GEOLOGICAL STORY OF ISLE ROYALE

Franklin C. Potter

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NOTE: The pictures listed above are to accompany the manuscript. However, the pictures are not available at this time but will be forwarded as soon as possible after the park opens next spring.

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ISLE ROYALE

Introduction

Whether this is your first visit to Isle Royale or your tenth, you cannot have failed to be impressed by its rugged beauty. But have you ever stopped to ask yourself whence came this rugged island with its rocky shores and fringe of numerous islands, its picturesque harbors, and many inland lakes? And why do these lakes and harbors all have roughly the same elongated pattern and extend parallel to each other between the ridges which also are parallel to each other and to the length of the island? Have you taken the trip to Lookout Louise and wondered about Monument Rock? As you hike along the well marked trails have you ever speculated about the rocks beneath your feet, the smooth surface of the sloping bedrock, and in places the large angular boulders over which you must scramble? Would it surprise you to know that these rocks once were hot, molten lava that at a much later time were completely covered by glaciers? Have you taken a trip either by boat or on foot to the old Siskiwit Mine where Indians and later white men dug for copper and have you thought about the source of the copper? Or how those greenstones, for which so many people are searching, were formed?

The answer to these and many other such questions may be found in the fascinating geologic story of Isle Royale which is primarily concerned with two of the major processes that from time to time alter the face of the earth, namely, igneous activity and glaciation. It is an old story, going back almost to the beginning of known geologic time because here are found some of the ancient rocks, estimated to be some hundreds of millions of years old. And yet we also find here evidence of the very recent work of the glaciers, the last of which melted away from the Lake Superior region a mere ten thousand

or so years ago. Let us examine a little more closely the record of events that led to the formation of this island as we see it today.

PHYSIOGRAPHY

Before delving into the geologic history of this area perhaps it would be well to become better acquainted with the present day surface features of this interesting wilderness area.

Major Features

Your map shows you that the axis of Isle Royale and its associated islands trends between North 55° East and North 60° East, giving the island a decided northeast-southwest alignment. And, if you approached the island from the Michigan shore you probably discerned the fringe of rocky islands paralleling the long dimension of the island, and then the series of ridges rising higher and higher inland. Two major ridges traverse the greater part of the length of the island - Greenstone Ridge and Minong Ridge. Should you care to hike the fifty mile length of the island you would find that the trail, for the most part, follows Greenstone Ridge, which might be called the backbone of the island. It is a continuous ridge except for a few gaps, whereas some of the minor ridges are not continuous for the length of the island. All, however, are parallel to its longer axis and some of them are short, parallel ridges arranged in echelon. The explanation of this last arrangement may lie in the cross faults (breaks in the rocks) which are known to exist on the island and which are responsible for the gaps in the ridges. The two highest points on the island are on Greenstone Ridge: Ishpeming Point near the center, and a higher, unnamed point near the southwestern end of the island. Both of these points are slightly more than 700 feet higher than Lake Superior and a little more than 1300 feet above sea level.

Minong Ridge, which is the second ridge of importance, is located near the northwestern side of the island. Numerous lower ridges, which do not traverse the length of the island, exist wherever the rock layers are hard enough to resist erosion to a greater degree than those on either side. Hiking along the trails you will notice that the lower areas are mostly covered by forests, brush, or swamps, which effectually conceal the bed rock, but higher on the ridges are large areas of bed rock completely bare of soil and plant covering, other than the lichens. These lichens at many localities impart a grayish, blackish, or more rarely an orange color to the rocks.

Dip of the Rocks

As you sit down to rest or sun yourself on the rocks overlooking Rock Harbor or on the outer side of one of the fringing islands, you should notice that the rock surfaces, for the most part, slope rather gently toward the southeast. But if you climb these slopes northwestward to the top of the nearest ridge you will notice that the land on the other side of the ridge falls away rather steeply to a valley or a bay below. This slope of the rock layers is called the "dip" of the rocks, and, as the rock layers all dip in one direction (to the southeast) the ridges formed by these layers are said to be "monoclinal" (one slope). The direction in which the rocks outcrop (crop out at the surface) - at right angles to the dip - is referred to as the "strike" of the rocks. Hence, it is evident that the strike of the rocks is parallel to the long axis of the island; just as the ridges are monoclinal and assymmetrical in profile with a gentle dip slope to the southeast and a steep escarpment side to the northwest; so the longitudinal valleys or lowlands likewise are somewhat asymmetrical with their northwest slopes conforming to the dip of the underlying, more resistant formations and their southeast sides abutting the escarpment of the next ridge.

Take the short and easy trail from Rock Harbor to Tobin Harbor and notice the difference in the grade of the slope on the southeast and northwest sides of the ridge. And now notice that Tobin Harbor extends parallel to Rock Harbor and its lovely little islands lie in a line conforming to the strike of the main island. Cross this beautiful harbor by row boat and take the trail to Lookout Louise. Again notice how each ridge slopes up more or less gently to its crest, but once at the top the land falls steeply to the adjacent lowland. The end of the trail on the highest ridge is Lookout Louise and perceive that Duncan Bay below lies parallel to the other bays and to the strike of the island. This, then, is the pattern of all of the lakes and bays of the island except for a few, such as McCargo Cove and the outer portion of Chippewa Harbor.

Glacial Scouring

The formation of the bays was due to erosion of less resistant rock between the more resistant layers, which now form the ridges. This erosion was the result of stream action, glacial scouring, and post-glacial lake erosion. Most of the bays undoubtedly existed as valleys in pre-glacial times since Lake Superior probably did not exist before the Ice Age, but the valleys were enlarged and deepened by glacial erosion. Oddly enough, the direction of the advance of the ice coincided roughly with the strike of the island, so the direction of glacial scouring naturally followed and deepened the already existing valleys. That the ice advanced from slightly east of the strike of the island is attested to by the greater development of the bays on the northeastern end and southeastern side of the island. The great weight of a glacier enables it to push along in front of itself the loose material that in most places overlies bedrock. In addition, fragments of rock of all sizes

are incorporated into the base of the ice and as these solid fragments are rubbed against the rock surface below they wear it away by abrasion. This process is known as "glacial scouring".

The continental glaciers, which first appeared in this area between one and two million years ago, completely covered the island and swept away most of the pre-glacial soil and rock mantle, thereby uncovering bedrock. And since the last of the ice melted away only ten thousand or so years ago there has not been sufficient time for the formation of another complete mantle of soil. Consequently the present stony soil is thin and patchy and does not support a luxuriant vegetation. Walking across the exposed bed rock you surely have observed that much of it is smoothed and rounded, due undoubtedly to glacial polishing. Although glacial striae (scratches) have been reported as being very abundant, most of those examined were rather faint and indistinct. Also, in some localities, minor joints coincide rather closely with the direction of the ice movement and it is possible that some of these have been mistaken for glacial scratches. (Glacial scratches or striae were made in the solid rock when unusually hard rock fragments were dragged along in the base of the ice.) However, if you have a good eye you may be able to observe several examples of glacial grooves in the rocks of Scoville Point. Some smaller amount of polishing has been caused by water action in post-glacial time when the lake stood at higher elevations than it does today, but by far the greater amount was accomplished by the huge ice masses. The fact that some of the well polished surfaces extend some distance below the present lake level bears out this premise. Furthermore, the rounded and smoothed surfaces are much more abundant on the parts of the island exposed to the direct ice action than on the sheltered side and end of the island, and the rocks on these sheltered positions tend to be

irregular and jagged as though due to ice plucking (the extraction of rock fragments from the surrounding rock as water from daytime melting in the glacier would percolate to the base of the ice and refreeze the next night around irregular rock projections which then could be wrenched from place the next day as the glacier resumes movement). In short, the bulk of the evidence substantiates the theory that these smooth and rounded rock surfaces (smoothed and rounded on the side or end from which the ice advanced, but jagged or irregular on the lee side or end) were produced by glacial erosion and polishing. When viewed from the rounded side such rock masses resemble sheep somewhat, especially as sheep may appear in profile when huddling against a strong wind or storm. To geologists, therefore, such features are known as roche moutonnees (sheep-back rocks).

Higher Lake Levels

As the ice melted and withdrew from the Great Lakes region it left a great body of water, known as Glacial Lake Duluth, the surface of which stood at a considerably higher elevation than does Lake Superior today. At that time Isle Royale was completely submerged. The evidence is only partially present on the island, but on the Wisconsin-Michigan and the Minnesota-Ontario shores the highest beach lines are found to exceed the highest elevation of the island. Numerous beach terraces exist on the island itself; they represent successively lower stages between the highest level of Glacial Lake Duluth and the level of Lake Superior at the present time. A special study of the elevated beach lines by Stanley[1] mentions the Fort Brady Beach in particular. Monument Rock, that imposing rock stack on the trail to Lookout Louise, was formed at the time of the formation of the Fort Brady Beach and it is one of its outstanding features. Stanley lists the elevation of this old beach line

as 702 feet (100 feet above the present lake) at Siskiwit Bay, and 752 feet (150 feet above lake level) near Tobin Harbor. All of these old strand lines on the island and both shores of the mainland are lower to the southwestward and higher to the northeastward as indicative of the tilting of the earth in this region that has occurred since the formation of these strand lines and which apparently still is continuing. Although many of the raised beaches on the island cannot be traced continuously, but are represented only by isolated patches that are recognizable, the evidence is conclusive. Visitors to the island during the periods of mining activities reported many more beach terrace locations than are readily visible at the present time, for during mining explorations and activities many areas were burned to expose the rock surface, and therby such features as terraces were freed from the concealing thickets and forests. Some of the lower beach levels are distinctly visible by their regularity of elevation and by the presence of beach cobbles (rock particles 64 to 256 millimeters in diameter) or shingle (flattened or disc-shaped cobbles or pebbles) as well as terraces, sea cliffs, sea caves, and stacks.

STREAM ADJUSTMENTS

Have you tried fishing for trout in some of the streams of the island? In general the stream courses are determined by the rock structure, for, as we have already observed, most of the valleys are parallel to the strike of the island and they are located along the weaker formations which are much more susceptible to erosion. Near the ends of the island the streams continue their courses along these valleys to the bays or the open lakes; those located toward the center have found cross valleys, probably in most instances the results of cross faults, in seeking outlets. Most of the streams have

but slight gradients although in a few instances, such as the outlets of Siskiwit Lake and Hatchet Lake, rapids and cascades add to the beauty of the stream. Since the lakes occupy rock basins scoured by glacial erosion, and since the soil covering of the island is negligible in quantity, there are very few deltas being formed. Indeed the streams have deposited but very little sediment in the small lakes into which they flow. Geologically speaking, lakes are very short lived. They tend to be obliterated by draining as the stream flowing from them lower their outlets or by being filled in by sediment carried into them by the inflowing streams. In addition many shallow lakes are being filled by the growth and accumulation of plant matter which may be converted into peat. This extinction of the lakes on Isle Royale is being effected more by plant growth than by the other two methods mentioned. Many of the smaller lakes already have been converted into bogs by this process.

PARALLEL RIDGES AND VALLEYS

Thus we have a general picture of the island composed mainly of parallel ridges and valleys traversing the long axis of the island in a northeasterly-southwesterly direction. These ridges are the outcropping edges of resistant layers of igneous rock that slope to the southeast, whereas the valleys have been worn from less resistant layers. This arrangement has produced gentle slopes along the southeastern shore both above and below the surface of Lake Superior whereas along the northwestern shores cliffs and escarpments ranging from a few feet to twenty feet or more rise abruptly from the water's edge and deep water is encountered close to shore. This same profile is to be found in the valleys and in the bays which are but the extremities of the

glacially deepened valleys that are low enough to be invaded by the waters of Lake Superior. The island fringes on the outer borders of Siskiwit Bay, Rock Harbor, and Todd Harbor represent other monoclinal ridges of resistant rock that have been eroded along cross faults to form the shallow gaps. And the rock reefs continuing for some distance from either end of the islands are simply continuations of the ridges of the island.

