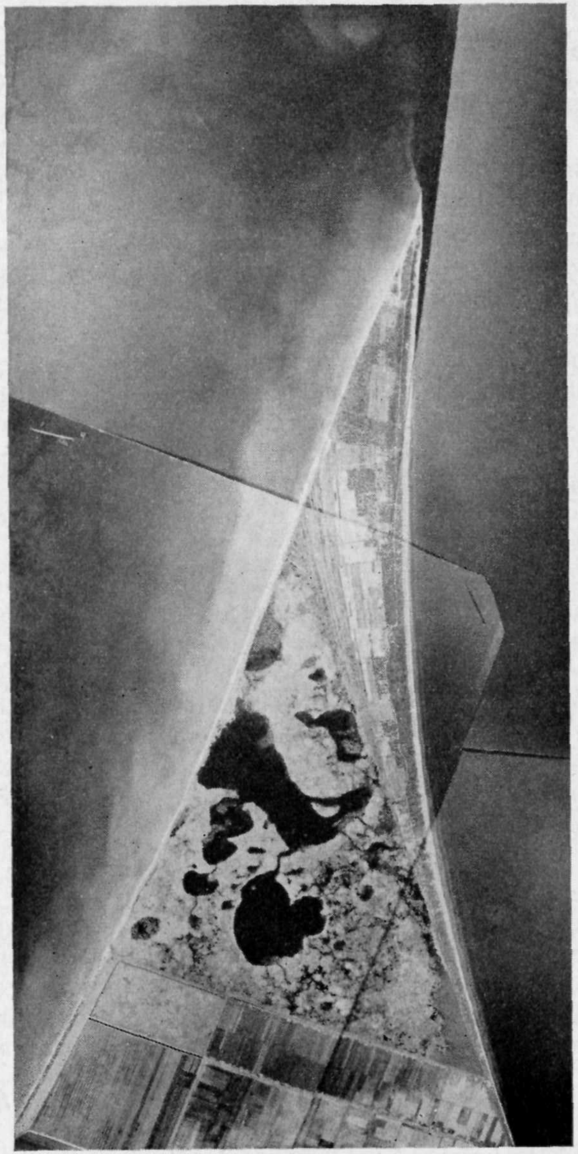
Atlantic and Indian Oceans, and about half of that of the Pacific Ocean. It varies from brick-red to brown and is very fine-grained. It seems to be a combination of many things like wind-blown dust from the land, volcanic ash blown out over the sea in winds, meteoric dust, and perhaps some land-sediments straying out over the depths in ocean currents.

Great numbers of microscopic organisms live in the surface waters in some parts of the ocean and secrete around themselves little skeletons of calcium carbonate or silica. When the animals die their shells sink slowly to the bottom of the sea. If muds and other masking sediments are present in large quantities it may be that the shells go unnoticed. But if little or no muds are coming into the area the tiny shells accumulate and form ooze. These oozes, of several kinds, cover vast areas of the ocean bottoms. One type alone, named globigerina ooze for the little creature which makes it, covers some 50 million square miles.

We have seen, now, enough of the overall picture of oceans and the basins they lie in to investigate the place where most of us see the ocean—at the shoreline. It is here that the waves come in procession from out beyond and crash against the land, or, in calm weather, wash gently the rocks and the beaches. It is here, too, that waves form the most effective tools of erosion at the command of the sea, tearing down cliffs and scattering the debris along the shore as beaches, bars and spits.

Waves

The movement of ocean waves produces hydraulic forces of considerable size by sheer impact of moving water. Investigators have estimated that storm waves produce pressures as high as 50 pounds per square inch. This may not sound like much until we see that it is about $3\frac{1}{2}$ tons per square foot and



Point Pelee juts out into Lake Erie from the south side of Ontario. In this composite picture made from several aerial photographs you can see how the waves and currents are swirling up the water and sand on the east side of the point and south of it into deeper water. You can also see the marks of older shorelines on land. The neat rectangular areas are fields under cultivation and the dark, irregular areas are boggy ponds.

a seawall or a rocky point of a few hundred square feet would have to stand pushes of hundreds of tons as the waves come in one after another. Records of great gales are full of stories of enormous boulders of hundreds of tons being moved about by storm waves, and breakwaters of even thousands of tons being washed away. The alternating great pressures of the advancing waves and their withdrawal effectively wear away the rocks in some places. Air is forced into pore spaces of rocks and into openings and cracks under great pressure by the waves and helps in the process of destruction.

But the most effective way the waves work is by abrasion. You may recall that in an earlier section we mentioned James Hutton, a Scot who was among the first of the modern school of geological workers. Here is what he said about abrasion along shores undergoing active erosion:

> "On such shores, the fragments of rock once detached become instruments of further destruction, and make a part of the powerful artillery with which the ocean assails the bulwarks of the land; they are impelled against the rocks, from which they break off other fragments, and the whole are thus ground against one another; whatever be their hardness, they are reduced to gravel, the smooth surface and round figure of which are the most certain proofs of a detritus which nothing can resist."

No one can doubt this who has stood on the shore, as Hutton did so long ago, and watched waves sweep forward, tumbling rocks of all sizes against one another and the cliffs and then the backwash with a repeat of the tumbling and rolling action. On many beaches the backwash has a distinctive roaring sound because of the pounding of the boulders and cobbles in motion against one another. No wonder wave-worn boulders are rounded.

Sand and Mud

Now, what happens to the material that is worn away from shores and ground up by waves? It must go forward on the waves to be deposited on or near the beach or backwards towards the sea. If backwards, the waves may deposit the stuff in deep water immediately or feed it to currents which, in their turn, transport the sedimentary materials into deep water. These currents may come from large-scale ocean movements generated by the earth's rotation, the tides, the great winds in certain sections, or differences in temperature in ocean waters in different parts. Locally they are apt to be the result of the waves themselves hitting the shore obliquely.

Beaches, then, such pleasant places in fine weather, really represent destruction of cliffs or older deposits of sands and gravels. Waves break off pieces of rock and grind them against one another. Particles of sand gradually get rounded off and weaker materials get ground even finer than resistant ones. Because of this grinding and elimination of softer materials most beaches have a large proportion of particles of quartz, a commonly occurring, hard, resistant mineral. It is perhaps intriguing to think that the great mass of quartz sand on a beach has come from a much larger mass of rock by the gradual elimination of other materials.

Any handful of sand will show many other mineral fragments besides quartz such as black specks of a magnetic iron mineral, magnetite; pink, glassy garnet; green, glassy olivine; grey, pink or brown feldspar; shiny, flat flakes of mica which may be brown or silvery. In some beaches very rare minerals are concentrated by wave action and may even form valuable mineral deposits. It is always worthwhile to examine sand closely for it may be full of interesting and beautiful mineral grains.

It is interesting to note the way that water in motion, whether in waves or in currents, selects different materials

Waves and currents are tearing down an island of sand on the north side of Terra Nova Park and stringing the sand out into a long spit. Beaches and the curving road appear in this aerial view as dazzling white while the sea is very dark looking because we are actually looking down into its depths. You can see the large shoal area around the island and the point of land to the left.

from a mixture and concentrates them. Watch carefully where waves sweep onto a sandy beach and see, at the very maximum line of forward sweep of the water, a tiny little zone of light materials left behind, things like flakes of mica, or fragments of shells and wood. Areas of darker sand occur on some parts of the beach where waves have carefully selected dark mineral fragments, because of their weight or shape or size, and deposited them. Where ripple marks have formed you may note that the sand in the tops of the ripples is of various minerals in slightly different proportions from that in the troughs between them.

The sedimentary materials being sucked away from the line of waves at the shore are moved selectively too. Finer particles will be moved farther seaward and the coarser or heavier particles will be deposited on the bottom sooner or nearer shore. The farther seaward one goes, the finer the sedimentary materials so that hundreds of miles from land only the very finest of clay particles remain in suspension, and even these gradually sink to the floor of the ocean to become part of the bottom muds and oozes.

Different Kinds of Shorelines

We have seen something now of the bottom of the ocean and what it is like, about the kinds of muds and oozes which cover it, about the way waves wash in against the shore and wear it away, about beaches and sands. Now what about different kinds of shorelines? For these, after all, are what we usually see in our travels, and, further, what we usually come to appreciate as marine scenery. Why is the deeply indented shoreline of British Columbia with great fiords and deep narrow inlets so very different from the smooth, straight shore of Oregon? Why is the equally spectacular fiord-land of Labrador so very different from the smooth, straight shorelines of Anticosti Island, of Gaspé? Why, indeed, are

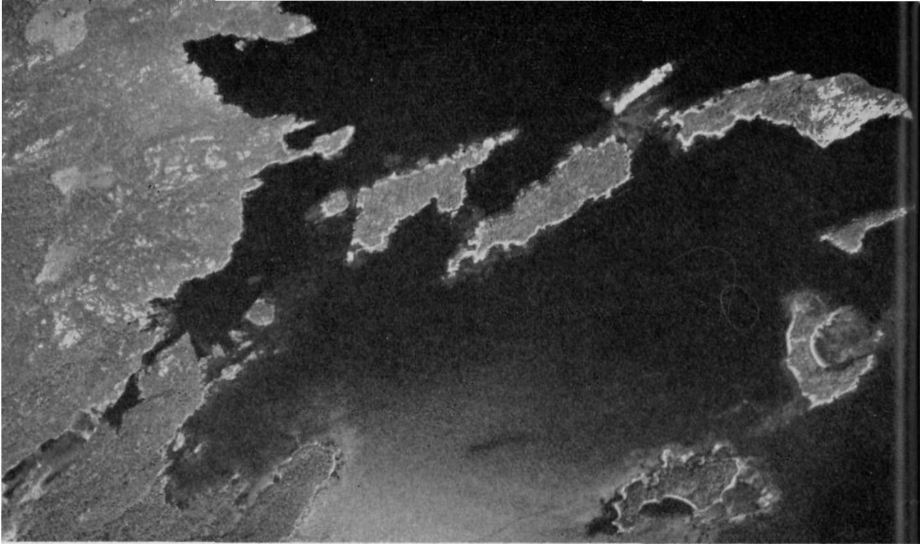
there so many islands in Notre Dame Bay and the Terra Nova National Park area on Newfoundland's north coast, and hardly any at all on the west side of Hudson Bay? Why are some shorelines so steep and rugged and others so low and flat?

To understand kinds of coastlines we must recall that oceans and continents are separate, and that the ocean basins are a little more than brim-full, so that the oceans overlap shallowly on the edges of the continents. This means that the slightest alteration of the sea-level relative to the land will mean a big change in the shoreline.

Study of the earth's past has shown that the oceans and the continents have always been in a state of adjustment, of ups and downs with consequent raising and lowering of the sea level at any one place. Thus shorelines in some places show how the sea has encroached on the land; that in others it has withdrawn from the land, so that the place where waves used to wash the rocks, is now dry land; still others are places where the sea level has been more or less stationary for very long periods of time. Here, right away, is a basis for classifying shorelines, whether they are submerged or emerged or stationary. There are lots of other ways to classify shorelines: the tourist-resort owner, wanting to expand his facilities, will classify shorelines on the presence or absence of good swimming beaches or surfing beaches, the sailor on whether good harbours are to be found there, the fisherman on the fish populations off-shore, and so on.

It makes a great difference to the shoreline of submergence or that of emergence just what kind of topography is being submerged or emerged. Thus shorelines may be classified as shorelines of plains or flat areas, and shorelines of mountainous areas.

About the most satisfactory classification for both geologist and traveller, however, is one which is based on whether or



Sometimes a view from high in the air helps us appreciate the overall pattern of the landscape which is not easily visible when we stand in the midst of it on the ground. Here is an aerial view, in Terra Nova National Park, which shows how drowning of a rolling landscape produces an irregular shoreline. Former hills appear as islands and valleys are filled with water to become inlets and coves.

not the waves and currents are the principal causes of the shapes or configurations of the shorelines. This may seem odd but, if we remember our continental margin again with the water spilling shallowly up on its gently inclined edge, we can easily see that many shorelines would be the result of submergence of the land in the sea, because the continent has gone down a little or the sea has risen a little. If we submerge or drown a piece of landscape in the sea, the shoreline will take its shape from the land. If an irregular, hilly piece of land is submerged beneath the sea the hills may stick out of the water as islands or long headlands and the valleys, now filled with sea water, will form long bays or estuaries. The more irregular the land, the more irregular the new coastline will

be when it is submerged. Thus our island-studded coastlines, be they on the east coast or the west coast, on the shores of large lakes or in the Arctic Ocean, are almost always the result of water drowning the land. Thus the shapes of some shorelines are due not to marine agencies at all but to land erosion, followed by drowning. So we find lots of different kinds of shorelines whose primary features are due to the drowning of river valleys, the drowning of areas eroded by glaciers, the submergence of areas of river deposition, glacial deposition, or even wind deposition.

On Canadian shores we have a large variety of submerged landscapes forming the present coastline. In northern Labrador and in much of British Columbia we find great fiords or glacial troughs, thousands of feet deep, leading into the land. They have been deeply cut by glaciers and then invaded by the sea, although in some places the ice may have been cutting below sea level in them. Drowning of a normal, rolling topography with river valleys and ridges produced what is now the island-filled northern coast of Newfoundland. This is how the marine scenery in Terra Nova National Park was formed. A short distance toward the west, the Exploits River can be traced on the sea bottom for 40 miles beyond its present mouth, out among the islands off the shore. The same history of submergence by the sea of a rolling landscape has produced the indented shore of Nova Scotia and New Brunswick.

Other coasts and shorelines have configurations which are primarily the result of waves and currents. Here we find the great cliffed shoreline. The pictures of Percé and the great limestone cliffs of Gaspé are familiar to almost everyone. The cliffed shores along parts of Lake Huron, some of the Arctic islands, and portions of the west coast, would belong here, for the cliffs have been cut by the waves themselves. Some coasts are made more regular by the cutting off of exposed

The southernmost tip of mainland Canada is this long spit of sand and gravel in Point Pelee National Park. It is made by the sweeping of currents which are generated by winds and waves on the north side of Lake Erie.

promontories and removal of islands. Others are made more irregular as waves and currents cut into soft rocks, making indentations and etching out harder rocks as points.