Because of this pattern of topography, physiographers have included Isle Royale in the Superior Highlands, an area characterized by alternating monoclinal ridges and valleys, sometimes referred to by earlier geologists as the "Sawteeth Mountains". The Superior Highlands is a sub-province of the larger physiographic province known as the Laurentian Shield, Archean Shield, or Pre-Cambrian Shield of North America. These names all refer to the age of the rocks that compose the area. Most of this province is located in eastern and northeastern Canada but a southwestern extension includes northeastern Minnesota, portions of the upper peninsula of Michigan, and north central Wisconsin.

GEOLOGIC HISTORY

Geologic Processes

Just as the rocks of Isle Royale give it so much of its rugged beauty, so too do they give the key to its geologic history. It is from the detailed study of these rocks that the geologist is able to determine something of their age and the events that have given them the characteristic features that we see today. Because these are very ancient rocks, more than five hundred millions (500,000,000) of years old, it will be necessary to go far back in geologic history to portray the events responsible for their form and pat-

tern as we see them today even though these are fundamental processes that are constantly at work to alter the face of the earth. This background will give us a better understanding of the geologic history as well as the basis of the geologic time chart which is the recording of events as they occurred.

That history repeats itself is just as true of geologic time as it is of recorded human happenings. From as far back as man can decipher the record, the surface of the earth has been subjected to a series of events that have been repeated over and over; namely times of mountain building when the surface of the earth has been elevated and sometimes crumpled and folded into complex mountain ranges and systems, followed by long periods of erosion which reduced the land to a more or less flat and low-lying surface. During these periods of erosion, the material, as it was transported away from the higher areas, was carried to lower elevations where it was deposited on flood plains or in shallow seas to form new layers of rock. (Such rocks that are formed by the cementing together of eroded rock particles sediments are called "sedimentary rocks"). Often associated with the periods of mountain building was igneous, or volcanic activity. (Igneous activity involves the movement of hot, molten melted rock either below magma or upon the surface lava of the earth, and this material, when cooled, constitutes "igneous rocks"). Igneous activity and the resultant igneous rocks play a major role in the story of Isle Royale.

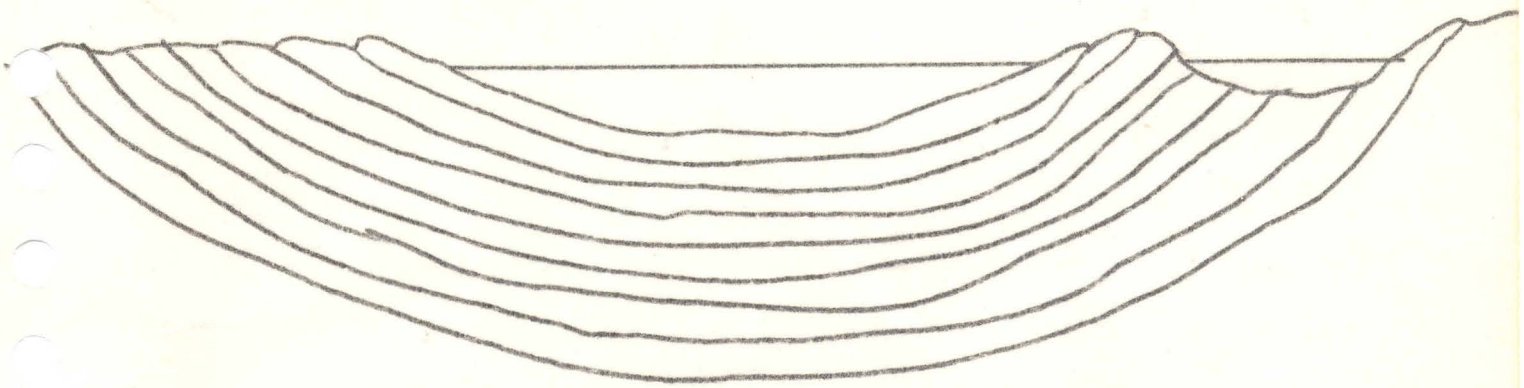
Lake Superior Basin

Within the Superior Highlands is the Lake Superior Basin which in turn contains Isle Royale, so one necessarily must examine the features of this region to understand the history of the island. Indeed, much of its story

has been determined by studies of the adjacent shores of Lake Superior. The Lake Superior Basin is located in the glacially gouged-out trough of a large syncline (down-folded and down-faulted area) of the earth's surface. The same kind of rocks are exposed on the Keweenaw Peninsula of Michigan and on the adjoining shore of Wisconsin as well as along the Minnesota-Ontario shore, and in the vicinity of Duluth and Superior the two sides of this down-folded area are so close to each other that they can easily be compared. In fact, the end of the down-folded structure may be traced southwestward into Minnesota from the end of Lake Superior.

Geologic Eras

With these physical characteristics in mind let us turn to their geological interpretation. In order to understand better the story of the formation of this island, let us look for a moment at the time table as devised by geologists as a frame of reference (See Geologic Column). As you will notice, there are five "eras", each of which (except for the Cenozoic) embraces one hundred millions of years or more. These eras were established on the basis of great interruptions in the physical history of the earth; the accumulation of sediments on the low margins of the continents is interrupted when the lands are elevated, hence the "breaks" in the record of sedimentation. They had far-reaching effects on the plant and animal life due to change of climate with uplift, restricting the size of shallow seas, the creation of mountain barriers, et cetera. Each "era" was terminated by great continental uplifts and mountain-making (called revolutions) which form the natural breaks in geologic history. Each era is in turn divided into periods of geologic time



SKETCH I

LAKE SUPERIOR BASIN

marked by lesser crustal movements known as "disturbances". The eras and periods are listed in order from the top down, from youngest to oldest. Generally the column is read from the bottom to the top, i.e. from oldest to youngest as this represents the order of the rocks themselves as usually the younger layers were laid down on the older ones.

Astronomers, physicists, and chemists generally agree with geologists that the oldest known rocks were formed more than two billions (2,000,000,000) of years ago. Estimates of the age of rocks are based on the rate of formation of sedimentary rocks, the amount of sodium in the seas - this sodium has been leached from rocks on land and carried by streams to the sea, and especially by an evaluation of radioactive elements in certain igneous rocks. Throughout the sedimentary rocks of the Paleozoic, Mesozoic, and Cenozoic eras fossils (evidence of the presence, or actual remains of plants and animals) may be found which provide clues to the age of the rocks and the conditions under which they were formed. Some fossils are almost the equivalent of dates. During the Archeozoic and Proterozoic eras, however, (which together embrace three-fourths of known geologic time) only the most primitive life existed and fossils therefore are almost entirely lacking. Because of this and because of the complexity of events which followed, less is known about these ancient rocks than about the younger ones. But, bit by bit, geologists have been able to piece together some of their story. It is with certain types of these ancient rocks that the story of Isle Royale is mainly concerned.

Earliest Geologic Time

Although the rocks exposed on Isle Royale are entirely of Keweenawan age,

the activities of that one geologic period represent but a fraction of the pre-Cambrian history of the region and to understand the geologic story it is necessary to start with the beginning of known geologic time. Obviously the earliest records are very incomplete and somewhat confusing and their interpretation has changed from time to time. Geologists' earlier concepts of the oldest of these rocks was that they represent the crust that first solidified from the molten mass that they thought was the earlier earth and they believed that below this crust the earth still was in a molten condition. But it has since been found that the Laurentian granites (see geologic column) while still in the molten state forced their way into the sedimentary and igneous formations of Keewatin age. Hence the Keewatin series must have been there before the granitic intrusions occurred. In brief, the oldest known rocks are sedimentary and volcanic formations and it is not known what kind of a "crust" they accumulated on. In fact, some geologists believe that the earth never did pass through a molten stage and if they are correct the term "crust" is an incorrect geologic term. However, the term is well established in geological literature and usage, but as now used it refers to the outer several miles of the earth and it certainly is not the original crust, even if there ever was one.

Laurentian Revolution

These first Keewatin sediments, lava flows, and ashbeds were originally laid down in rather flat layers but were later folded and uplifted during a great mountain building time (Laurentian Revolution). Along with the uplifting of those ancient mountains vast masses of molten rock, the present Laurentien granite, were forced toward the earth's surface but most of the mass stopped a mile or more short of that goal. Molten rock that cools underground naturally

cools more slowly than that which rises to the surface and one of the igneous rocks that forms at the depth of a mile or more underground is granite. (The slow cooling results in a characteristic coarse-grained texture). So whenever granite now is found at the surface it is evident that erosion must have worn away a considerable thickness of overlying rock. Briefly then, the Laurentian granite intruded the Keewatin series and it therefore is younger than they and the intrusion took place during a great uplift or mountain-building epoch.

Following this mountain-building epoch there occurred a long period of erosion lasting hundreds of millions of years. During this time the Laurentian Mountains were slowly being worn away and the eroded rock debris was deposited round about on the lower lands to form a new series of sedimentary shales, sandstones, and conglomerates now known as the Timiskiming or Knife Lake series. Only patches of these sedimentaries now remain and locally they have been given different names.

Algoman Revolution

Then there again occurred in this area an epoch of tremendous uplift and mountain-building with its accompanying intrusions of molten material. This time the granite intruded not only the Timiskiming series but also the older Laurentian and Keewatin rocks as well. The names given to this orogeny (mountain-building) and the associated granite are the Algoman Revolution and the Algoman granite respectively. Once again the long erosion cycle began, wearing away the mountains and depositing the sediments round about where they formed new sedimentary rocks. Of course these long periods of time and the rocks that represent the happenings - even though imperfectly known - might be

described in much greater detail as to the area and trend of the mountains, the kind and nature of the sediments, the conditions under which they accumulated, how thick they were, and what they now are like as a result of the different uplifts, foldings, faultings, intrusions, and other modifying influences to which they have been subjected. Since these rocks are not found now on Isle Royale itself - at least not at the surface, although some of them must lie buried here - this short outline will suffice for our purposes.

Proterozoic Era

Proceeding to the next great era of geologic time - the Proterozoic - we must examine the record in greater detail because the events of this era were largely responsible for the island as it exists today. Referring to the chart once more, you will see that in Huronian time (which was named from the area along the northern shores of Lake Huron where rocks formed during this era first were studied) massive beds of sedimentary rocks were formed. These consisted of beds of sandstones, limestones, and shales several thousand feet thick which were laid down in a shallow sea that covered this area - perhaps an arm of the sea which extended from the Hudson Bay area of today. Along with these sediments the most valuable of the iron ores of the Lake Superior region were being formed. During the millions of years that these sediments were accumulating it is believed that a great mass of molten material was slowly being forced upward from some unknown distance beneath the surface. Just why it is thought that this was happening will be discussed a little later as the evidence is revealed.

Keweenawan Period

The Keweenawan period is characterized by a complex series of volcanic and sedimentary rocks. Great cracks or rifts opened in the surface of the

earth along the axis of the present Lake Superior. Lavas poured from these cracks in what are called "fissure eruptions". These fissures or rifts differ from volcanoes proper in that they may extend one hundred miles, or even more, whereas volcanoes are relatively small openings which are more or less circular. Alternating with the spread of lava, there occurred the accumulation of layers of sand, clay, and gravel that were carried down the slope of the land by streams and deposited along the flood plains or, perhaps, in shallow seas. This series of lava flows, and associated sediments which have long since been cemented to form sedimentary rocks, carries the name "Keweenawan" from the type area - Michigan's Keweenaw Peninsula. Additional mountain building, with its granitic intrusion, occurred near the end of this stage of the earth's history and this third great granite of the Lake Superior region is known as the Killarney granite. The deposition of the copper that is found on Isle Royale and the Michigan mainland in these Keweenawan rocks occurred as a result of the igneous activity of the Killarney Revolution.

Because these ancient Keweenaw rocks are the ones that you see today as you walk about the island, let us interrupt the historical story long enough to examine them more closely and learn, if we can, what processes caused them to dip (slope) to the southeast. Surely they were not originally laid down with as steep a dip as they now possess, for, just as is happening today, sediments are laid down in horizontal or very gently dipping attitudes.

Keweenawan Lava Flows

The Keweenawan lava flows and sediments have been carefully studied on the Michigan mainland where they dip (slope) northwestward toward the long

axis of Lake Superior. These lava flows and intervening layers of clay, sand, and gravel were laid down on the land surface as it then existed and the earliest students of the region interpreted the rocks as having been formed on a land surface sloping northwestward (although not so steeply) as it does today. Later more critical studies revealed the following facts. Some of the lava flows in the Ironwood region preserve the record of lava flowing over a mud surface and squeezing some of the mud along in front of it as the lava advanced (and the lava was flowing from the north). The dip of the lava flows themselves fans out to the southward (modern lava flows invariably fan or spread out down the slope in the direction in which the lava is flowing). The thinning of the lava flows and the fanning of the dips to the southward indicates that the source of the lava was somewhere to the northward. In that direction the depths of the lake now conceal the probable source of the lava. Supporting evidence in the Copper Range is furnished by the attitude (position) of gas bubble holes in the lava rocks which also indicate that the slope of the land was to the southeastward. Some of the layering in the sandstone and conglomerate that accumulated as sand and gravel during the quiet periods between the outpourings of lava likewise indicates that the currents of water depositing these sediments were flowing down the slope - to the southeastward.

Reversal of the Dip

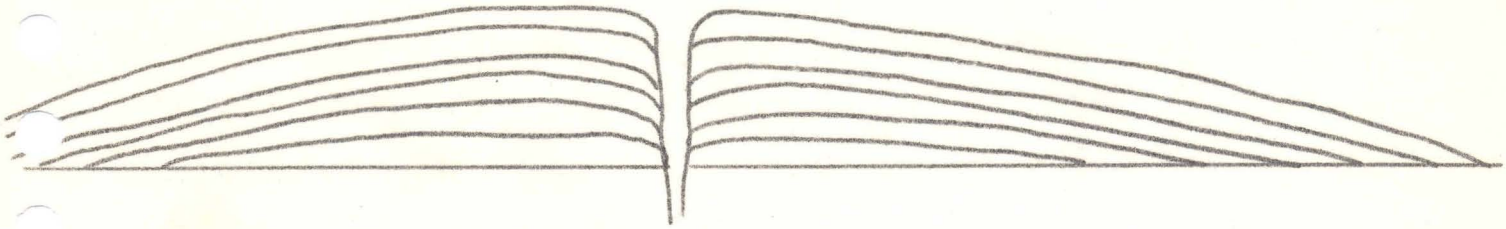
During the preceding Huronian times when earlier lava flows and layers of sediment were accumulating on the southeastward dipping slope, the higher land to the northwestward occupying the site of the present Lake Superior must have been slowly settling, for the slope of the earlier formations was

being reversed from the southeastward to the northwestward. The continued outpourings of lava, however, at least partially compensated for the amount of settling so that the land occupying the present Lake Superior area continued to stand above its surroundings. Isle Royale is on the opposite side of the Lake Superior Basin from the Keweenaw Peninsula but its story is the same except that the slope there is and was reversed from that of the Michigan-Wisconsin side. The rocks composing Isle Royale now dip southeastward but they were laid down on a northwestward sloping land surface.

What caused the elevation in the area of the present Lake Superior Basin? Why did the earlier rocks settle downward near the center of the higher land area? Whence came the lava flows? Why were the slopes later reversed?

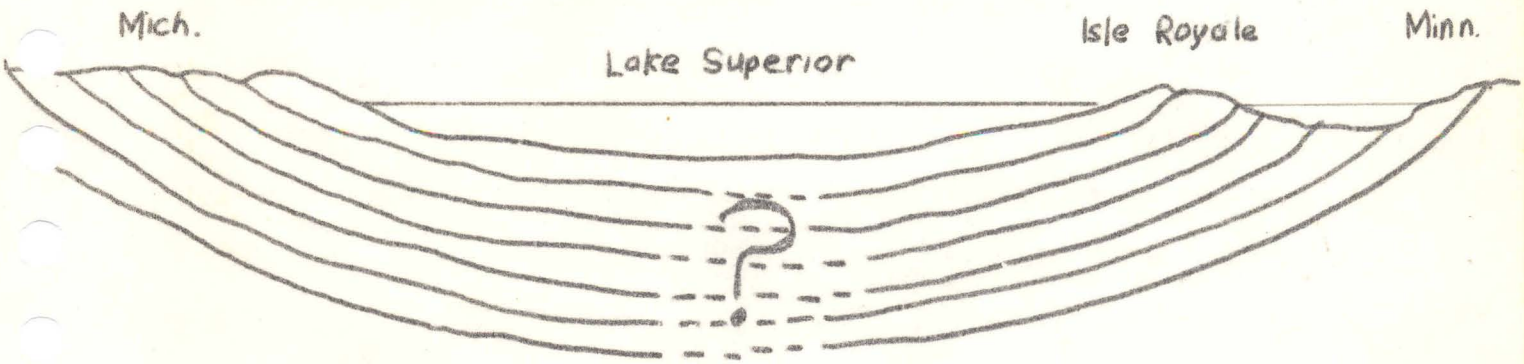
Intrusion of the Batholith

To account for this sequence of events the long, slow rising during perhaps all of Huronian and Keweenawan time of a great mass of molten rock which eventually cooled and solidified without reaching the earth's surface, has been postulated. Such a mass has been named a "batholith". Batholiths (deep seated rocks; huge mass of igneous rock without a known bottom) are known definitely in various parts of the world where erosion of the overlying rock has uncovered the granites and granite-like rocks that compose such masses. The Sierra Nevada Mountain mass in California and the copper impregnated hill at Butte, Montana are but two examples. What causes great masses of the earth at unknown depths to liquefy and move surfaceward is but one of the unanswered questions in geology. Numerous explanations have been offered but no one is generally accepted. Somehow or other greater heat is produced,



SKETCH II a

CROSS-SECTIONS OF LAKE SUPERIOR BASIN BEFORE AND AFTER THE REVERSAL OF THE DIP



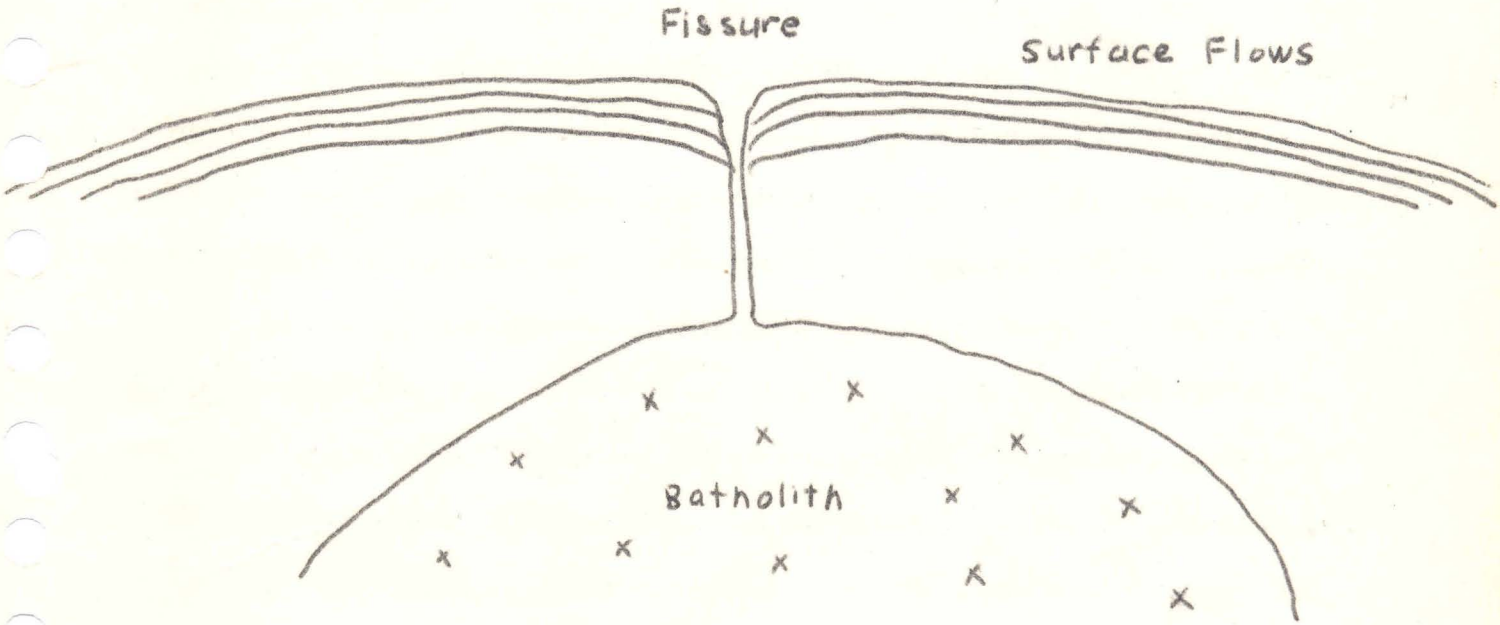
SKETCH II b

or the pressure of overlying rocks is partially released so that the hot rock matter at depth can become liquid, and if it has an opportunity to move it will move upward. The pressure of the overlying rock will force the liquid rock material upward - from places of greater pressure to places of less pressure.

Size of the Batholith

The size of this postulated rising mass of magma (liquid rock within the earth) can only be estimated. The geologist[2] who proposed the theory presented estimates which are summarized below. The area of lava flows (some of this molten rock was forced to the earth's surface) extends from Minneapolis to the end of the Keweenaw Peninsula - a length exceeding three hundred miles. From northwest to southeast the width of the area of flows measures eighty miles. In other words, the lava flows covered an area of twenty-four thousand square miles. If the average thickness of the flows is four miles, the total amount of liquid material that poured from the earth occupies 96,000 cubic miles. And the amount of magma that cooled and solidified within the earth (the batholith) is believed to have been much greater than the amount that reached the earth's surface in the form of lava flows.

The formation of a batholith is believed by geologists always to coincide with mountain building and the mountain building of the Keweenawan period has been named the Killarney Revolution. The formation of mountains is believed by some not to be caused by the batholithic intrusion but rather that the batholith is a result of the mountain building. Perhaps the upfolding of portions of the earth's surface releases the pressure underneath sufficiently to permit the hot rock materials to become liquid (most sub-



SKETCH III

LAKE SUPERIOR BATHOLITH

stances, both rock and mineral, occupy more space in the liquid state than when solid). The molten material (magma) eventually cools and solidifies thereby contracting and allowing some settling of the earth above. This settling of the earth plus the weight of solid rock above the magma, which undoubtedly was a major factor in squeezing out some of the magma to form the surface flows (and in late Keweenawan time a lens-shaped intrusive body Laccolith of the Duluth gabbro), seems to have been the cause of the settling of the earth to form the syncline (the large down-folded area) which now constitutes the southwestern portion of the Lake Superior Basin. The previously high land area from the crest of which the lava flowed down the slope to the northwestward and to the southeastward thus was depressed so that the two sides of the former highland then sloped downward into a syncline.