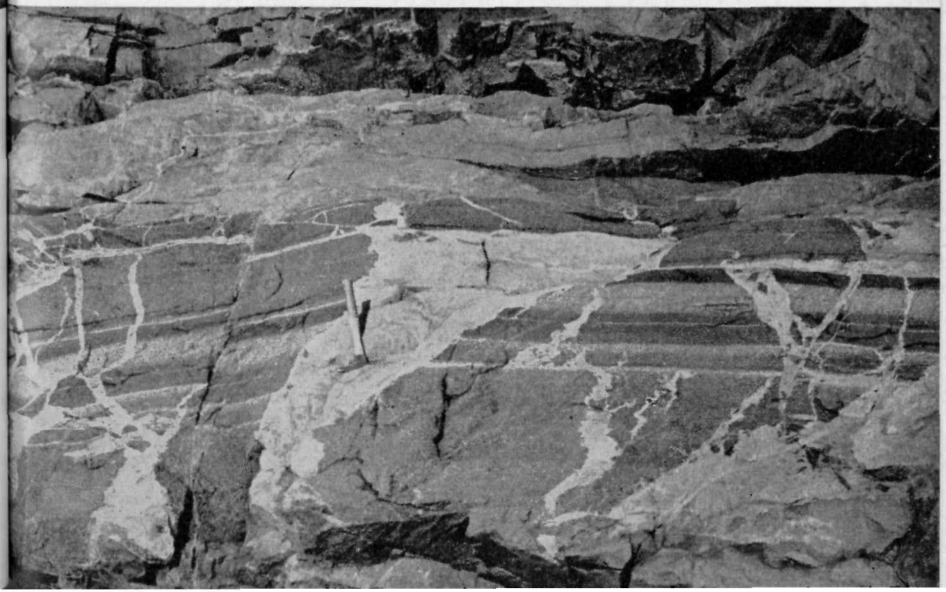
Waves and currents may shape shorelines by adding beaches and bars of sand and gravel torn from eroding shores nearby. The long point of Point Pelee National Park was made by currents and waves. Thus, bays may be filled in or cut off by wave deposits, islands may be joined by bars, or irregular coastlines made smooth by the formation of long, straight off-

shore bars. A glance at the map of eastern North America will show a shoreline, made straight and even in this way, which extends from Cape Cod southward to the tip of Florida, around the Gulf of Mexico and on down to Yucatan. Coral islands, and shorelines which have been altered greatly by coral reefs, such as the magnificent Great Barrier Reef of Australia, belong in this class also.

Summary

When next you visit the shoreline, be it that of a small lake or the mighty Atlantic, that of a wide river or the stormy old Pacific, you will see there the meeting place of water and land. As waves lap the shore gently or come crashing in with force of untold might, grains of sand are disturbed, muds stirred up and resettled, boulders ground against one another. The ocean water off Newfoundland, today cold, filled with icebergs, teeming with cold-water fishes and micro-organisms,

Intrusive igneous action takes place below the surface of the earth, and the results of it are only exposed to view after long erosion. In this exposure on the coast of Newfoundland we can see how the dark banded rock was split apart by the intruding white rock, which then solidified.



may in a little while find itself in the warm stagnance of the Sargasso Sea, or bathing the shores of Europe as part of the Gulf Stream, or perhaps part of the tumultuous waters of the 'roaring forties' in the southern oceans. Vancouver Harbour water may one day be part of a languid scene in the South Pacific or find its way into arctic seas.

Where you see waves and currents cutting at cliffs and building bars and spits with the debris, or spreading it out over beaches where you walk, you may relate the processes you are observing to the constant striving for equilibrium in nature. For you are looking at a tiny fragment of a vast process of disturbance and adjustment, here something torn down and there something being built up, as Nature moves on in her cycle.

GLACIERS

Introduction

Some of Canada's National Parks owe their natural beauties to the sea. Some are wonderful places to visit because of their spectacular mountains. Some are where they are and what they are because of lake scenery or rivers. But, no matter where they are in Canada or what they are particularly renowned for, they have one thing in common, the most important single event in their histories was the passing of the great icecap over northern North America in recent geological times.

No matter where people are, the scenery they look at is a heritage from times past, some of it extending back into geological history for millions of years, some of it being actively carved yesterday and today, but all of it greatly modified by that age of glaciers. It is thus of great importance that we understand something of this part of the evolution of scenery, for all of us are evidently controlled by it in one way or another.

Angel Glacier, on the side of Mount Edith Cavell in Jasper National Park, issues in this thin tongue from the snowfields higher up. The fan-shaped deposit below the ice contains boulders and ground up rock which the glacier has brought down from the eroding mountains above mixed with snow and ice debris from the wastage of the glacier itself. Pictures taken 50 years ago show the tongue of ice to have been several times as wide as it is now and reaching well down below its present level. The light coloured scar on the rocks shows its former approximate outline.

This, the important event in our scenic history, began perhaps a million years ago—no one knows exactly—but it seems to have been about that long ago. Now a million years seems like a long time to those who are not accustomed to thinking in terms of geological time or the time which has elapsed since the earth first took the independent shape it now has. At this moment we will only say that physicists, astronomers and geologists, all working from different viewpoints, generally agree that the earth is something like four to five thousands of millions of years old. Thus the geologists who say that the glacial age began about one million years ago are talking of something recent, speaking in terms of earth history.

An Icecap is Formed

About a million years ago, then, the climate in part of the world, including all of northern North America, began to get cooler very gradually. The winters became a little longer and the summers were not quite as warm as they used to be. Snow which fell in winter began to stay on the ground longer and longer each spring and it came a little earlier each fall. The climate continued to get colder. Eventually the snow stayed all year round in some sheltered spots such as steep valleys and on the north slopes of hills away from the sun. Finally, the temperature rarely went above freezing even in mid-summer, and the snow stayed on the ground, everywhere, all year.

As the seasons went by the snow continued to get deeper, at first tens of feet, then hundreds of feet. When it reached this great thickness the weight of the upper layers of snow on the lower layers caused the bottom snow to change to ice in the same way that snowballs are made by squeezing. As the great blanket got to be thousands of feet thick, the enormous weight of the upper layers squeezed the bottom icelayers so that they began to flow outward from the higher parts of the land, where accumulation was greatest, towards the edges and the sea. Finally, the whole northern part of North America, including almost all of what is now Canada and some of the northern United States, was covered with a great icecap with the snow accumulating on top, getting covered by more and more snow, and turning to ice by the pressure of its own weight. The lower layers flowed out over the country, either to the sea, where it melted or broke off and drifted away, or to warmer parts where it gradually wasted.

Just why this general refrigeration of the world should have taken place no one knows for sure. It may be that the temperature of the surface of the earth was greatly changed by variations in the sun's radiation, either because of changes in the sun itself or because of unusual amounts of volcanic dust in the air. Changes in the amount of carbon dioxide in the atmosphere may also have altered its ability to transmit the sun's heat to the earth's surface. Whatever the cause, there is no doubt that it did take place.

For many thousands of years northern North America lay beneath the icecap, an unbroken wintry scene just like that which we so often see pictured in Antarctica today. But eventually the cycle of climatic change, which brought the cold in the first place, began to swing back and the climate began to get warmer. Over the centuries the icecap began to lose a little more of its volume by melting than it gained by fresh snowfalls. So it began to shrink. Each summer was a little warmer than the one before it and the winters gradually got less severe. A small part of the covered country was uncovered and each year this uncovered part grew larger and larger. Eventually little was left of the icecap but small remnants in the highest parts and the most northern parts of the country.

But the country which was passed over has never been the same.

What the Icecap Did

The great mass of ice pushing over the face of the earth scraped everything loose before it. Soils were torn up and carried away. Great blocks of solid rock were plucked from the earth and carried off, sometimes for many miles. The bedrock was scraped clean and polished by the moving ice which was armed with boulders and debris frozen into it. Hills were rounded off and old river valleys were scoured out and steepened. Where the ice came down to the sea it scooped and

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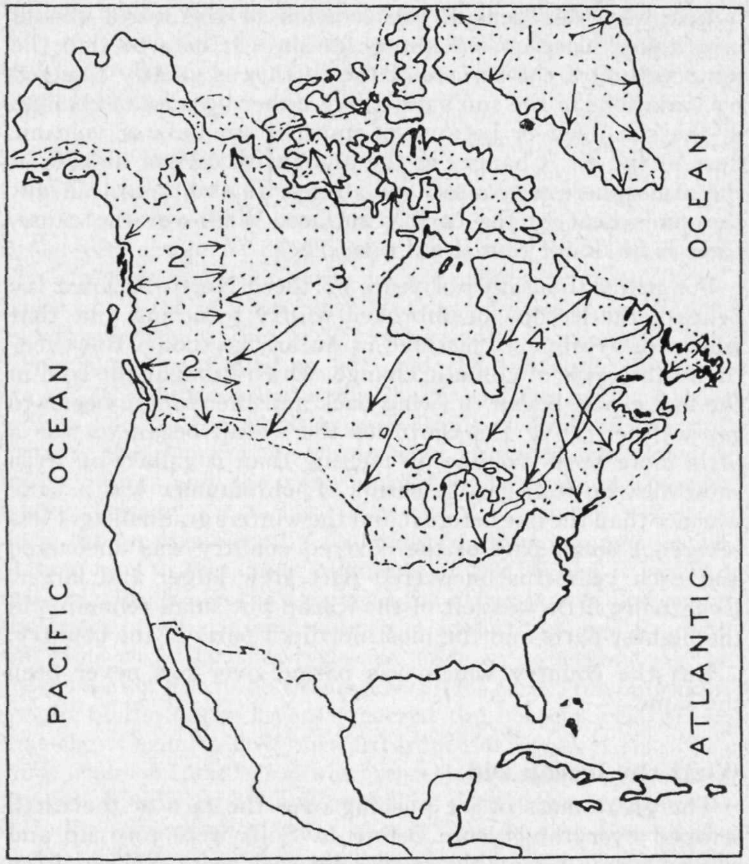


This outline map of North America shows the extent of the great icecap which covered all of Canada and some parts of the northern United States. The accumulation of snow was such that the ice formed from it moved in the directions shown by the arrows from four major centres. Greenland, (1) had a small icecap of its own which radiated generally outward from the central ridge. The western mountains, (2) were glaciated by a complex of mountain glaciers which flowed westward to the sea, and eastward to meet the ice from a centre, (3) which lay to the west of Hudson Bay. Another major centre (4) lay to the east of Hudson Bay. One can see from this map that the scenery of all of Canada was modified by the coming of the ice, its scraping over the country and its leaving behind of an irregular blanket of debris.

wore away the inlets, deepening some, straightening others, and making new ones where there had been none before.

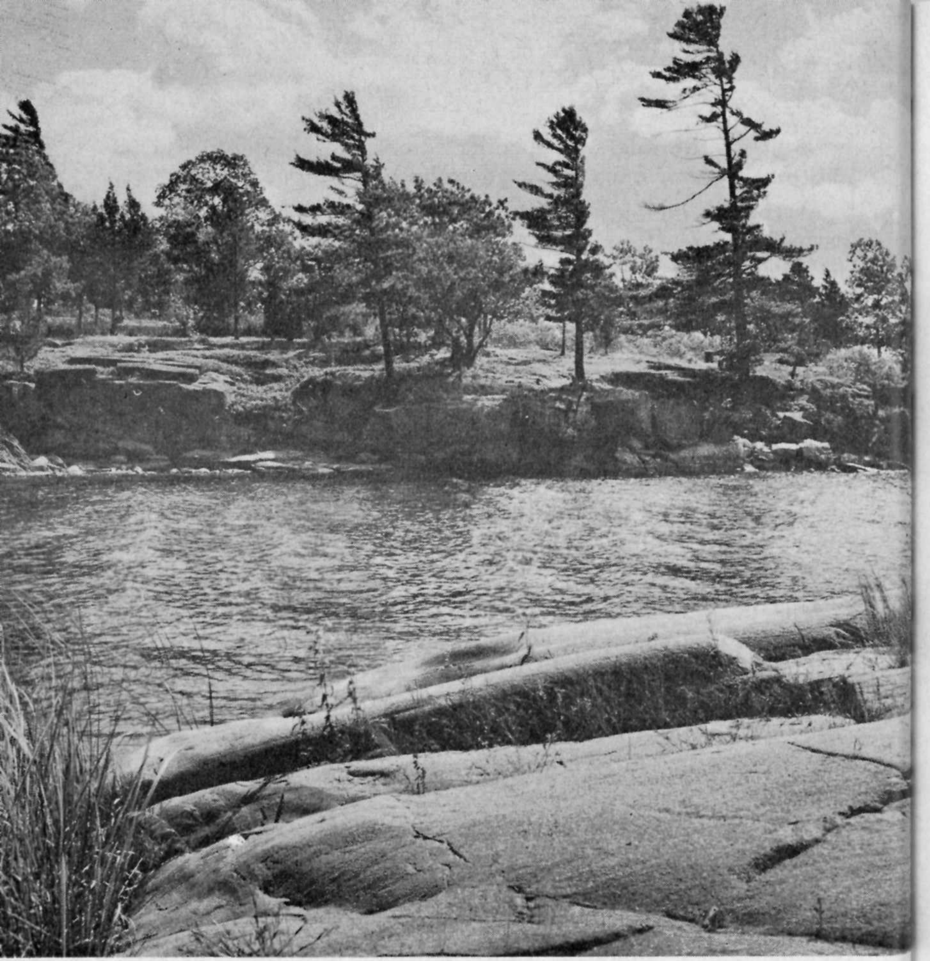
As the ice melted, the materials it was carrying were deposited in a scattered manner all over the country. Big boulders were left stranded on the hills. Piles of ground-up rocks and old soil were dumped here and there. Some of the debris was washed by the meltwaters into the valleys, but the hills were generally left naked.

When the ice had first come, all the plants and animals were forced to move southward to warmer parts. Some of them, however, were not able to adjust themselves and perished. After the ice had melted, trees seeded themselves back over our land and tried to get a foothold on the bare hills and stony soils, succeeding in many places but finding it impossible where there was *only* rock.

This is quite a story and until now we have offered no evidence to prove it. The simplest and most logical thing to do first would be to compare what we have said with what we can see now in regions where glaciers of the same kind are still active. For this we have to go either to Antarctica, far northern regions or to almost any of the very high mountain ranges of the world.