Faulting

Sometime during this downwarping of the earth's crust or shortly thereafter a great fault (a break in rocks along which movement occurs) developed in the Keweenaw Peninsula. The rock mass to the eastward was elevated whereas those rocks which were tilted to slant downward to the northwestward were lowered along the fault thereby younger sedimentary rocks from the eastward were shoved over the end of the older copper-bearing formations. A similar fault is believed to be located somewhere along the Minnesota-Ontario shore but it never has been found. Perhaps this postulated fault was located out some distance from shore and rocks bordering it have been eroded away except from the lake bottom where they are not available for recognition or study.

Horst

Since Isle Royale itself projects above the southeastward dipping flank of the syncline we must seek for some explanation as to why it projects above its surroundings. Soundings in the lake reveal deep water between the island

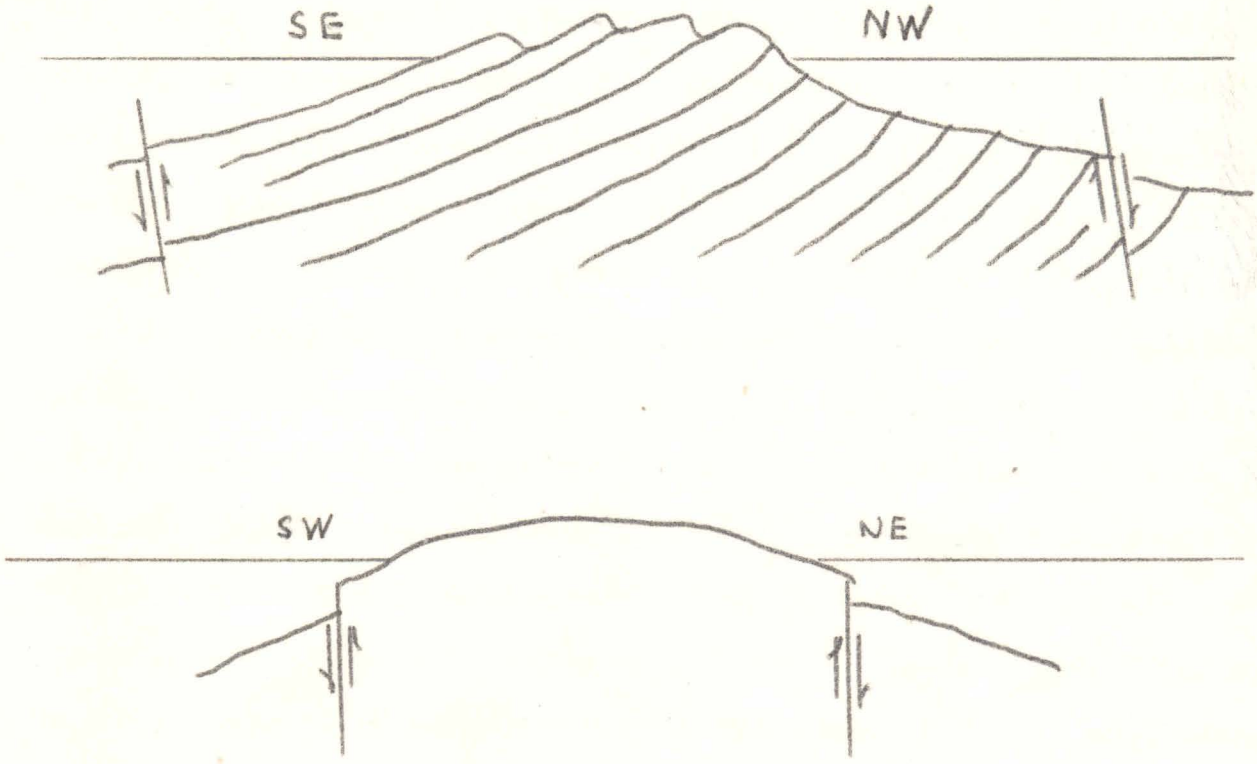
and the Canadian shore and it seems logical to suppose that a fault is responsible for the considerable difference in elevation - Isle Royale versus the rocks of the bottom of the lake. (Two cross faults also seem necessary to account for the ending of the island since it does not gradually bend down to the bottom of the lake at each end. Other cross faults are known to exist on the island). Areas bounded by faults along which they have been elevated above the surrounding region are known as "horsts", and Isle Royale seems to be such a mass.

Vesicular and Amygdaloidal Rocks

All lavas contain some gases and many lavas contain so much that it has not entirely escaped before the lava cools and hardens. If the gas collects in bubbles, and if the bubbles still exist at the time of solidification, the bubble holes may be very noticeable in the resulting rock. These "vesicles" tend to be concentrated in the upper portions of individual flows and in some instances they are of value to the geologist in distinguishing one flow from another. Such vesicular lava rocks occur on both shores of the mainland and on Isle Royale. Later hot gaseous or liquid solutions, rising from below, or ground water, descending from the surface, often deposit minerals which partially or completely fill the vesicles or other openings that are encountered in rocks. The filling material may be copper which will be discussed more fully under another heading. The filled vesicles usually are referred to as "amygdules" and amygdaloidal rocks are abundant in the Lake Superior region including Isle Royale. Amygdaloid Island off the northwest shore of Isle Royale is composed primarily of such rocks.

PALEOZOIC ERA

Returning now to the historical account let us see what took place in this region during the next great era of geologic time. Early in the Paleozoic



SKETCH IV

PROBABLE FAULTS BORDERING ISLE ROYALE

era evidences of plant and animal life (fossils) begin to appear in abundance in the rocks of sedimentary origin in many areas and these serve as excellent markers or dates for the various layers. However, since only small patches of Paleozoic rocks are present in the Lake Superior region we may assume that they did not accumulate in great quantities, and that those that once were present have since been mostly eroded away. From the study of surrounding areas geologists believe that through the various periods of the Paleozoic era the Lake Superior region for the most part was a low-lying land mass. As such it was not being worn away much for the rivers flowing on a low-lying land have but little gradient (slope) and the clastic sedimentary load of a river varies directly with its velocity. Occasionally downwarping was sufficient for the area, or parts of it, to be flooded by shallow extensions of the sea such as Hudson Bay of the present time and during such inundations sediments (long since converted into rock) accumulated on the floors of the shallow seas. The Silurian period was such a time and isolated patches of Silurian limestone over the Shield, which so far have escaped being entirely eroded away, bear testimony to the general submergence of that time. It is interesting to note that the Silurian sediments are limestone. Since no sand, clay, nor gravel deposits are known it is assumed that nowhere nearby was there high land because if that had been, rivers would have carried sand, gravel and clay to the nearby seas. The limestones contain numerous coral reef remains. Since reef-building corals today live only in tropical seas we are faced with the necessity of deciding between two possibilities; either that Silurian time was tropical or semi-tropical this far north, or that reef-building corals at that time could live in cooler waters. At any rate it was a shallow sea and the clear water was conducive to the growth of such bottom-dwelling plants and

animals as the reef-building corals that today can live only in shallow, clean, warm water.

MESOZOIC AND CENOZOIC ERAS

Through the Mesozoic and Cenozoic eras too this region is believed to have existed as a low-lying land mass. Again there is no evidence of major uplifting of this land area and neither is there any indication of submergence with the resulting accumulation of sedimentary rocks. The accumulation of sediments with fossils of the organisms of the time did, however, occur farther to the westward. In the Great Plains region of the northern United States and southern Canada some Mesozoic formations that accumulated on land contain remains of various reptiles including dinosaurs. Since the dinosaurs were cold blooded reptiles and many of them so large that they could not hibernate below the frost line, they certainly could not have survived the present winters of the northern Great Plains area and we are forced to conclude that the Mesozoic era also was characterized by milder climates than that of the present time.

THE ICE AGE

FORMATION OF GLACIERS

With the advent of the Pleistocene or Ice Age, however, this area was affected and the evidence is recent enough to be clearly decipherable. For some reason or other; such as uplift of the land area, cooling of the climate, or because of some combination of events, more snow fell during the winters than melted during the summers so that on the flat lands of central Canada snow fields formed and grew in size. After a growth period, probably of thousands of years, the masses became converted to ice in their lower portions and the pressure of the higher, central portions of the masses pushed the borders of the ice outward in all directions. These masses of moving ice, known as glaciers or ice sheets, moved as long as they were pressed onward

from behind and above, and their front edges continued to advance as long as the forward movement exceeded the rate of melting and evaporation. In the United States the glacial ice moved as far southward as the present location of the Ohio River in the eastern portion of the country and west of the Mississippi River as far southward as the Missouri River. Of course smaller glaciers in the Rocky Mountains, Cascade Mountains, and Sierra Nevada Mountains existed farther southward because of the higher elevations, lower temperatures, and heavier snowfall.

MULTIPLE GLACIATION

All told there were four different major advances and retreats of the ice and the record of the last, the Wisconsin Ice Sheet, is the easiest to read. For one thing, the evidence of its presence and activity is youngest and therefore less obliterated by weathering and erosion. Also for areas that were covered by two or more of the glaciers, the last one to move over a region either destroyed the evidence of the earlier ice sheets or covered the evidence with its own deposits of gravel, sand, and clay (glacial drift).

While these enormous glaciers - similar ones occurred in Europe and Antarctica - were in existence, the ocean levels must have been lower than they now are because of the great amount of water that was withdrawn from them to form the ice masses on the lands. Glaciers existed also in many mountain areas in larger size and greater numbers than are found at the present time. Competent authorities believe that if the great existing ice caps of Antarctica and Greenland and the smaller mountain glaciers were all melted, so much water would be liberated and find its way to the sea that the general ocean level would be raised approximately one hundred feet. Also it is believed that the central portions of the areas covered by the Pleistocene Ice Caps should have been lowered (pressed down) by the weight of the enormous masses

of ice. The present Greenland Ice Cap has been subjected to tests by sonic devices which indicate a thickness in the center of more than one mile. If so, such areas should have risen again with the wasting away of the ice. In support of this reasoning is the fact that eastern Canada has been rising since the ice melted away and these areas still are slowly moving upward. Thus the tilting of the basins of Lake Michigan and Lake Superior fits into the general geologic picture and seems to be quite understandable and proper.

GLACIAL LAKE DULUTH

As the last of the glaciers melted away from this area, the great syncline or downfolded area that had developed in this area in earlier times, and which was further deepened by the erosion of the ice, was flooded with water and Glacial Lake Duluth came into being. However, because of the tremendous amount of water supplied by the melting ice and because of damming by the ice of the St. Lawrence outlet, the early lake was much larger and stood at a much higher level than Lake Superior does now. Indeed, Isle Royale, was completely submerged for quite some time and it was not until the lake level receded somewhat that the island was revealed. Even then it emerged slowly and its growth can be traced by the series of old shore lines that exist above the level of the present lake. Let us see by what geologic processes these old shore lines, and their associated features, were formed.