Two Kinds of Glaciers

At first glance, glaciers of today seem to be of two distinct types, ones which are confined to valleys in mountainous regions, called Alpine or valley glaciers, and those of very large spread, icecap or continental types. We find on closer inspection, however, that there is no real dividing line, for icecaps commonly reach the sea through glacial tongues in valleys which are really the same as valley glaciers and the latter sometimes join together to form ice sheets. They all, however, have two parts in common, an accumulating area



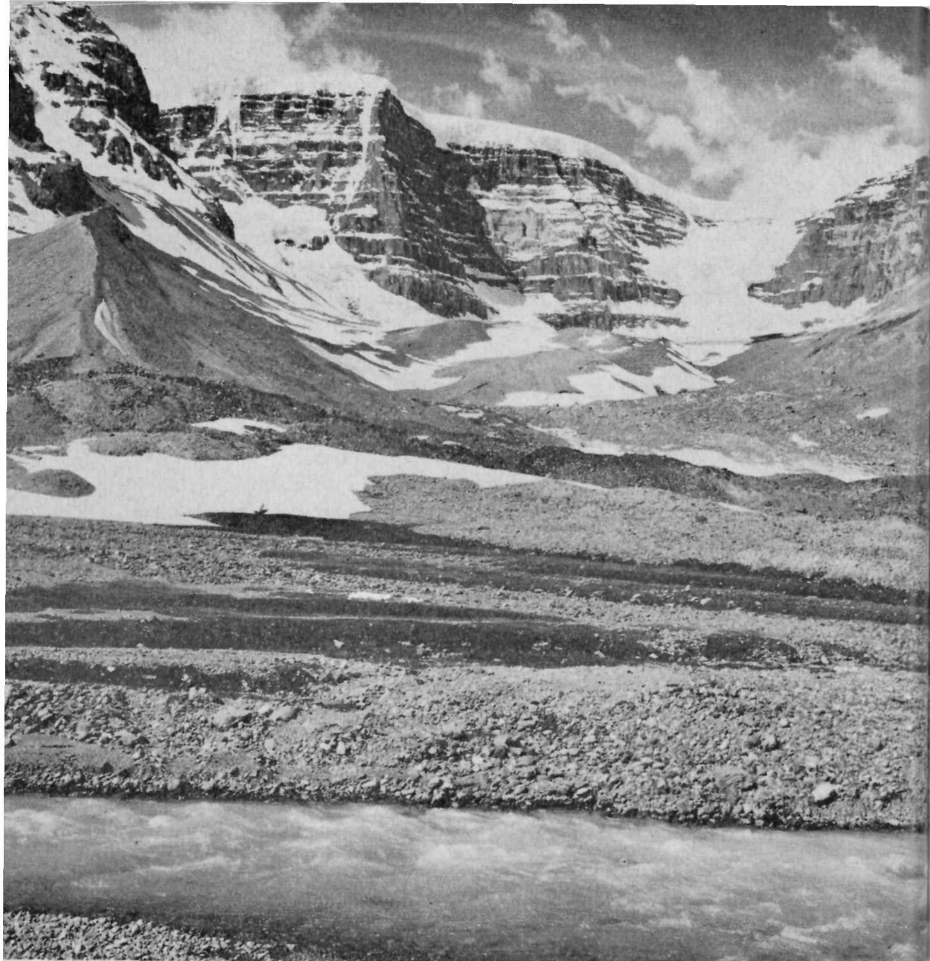
Ten thousand years after the great icecap that once covered Canada melted the polished, scratched, and rounded rock surfaces show clear evidence of its passing. Here in St. Lawrence Islands National Park the pattern of the rock surfaces, the water, and the pines make an interesting study of arrested motion.

or snowfield and a wasting area where solid glacial ice is melting or floating away. Perhaps high in the mountains snow is accumulating without melting. As the mass of tiny crystals gradually accumulates, the ice on the bottom becomes plastic and begins to squeeze out from under and overflows down valleys. If the lower regions are warmer than the snowfield areas, melting may overtake the ice and the glacier will disappear as a stream of cold water.

Icebergs

If the ice meets the sea, portions of it may break off and form icebergs. Most of the icebergs which come drifting down to the north and east coasts of Newfoundland each spring and summer are actually pieces of the Greenland icecap which reaches the sea in numerous valley tongues. As the ice pushes into the sea it is broken off by its own buoyancy and the pieces move slowly southward in the Labrador Current. Thus these icebergs began as snow, which fell in the interior of Greenland, perhaps hundreds of years ago, gradually turned to massive ice and then flowed down to the sea. This history explains why they are not salty, as any fisherman knows who has had a drink of the delicious, cool meltwater which comes off them in summer. Flat, tabular icebergs of great size break off the part of the icecap in Antarctica that is formed directly on the sea.

The kinds of ice in northern and southern icebergs are different, for the Antarctic ice is a little lighter because of its origin on the sea and is clean because it formed away from the rocks. The Greenland bergs, on the other hand, pushed down narrow valleys and squeezed out through rocky canyons, with the result that they are often contaminated with bits of rock and earthy debris, particularly on their bottoms. After they crack off and move slowly southward, the upper part in the sunlight melts and some of the submerged parts too. It is therefore common for the shape to change and, when this



Dome Glacier in the right background comes from the refreezing of masses of ice and snow which tumble over the cliffs from the edge of the Columbia Icefield along the skyline. This "reconstituted" glacier was once much larger than it is now and filled the whole valley pushing up the sharp edged wall of debris in the left portion of the photograph. The swift flowing stream in the foreground is mostly meltwater from the Athabasca Glacier and the mass of boulders and rock rubble has come largely as outwash from the melting ice. You can see that the rocks of which the mountain bowl is made are flat lying from the way the snow lies on the ledges made by the bedding.

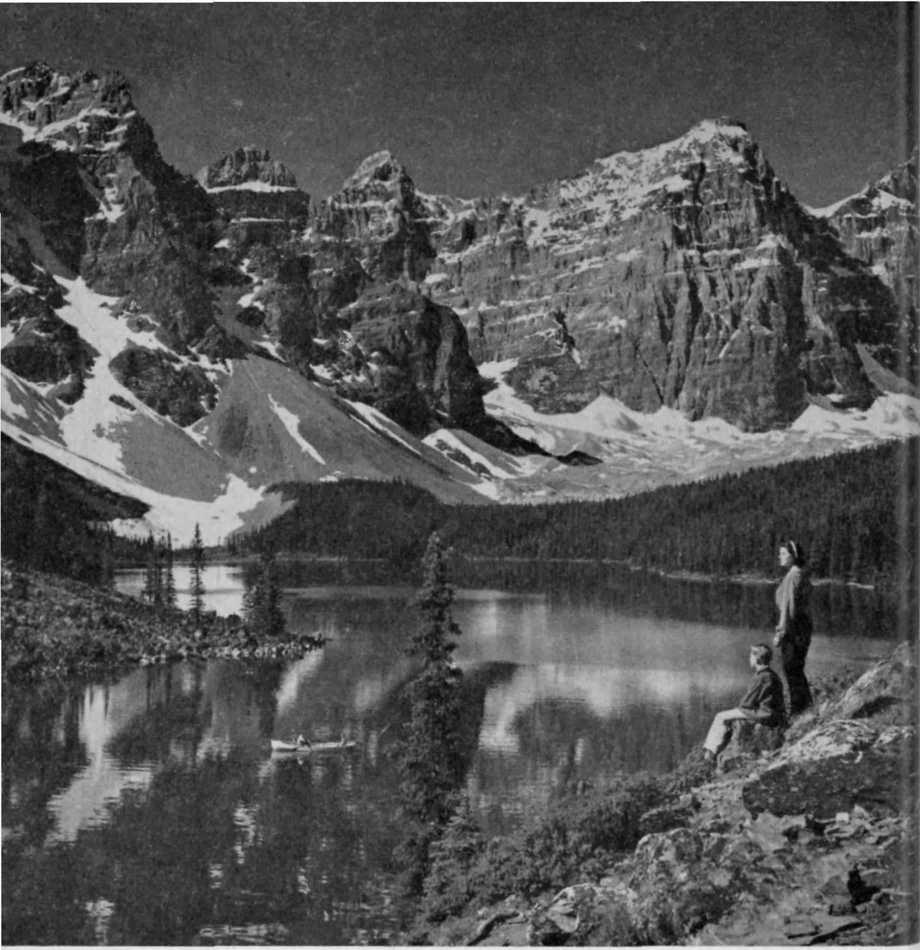
happens, the berg may eventually roll over and float in another position, perhaps revealing its load of rocks. This is a magnificent sight on a clear summer day with the dazzling white berg slowly rolling over on a blue sea and the seawater pouring off it in a thousand cascades. Occasionally they split in two with a roar like heavy gunfire. In summer icebergs are common in the sea off Terra Nova Park and you may actually see one turn over and split in two.

The glaciers which squeeze out of the Greenland valleys to the sea really represent the drainage of an area which is unable to rid itself in any other way of the precipitation which falls on it. Glaciers of this kind are thus truly "rivers of ice".

How Glaciers Flow

All along we have been referring to the "flow" of glaciers and have not yet remarked on the fact that ice, a solid, should be able to "flow" and thus carry precipitation from one area downhill to another. In earlier times when people had not begun to study them in detail, glaciers were looked upon as solid, inert masses of ice. Systematic studies, begun about 150 years ago, however, soon showed that ice in Alpine glaciers indeed moves, and, further, that it moves in much the way that river water moves. One of the earliest and simplest of experiments was the placing of a number of stakes or distinctively marked stones on the surface of a glacier. They were carefully surveyed from stations on the solid rock of the valley wall and then at intervals they were surveyed again. The change of position of the markers was a simple yet effective measure of the movement of the glacial ice.

The centre of the ice usually flows faster than the edges because of friction along the sides. The upper part flows faster than the bottom because of friction there. We know that valley glaciers have tributaries and that the whole glacier system looks like a river system. We know that irregularities in the



Glaciers and rivers carved these beautiful mountains from a great mass of rocks which was earlier uplifted by enormous forces within the earth. Here, in Banff National Park, Moraine Lake lies in a rocky bowl which is slowly wasting away to produce the talus slopes which you can see sloping down from the cliffs. The hollow, which holds the lake, was made by glaciers which scooped out the basin and partly dammed it up with masses of clay, sand and bouldery gravel.

bottom may cause the glacial ice to stretch and even break to form crevasses or open splits which climbers dread. In some places where the bed of the glacier valley becomes a great deal steeper in a short distance the glacier ice may split and break up into lumps which make the great icefalls familiar to all who have read of the climbing expeditions in such places as the Himalayas. Ice-falls may be seen on a modest scale in Canada's western parks at several places.

Not only does glacial ice flow at different rates within the same glacier but from glacier to glacier the rates differ even as in rivers, and in the same glaciers the rates may differ from year to year. One would expect that a very large snowfield with a small outlet would require a faster-flowing glacier to carry away the precipitation than a smaller snowfield with a larger outlet.

The fastest-moving glaciers, perhaps those of the margins of the Greenland icecap, may move forward 80 feet a day or about five miles a year. Moderate-sized glaciers in the Alps and other mountain regions, where snow-gathering areas are not so large in proportion to outlets, may move as slowly as 100 feet a year or as fast as 600 feet a year. Some of the huge glaciers of central Asia may reach a half-mile a year. Athabasca Glacier in Jasper National Park averages a little more than 50 feet a year.

We still have not answered the question as to how the seemingly solid glaciers 'flow'. Ice is fairly plastic near and at the melting point. This is brought about by what is known as translation-gliding in which crystals of ice are able to shear along certain directions and not come apart, or "lose mechanical cohesion", as the experts would say. Thus, under pressure of overlying or up-hill ice, the individual grains of ice are able to divide into parallel slices and these move microscopic distances past one another without the ice losing its solid structure. When all the millions of little crystals in a glacier do this the ice seems to flow forward.

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Another property of ice that helps it flow like a thick liquid is its quick refreezability. If movement is such that the ice actually breaks, on a big or little scale, the broken pieces quickly freeze again into a solid mass. Both these processes are on a scale we cannot see but when they occur in millions of grains of ice in a glacier they combine to make a "plastic flow" which is visible.

The Effects of Moving Ice

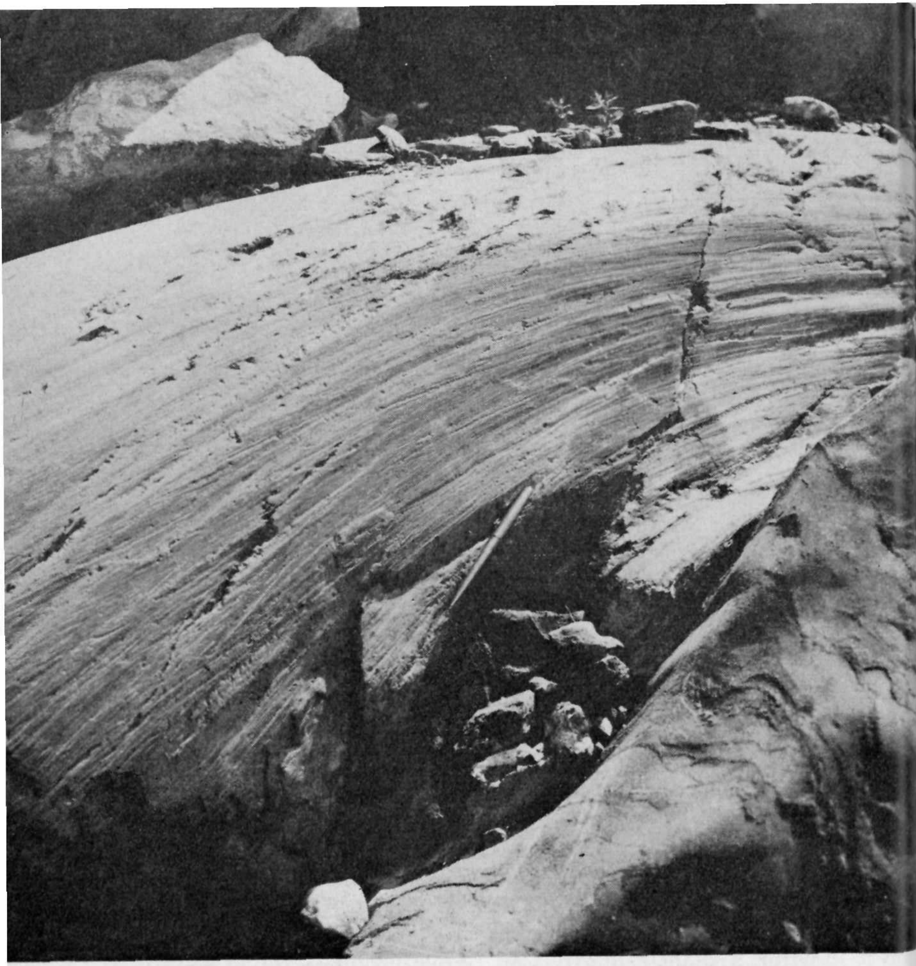
This movement of ice down narrow valleys or over broader areas has a profound effect upon the ground or the rocks underneath. The pushing forward of a wall of ice many feet high acts like a snowplough, until the pile of material in front gets too much to push so the ice rides up over the top of it, carrying with it as much as it can carry and leaving what it cannot.

Wherever the ice stops, this ploughed up material will be left as a ridge to mark the farthest penetration. The fronts of glaciers all over the world are marked by these front ridges or terminal moraines. Vast terminal moraines still mark the southern limit of penetration of the great continental glacier which covered Canada and the northern United States. These extend as ragged lines across the northern and north-central States and emerge on the eastern side as ridges which together make up Long Island and Cape Cod.

If the ice were to cross the grain of the country, ridges would be heavily scraped and eroded and valleys filled with glacial rubble. Rock basins would be scoured out and perhaps deepened. Rock surfaces would be scratched by the moving ice and particularly by the boulders and debris frozen into the bottom of it. All these would be left behind as evidence of the passing of the ice. An examination of any part of Canada shows, indeed, that it is a scratched-up country, for on fresh rock outcrops scratches and traces of scour and abrasion are almost universally evident.

Here, in Georgian Bay Islands National Park, the waters of Lake Huron wash surfaces of ancient rock which were polished and smoothed by the movement of the great icecap which covered northern North America in geologically recent times. In the left foreground, and again on the farther end, you can see channeling and scratching. You may also see that wave erosion has made no impression at all on the hard, resistant rocks.

After a glacier has passed, irregular deposits of material are to be found dumped over the country as a general cover. If you look at road cuts in many parts of Canada you will see a mixture of boulders, partly rounded and partly faceted, scratched and of various kinds, mixed with sand and rock-flour, without any sign of water action. This is called glacial till. With the melting of the ice a great deal of debris, already



Moving glacial ice scratches and channels rocks to produce surfaces like this one on the side of Grand Glacier in Glacier National Park. Now, after the ice has melted away from this spot, the scratched and polished surface shows clearly the direction of movement of the ice.

Ripple marks are commonly formed where waves sweep in over shallow, sandy bottoms. It sometimes happens that these surface features are covered by later muds and sands and are preserved throughout the process of hardening to solid rock. Thus, in some rocky outcroppings, we can still see the ripple marks which were made hundreds of millions of years ago by waves of seas which have long since disappeared.

dropped and overridden by the ice and also coming free as the ice melts will be picked up by the melting water, carried a short distance and then dropped again. The short ride in water, however, is enough to wash out the finest particles and separate the rest into layers, so that these outwash deposits, as they may collectively be called, are always banded or stratified. These too are very common all over Canada and the northern United States. Some of these water-washed glacial deposits are in the form of small steep hills or kames. Some are in the form of terraces along valley sides and others as a general blanket over the country. They are almost always the source of excellent gravels for road- and railroad-building.

Now we have come to know that Canada was once covered by an enormous icecap that scraped and scoured the country, filled in old valleys and dug out rocky basins, and left the country covered with an irregular blanket of glacial debris. We also know that we have only to go to Greenland, Antarctica, or high mountain regions to see the same processes at work today.

Where Did Our Icecap Begin?

Before we leave glaciers let us examine a few other questions about them and their effects on the scenery. Where, for example, did the snows accumulate or, put another way, where did the ice come from? By putting all the evidence together things like the directions of scratches on the rocks, and tracing stranded boulders back to their places of origin geologists can see clearly that four major centres of snow and ice accumulation accounted for our glacial age. One was situated in the Ungava Peninsula just east of Hudson Bay, and another was situated west of the main body of Hudson Bay. The ice from these two centres joined together and covered all of Canada from the western mountains to the Atlantic, and the United States north of the Missouri and Ohio Rivers, and eastward to Long Island. The western mountains supported another icecap made up of the coalescing of what started as many individual ice fields. It eventually flowed off the mountains to the sea on the west, and eastward to join the other ice just mentioned. Remnants of this mass of ice are still to be found in the high mountains. The largest is the Columbia Ice-field, which is shared by Banff and Jasper Parks. It is interesting to note that its meltwaters pass into three oceans: through the Saskatchewan to Hudson Bay and the Atlantic; through the Athabasca to the Arctic; and through the Fraser and Columbia Rivers to the Pacific.

Great Glacial Lakes

Can you imagine what must have happened when the ice was retreating northward as the climate gradually warmed up? The southern edge of the ice must have slowly retreated

northward, uncovering the country back towards the sources of supply. In Canada this process led to the formation of many large lakes as valleys and lowlands were uncovered while their outlets were still blocked either by ice or by glacial deposits. Thus one enormous lake, called, in retrospect, Lake Agassiz and larger than the combined areas of all the Great Lakes, was formed over what is now southern Manitoba and adjacent areas. Into this great lake, rivers and meltwater streams poured mud and silt which settled to blanket the bottom. After the glaciers retreated still farther, outlets to the north were uncovered and the lake gradually shrank. Lakes Winnipeg, Manitoba and Winnipegosis are remnants of it. The sediments laid down in this largely vanished lake are now the rich soils which cover much of southern Manitoba and make it one of the finest wheat-growing areas in the world.

Another of the very large lakes of this time was one which lay astride the Ontario-Quebec boundary in the latitude of Cochrane and Amos. Remnants of this one are to be found in Lakes Timiskaming and Abitibi and its passing is marked for us by the clay soils which cover several thousand square miles in that area.

Rivers and Lakes

After the glacial ice melted away the general shape of the topography had not altered very much but in detail the surface was entirely different. When the country was once again left open to ordinary climatic events, rivers tried to resume flow where they used to, but often found their old valleys blocked in places with glacial debris. Some parts of their valleys were entirely filled, but others were hardly touched. Rock basins and depressions made by glacial dams now collected water which overflowed and spilled out where it could. The result was a completely disrupted drainage pattern with only the broad outlines of the pre-glacial drainage

A hiker pauses to look across a great chasm towards Mount Stanley in Kootenay National Park. The snow patches among the peaks and the small glacier clinging to the side are the shrunken remnants of a great tongue of ice which carved the steep valley and made the enormous cliffs in the lower part of the rock wall opposite.

left. Rivers wandered from lake to lake, partly in old, well-established valleys, partly in new courses which could only be described as haphazard. The drainage in some places was so erratic and so dammed-up in depressions that as much as 60 percent of the area became lake and swamp. Ever since this happened streams have been seeking to establish equilibrium again by cutting down the outlets of lakes, removing obstructions that make waterfalls and rapids, straightening out erratic courses. Thus, visitors to the Muskoka Lakes, or those in the Laurentians north of Montreal, on lakes in Nova Scotia or in Prince Albert National Park all owe the beauty of the lake scenery to the cold, white ice of thousands of years ago that dammed up streams, pushed them out of their valleys and scraped out rocky basins.

Hydro-electric power developments are usually dependent on glacial history too, because it is in the glacial lakes that water is stored, and the falls that the power-plants are built on were formed where disrupted rivers fall over the sides of old valleys or off the edges of plateaus where they would not have ventured if the glaciers had not long ago changed their courses for them.

Great Lakes and the St. Lawrence

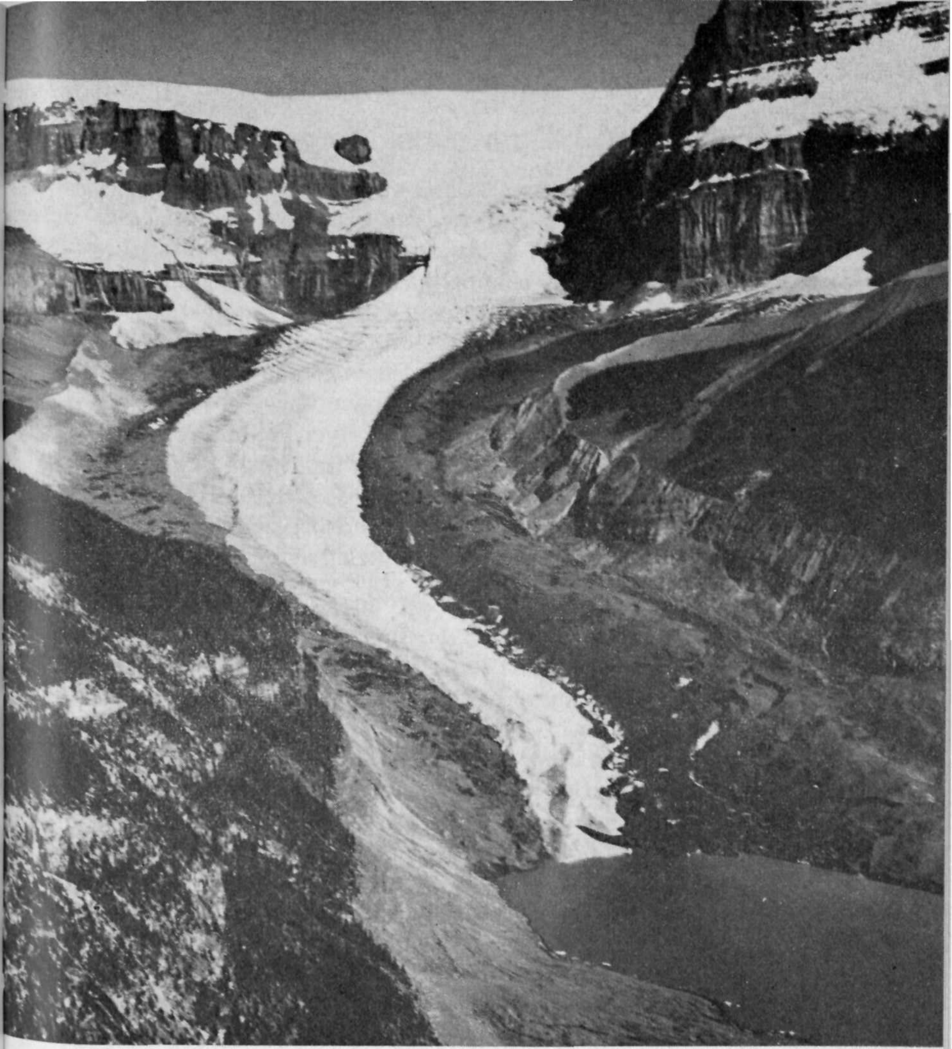
One cannot avoid talking of the Great Lakes and the St. Lawrence River when one looks into the effects of the glacial age in North America, for these enormous bodies of fresh water are direct results of the Ice Age. Prior to the amassing of an icecap, that part of North America consisted of a number of basins and valleys with drainage variously to the south and east. When the glaciers moved down over the land these basins were dug out and deepened and great piles of debris placed to the south of them. In addition, the crust of the earth in that region was actually bent downwards by the weight of the great mass of ice.

When the glacial ice had melted back to uncover the area, the basins were no longer able to drain themselves by the old routes, so filled up and found their drainage where they could. We know that at first this was different for old shorelines show that the lakes were much larger then, and we see evidence of rivers draining from Superior and Michigan southward to the Mississippi system, and from the others by various routes eastward to the Hudson River. The present topography took shape after a complicated history of alterations, as the land gradually came clear of glacial ice and as the whole area gradually came up again after the weight of the ice was removed. One of the new outlet rivers found itself flowing over a limestone cliff and formed the ancestor of Niagara Falls. During the thousands of years since then the falls have cut back to their present position, leaving behind the great gorge to mark their passing.

Summary

Glaciers are active now in all the high mountains, for even on the equator, if mountains are high enough, permanent ice is to be found modifying the scenery. Even now as we are reading about it, plastic ice is squeezing down the Greenland valleys, and giving birth to this year's crop of icebergs in the Atlantic. Rocks are being scratched, boulders are being lifted from the bedrock and carried off, piles of rock, sand and clay are being dumped at the ends of glaciers. The mountains of Antarctica are being heavily abraded by moving ice.

As we pause to look at a mountain glacier in Western Canada or polished and scratched rock surfaces in the east we must remember that we have no guarantee that the climate will continue to be as warm as it is now. Perhaps, once again, gradual refrigeration of the world climate will set in and once again an icecap will come scraping and creeping down from the north to cover all. Let us be very patient, however, for we may have to wait several thousand years to find out.



Columbia Glacier spills over from the Columbia Icefield, along the top margin of the picture, to push down the valley where melting finally overtakes it. Its sides are deeply covered in rock rubble which was mounded up into the steep sided lateral moraines at a time when the glacier was much larger than it is today.

ISLANDS

Many thousands of generations of men have passed since the first of them found that an island makes a fine place to build a protected camp, away from wild beasts and tribes with unfriendly ideas. Islands have long intrigued people from a scenic point of view. For us they are interesting not only for their scenery but also for their origins. Some are made when molten rocks are exuded onto the sea floor and gradually pile up to thrust at last above the sea. Some are found as masses of fine mud and silt in river deltas. Some are found as remnants of cliffs cut off from the mainland by erosion. Still others are made of the stony skeletons of minute organisms. But let us examine the kind of islands one at a time so that we may appreciate a little better how they are formed.

Islands of Submergence

You may recall from an earlier section that oceans seem to lie in distinct basins with the continents standing up as sharply marked blocks, and that the ocean basins are brim-full. We mentioned also that very slight adjustments of the relative levels of oceans and continental masses result in very large changes in shapes of shorelines as the oceans lap up on the shallowly dipping edges of the continental blocks. This all leads us to the idea that some shorelines are parts of the land mass which have been submerged in the sea. Hills on the old landmass would be surrounded by water in some cases and become islands. Long ridges would become long peninsulas sticking out to sea and the adjacent valleys might become deep indentations.

This is the way that most islands are formed. The myriads of islands off the coast of Newfoundland including those in

Terra Nova Park, Nova Scotia, and New England came about this way as did the islands of the west coast of Canada and the Alaska Panhandle.

You may remember that glaciers commonly blocked off the old courses of rivers with deposits of till and outwash so that lakes were formed. This effectively submerged parts of the landscape so most of the islands in lakes in Canada were formed by submergence. The scenery in St. Lawrence Islands National Park was formed in this way. Now what kinds of islands would be produced by submergence would depend entirely on what kinds of topography were submerged. A gentle rolling, river-worn country would produce islands of gentle contours while a rugged, steep topography would produce a rugged shoreline with rugged and irregular islands. In some places glacial deposits have been drowned so that islands are entirely made of glacial debris.

Thus when we sit on the shore and admire islands of submergence it is interesting not only to speculate on their origin but also on what the country must have looked like prior to the flooding of the land.

Volcanic Islands

Volcanic islands are not seen in Canada but are very important in some parts of the world. The Hawaiian Islands are really the tops of great volcanic piles which lie in some 15,000 feet of Pacific Ocean water. The Azores and islands of the mid-Atlantic like St. Helena and Ascension are the same. Bermuda is a mass of coral which rims the very top of another great volcanic island in the Atlantic. Many of the islands of the South Seas are of this kind, too, with older histories of violent volcanic activity which contrast sharply with the peace and quiet of the present.

Islands Made by Rivers

When large rivers carry sedimentary materials down to the sea great deltas are sometimes made. These usually consist of many islands separated by channels of the river as it breaks up into what are called distributaries. The Mississippi, the Nile, the Amazon—all the great rivers of the world have these. The deltas of the Mackenzie, Fraser, and Athabasca Rivers are studded with islands.

One does not have to go all the way to deltas to find islands of river deposition, for islands of sand, gravel and mud are often formed in times of high water in the river channels themselves and left high and dry during normal water. In some rivers the channels are so completely choked with sediments that the rivers are forced to wander in and out among the islands of their own making and look a little like braided plaits. On that account they are called braided streams. Some of the streams which issue from modern western Canadian glaciers are like this because of the great quantities of glacial debris fed to them by the melting ice. Rivers occasionally make another kind of island as they cut into the rocks which underlie their valleys. If a river encounters a zone of rock which is tougher to erode than the average it sometimes cuts around both sides of it making an island in mid-channel.

Islands Made by Waves

When shallow, shelving ocean bottoms are attacked by waves it often happens that long islands are formed a short distance from and parallel to the shoreline. As waves sweep in they eventually stir up bottom sands and muds and may carry them forward towards the shore. If the waves break at some distance out from the shoreline their load of sand and mud may be deposited at the line of breakers or just inside it. Storm waves may pile such materials high enough so that islands appear at times of normal water level. Long offshore bars and islands formed in this manner parallel the coast from southern New Jersey southward to Mexico and many resort cities are built on them.

Islands of Erosion

When a shoreline is attacked by wave erosion it rarely is cut away evenly for always some parts of it are less resistant than others and wear away more quickly. If waves thus eat into the softer parts the harder parts may be left sticking out as points. These may become cut off completely to form islands if the waves can cut in around behind them. Almost all exposed coastlines have islands of this kind on them.