SHORE LINES

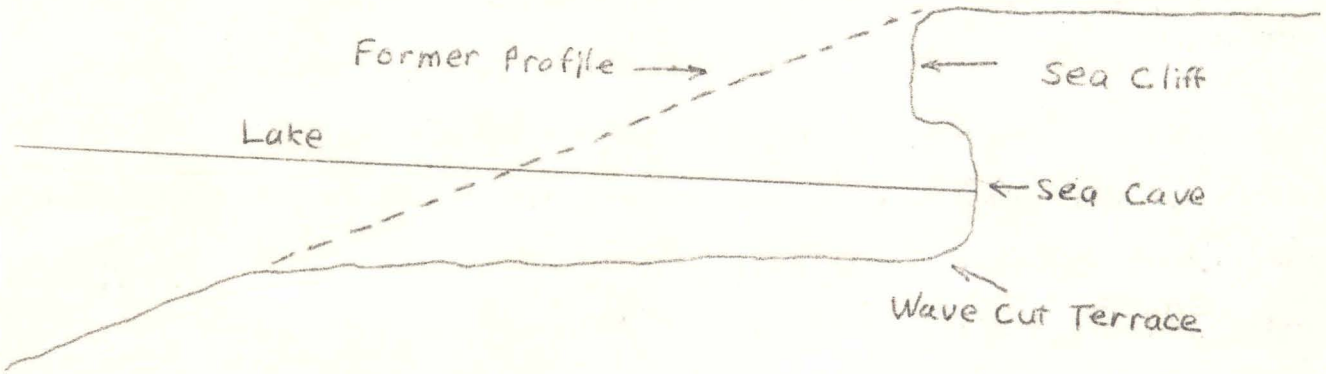
A beach normally is a battleground between the land and the water. While wave erosion is wearing away the land along some shores, waves and currents may deposit the resulting sediment to build the land seaward at some other locality.

WAVE-CUT TERRACE

Once a lake comes into existence it begins to modify its shoreline - the place where land and water meet. If the lake is large enough and exposed to the force of the wind, it will develop waves and these constitute the major agent of erosion that a lake possesses. As the waves progress shoreward their bases drag on bottom and at the line where storm waves attack the bottom they cut a notch if a shallow, sloping bottom exists. This notch gradually is widened to form a wave-cut terrace or platform. The distance from the shore to where the wave-cut terrace is started depends on the degree of slope of the bottom and the height of the storm waves which extend below the water level as well as above, just as all waves do. The cutting power of the waves is caused in part by the impact of the waves but most of their work on the bottom is accomplished by rock tools. Silt, sand, gravel, cobbles, boulders, all of these are utilized, although only very powerful waves can move boulders. The finer rock debris, especially silt and sand, is moved back and forth by the incoming waves and the retreating undertow so that even if the bottom be solid rock (as it is on the margins of Isle Royale), it literally is "sandpapered" to form the wave-cut terrace. Very slowly, but steadily, the wave-cut terrace is widened landward and the cutting is especially rapid during severe storms.

SEA-CLIFFS

Eventually the terrace may reach the shoreline although usually shorelines are migrating landward just as are the terraces although invariably at a slower rate. If the terrace does reach the shore, the waves attack the shore unobstructed by shallow water and in resistant rocks sea-cliffs are formed which extend below and above the level of the water. Gradually the sea-cliff in turn is cut landward by a combination of processes. The normal weathering of rocks by mechanical means such as freezing of water in crevices and by the expansion of growing tree roots



SKETCH V

SHORE PROFILE WITH TERRACE AND CLIFF

prying the rock apart, and the expansion and contraction of the outer rock as it alternately warms and cools slowly loosens pieces which readily fall from the steep (often vertical or even overhanging) face of the sea-cliff. Chemical weathering likewise aids in the loosening and altering of the rock by oxidation, carbonation, solution, etc. If only some of the minerals composing the rock are chemically altered, the disintegration of the rock proceeds nevertheless for as many minerals alter chemically they increase in volume and pry the remainder of the surrounding rock mass apart. Or, if these altered minerals dissolve or occupy less space they thereby provide space for air, water, plant roots, and plant acids to enter the rock more easily and accomplish additional physical and chemical disruption.

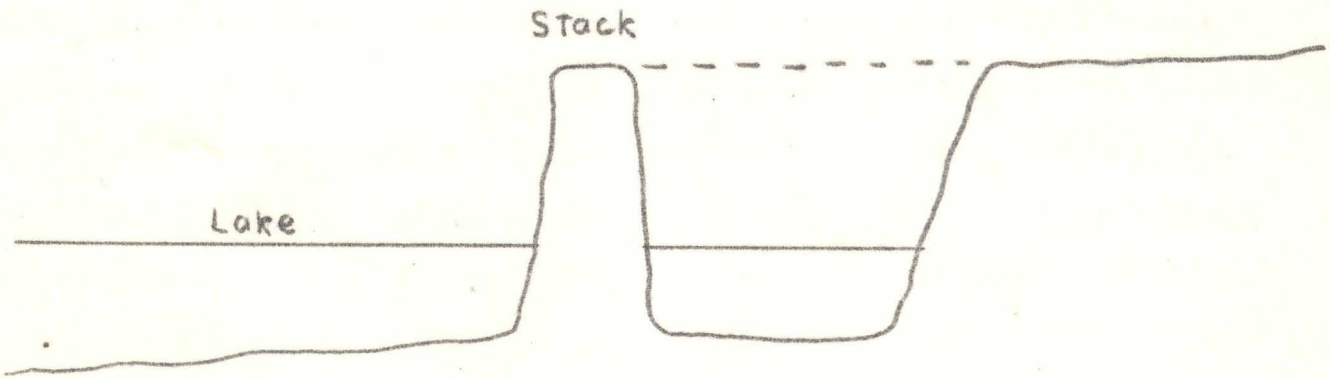
The waves themselves cut into the lower part of the sea-cliff chiefly by compressing the air in the cracks of the rocks as they collide with the rock with a force of many pounds - or even tons - of pressure per square foot. Then as the waves recede the compressed air rushes from the cracks with much force and this action many times repeated can gradually loosen blocks which fall and the cliff slowly migrates landward. If too much loose rock material falls from the cliff and accumulates at its base, the force of the waves is broken by this rock beach and the sea-cliff becomes less and less steep as the debris accumulates at its base and only the upper portion of the cliff is losing material. But if the waves can roll the smaller fallen particles back and forth on the wave-cut rock terrace they gradually are worn smaller and finally are carried away. Also sand and silt rubbed against the fallen blocks of larger size will gradually "file" them to smaller sizes until the waves can move them in turn. So, if the waves can keep pace with the erosion of material from the face of the cliff by removing the fallen material as rapidly as it falls, the shoreline will continue to move landward as a cliff.

STACKS

As the wave-cut terrace and sea-cliffs are extended landward, areas of unusually resistant rock or areas of rock with very few joints (cracks or breaks) will naturally be more resistant to being cut away by the wave action and other agents of erosion. As the rocks on either side are removed the more resistant mass will project farther lakeward than the adjoining shoreline and form a peninsula on a miniature scale. In many instances erosion and wave action will utilize cracks to cut in behind such masses thereby separating them from the shore so that they become islands. Such more or less steeply-sided islands rise above the wave-cut terrace as stack-like masses to which geologists have applied the name "stacks". An excellent example is located near the southwest end of Raspberry Island in front of the "Grotto". The Grotto is just the reverse of a stack - along joints, the waves have eroded a recess or pocket into the shoreline. Numerous other stacks exist in the islands fringing some of Isle Royale's harbors and in places off the shore of the main island. Not all of them are as commanding in appearance, however, as the one mentioned.

MONUMENT ROCK

Since, older, higher shorelines were formed on Isle Royale during the higher stages of Lake Superior with conditions similar to those now prevailing, it would seem reasonable to assume that stacks and other shore line features might be found at higher elevations along the old shore lines. One excellent example is Monument Rock on the Blake's Point peninsula. This feature, almost one hundred feet in height, stands a few feet in front of a rather steep cliff and is a stack adjacent to a sea-cliff. Rough rock boulders at the base of the cliff represent fallen blocks that had not been worn away or rounded by



SKETCH VI

DIAGRAM OF STACK

sand and wave scouring before the lake sank to a lower level. Of course some of them may have fallen from the cliff since the lake level dropped. "Skerries" is a Scotch term that is applied to such features and where a series of fringing islands of such an origin occur they may be referred to as a "skerry guard".

SEA-CAVES

During the formation and retreat of sea-cliffs the erosion of the cliff does not proceed uniformly. Where less resistant rock or numerous joints facilitate rapid erosion, the cliff moves landward at a more rapid rate. And, if the cliff is higher than the storm waves, the erosion is more active on the lower part of the cliff which receives the direct impact of the powerful storm waves. As a result of these inequalities some portions of the cliff near the water level are worn back so far that recesses with overhanging roofs result. Although not caves in the true sense, the name "sea-caves" is applied to such features. While boating along the shores of Isle Royale sea-caves are commonly encountered. They are especially numerous along the southeast shore between Conglomerate and Siskiwit Bays and in Todd Harbor. The higher level abandoned shore lines also reveal some sea-caves that have not as yet been obliterated by erosion and collapse. Susy's Cave along the inner shore of Rock Harbor is such a sea-cave. If an opening should form by collapse of the inner portion of the roof of a deep sea-cave, the remaining portion of the roof is left as a natural bridge. Such bridges may be arch-shaped and the name Arch Rock commonly is applied as in the case of the one that existed in the Washington Harbor area until about 1900 when it collapsed as all natural bridges do eventually. An "Arch Rock" also is reported as existing somewhere in the Todd Harbor area. These undoubtedly were and are similar to the well known Arch Rock on Mackinac Island. Susy's Cave actually is a natural bridge for a small opening has

developed in the back of the former cave. The so-called natural bridge on Amygdaloid Island was changed from a recess in the rock to a bridge as a result of mining excavations during one of the periods of mining on the island.

Since Isle Royale in general is composed of rocks rather resistant to erosion and since the lake has dropped to its present level very recently (geologically speaking not more than a few thousand of years ago), there has not been time for much of a wave-cut terrace to be excavated at the present level nor enough rock debris to form extensive wave-built terraces. Some of the fringing islands, however, are relatively flat and coincide so much in elevation as to suggest that their surfaces were planed off by lake erosion during one of the higher stages of Lake Superior or Glacial Lake Duluth.

BEACHES

In general beaches are developed only at the heads of coves and bays and are composed largely of gravel and shingle. Shingle is the name applied to flattened disc-shaped (rather than spheroidal) particles of rock of cobble size (larger than gravel and smaller than boulders). Shingle beaches are common in many places along the present shores and also along some of the higher abandoned shorelines. One of the best of the latter occurrences is located along the old shoreline trail leading from the Rock Harbor Lodge to Scoville Point. The character of the material in each beach clearly indicates its local origin (except for occasional erratics - boulders of rock not occurring on the island, but brought from elsewhere by the ice sheets) and in most instances the source rock can be found within a distance of yards or rods. At many of the beaches where chlorastrolites (greenstones) are found, the greenish colored amygdules are visible in the rock near and below the water's edge where the erosion of the softer parent rock slowly is freeing more of

the amygdules which are more resistant to erosion and weathering. Or, if they are not being liberated at the place where they are being found, the source usually can be located near at hand and the dominant wave and current action moves them when liberated to the beach where they are found. This is especially evident at the greenstone beaches on Smithwick Island and Caribou Island, both of which fringe Rock Harbor. Many of the greenstone amygdules that are observed still in the lava rocks are rather irregular in shape and when first liberated they retain their angular shape. As a result of transportation to the beach and subsequent back and forth movement by the waves, however, these grains and pebbles become progressively more rounded through abrasion. The continued abrasion may wear away the outer layers to reveal the mosaic-like markings which characterize these minerals and which make them attractive. The same association of thompsonites, agates, and other minerals on beaches at or near the source of supply is evident, and they likewise are progressively rounded and worn to smaller sizes thus revealing the rings and inclusions in some of the agates as well as the "eyes" in the thompsonites. Eventually all of these semi-precious gems are worn so small as to be valueless and were they sufficiently abundant, at some future time there could be sand which locally would be greenstone sand, agate sand, or thompsonite sand.