Coral Islands

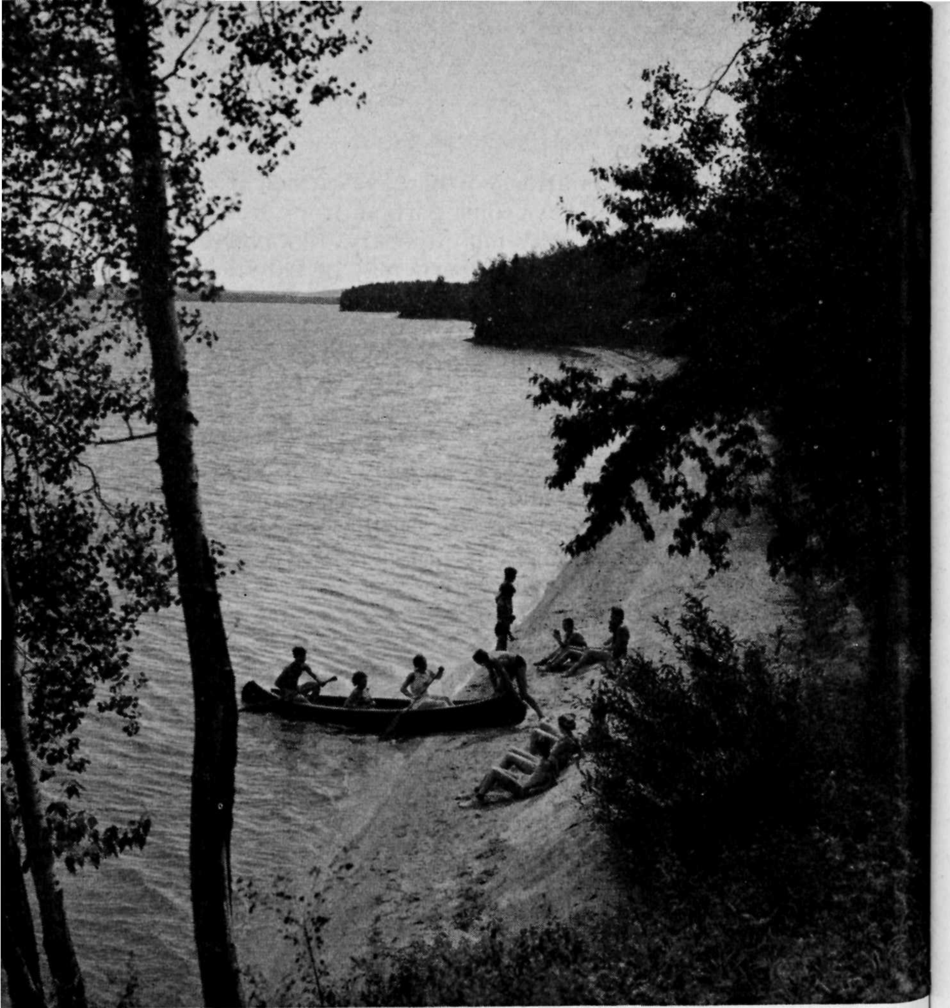
Corals are tiny sedentary animals which secrete heavy stony skeletons around themselves. They live in vast colonies in warm tropical waters and, over long periods of time, their hard parts may make great masses of limestone rock. Many of the volcanic islands in the warmer parts of the world have fringes of coral around their shores. Still others have reefs of coral which ring them just beyond a lagoon. A third type is the coral atoll, which is a ring of low coral islands with a sunken volcanic core completely covered with corals and coral debris. Again we do not have these in Canada but we add them to complete our list.

LAKES

We have just been discussing the origin of islands which are bodies of land entirely surrounded by water. Let us turn to lakes for a moment, to think of them as bodies of water entirely surrounded by land, to see how they originate. We pay a lot of attention to lakes because of their scenic beauty, their use to mankind as sources of water for domestic and industrial use, their function as reservoirs for hydroelectric developments and flood control, and even for their good fishing.

Glacial Lakes

Most lakes in the world have come from the disruption of normal drainage systems by glaciation. You may recall from



Beach scenes on lakes, like this one at Lake Waskesiu, Prince Albert National Park, Saskatchewan, are found in many parts of Canada. The lake was made by the glaciers which once covered the area, scraping away the old soils, damming up the old river systems and spreading sands and gravels widely over the region. Waves from the lake have washed the sand clean and piled it up into ridges along the beach.

our section on glaciers and how they work that, when icecaps or glaciers on a large scale scrape over the country in times of general refrigeration of the climate, soil and loose rocks are picked up and carried off by the ice to be dropped again when the load gets too big or when the ice melts. Shallow rock basins may be scooped out and valleys may be much modified. When the ice age is over after the climate warms up again, rivers may find the major outlines of the country unchanged but the details very different. Valleys may be blocked off in some places and rivers forced out of their channels. Water collects in all the places that accidents of glacial deposition have left hollows and lakes are formed.

Hundreds of thousands of such lakes dot the surface of Canada. In some areas as much as 60 percent of the whole surface consists of lakes. They vary from small puddles to giants like Lake Superior which has an area of 40,000 square miles and is the largest body of fresh water in the world. They may be a thousand feet deep or they may be little more than shallowly flooded boulder fields. They may be about the same size and shape as when they were first formed, or they may be largely drained, either because of the opening of new outlets or because their outlets have been cut down below their original levels by stream erosion. We have already mentioned that vast glacial lakes were formed when the ice was retreating in the face of a warming climate and water was trapped between higher lands to the south and the ice front on the north. When the ice withdrew still farther north outlets were opened up which largely drained the Lakes. Nowadays we look at Lake Winnipeg, Lake Winnipegosis and the complex of adjacent lakes as the remnant of a much larger lake formed in this way. Old shorelines and beaches can be clearly seen many miles away from the present lake waters. The Great Lakes were much larger at one time than they are now and old beaches, beach bars and even islands are now high and dry, miles from the shoreline.

Some of the most beautiful of all glacial lakes are the small ones called tarns which nestle in "cirques" or glacially carved bowls in mountain regions. As moving ice scoops out the bowl-like cirques the waste is piled up somewhere below. It often happens that small depressions within the glacial bowls are filled with water when the glaciers retreat or disappear. These are often very beautiful with their settings in rocky bowls, almost surrounded by great cliffs, and snowfields or even glaciers above them to reflect in their waters.

Lakes Made by Landslides and Lava Flows

Rivers are occasionally dammed by landslides and lava flows to form lakes. Their size would depend on what shape the river valley is and how big a dam was made. One which was formed by a giant landslide in central Asia, is 45 miles long and 1,650 feet deep. Earthquake Lake was formed in the valley of the Madison River in Montana in August, 1959, when an earthquake set off a landslide which made a dam of rock rubble 200 to 400 feet deep. Mudslides in smaller streams on the other hand may raise the water level only a few inches and be entirely worn away in a few days. Lava flows rarely make dams in stream valleys.

Lakes Made by River Erosion

When streams flow on flat surfaces they often have very crooked and winding courses. If a looping bend or meander in a river gets tight enough the river may cut through the narrow neck of land and by-pass the loop. The two ends of the cutoff may be rapidly silted up by the main river, leaving what is called an oxbow lake. The courses of many rivers are studded with oxbow lakes.

Lakes by Interior Drainage

It occasionally happens that sections of the earth's surface are made lower than their surroundings as a result of great

earth stresses which cause some areas to fold or to sink downward because their supports are removed. In some limited areas depressions may be caused by wind erosion or irregular distribution of glacial deposits. If there should be precipitation in such an area, the waters would run towards the centre of the basin and a lake would be formed. If there is enough precipitation in the area to fill the depression the water will rise until an outlet is found and a normal drainage system established for the lake.

In some areas, however, precipitation can only fill the depression partway before evaporation or seepage through the ground keeps up with the inflow of water. Since all rivers carry some salts in solution in their waters, evaporation in lakes with no outlets will leave the salts behind to form salt lakes. The Dead Sea, the Caspian Sea, Salt Lake in Utah and hundreds of small salt lakes in southern Saskatchewan and Alberta are formed this way.

Man-made Lakes

In many parts of the world the only lakes are man-made. Streams and rivers are dammed with earth, wood, concrete and steel for hydro-electric power installations, flood control, domestic water reservoirs and a great variety of other purposes.

The shapes of such man-made lakes are usually distinctive because they are usually water-filled valleys. The lakes thus formed are elongated parallel to the main river course, wider at the dam end than on the upper end, and they usually have arms which are the flooded valleys of tributary streams.

Animal-made Lakes

Small lakes are made by beavers in many parts of Canada by damming streams with sticks and mud. Some of these cover several acres and it is usual for several to be found in a series along a stream course. As the water spreads into the woods on the sides of a dammed brook the trees usually die off leaving a stub filled and rather unattractive pond or lake. If the animals are killed off or the site abandoned for any other reason it is usual for the dam to be breached quickly and the lake drained.

Volcanic and Structural Lakes

Lakes are sometimes formed in the craters of inactive volcanoes or in pits which are formed when old volcanoes collapse. Such a lake is Crater Lake in Oregon and several of this kind are known in Mexico. Small lakes are also formed when basins are formed by the subsidence of small areas because of structural weaknesses of the earth.

Sink Lakes

Limestone, gypsum and salt are materials which occur in normal sedimentary rocks in many parts of the world. These are all very soluble in ordinary underground water. If, over a period of time, large openings or caves are dissolved out of such rocks near the surface, they may be unable to support their roofs and collapse. Some of these sinks then fill with water to make small ponds and lakes. Several areas in Nova Scotia, Newfoundland and New Brunswick are pitted with sinks and sink lakes, as are some sections of northern Alberta and the western mountains. Some of these occur just outside the boundaries of Cape Breton Highlands Park.

Conclusion

Lakes are formed in many ways by damming of the natural flow of water on or near the surface of the earth. They are all temporary, however, for the outlets are constantly being cut down to drain them, silts settle out of the quiet waters to fill in the basins and vegetation spreads out from the shores to cover them.

GEOLOGICAL TIME

Introduction

People have always been interested in time and its passage, looking ahead to future things and back to what has already taken place. In a very early chapter we showed that physicists, astronomers and geologists have come to the conclusion, from different lines of evidence, that the earth is between four and five billion years old. Thus, in geology, we have to deal with a very long period of time compared to the three score years and ten of a human lifetime, and we realize from this what a tiny fraction of earth history that each one of us will see.

In human affairs we divide time in two separate ways—the absolute way and the relative way. The absolute way depends on an accurate measure of time. Thus, we may say of an event that it will take place in two hours and twenty minutes or that it took place 241 years ago. The relative scheme uses major happenings, so that we date an event as being pre-war or post-war, as being pre-Confederation or post-Confederation. Until recently, when a small beginning has been made, no accurate and widely applicable system of measuring absolute time has been available to the geologist. On the other hand a record of the earth's past is preserved in the rocks and has shown many events of world-wide importance. It was, therefore, natural that geologists should have developed a relative calendar for the measurement of geological time.

Great Events of the Past

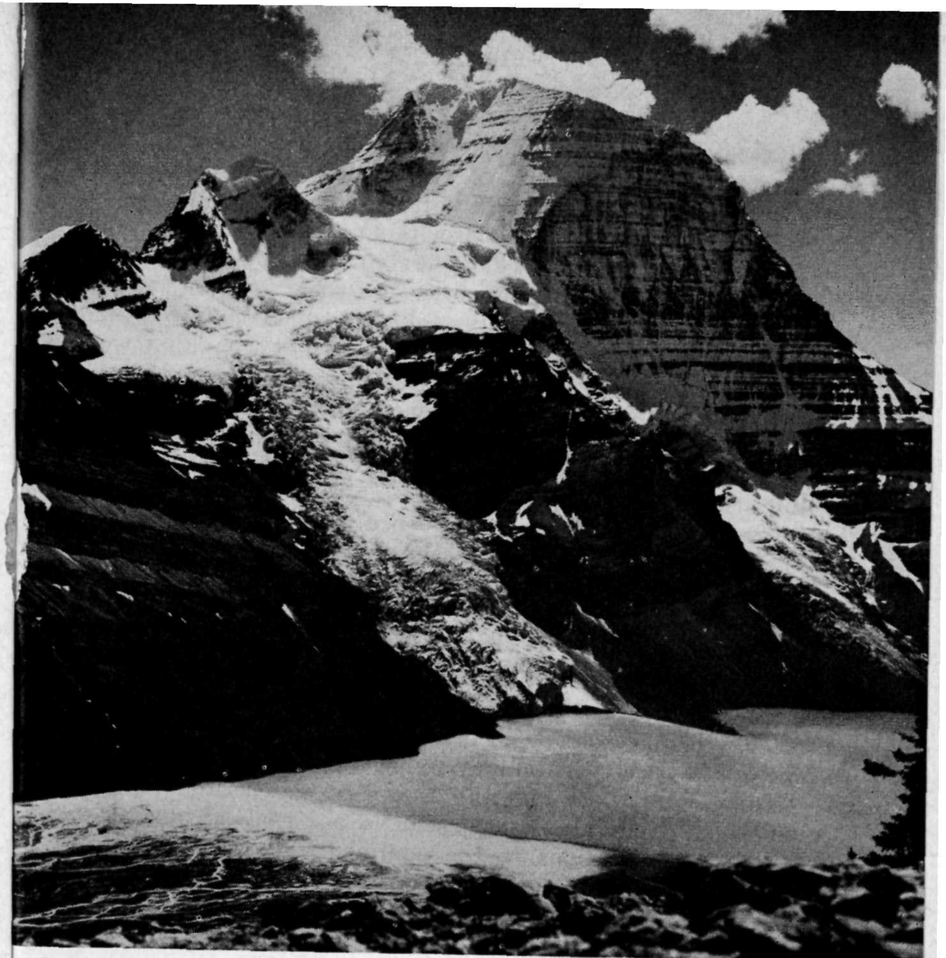
What are these events and what kind of record could they leave in the rocks to tell us of their happening? The earth's history seems to be punctuated at irregular intervals by great upheavals of parts of its framework. This kind of thing the geologist refers to as mountain-building because mountain systems result from the folding and buckling of the earth's outer layers. No one really knows why these great periods of disturbance take place. They may be related to the shrinkage of the earth as it cools down. They may be related to movements of the continents on some sort of a mobile or plastic substrate. Regardless of why they take place, they do take place, and these great events make convenient dividing lines in time.

The earth's history, too, is periodically marked by great volcanic outpourings. These seem to be related in some places to the periods of mountain-building we just mentioned. These outpourings leave behind them great masses of volcanic rocks. ashes, and dust, which the geologist can recognize even millions of years later.

Even more important are events related to the seas. You may recall how the ocean basins are quite well marked from the continental masses which rise from the ocean depths. The edges of the continents are gently sloping for the most part, and, coupled with the fact that the ocean basins are full to the brim, this means that the slightest adjustment of levels of either one will alter the distribution of shallow seas, which sit on the continental mass even as Hudson Bay and the Baltic Sea do now. The geological story is filled with chapters which seem to begin with the spread of shallow seas on the continents and end as they withdraw again.

The Fossil Calendar

Still another series of events which provides a method of dating rocks on a comparative calendar relates to living things, and their remains which are found in the rocks. Creatures which live in certain environments may leave behind them hard parts, like bones or shells, which will serve to identify them exactly. Thus a clam may live on a muddy bottom in the sea. On its death, the soft fleshy parts may disappear but the hard shell remains. As muds accumulate on the bottom of



The very beautiful snow and glacier covered northern slopes of Mount Robson with Berg Lake below supply this spectacular view from the western boundary of Jasper National Park. The horizontally layered rocks of Precambrian and Cambrian age are typical of most of the famous peaks in the Canadian Rockies.