NO SAND BEACHES

True sand beaches have not been found on Isle Royale. Apparently there has not been time for many rock fragments to be reduced to sand size since the time of glaciation, and glaciation of the island resulted in the removal of practically all of the weathered and partially weathered rock debris including sand, that existed there before the Ice Age. Sand beaches eventually will form in many localities along the southeast shores of Isle Royale and its fringing islands for it is in this section that sandstone and conglomerate

rocks are most abundant. Also beaches of finer rock particles are more likely to form along that coast because of the predominant dip of the rock formations in that direction thereby facilitating stream transportation and wash in that direction. Other sands that will contribute eventually to beach formation originate from disintegration of some of the lava rocks that are composed of mineral particles in the form of spherules or ovate particles that are of the size to be considered sand. As these rocks disintegrate such mineral particles are liberated to form sand.

LIMITED DELTA FORMATION

Delta formation which is so characteristic of many shorelines is practically non-operative on Isle Royale despite the fact that Washington Creek has built a small delta in Washington Harbor. The paucity of streams, and the small size of those that do exist would militate against extensive delta building. Furthermore the removal of most of the pre-glacial mantle from the island by ice sheets has left but little rock waste for the streams to remove. In future geologic times the streams will have more available material, but at least little will be carried to the lake and delta building will not be important nor extensive. And as the rock slowly disintegrates into soil the forest cover will build up, thus retarding erosion and, at the same time will add to the beauty of the rugged island.

COPPER DEPOSITS

The copper deposits of Isle Royale are of the same type as those found on the mainland of Michigan, as is to be expected from the presentation of the geological structure and geological history of the area. Although historical mining of copper on Isle Royale has been unprofitable, the thousands of small pit mines testify to the success of the Indian miners, in fact, on

the basis of activity they seem to have been more successful on the island than on the mainland - just the opposite of the historical miners.

Copper deposits vary in nature in different areas of the world and although there has been disagreement in the past most of the present day specialists in mining geology agree on the general theory as to the formation of the Michigan copper[3]. Underlying the Keweenawan rocks along the Minnesota shore is the Duluth gabbro of the intrusive type of body, known as a laccolith. Similar rocks are found in Wisconsin and it is generally agreed that these are outcrops of the same body which extends under the lake from one side of the Lake Superior synclinal basin to the other and actually the settling of the basin after the outpouring of the surface flows is believed to be a result of the intrusion of this Duluth gabbro. Some smaller intrusive bodies that are located near the base of the Keweenawan series in the Keweenaw Peninsula of Michigan probably are extensions of this same mass or were derived from the same mass underground that supplied the Duluth gabbro magma to the laccolith under the basin in which the lake now is located.

SOURCE OF COPPER

In some copper-rich areas descending ground water dissolved copper from rocks near to the earth's surface before carrying it to greater depths and redepositing it in concentrated deposits that are rich enough for profitable mining. In the Lake Superior region, however, many of the lodes or deposits are located below rather impervious rocks which would have prevented waters from passing through them. This fact together with other evidence has supported the idea that the copper-bearing solutions must have been moving in the opposite direction, that is, upward. Thus the Michigan copper deposits are ascribed to the theory of ascending origin, and the copper is regarded as having been carried upward by solutions emanating from the Duluth gabbro. That

great mass of molten magma worked its way upward until, for some reason or other, its general movement ceased. As the main mass stopped its upward movement some gases or liquids were so highly heated that they continued to work their way surfaceward. Perhaps they were squeezed out as the cooler parts of the magma began to crystallize and contract to form the gabbro rock. At any rate certain solutions continued to ascend as is the case with practically all magmatic bodies that stop their upward journey before reaching the earth's surface.

COPPER DEPOSITS

Such solutions often carry certain minerals in much greater abundance than is usual for those minerals. These very hot solutions tend to be both under high pressure and highly mobile although their success in penetration of overlying rocks necessarily varies with the nature of the rock and the passageways that might or might not exist. The solutions either entered the lodes (the present areas of concentrated copper) directly (if the lodes extended as far downward as the Duluth gabbro), or if faults or fissures existed such routes were utilized by the ascending solutions. For the formation of copper deposits on a commercial basis the presence of extensive routes or channels of some type of high permeability was absolutely necessary so that the copper-bearing solutions could rise from the magma below. Such permeable channels in the Keweenawan rocks of the Lake Superior region were of three types.

CONGLOMERATE DEPOSITS - LODES

The layers of conglomerate rocks were much more permeable than the other sedimentary rocks or most of the igneous rocks. As the copper-carrying solutions followed the conglomerate layers upward they gradually cooled and began depositing the minerals that they carried and in this manner the copper accumulated in the cavities in the conglomerate that had previously provided the

route of travel for the solutions, or in some instances, some of the conglomerate pebbles were dissolved by the solutions and copper was deposited in the spaces previously occupied by such pebbles. Often, however, copper was deposited in both situations. Since the relatively pervious conglomerate beds, like other bedded rocks, are tabular (tablet-like in shape), the ore bodies (lodes) associated with them are necessarily tabular in shape also.

AMYGDALOIDAL DEPOSITS

The second type of permeable channel existed in the upper portions of those lava beds that were highly vesicular. Where the vesicles (gas bubble holes remaining from the liquid stage of the lava) were numerous enough and sufficiently well connected they likewise provided excellent channels for the ascent of the copper-bearing solutions. The tops of some of these vesicular zones furthermore are of a shattered nature. As the flows moved along even after the surface had cooled sufficiently to "crust over" a certain amount of breaking occurred to produce the conditions for the future breccia. And if sediments were deposited on the top of the vesicular flow some additional fracturing occurred. The net result of this activity was to produce a kind of mixture, long since converted to rock, known as scoriaceous amygdaloid, amygdaloidal conglomerate, or "ashbed". Since the rock fragments being laid down to form sedimentary layers were derived from the weathering of the same kind of rock farther up the regional slope, their incorporation with the local broken pieces of irregular top of the same kind of vesicular flow rock formed a sedimentary rock of rather uniform character. This new sedimentary rock could be called a breccia if the pieces composing it were angular, or a conglomerate if they were more rounded in outline. The term "ashbed" was applied by those earlier geologists in the region who believed that volcanoes had blown

solid particles of rock into the air to fall to the ground and accumulate as fragments of volcanic bombs or as finer material called volcanic ash. True ashbeds probably do not exist in the Keweenawan series. The copper and associated minerals, that were deposited by the ascending solutions in the scoriaceous amygdaloids and adjoining (overlying) breccias or conglomerates, were limited somewhat to the vesicles but in the associated zones they likewise tend to fill the interstitial holes. The copper amygdules (filling former vesicles) are referred to as "shot copper" by the miners since the rounded copper particles do somewhat resemble shot in outline and size.

VEIN DEPOSITS

Any fractures (breaks) or fissures (open passageways) in the rocks, especially the larger and more continuous, likewise served as avenues of ascent for the solutions - particularly those passageways that were relatively free from gouge (clay-like material produced by pulverizing of rock along the fracture during times of movement). These fissure deposits are known as veins and they fill, partially or completely, the fractures or fissures. They too are tabular in shape, but many of them are more continuous and they may cut through various formations rather than be confined to one formation as are the lodes. Some of the copper from the veins is known as "sheet copper" when it occurs in sheet-like bodies parallel to the walls of the vein. The distribution of the copper in the fissure veins is less regular and uniform than that in the lodes in the amygdaloid layers. In addition to the sheet copper there is a "stamp copper" that is scattered through the vein material in small grains (these rocks must be broken in the stamp mill to extract the copper), and irregular masses of almost pure copper ranging from a few pounds to many tons in weight. In mines on the mainland several masses of copper estimated at nearly five hundred tons each have been encountered in fissure veins.

The pattern of fractures and fissures therefore determines the pattern of the copper in the veins and from one locality to another both on the mainland and on Isle Royale the veins vary in thickness, continuity, pattern, and detail. In practically all of the deposits, however, the copper is native (metallic, in almost pure state) and usually associated with small amounts of native silver.

ROCKS

CLASTIC SEDIMENTS

The sedimentary rocks of Isle Royale are simple for the most part. To insure an understanding of these rocks an understanding of the names (based on the size of the particles) is necessary. Perhaps the basic sediment is sand, which by definition is composed of any rock or mineral particles measuring 1/16 to 2 millimeters in diameter. A rock composed of cemented sand is, of course, known as a sandstone. Particles of rock or mineral smaller in size than sand grains are known respectively as silt and clay and the rocks composed of silt particles are named "siltstones"; consolidated clay forms the rock known as "shale".

boulder cobble pebble	- conglomerate or breccia
sand	- sandstone
silt	- siltstone
clay	- shale

Particles larger in size than sand grains are known as pebbles (gravel), cobbles, and boulders; rocks composed of them are named "conglomerate" if the individual particles are more or less rounded. For those rocks formed of pebbles, cobbles, and/or boulders that are more angular than rounded the name "breccia" is applied. Sandstones, shales, conglomerates, and breccias are the common sedimentary rocks of Keweenawan age in northern Michigan. Since the

rock fragments composing them were derived from the weathering of the Keweenawan lava flows the sediments possess numerous characteristics of the lava rocks themselves. The breccias and conglomerates in particular bear considerable resemblance because many of the individual cobbles, boulders, and even pebbles are large enough in size to reveal the fact that they are fragments of the lava rocks.

SEDIMENTARY ROCKS

The sedimentary rocks listed are all of the clastic or fragmental variety, that is, the weathered particles of previously existing rocks were transported in essentially their former condition as solid particles to new localities where they were deposited and cemented together to form new rocks. Undoubtedly some of the streams flowing from this region carried dissolved minerals such as lime to the sea where the rock "limestone" was formed, but there is no record of such chemical sedimentary rocks being formed in the Lake Superior region during Keweenawan time. The local rocks all have characteristics indicating that they were deposited largely, if not entirely, under terrestrial conditions, that is, on the land rather than in the sea. Rivers carried rock particles which were deposited on their flood plains or perhaps in low-lying basins.

CONGLOMERATES AND BRECCIAS

Some conglomerates were formed on the tops of scoriaceous flows and in such instances the two formations may literally grade into each other. The irregular top of the flow suffered a certain amount of fracturing during the final stages of its movement and beginning immediately thereafter fragmental material from farther up the slope of the flow was carried by running water where streams developed, to lower stretches of the same flow. Thus transported pieces of scoriaceous lava were laid down on the same kind of lava rock

still in place, therefore there are transitions from lava (igneous) rock upward into sedimentary conglomerate or breccia. In some of these formations the individual particles are so small in size that they resemble volcanic dust or ash which are rock particles of very tiny size that were blown from volcanoes in the solid state. Some of the early geologists therefore applied the term "ashbed" to some of the rocks that are composed of very fine rock particles cemented together. Although it is entirely possible, even probable, that some solid material was blown from the fissures that emitted the lava, and that "spatter cones" may have formed here and there along fissures, it now is believed that most of the so-called "ashbeds" on Isle Royale are composed of weathered flow material that was transported by running water down the land surface and redeposited by that medium.

IGNEOUS ROCKS

The igneous rocks of Isle Royale and the mainland shores are mainly of the basaltic (basic) type although a few acidic layers do exist. As mentioned earlier, these are believed to be fissure eruptives. The number of individual flows is not known. When considerable intervals of time elapsed between eruptions sedimentary beds accumulated, but when the flows occurred at frequent intervals there was no time for sediments to form and accumulate so that the flows overlie one another with no intervening sediments.

TEXTURE

The texture of the lava rocks is the most useful characteristic when classification is attempted - at least in the field, where chemical analysis and microscopic determination is not feasible. The first and only thoroughly extensive study of the rocks of Isle Royale was made by A. C. Lane[4,5] shortly before 1900 and he had also studied the rocks of the Keweenaw Peninsula and

was able to identify some of the beds as being common to both places. For convenience in recognizing and classifying some of the rocks in the field he proposed certain general types which still are used to some extent. It must be understood, of course, that gradations occur between all of the different types no matter what system of classification is used. It is to be hoped that sometime in the future a geological exhibit will be installed in the park or that some of the rocks will be labeled so that visitors will be able to see the different kinds of rocks compared and contrasted in the visual form.

KINDS OF IGNEOUS ROCKS

OPHITES are lava rocks whose texture is visible in the roughly circular mottling produced by crystals of the mineral pyroxene that in these rocks surrounds and incloses the feldspar crystals. The inner portions of flows cooled and crystallized more slowly than the outer portions, therefore, nearer their centers the crystals are larger and the resulting mottled appearance (ophitic texture) is more evident, especially in the more feldspathic (less basic) flows. The "luster-mottled melaphyres" of some of the earlier investigators of the region are these same ophites or ophitic lavas. The more basic flows have the ophitic texture more uniformly developed and it tends to be more conspicuous even to the margins of the flows and in the very thin flows. From this it is evident that basic lavas cool more slowly than acidic ones thereby allowing more time for the crystals of the various minerals to grow to larger sizes before the mass solidifies and crystal growth ceases.

PORPHYRITES are rocks of medium rather than high basic content, and they grade into rocks that may be described as being of medium acidity. They contain well defined crystals which usually are feldspar minerals and larger than the average crystals constituting the groundmass (the main mass) of the rock. Porphyrites are similar to granite but they contain less quartz.

MELAPHYRES are dark (blackish or dark greenish-black) colored rocks with no distinctive texture such as occurs in the ophites and porphyrites. Probably most of the melaphyres of the earlier students of the region would now be described as basalt porphyry, or some as basalt. (a porphyry is a rock containing some crystals distinctly larger than the average size of those comprising the mass of the rock). If the larger crystals (phenocrysts), are of the same mineral as the smaller crystals in the ground mass they will not be conspicuous, instead they will be detected only with difficulty.

GREENSTONES. Although this term is very loosely used in the Lake Superior region the fact that the Greenstone Ridge is the highest and most outstanding of the ridges on Isle Royale and the fact that Lane designated the rock composing it as greenstone entitles it to special mention. In this instance the name "greenstone" refers to a rock otherwise known as olivine basalt. Basalts are fine textured basic rocks and "olivine basalt" in addition contains considerable amounts of the dark green to yellowish-green mineral known as olivine.

AMYGDALOIDS. The terms "amygdaloid" and "amygdaloidal" refer to the filled vesicles which characterize many of the flows or more especially their upper (and more rarely their lower) zones. In a strict sense the vesicles are the gas bubble cavities or holes that formed in some of the more fluid - especially the more basic - lavas. Where ground water or ascending solutions have filled these vesicles the fillings are referred to as amygdules and the rock may be termed an amygdaloid or an amygdaloidal lava, or amygdaloidal basalt. Thus the amygdaloidal rock shown on Lane's map as a strip along the northwest side of the island, and especially well developed on Amygdaloid Island is a formerly vesicular flow whose vesicles have long since been filled with minerals deposited in them.

RESUME OF THE KEWEENAWAN ROCKS

In general the lower portion of the Keweenawan series on the mainland of Michigan is a series of sedimentary rocks. These grade upward into an alternating series of sediments and extrusive lava flows which in the middle of the series is primarily a succession of basic lava flows with very few intervening sedimentary layers. Upward in the series the sedimentaries again become dominant representing a time when fewer and fewer flows occurred at greater intervals. The upper portion of the series is entirely sedimentary. Late in the period the deep-seated magma that had supplied the material for the eruptive flows from the fissures is believed to have provided additional magma that squeezed between the basal layers of the Keweenawan series and the older Archean and Huronian rocks below to form the thick laccolith of the Duluth Gabbro. Tongues of this mass forced their way into the overlying Keweenawan sediments and flows on the Michigan mainland to form the intrusive rocks that occur at intervals. Also hot solutions invaded the more pervious layers such as the conglomerates and vesicular flows and followed fracture zones to fill the vesicles with amygdules and to introduce the copper and associated minerals that were concentrated to form the lodes and veins of economic value on the mainland of Michigan and to a limited extent on Isle Royale.

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Geologic Time Chart

Eras	Periods	Dates and Events
Ceno-zoic	Cenozoic	Glaciation 1,000,000 B.C. Laramide
Mesozoic	Cretaceous	Revolution (Rocky Mts.) 70,000,000 B.C.
	Jurassic	Nevadian Disturbance
	Triassic	Appalachian
Paleozoic	Permian	Revolution 200,000,000 B.C.
	Pennsyl-vanian	
	Mississip-pian	
	Devonian	Acadian Disturbance 260,000,000 B.C.
	Silurian	350,000,000 B.C.
	Ordovician	400,000,000 B.C.
	Cambrian	Penokean
Protero-zoic	Keweenawan	Orogeny 500,000,000 B.C.
	Huronian	Algoman
Archeo-zoic	Knife Lake	Revolution Laurentian
	Keewatin	Revolution 2,000,000,000 B.C.

INDEX OF GEOLOGIC TERMS

Defined especially in terms of their meaning in this presentation.

ABRASION - mechanical wearing of rocks or rock particles.

ACIDIC FLOWS - a series of individual flows of lava, either the molten mass while flowing or the resulting layer of lava rock; that are composed primarily of acidic solutions or acidic minerals such as quartz and feldspar.

AGATE - a mineral composed of silicon dioxide (SiO_2) often in strata or bands indicating successive stages of deposition. The bands may be clouded or differently colored.

ALGOMAN (GRANITE or REVOLUTION) - a place name for a granite and a revolution that occurred at the close of the Archeozoic Era.

AMYGDULE (AMYGDALE) - the mineral matter filling former vesicles in some igneous rocks; the amygdules usually are of different material and differ in color from the inclosing rock.

ARCHEOZOIC or ARCHEAN ERA - era of the oldest known rocks. Archeozoic means primitive or beginning life.

ASCENDING SOLUTIONS - gaseous or liquid solutions that are rising (ascending) toward the earth's surface.

ASHBED - beds or layers of very fine dust blown from volcaneos as solid particles or the resulting rock formed from the cemented ash.

AXIS - an imaginary line or plane bisecting a structure such as a syncline or an island.

BASALT - a fine-grained basic igneous rock of dark color composed primarily of the minerals hornblende, pyroxene, and olivine.

BASIC LAVAS - lavas either liquid or solidified that contain more basic minerals, such as hornblende and pyroxene, than acidic ones.

BATHOLITH (DEPTH ROCK) - huge intrusive bodies of coarse grained (granite-like) igneous rocks with no known floor.

BEACH - a deposit of wave-handled rock debris rising above the water's edge.

BEACH TERRACE - an elevated or uplifted beach that is no longer located at the water's edge.

BEDROCK - rock that is in place, in beds or layers, and is more or less solid.

BOULDER - clastic rock or mineral fragments whose diameter exceeds 256 millimeters.

BRECCIA - a clastic sedimentary rock composed of pebbles, cobbles, and/or boulders that are angular in outline. Similar to conglomerate except that the fragments composing the conglomerate are rounded in outline.

CARBONATION - chemical weathering produced by union of carbon dioxide and certain minerals.

CENOZOIC (RECENT LIFE) - the fifth era of geologic time.

CHLORASTROLITE (GREENSTONE) - a rare semiprecious mineral (variety of thompsonite) occurring as amygdules in the basic igneous rocks. Green in color and characterized by mottled appearance.

CLASTIC - clastic sediments are rock fragments that have been disrupted mechanically - not chemically.

CLAY - a clastic sediment composed of particles measuring less than 1/256 of a millimeter in diameter.

COBBLE - a clastic sediment composed of rock or mineral fragments measuring 64 to 256 millimeters in diameter.

COLUMN (geologic) - the geologic column is a listing in columnar form of the eras, periods, and epochs of geologic time.

CONGLOMERATE - a clastic sedimentary rock composed of cemented pebbles, cobbles, and/or boulders.

CONTINENTAL GLACIER (ICE SHEET) - a large size glacier covering a continent or an appreciable portion thereof.

CORAL REEF - reefs built in shallow water by various organisms, both plant and animal, such as corals.

CROSS FAULT - a fault extending more or less at right angles to the axis of a valley or ridge (see Fault).

CROSS VALLEY - a valley extending across the axis of a structure.

CRUST - the outer several miles of the earth. Formerly restricted to what was thought to be a thin crust surrounding a molten interior.

CRYSTAL - the occurrence of a mineral with definite geometrical outlines.

CRYSTALLIZE - the cooling of a magma slowly enough so that the constituent minerals can solidfy in crystal form.

CYCLE - a regular period of events. Erosion Cycle - a cycle of erosion beginning with mountain building (orogeny), the mountains are eroded away, and the orogeny begins a new cycle.

DEBRIS - any accumulation of rock fragments.

DELTA - a sedimentary deposit, sometimes triangular (delta) shaped, built by a stream at its mouth.

DEPOSIT - any accumulation of rock or mineral matter such as: a delta, a lode, a vein, beach deposit, etc.

DINOSAUR - any member of a large group of reptiles that lived during the Mesozoic Era.

DIP - the angle of inclination of a rock bed or a fault plane from the horizontal plane.

DISINTEGRATION - the physical weathering (disrupting) of rock.

DISTURBANCE - the minor changes in elevation of a land mass or a portion of it such as mountain-building in a limited area, at the close of a geologic period.

DOWN-WARPING - warping involves the bending of the earth's rock into gently dipping structures (contrasted with sharp folds). Down-warping distinguished the areas depressed from those that are up-warped.

DRIFT (GLACIAL) - any rock debris that has been transported and deposited by glacial ice.

DULUTH GABBRO - gabbro rock of Keweenawan age that is named after the Duluth area where it first was studied (see gabbro).

EPOCH - a subdivision of geologic time shorter than a period; any interval of time.

ERA - one of the five great subdivisions of geologic time. See the geologic column or time chart.

EROSION - the transportation of weathered (disintegrated and decomposed) rock debris by wind, water, and ice.

ERRATIC - large glacially-moved boulders that are foreign to the underlying rock.

ERUPTION - the ejection of gas, liquid, and/or solid material from a volcano or fissure.

ESCARPMENT - the steep side of an asymmetrical ridge; any steep slope.

EXTINCTION (of a lake) - the obliteration of a lake by the accumulation of plant matter, the deposition of sediment, or drainage by lowering of the outlet.

EXTRUSIVE FLOWS - lava flows at the earth's surface (usually covering very large areas) that flow (are extruded) from fissures.

FAN OUT - spread out or deploy in fan shaped arrangement.

FAULT - a break in rocks along which there has been appreciable movement.

FELDSPAR - the most abundant mineral group; important constituents of igneous rocks. Soda-lime and potassium silicates.

FELDSPATHIC - like feldspar, containing feldspar.

FISSURE - when the walls of a joint or fault are separated the space between them is known as a fissure; a crack from which lava may be extruded.

FISSURE ERUPTIONS - lava eruptions emanating from fissures rather than volcanoes.