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the sea the shell may become deeply buried. The muds turn to rock with the passage of time and still the shell remains identifiable. Such remains of ancient living things in rocks are called fossils. They provide us with a cross-section or sampling of the life of the time at which the containing rock was accumulating as a sediment. If this were the whole story we would be no farther ahead in dividing geological time. We have found, however, in 170 years of careful study that the oldest rocks are without traces of living things, that recent rocks contain fossils of things much like those of today, and that rocks in between are full of remains of organisms which show that life was different from what it is now. As a result we believe that life has changed since it first appeared on the surface of the earth, through a traceable sequence to its present-day state. This means that we have a changing pattern of life across a period of time; fossils which show what the pattern was at the time the containing rock was laid down as a sediment; and, therefore, a way of fixing the age of that rock relative to the changing pattern.

In review, then, we have several kinds of events by means of which it is possible to draw up a time-table to mark the geological past; mountain-building episodes in which great folding, faulting, and upheavals took place; volcanic outbursts in which massive outpourings of lavas, ash, and dust mark the event; invasions of the continents by shallow marine waters which leave their record in the rocks; and a changing pattern of living things which means that rocks which contain their remains may be dated relatively by them.

The Latest is on Top

Even if none of these methods were applicable we could still draw up a sort of geological calendar based on the Law of Superposition, a grandiose title for a simple principle. Very soon after it was realized that sedimentary rocks are formed

from muds, sands and gravels on the bottom of the sea or in river deltas, it was realized that the last ones to be formed lie on top of those which were formed earlier. This seems very sensible, for if we scatter layers of sand on the floor, one after another, the last one should be on top of the pile and the first on the bottom. This is all there is to the Law of Superposition —in a sequence of layered rocks the youngest lie on top and the oldest on the bottom, so that more recent geological events would be recorded in the younger or top rocks and older ones in the ones underneath. Now when you look into the Niagara gorge or any other river valley, or at the great walls of rock in the western mountains, you may recognize that the rocks in the upper parts were laid down after the ones in the lower regions, perhaps thousands or even millions of years later. Even if mighty upheavals of the earth's outer layers disturb the flat-lying rocks and tilt them out of their original positions the Law of Superposition still holds in a broad way. In a few, rare localities, sequences of layered rocks are actually turned upside down, but in these places folding and faulting are so severe that the geologist is on the lookout for the exception to the general law and uses other methods.

From all these sources of evidence, then, a history of the geological past was built up from the record without benefit of any way of telling absolute time, but only with ways of telling the order in which ancient events took place, and something of their size and importance.

Radioactive Clocks

The measurement of geological time on an absolute scale is a complicated physical and chemical exercise in techniques but like many complicated technical processes it is based on a fairly simple principle. Certain minerals are subject to radioactive decay as soon as they are formed. Radioactive decay takes place at a constant rate and produces recognizable

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by-products. Thus, if the ratio of the by-product to what is left of the original mineral material is measurable, and if the rate of decay is known, then an accurate measure of the time which has elapsed since the mineral was formed is possible. Several different minerals with several different radioactive elements in them provide us with several different methods of measuring geological time on the absolute scale. Measurements of time in this way have confirmed to a surprising degree the relative calendar.

The Geological Calendar

It is time, now, to have a look at the geological calendar we have been describing. Like any other calendar it has time units of different sizes on it. It is also filled with strange names but this is understandable in view of the way it was developed over a period of time by the relative methods we have described and by different workers in different parts of the world. Thus the Devonian period is named for Devon, where the rocks which represent that period of time are reasonably well exposed and where they were first described. Others have been named for other places for similar reasons and include Permian for the Russian province of Perm, Jurassic for the Jura Mountains. Some of the names of the periods come from the kind of rocks commonly found in them in their original localities. Thus we have Cretaceous, from the Latin name for the chalk which characterizes rocks of that age in Britain and France, and Carboniferous for the period in which coal was commonly formed.

In the accompanying geological calendar you will find the names of the time units, how long each was and how long ago, and something of the events which took place in those periods. It is important to think, as you read it, of the way in which it has been drawn up and that the figures on it are pretty accurate but really are intended to give us a general idea of when these ancient events took place.

Living Things and Their History

From the geological calendar we can see that the history of life on earth extends back into the shades of the past perhaps a billion years. Fossils show us that a great change seems to have taken place at about the beginning of the Cambrian, when fossils suddenly appear in great numbers and in greater variety than in earlier rocks.

Now the living things which are found in abundance as fossils in the Cambrian are very different from the creatures we find about us now; different in two ways—different in kinds and different entirely in the balance of numbers. Nowadays we think of the vertebrates, the animals with backbones like fish, reptiles and mammals, as being the dominant and most successful creatures of the time. In the Cambrian, vertebrates were as yet unknown. Further, the lands stood treeless and naked and the seas were apparently dominated by a couple of forms of invertebrate life, the one, brachiopods, somewhat like clams in their organization, and the other, the trilobites, a group of long-extinct crustaceans, or lobster-like creatures.

The story of the gradual change from these modest beginnings in the Cambrian, some 500 million years ago, to the diversity and complexity of modern life is one of the most fascinating of all branches of knowledge. The first forests spread over the land late in the Silurian period, perhaps 340 million years ago, and coincided more or less with the rise of the fishes in the oceans of the day. Great forests of trees, now extinct, spread over enormous swamps marginal to the seas of the Carboniferous period some 270 million years ago and gave rise to vast deposits of coal in many parts of the world.

The Triassic and Jurassic, beginning 200 million years ago, were marked by the amazing success of the reptiles which culminated, in the Cretaceous period, in creatures of enormous size and variety, including the dinosaurs. These creatures have been extinct now for 60 to 70 million years. They were replaced

THE GEOLOGICAL CALENDAR

Era	Period	How Long Since It Began in Millions of Years	Major Physical Events in Canada	How Living Things Were Changing
Cenozoic	Quaternary Pleistocene	1	Scenery became what it is today after a period of heavy glaciation which covered much of Canada and the northern United States.	Life became essentially modern. Most of man's history is in this short period of time.
	Tertiary Pliocene Miocene Oligocene Eocene Palaeocene	70	Erosion with various uplifts of the land in the east. Western mountains were deeply eroded with filling in of basins between them, with several periods of uplift.	Modern plants spread widely. Mammals which were rare and primitive at beginning diversified and became numerous with rise of modern forms. Seas teemed with modern-looking invertebrate animals.
			Rocky Mountains folded and uplifted	
Mesozoic	Cretaceous	125	Long and profound erosion in all of the east. Vast inland seas laid down rocks which now cover much of great plains area. Some making of mountains near the Pacific Coast.	Reptiles began modestly in Triassic, then had great climax in dinosaurs, flying reptiles, marine forms in abundance in Jurassic and Cretaceous, then sudden extinction. Forests started as mostly conifers and ferns but saw spread of flowering plants and grasses in late Mesozoic. Marine invertebrates included many which are now extinct.
	Jurassic	165		
	Triassic	200	In east, lava flows and erosion with infilling of local basins like the Bay of Fundy region. In west some mountain building and some flooding of the interior by seas.	
			Mountains formed all along eastern seaboard of North America extending up into Maritimes and Newfoundland.	Permian saw end of many forms with long and successful histories in invertebrate world.
Palaeozoic	Permian	230	Widespread deserts surrounding shallow inland seas.	Late Palaeozoic forests mostly of spore-bearing and fern-type trees. First reptiles and insects in Pennsylvanian.
	Pennsylvanian	260	Coal deposits laid down in great swamps in some parts of the Maritimes.	First forests in late Silurian or early Devonian.
	Mississippian	290	Red beds and gypsum in parts of Maritimes. Marine deposits in West.	Devonian seas dominated by primitive fishes; corals and crustaceans common.
			Severe folding and faulting of older rocks in eastern area	
	Devonian	330	Great inland seas like the modern Hudson Bay covered much of what is now North America and in them thick accumulations of sedimentary rocks took place.	Early Palaeozoic saw fishes replace invertebrates as dominant marine forms. Lands were probably naked of vegetation in beginning but plants gradually spread over favorable areas.
	Silurian	360		
	Ordovician	420		
	Cambrian	500		
			Long erosion in most parts of North America	
Precambrian		4,000 ±	Ancient rocks which have since undergone great changes during mountain building and igneous intrusion were laid down, folded and deeply eroded many times. The bottoms of a few of the western mountains show these old rocks in little disturbed condition.	Many of the invertebrates were living in Precambrian times but the fossil record is very sparse because of the lack of preservable parts and destruction of most fossils by metamorphism.

at the end of the Cretaceous by the mammals which have gradually developed to their present-day variety and specialization of purpose and habitat. The appearance of the flowering plants dates only from the same Cretaceous period. And our own ancestors? Well, the best estimates place the first primitive man on the very top leaf of our geological calendar, probably within the last two million years.

Scenery on the Calendar

The modern scene around us results from a compounding of very ancient events with very recent developments on the geological calendar. The lakes we go to in summer may have been produced by the glaciers disrupting the drainage of the area within the last 50,000 years, but the rocks which enclose them may be a billion years old. The Falls of Niagara may have been made only 15,000 years ago yet the rocks wh'ch make them possible are of Silurian age and were laid down in the seas of 350 million years ago. The rivers which roar through the canyons and steep valleys of the western mountains may be but a few tens of thousands of years old, yet their valleys are cradled in rocks which range from the billion-year-old Precambrian to the nearly recent. The whole complex of living things on the earth at present is the culmination of a gradual changing pattern or evolution from beginnings lost in the haze of time but which must have been nearly a billion years ago. The whole subject of geological time and the enormous span of years which we have to deal with makes man's appearance on earth a very recent event indeed.

EARTH'S ARCHITECTURE

Sedimentary rocks are laid down on the bottom of the sea in more or less horizontal layers or strata. In places where the sea has withdrawn from the land such sedimentary rocks may

be seen in their original horizontal positions. Great areas around the west side of Hudson Bay are like this as are the St. Lawrence Lowland and the Niagara Peninsula.

Flat Rocks and Folded Rocks

On the great plains of Central and Western Canada we note that for thousands of miles the rock formations are flat-lying layers of limestone, sandstone, and shale with occasional layers of conglomerate. We know that they were laid down in ancient seas which once covered those areas, for the rocks are full of marine features, like ripple marks, and fossils or marine creatures. It would seem that the flat rocks of that area are in the same position in which they were laid down. If we travel a little westward, however, we find that the rock layers are undulating blankets which are more and more steeply undulating the farther west we go. It appears that here the rocks have been squeezed and compressed so that they have folded, in much the same way that a carpet is thrown up into wrinkles when we push our foot against it. In the Rockies themselves we can look up at the sides of great mountains and see the folded and wrinkled rock layers or strata in all sorts of contorted attitudes.

Faults

Here, too, we can see where compression became so great that the strata were no longer able to take up the slack by folding but were broken, and the broken slices pushed over one another. These breaks in rocks along which movement has taken place are known as faults. In some places the broken masses of rock can be matched with the roots from which they were torn and the amount of the movement can be worked out. It may be only a few inches or it may be several miles. There is hardly anywhere where the rocks are not broken on some scale by these faults.

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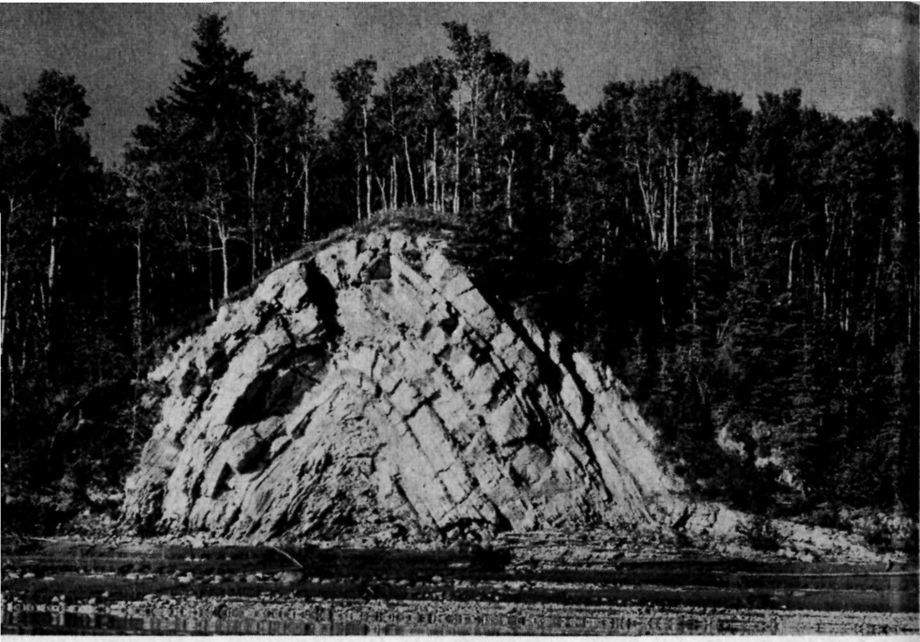
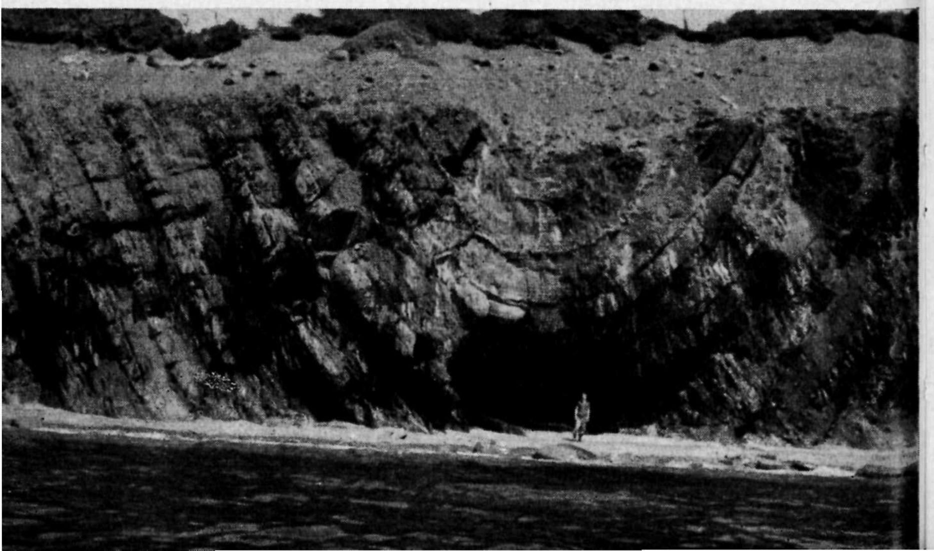


Great pressures in the outer parts of the earth's framework buckle and fold the rock layers in much the same patterns that you can make by pushing your foot against the carpet on a hardwood floor. In this photograph gypsum beds opposite Peace Point in Wood Buffalo National Park are shown pushed up into an anticline or upfold.