FLOOD PLAIN - the part of a river valley that is subject to flooding.

FLOW (lava) - the liquid (or the rock resulting from its solidification) discharged from a volcano or fissure.

FOLD - when horizontal rock layers are subjected to strong pressures they may be warped or bent into folds.

FORMATION - an assemblage of rock masses that have been grouped into a unit for convenience in description and mapping.

FOSSIL - any recognizable organic structure or impression of the structure preserved in rocks from prehistoric time.

FRACTURE - a break in otherwise solid rock.

GABBRO - a coarse-grained medium basic igneous rock.

GAP - an opening or pass in a ridge or mountain.

GEOLOGY - is the study of the earth including its rocks, atmosphere, and water, and the life upon it.

GLACIAL LAKE DULUTH - a lake (higher in level than Lake Superior) that existed for a short time near the site of Duluth during the wasting away of the Wisconsin Ice Sheet.

GLACIAL POLISH - rock surfaces polished by glacial abrasion.

GLACIAL SCOUR - rock surfaces scoured by glacial action.

GLACIATION - the alteration of the surface of the earth as a result of glaciers having passed over the area.

GLACIER - a moving mass of ice.

GOUGE - finely ground rock (clay) produced by movement along a fault.

GRADIENT (of a stream) - slope; the number of feet drop per mile.

GRANITE - a coarse-grained acidic igneous rock with visible quartz.

GRAVEL - pebble size (4 to 64 millimeters in diameter) clastic sediments.

GREENSTONE - an indefinite term (sometimes applied to chlorastrolites) usually applied to greenish-colored eruptive rocks; the term is falling into disuse.

GROUNDMASS - in an igneous rock containing different sized mineral particles the matrix or mass of smaller sized particles is the groundmass.

GROUND WATER - the sub-surface water, mostly derived from precipitation, that lies below the water table.

HURONIAN PERIOD - oldest geological period in the Proterozoic Era (see geologic column).

HORST - a rock mass bordered by faults along which it has been elevated higher than the surrounding area.

ICE AGE (Pleistocene) - the recent epoch of continental glaciation.

ICE PLUCKING - the various ways in which rock debris is picked up and made a part of a moving ice mass.

ICE SHEET (Continental Glacier) - a large size glacier of Ice Cap covering a continent or an appreciable portion thereof.

IGNEOUS (activity) - the phenomena associated with molten rock masses and their movements.

IMPERVIOUS - lacking pores; a rock which solutions are unable to penetrate.

INTRUSION - a mass of magma or its solidified derivatives which has forced its way into an older rock mass as contrasted with an extrusion where the molten rock has flowed out to the earth's surface.

IRON ORE - an ore (iron) is a mineral aggregate from which one or more metals can be extracted at a profit.

JOINT - a fracture or break in rocks along which there has been no appreciable displacement.

KEEWATIN - (Period) - time of formation of rocks of earliest known geologic time; sedimentary and volcanic series of rocks.

KEWEENAWAN - (Period) - latest period of the Proterozoic Era. Type area is in Michigan's Keweenaw Peninsula.

KNIFE LAKE SERIES - second (younger) series of sedimentary rock of Archeozoic Era (same age as Timiskaming).

KILLARNEY (Revolution and Granite) - mountain-building at the close of the Keweenawan Period.

LACCOLITH (cistern rock) - is a large lenticular mass of intrusive igneous rock.

LAURENTIAN (Revolution and Granite) - mountain-building after the Keewatin Period in the Archeozoic Era.

LAVA - magma that reaches the surface, or the rock resulting from its solidification.

LAVA FLOWS - flows of molten rock on the earth's surface, or the solid rock resulting from them.

LEACHED - the process of soluble minerals being dissolved and carried away.

LIMESTONE - a calcareous sedimentary rock composed essentially of calcium carbonate (lime).

LIQUIFY - the process whereby solid rock becomes a liquid.

LODE - the area of several closely-spaced veins (of copper) that can be mined at a profit.

LONGITUDINAL (longitude, length) - the longer dimension of a structure such as: an island, a range, a valley.

MAGMA - molten rock below the earth's surface.

MANTLE - the blanket of weathered or partially weathered rock debris that in most areas covers bedrock.

MELAPHYRE - fine-grained (dark colored) basic porphyries.

MESOZOIC (middle life) - the fourth great era of geologic time.

MINERAL - a naturally occuring substance with a distinctive set of physical properties and a characteristic chemical composition.

MOLTEN - in the melted state or condition.

MONOCLINAL (one limb) - a one-sided fold, the rock layer is bent in one direction only.

MOUNTAIN BUILDING (Orogeny) - the elevation of portions of the earth's surface usually involving folding and faulting.

NATIVE COPPER - the mineral copper not combined with other substances, copper essentially in the metallic state.

OLIVINE - a greenish to brownish colored magnesium and iron silicate mineral, characteristic of basic igneous rocks.

OPHITE - basic igneous rocks similar to gabbro with an ophitic (mottled) appearance due to the texture and arrangement of the pyroxene and feldspar crystals.

ORE - a mineral aggregate from which one or more metals can be extracted at a profit.

ORGANISM - a living entity, either plant or animal.

OROGENY - mountain-making or mountain-building.

OUTCROP - an exposure of bedrock.

OUTLET - the place of departure or overflow of a lake.

OXIDATION - chemical union of any substance with oxygen; one of the methods of chemical weathering (decomposition).

PAIEOZOIC (ancient life) - the third great era of geologic time.

PALISADE (a row of stakes) - a cliff characterized by rock columns (columnar structure).

PERIOD - a unit of geologic time; a sub-division of an era which usually began and terminated with a disturbance.

PERMEABLE - a rock or rock substance which will permit the passage of liquids.

PERVIOUS - same as permeable.

PHENOCRYST - in a porphyritic rock the larger crystals embedded in the groundmass are known as phenocryst.

PHYSIOGRAPHIC - the study of physiography; the various land forms sculptured erosive agencies.

PLAIN (plane) - a low level, flat to gently-rolling land surface.

PLANATION - the process of planing (eroding) to a lower and more nearly level surface by an agent of erosion.

PLEISTOCENE (most new) - most recent epoch of glacial time.

PLUCKING - see Ice Plucking

PORPHYRITE - fine-grained porphyritic rocks of medium acidity or medium basic content.

PORPHYRY - an igneous rock composed of mineral grains of two distinctly differ-

ent sizes: the larger are phenocrysts, the smaller constitute the groundmass or matrix.

POST-GLACIAL (time) - time after the Ice Age.

PRE-GLACIAL (time) - time before the Ice Age.

PROFILE - cross sectional view in outline of a ridge, valley, etc.

PROTEROZOIC (former life) - the second great era of geologic time.

PYROXENE - a green or black basic mineral composed of calcium and magnesium silicates. Common in basic igneous rocks.

RADIOACTIVE ELEMENTS - complex elements such as uranium that break down chemically to form simpler minerals. The alteration occurs at a fixed rate which interpreted is used as a device for measuring the age of rocks and the age of the earth.

RAISED (ELEVATED) BEACH - beach that has been raised above water level.

RESISTANT ROCK - rock that is resistant (through hardness or compactness) to weathering and erosion.

REVOLUTION - a major crustal movement (mountain-building) of the type that differentiates eras.

RIDGE (range) - an extended or linear hill or mountain.

RIFT - crevasse or cleft produced by splitting.

ROCHE MOUTONEE (sheep-back rocks) - rock masses smoothed and polished on the side from which the ice came, but jagged and irregular on the lee side due to plucking.

ROCK - mixtures of various minerals in various proportions.

ROCK BASIN - a basin excavated from bedrock and usually containing little sediment or mantle; produced by glacial erosion.

ROCK REEF - solid rock reefs (underground ridges) extending from the shores as projections of the resistant, ridge-forming, rock layers.

SAND - clastic rock or mineral fragments measuring 1/16 to 2 millimeters in diameter.

SANDSTONE - a sedimentary rock composed of cemented sand grains.

SCORIA - a red or black colored, glassy textured igneous rock containing numerous vesicles.

SCORIACEOUS - like scoria.

SEA-CAVE - along vertical cliffs adjoining the sea, wave erosion may cut recesses into the cliff - such are called sea-caves.

SEA-CLIFF - vertical cliffs produced by wave erosion along shores composed of rocks resistant to erosion.

SEDIMENT - rock fragments or rock debris derived from the weathering of rocks, includes chemical and clastic sediments.

SEDIMENTARY - pertaining to sediments.

SEDIMENTATION - the processes forming, transporting, and depositing sediments constitute sedimentation.

SERIES - a sequence of rocks that formed in a geologic epoch.

SHALE - a clastic sedimentary rock composed of compacted clay.

SHINGLE - flattened disc-shaped (rather than spheroidal) particles of rock of cobble size - 64 to 256 millimeters in diameter.

SILT - a clastic sediment composed of particles measuring 1/256 to 1/16 millimeter in diameter.

SILTSTONE - a clastic sedimentary rock composed of compacted silt. Gritty like sandstone but composed of finer particles.

SILURIAN - the third period of the Paleozoic Era.

SKERRY (Skerry Guard) - island, or a group of islands, fringing a shore, produced by shoreline erosion.

SOLIDIFIED - the cooled and hardened magma or lava.

SOLUTION - a liquid or gas containing dissolved minerals.

SPATTER CONE - a small cone along a fissure formed by globs of viscuous, partially cooled lava that adhered to each other.

STACK - a steep-sided remnant (island) of a retreating coast on a wave-cut terrace.

STRAND LINE - the definite line of contact between the water and the land.

STRIAE (Striations) - scratches and grooves produced in rocks (usually bedrock) by glacially moved rock fragments.

STRIKE - the direction of the line formed by the intersection of a rock layer with a horizontal plane.

SUBMERGENCE - the flooding of a land area by lowering of the land or rising of the water.

SYNCLINE - an area of down-folded rocks.

TABULAR - arranged in table or tablet-like form.

TERRACE (Wave-Cut) - a rather level surface over which the sea has advanced by cutting away a sea-cliff.

TERRESTRIAL - pertaining to the earth or land. Terrestrial sediments are deposited on flood plains rather than in lakes or oceans.

TEXTURE (of igneous rocks) - the appearance of a rock as determined by the size, shape, and arrangement of the constituent minerals.

THOMPSONITE - one of the zeolite group of minerals; hydrated silicate, usually pink or white in color, possessing "eyes" which are concentrically layered portions differing from the remainder of the mineral.

TILTING - inclining, slanting, or otherwise changing the position of part of the earth's surface or its rock layers.

TIMISKAMING - second (younger) series of sedimentary rocks of Archeozoic Era. (Same age or the equivalent of the Knife Lake series).

TOPOGRAPHY - configuration of land's surface.

UPLIFT (Continental) - elevation or raising of a continent by earth forces.

VEIN (Fissure) - a tabular mass of ore more or less sharply delimited from the rock inclosing it is termed a vein. A fissure vein formed in a fissure.

VESICLES - gas bubble holes remaining from the liquid stage of the rock.

VOLCANIC ACTIVITY - igneous activity with surface (volcanic) manifestations.

VOLCANIC BOMB - mass of partially cooled lava hurled from a volcano, liquid enough for its ends to become spirally twisted during flight.

VOLCANO - an eruptive apparatus, a conduit connecting the earth's interior and exterior. Usually a volcanic mountain or cone is built around the vent of the volcano.

WAVE-CUT TERRACE - see terrace.

WISCONSIN ICE SHEET - the last of the ice sheets (continental glaciers) to cover substantial portions of North America during the recent Pleistocene Ice Age.