Some faults make conspicuous landmarks either by the actual motion of one rock wall upward to produce a great line of cliffs, or by providing a zone of weak rock along which rivers may place their valleys because of the ease with which the broken rock can be removed by the running water. The western mountains of Newfoundland end in a great series of cliffs almost 200 miles long. Here a fault system marks a line where the rocks on the eastern side have risen thousands of feet upwards to form the cliffs and to expose older rocks on that side. The mighty Sierra Nevada, in California, 75 miles wide and 400 miles long, is the result of a great tear or fault in the earth's outer layers with tilting towards the west. The long straight valley which leads southwestward from Aspy Bay in Cape Breton has a great fault wall on the northwest side. The Cabot Trail climbs up this great scarp in Cape Breton Highlands National Park. The earthquake in Montana in the summer of 1959 resulted from movement along a fault which left a freshly made cliff 15 feet high and many miles long in the valley of the Madison River.

Most mountains are the result of both folding or wrinkling of the outer layers of the earth, and faulting. Fabulous contortion of the rocks took place to produce the Alps in Europe. Parts of the Appalachian Mountains are sliced blocks of twisted rocks which once lay horizontal on the floor of an ancient sea. In the Rockies and Selkirks in the National Parks of Western Canada many examples of this folding and faulting are seen.

The movement along faults is sometimes actually visible at the time of break, although it is best to be somewhere else at the time. Hundreds of people were in the vicinity of the fault in Montana mentioned just above. The California earthquake of 1906, after which a great deal of San Francisco burned, was due to horizontal movements along a 250-mile section of the San Andreas fault. One side of the fault moved horizontally past the other by a maximum of 21 feet. In other

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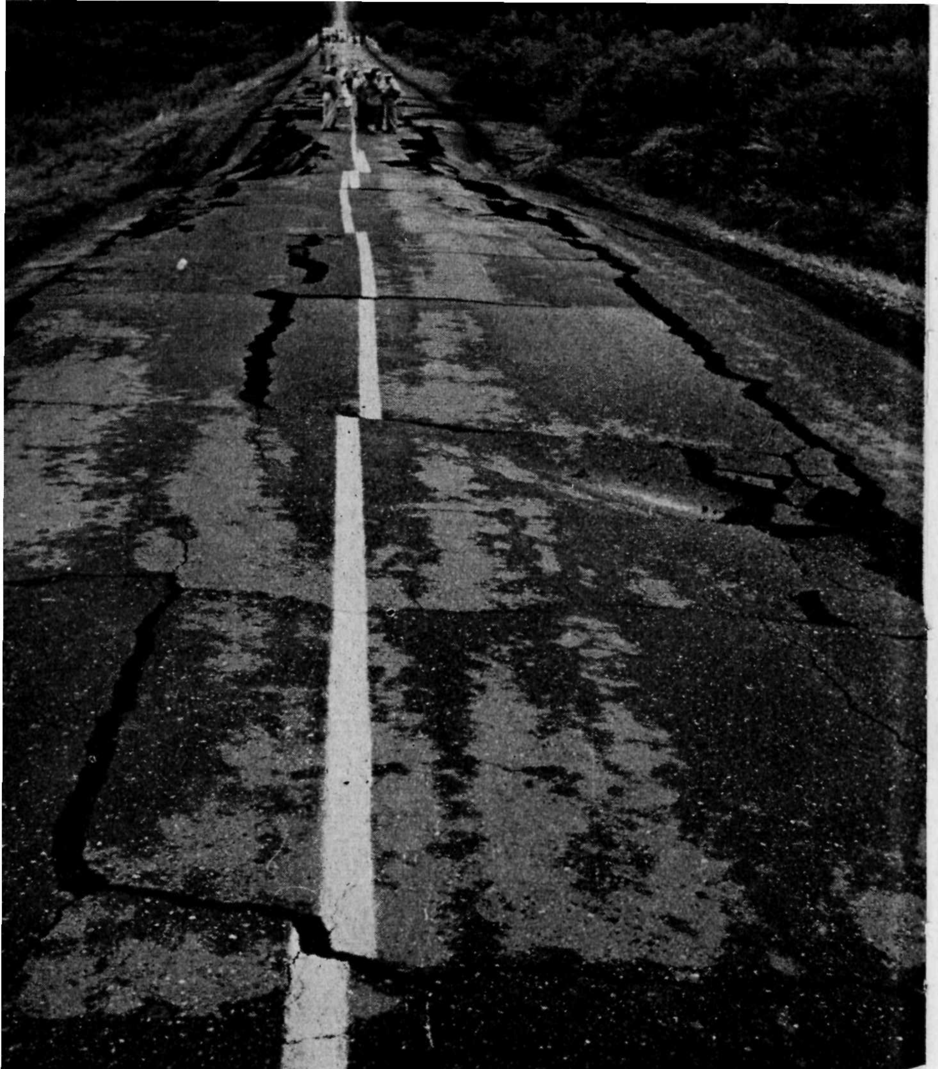


The earthquake in Montana in the summer of 1959. Movement of the earth is graphically shown by the displacement of the pavement and the broken centre line on this road.

places the sudden movement along faults, really a snapping motion which suddenly releases gradually accumulating stress, has produced assorted movements of a few inches to 80 feet. Earthquakes are really the shock waves which move out from the great bang that results when the rocks break and move abruptly past one another.

All this description seems to mean that the outside layers of the rocky earth are flexible up to a point at which they break and tear. The result is that folded, twisted, and contorted strata with faults or breaks in them are common in some parts of the world. In other places the strata or layers are as flat and undisturbed as the day they were laid down on the bottom of the sea.

Igneous rocks bend and break in the same way as sedimentary rocks but one would not expect great masses of granite to do much folding. Sometimes in granite masses faults seem to be about the only visible structure.

It may seem a little difficult to think of rocks being folded because in our ordinary experience they are strong and resistant. Forces within the earth, however, are adequate to bend and break even the resistant rocks.

Kinds of Folds and Faults

The kinds of folds and faults which are produced can be classified into a few groups, and while this is a subject for the experts we can improve our appreciation of scenery and what we are looking at by learning a little about them.

If we wrinkle up a carpet on a floor we can see that two kinds of folds are produced, which we can call upfolds or arches and downfolds or troughs. Each fold has two sides. In the upfolds the two sides dip away from each other as we travel down from the crest and are called anticlines on this account. The sides or limbs of the troughs or downfolds dip toward

Mountains to the east of Banff lie in that part of the Rocky Mountain system that is characterized by great folding and faulting. The rocks on the far wall in this view show a syncline or downfold to the left and an upfold or anticline to the right. Waste from the eroding mountains accumulates as scree slopes below.

one another and are called synclines. Anticlines and synclines are similarly produced in rocks by compression or squeezing together.

Faults or breaks along which there has been some movement may be produced by compression too. Rocks may first fold and crumple when they are squeezed. If the compression gets more severe the rocks may break along irregular planes

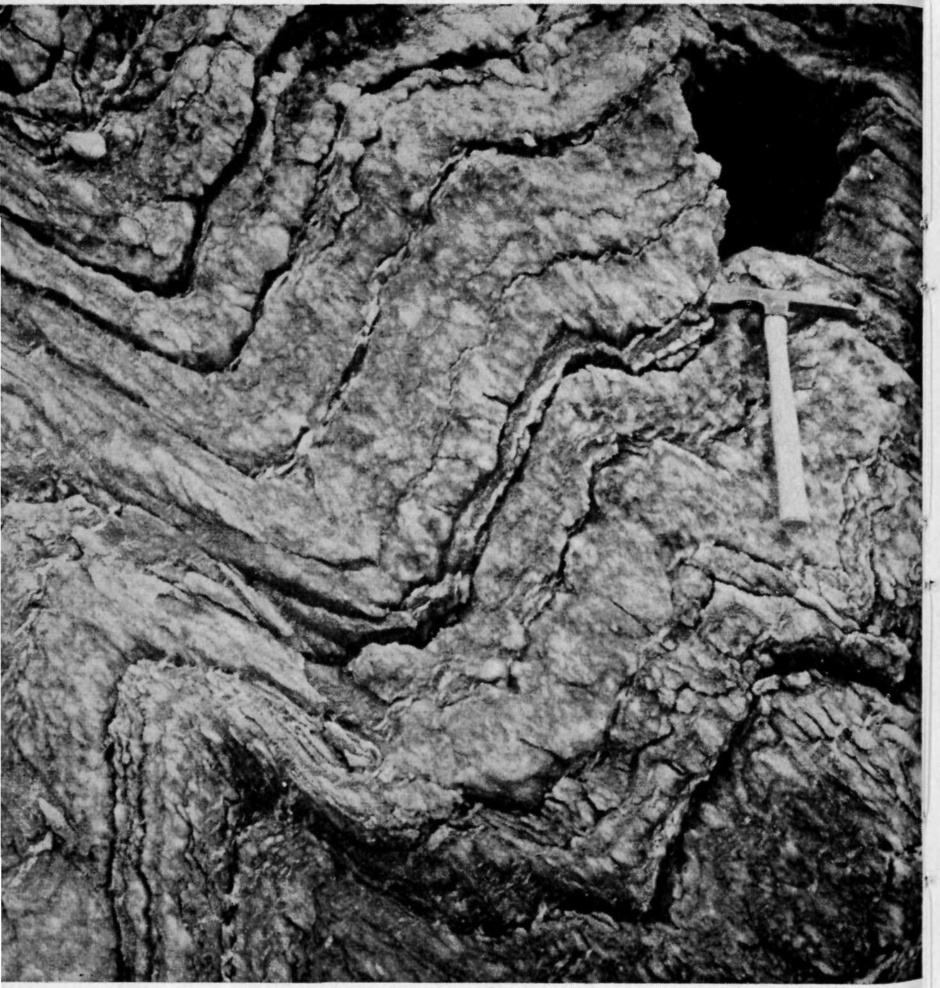
with a low dip and the upper slice may move across the lower. Such faults are called low angle thrust fault and movement along them may be as much as several miles.

Other faults are produced when rocks are stretched. Most of these are steeply dipping and, when anybody looks at one in the side of a mountain, it gives the impression that the rocks have been broken apart and one side has dropped down. When large granite masses cool they shrink a good deal and tension or stretching may cause numerous faults along their margins. If there is no movement to speak of along such breaks they are called joints. All rocks seem to be broken in this manner in some degree and in some places the joints are so closely spaced that it is difficult to get out a block of stone more than a few inches long.

Veins

When joints or cracks in rocks are filled with some material other than the surrounding rock we refer to the structure as a vein. Groundwaters percolate through adjacent rocks and may dissolve out some material such as calcium carbonate or lime and then precipitate it in openings. Waters from hot igneous masses, deep below the surface, may also fill spaces in rocks and veins. Calcite and quartz are the most common vein fillings and you may be able to identify these minerals from the Table of Minerals facing page 28.

Veins may be several feet thick and a mile long or may be paper-thin and only a few inches long. They may be filled with coarse grains of some mineral or with a fine featureless mass. When veins are not completely filled the openings in them may be lined with lovely crystals. Some veins have valuable minerals concentrated in them and are mined.



Anticlines and synclines (upfolds and downfolds) almost always occur together. Here a rock has been folded into a wavy pattern by compression.

Summary

Rocks are not solid and immovable as they may seem but, instead, may be wrinkled and folded, broken and pushed about. Cracks and openings in them may be filled with secondary materials to form veins.

THE FORMATION OF MOUNTAINS

Introduction

No one defines mountains very carefully beyond saying that they are places which are higher than their surroundings. The reason for this is probably because it takes different things to make mountains in different places. In Montreal, "The Mountain" is Mount Royal, a place which stands about 500 feet above its surroundings. In Hamilton, "The Mountain" is the edge of a terrace which is only a few hundred feet high. In the Maritimes and Newfoundland it takes a thousand feet or so to qualify. But none of these would be much more than a slight rise if it were to be found in western Alberta or British Columbia where even the "foothills" are that high.

We can agree, however, that mountains are relatively high places and that, as a result, they are subject to erosion. Streams flow faster on them and cut deeper into them. In high mountains glaciers cut into the rocks and frost splits them apart. Landslides and talus slopes indicate more of the erosion that takes place there.

What makes the mountains high in the first place is not entirely understood. We can only say that great pressures in the earth's outer layers seem to buckle up great belts of the outer part of the earth's frame, wrinkling and breaking the rocks in some places, but only uplifting them gently in others. This means that the kinds of rocks and the kinds of structures within them will be different in different mountains.

Volcanic Mountains

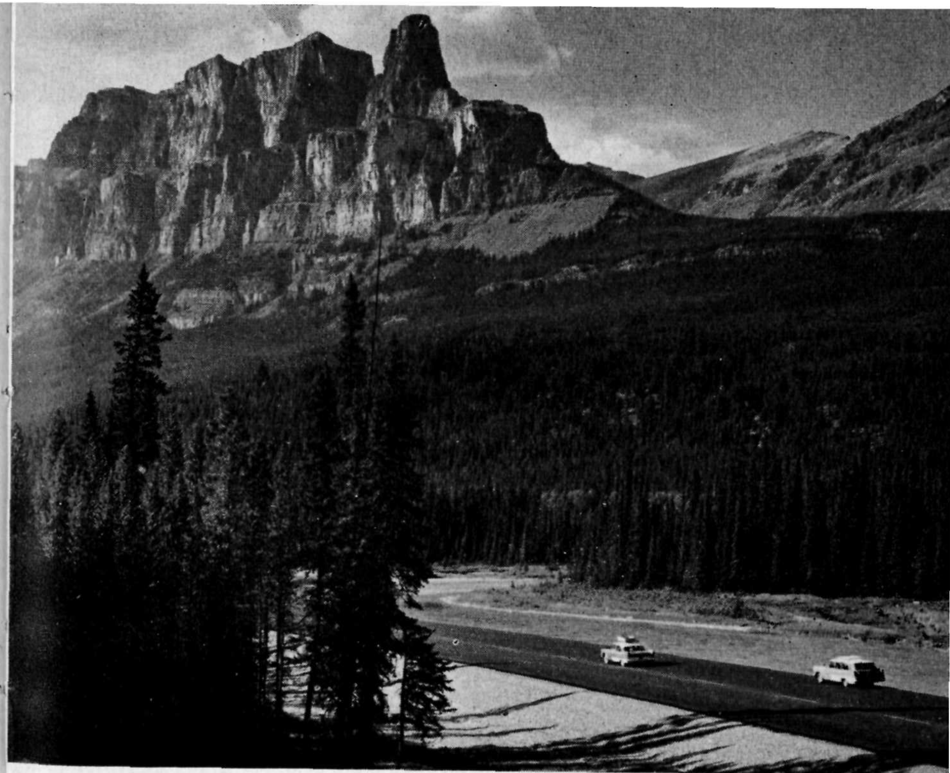
Mountains are sometimes made by the accumulation of masses of molten rock and ash which pour out onto the surface of the earth. Sometimes these mountains are beautiful, symmetrical cones like Fujiyama in Japan, or Osorno in Chile. Some of them are in the sea and appear as islands when their tops stick out of the water as in the Hawaiian Islands and Bermuda. Others, like Etna and Vesuvius in Italy are less regular in their shapes.

Mountains by Subtraction

It is odd to note that the mountains which we look up to in our travels may be made by the subtraction of something rather than the piling up of something. Suppose an area were to be broadly uplifted so that a high, flat region resulted and then rivers were to cut deeply into the high plateau and cut it up. Eventually the region may be cut down to a much lower level with only a few high-standing remnants of the original highland left. These would appear as mountains. This subtracting effect is present in all kinds of mountains which have undergone erosion. Mountains which are made this way are usually composed of rocks which are harder than those which have been worn away.

Geosynclinal Mountains

When we approach a study of the origin of any of the great belts of mountains of the world, like the Alps, the Himalayas and the Rockies, we are at once impressed by their similarity of history. They all seem to have started with depression of long, trough-shaped areas in the earth's crust. This is exactly the reverse of what people would expect. Shallow seas spread into these very large depressions, which are called geosynclines. In North America we know of ancient seas in geosynclines which extended from what is now the Arctic Ocean, in the region of the Mackenzie Delta, all the



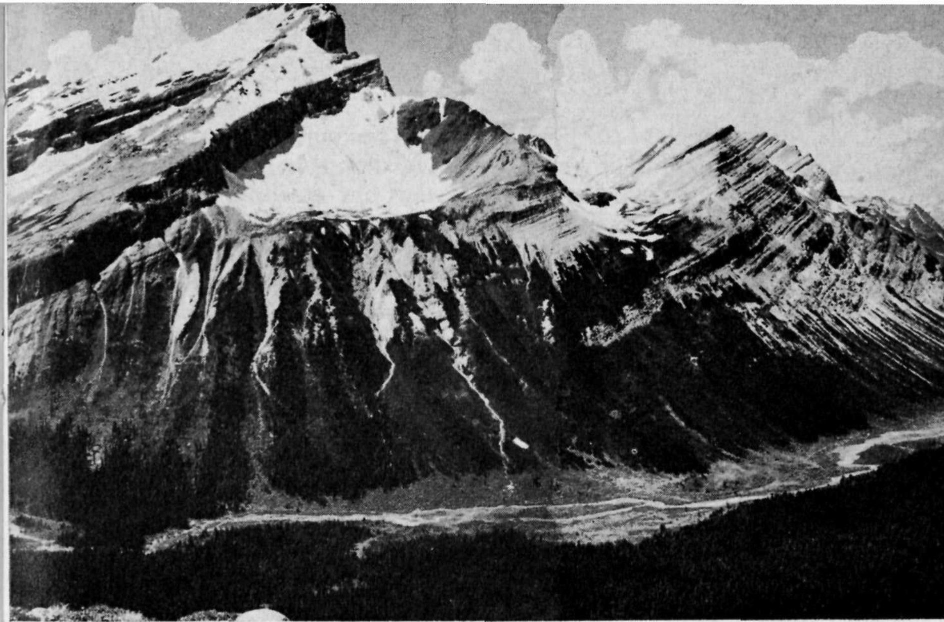
The ramparts of Mount Eisenhower overlook the valley of the Bow River and the Trans-Canada Highway in Banff National Park. The horizontal bedding of the sedimentary rocks combine with the vertical jointing to produce the pattern of erosion. Below the cliffs, talus slopes lead downward to the forested valley floor and the river which is carrying the wastes of the area towards the distant sea.

way to California, and from Newfoundland to the Gulf of Mexico. Masses of muds, sands and silts poured off the surrounding land areas into these troughs. After many millions of years of such accumulation these sedimentary materials were tens of thousands of feet thick.

The reason for the next step in the formation of this kind of mountain system is not known. But it is known that great compression next caused the thick masses of sedimentary material to fold and fault, and then to be uplifted, sometimes many thousands of feet. At about the same time this was going on, great masses of molten, igneous material were intruded into the cores of the buckling masses of sedimentary rocks. After this, things quieted down and the slow processes of erosion cut into the masses of folded and intruded rocks. This is the present stage of development of our own Rocky Mountains and this is the kind of history that accounts for the scenery of Banff and Jasper National Parks.

Now, if the erosion keeps on for millions of years after this, the mountains will be gradually worn away. It may even come to the time when the whole area is once again reduced to sea level. Now another stage in the geosynclinal mountain story is reached, and another event takes place. This time the areas of old, eroded rocks with their deeply folded and faulted structures and their igneous cores, are uplifted. Rivers once again cut into the rocks below. It is not long before they find that some of the rocks are more easily eroded than others so that valleys are cut into the soft rocks and hills are made of the harder, more resistant rocks by subtraction.

This is the stage of development of the mountains of eastern North America where you can see the results of this history in the Appalachian Mountains. You can see them in the rolling hills of New Brunswick, where Fundy Park is located, and in Terra Nova Park in Newfoundland. You can see them in Cape Breton Highlands National Park, perhaps the best of all, for here much of the uplifted flat surface of erosion is still visible in the interior of the island where the park road is at an elevation of more than 1,400 feet. Here, too, you can actually descend the steep-walled valleys and clefts which are cut into the old surface, for the road follows them in its ups and downs in this beautiful country.



Mumm Peak at the head of Smoky River in Jasper National Park near Mount Robson, is made of tilted Cambrain sedimentary rocks with older rocks underlying them to the right in this view. The lower parts of the talus slope have become partly covered with vegetation but openings are maintained where snowslides sweep down the slopes and where pieces of rock and frost-riven fragments keep dribbling steadily down.

Conclusion

Once again we see that an understanding of scenery heightens beauty in the eye of the knowing observer, for he is able to appreciate that mountains are part of a vast picture of wearing away and replenishment, of uplifting and wearing down in a story of the earth's surface which is marked by system and order.

ECONOMIC GEOLOGY

It has now been a very long time since man first began to notice that certain mineral materials which he needed were to be found in certain places. Perhaps it was when he noticed that certain clays for pottery were to be found only in certain river banks, or that certain kinds of desirable rocks like flint or chert were found on some beaches but not on others. The next advance was to notice that these useful things occur with some kinds of rocks and not with others rather than in some places and not others. Thus the flints were to be found in chalk beds and limestone layers on the beaches where these rocks were being eroded.

Now, thousands of years later, a whole science of economic geology has been developed and a vast technology for the useful application and modification of natural mineral materials has been invented. In this book we need only look briefly at what economic geology is and at its basic principles. At the outset one would expect that an understanding of the origin of minerals and rocks would form the basis for any beginning of understanding of why useful materials occur where they do and where else we should look for them.

Limestone, salt and gypsum are very useful industrial materials. Each of them occurs as ordinary, bedded, sedimentary rocks with other bedded, sedimentary rocks. This means that we would look for these materials only in regions of sedimentary rocks and that we would expect them to occur like other sedimentary rocks.

Oil comes from the partial breakdown of organic materials in the bodies of living things after they die and after they have been buried under sand, mud and silt. Thus oil should be looked for only in regions of sedimentary rocks which are younger than the time of the beginning of life about five hundred million years ago. Oil occurs in many rocks of sedimentary origin but accumulates in quantities big enough to be useful only where it can gather in pores and openings in the rocks without breaking away. Thus porous rocks with a capping of non-porous rocks are required. Under the great plains of Western Canada favourable places for oil are the ancient, porous coral reefs, now buried hundreds or thousands

of feet below the surface. Some of these reefs may actually be seen in the sides of some of the mountains in Banff National Park where erosion has exposed them. The oil in them has long since leaked away and been lost but they do show us what the old reefs were like.

Coal is formed when great thicknesses of forest debris or other vegetable material accumulates in swampy conditions which do not allow it to decay. After such an accumulation of plant material is buried beneath hundreds of feet of muds and clays, it turns gradually to coal by the loss of some of its substance in a sort of partial distillation, which is caused by the pressure of the overlying sediments, folding if there is any, and certain slow-moving chemical changes. Thus a lump of coal is no longer just a black lump of something to burn but a fossil fuel with a very long history going back to primitive forests of another era.

If we analyze all the rocks at the surface of the earth we find that metals are not very abundant. None, in fact, except iron and aluminium, are more than one percent of the total. This means that to find a deposit of copper or zinc or lead or gold we will be looking for a place where some natural process has concentrated it. This may happen in different ways.

If a tiny amount of gold is scattered through a rock, which is being weathered and carried off by one of the processes of erosion we examined earlier, it may become concentrated because it is so heavy. Thus along the sandbars and in the gravelly bottom of the Klondike River men found concentrations of fragments of gold eroded from the nearby hills. Some beaches show slightly darker and lighter areas where the waves are concentrating grains of particular minerals from the mass because they are heavier or lighter than the average.

Surface waters may concentrate certain materials as they percolate through the upper zones of rock and soil. This may be done either by addition or by subtraction or both. Suppose a weathering rock produces mixtures of several materials including iron. The iron may be concentrated by being dissolved in the ground waters, carried off somewhere else and redeposited in a more concentrated form. On the other hand, a similar concentration may be brought about by dissolving and removing everything but the iron. Many of the great iron deposits in Quebec and Labrador were probably low grade to begin with and were concentrated by one of these systems. Others may be in places where water concentrated iron-rich sands when the rocks were first being laid down as sediments in much the same way that iron sands are now accumulating on the north shore of the Gulf of St. Lawrence.

Other materials seem to be concentrated directly by igneous processes. When a great mass of rock is melted deep underground and starts to cool, several processes may tend to concentrate different compounds in different places. All the fluorine in the melt may collect in one pocket and millions of years after the rock has solidified, it may be found as a deposit of fluorite. Perhaps the lead and zinc will be carried off in hot waters, which seem to be part of all rock melts, and deposited in cracks and fissures in the rocks which surround the still molten body. Millions of years later erosion may lay these deposits open on the surface for man to discover.

Masses of molten rock which are cooling may crystallize very slowly so that some materials start crystallizing out while the remainder is still liquid. If these first crystals are heavier than the surrounding liquid they may sink to the bottom and accumulate there. This is another method of concentrating compounds which are in very small proportion to begin with in the large molten mass and may account for certain deposits of iron, chromium and nickel.

The old methods of prospecting for valuable mineral deposits were little more than hit-or-miss schemes whereby men went out and looked for something valuable. Nowadays some prospecting is still done that way by individuals hopeful of striking it rich, but for the most part it has become highly

Roadcuts east of Jasper townsite commonly reveal that the terraced hillsides there are cut in masses of bouldery gravel. These materials had their origin in glaciers which plucked them from the solid rock and carried them considerable distances before melting. Then the meltwaters carried the rock debris still further, rounding off the corners and washing out the finest clay particles before depositing them thus.

organized. Geologists pick out likely areas on the basis of a knowledge of the rocks and rock structures. Delicate instruments, often mounted in aircraft, measure the radioactivity, the magnetism and various electrical properties of the areas picked out. Then prospectors look at every available outcrop, geochemists measure to the millionth part the content of metals in soils and in the streams of the region. Drills are brought in to get samples in vital areas where no outcrops are to be found and which are thought to be promising. Small explosions may be set off a few feet under the surface and the echoes and reflections carefully measured to find out about the structures of the rocks below. These many tools are used to find mineral deposits but alas will fail to find what is not there.

In review we can say that economic geology has to do with the finding of bodies of useful mineral material and their extraction, the understanding of how minerals originate and thus why they occur where they do and, eventually, prediction of where other such bodies may occur. We find that certain minerals occur with certain kinds of rocks so we look first for those rocks and then for the minerals which we expect to be associated with them. Limestone, gypsum, salt, coal and oil occur in sedimentary rocks because they originate by sedimentary processes. Copper, gold, nickel, lead, zinc, silver, and a host of other metallic minerals occur in igneous rocks and around the margins of igneous bodies because they originate during the igneous process. Man has come a long way since he first discovered the flints and clays are found in some places and not in others.

Conclusion

Every human seems to have born in him something which quickens in the presence of booming surf on a curving shoreline, the roar of a great waterfall or the colour of the sunset on mountains. Sparkling crystals and pretty stones have attracted man's eye since time began for him. Knowledge of how these things are made and what is happening to them enhances an appreciation of their beauty and deepens curiosity about them. The sparkling diamond, the deep green emerald, the starred sapphire are beautiful in anyone's gaze but for the man who understands what they are and how nature produced them there is an additional beauty in their symmetrical internal arrangement, and in their history. For the incurious traveller who stumbles across a fossil it may be just another irregular marking on a stone. But, for the man

who is aware of what it means, there is an especial excitement as he sees the remains of a creature which lived and died, millions of years ago, when the earth was probably different from what it is now, and as he realizes that what he holds in his hand is a tiny fragment of a record of a billion years of living things which have changed gradually through the long passage of time.

A great wall of rock in the side of a mountain in Banff or Yoho is impressive to anyone, but is much more so when it is realized that the enormous thickness of layered rocks accumulated, inch by inch, as soft mud and sand and shells on the bottom of the sea, millions of years ago. It is beautiful at the shoreline at Terra Nova or in Cape Breton but it adds much to sense that what we are enjoying has resulted from a long history of erosion and deposition, of rising and falling of sea levels, of upthrusting and downwarping of parts of the earth's crust. What is just another rock cut in the parkway to one man may be, to another, the wondrous end result of seething igneous masses in the depths of the earth and their expulsion through a violent volcano, or of a gradual sedimentation in the lower end of a delta, which was thousands of miles from craggy mountains being slowly destroyed by weathering and erosion.

Perhaps the most intriguing thing of all is that, even as we are reading these lines and thinking about them, the whole complex of processes is steadily at work, scenery is slowly changing, life is slowly unfolding for each individual and for the whole living world. Nature is moving on in her cycle.

For further information, the following guides to the geology of specific National Parks may be purchased at National Park information bureaus or from the Queen's Printer, Ottawa. Money orders and cheques should be made payable to the Receiver-General of Canada.

The Story of the Mountains in Banff National Park by Dr. Helen R. Belyea, Ottawa, 1960. Geological Survey of Canada. 75 cents. This is a well-illustrated booklet on how geological forces have shaped the scenery of Banff National Park. Special detail is given on points of geological interest in the Park.

Rocks and Scenery of Fundy National Park by Dr. David M. Baird, Ottawa, 1961. Geological Survey of Canada. 75 cents. In 32 pages, this booklet describes the lessons of earth history that a visitor to Fundy National Park in New Brunswick can learn.

The Living Sands by Dr. David M. Baird, Ottawa, 1962. Geological Survey of Canada. 75 cents. A fascinating treatment of the sandy shoreline of Prince Edward Island National Park.

Yoho National Park—The Mountain, The Rocks, The Scenery, by Dr. David M. Baird, Ottawa, 1962. Geological Survey of Canada. $1.30. The geological features of this beautiful National Park are described in text and excellent photographs.

Behind the Mountains and Glaciers by Dr. David M. Baird, Ottawa, 1963. Geological Survey of Canada. $1.50. A detailed presentation of the geological features of Jasper National Park, with particular reference to the views of interest that can be seen along the Jasper-Banff Highway.

Guide to Geology of the Ontario National Parks by Dr. David M. Baird, Ottawa, 1963. Geological Survey of Canada. $1.00. In this fascinating guidebook, the geological features of the three National Parks in Ontario—Point Pelee, Georgian Bay Islands and St. Lawrence Islands—are explained in layman's language.

Questions on Canadian geology can be directed to The Director, Geological Survey of Canada, Ottawa.

Additional information on the National Parks of Canada is available from The Director, National Parks Branch, Department of Northern Affairs and National Resources, Ottawa.

NATIONAL PARKS CANADA

The animals, plants and all other natural features of the Parks are protected and preserved for all who may come this way. Please do not harm, remove or damage them.