GEOLOGY OF MICHIGAN

by

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CHAPTER I

INTRODUCTION AND ACKNOWLEDGMENTS

This little booklet on the Geology of Michigan is intended to serve a need which has been apparent for many years. Numerous requests for information regarding the geology and minerals of Michigan have been received from students, teachers, and others. It is also believed that this booklet will be of value to tourists and vacationists in calling attention to the geologic features of scenic interest, and giving an explanation as to their manner of formation and relation to the general geology of the State.

Several persons have given valuable aid in the preparation of this report. Mr. F. G. Pardee, Mining Engineer, and Mr. Wayland Osgood, Mining Geologist of the State Geological Survey were frequently consulted in regard to the Pre-Cambrian, and Mr. Osgood prepared the generalized geologic map of the Upper Peninsula. Dr. Andrew Leith of the University of Wisconsin very kindly furnished correlations of the Huronian of Michigan, from the unpublished revised edition of Monograph LII of the United States Geological Survey. Dr. W. A. Kelley of the Michigan State College arranged and directed preparation of the plates showing typical Michigan fossils. Dr. R. B. Newcombe, Petroleum Geologist, was consulted in regard to certain problems of the Paleozoic, and Dr. Richard A. Smith, State Geologist, read the entire report, making necessary corrections and offering valuable suggestions concerning its style and text. The manuscript copy was prepared by Mrs. Gertrude K. Barley and Miss Margaret Huston.

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CHAPTER II

DEFINITION OF GEOLOGY

The word geology is derived from two Greek words, ge meaning earth and logos meaning a discourse. According to the derivation of the word, geology therefore treats of the earth and everything pertaining to it. This includes a study not only of the minerals and rocks which make up the earth; the various features of the land such as mountains, valleys, rivers, lakes, the oceans, and the atmosphere; but also a study of the forms of life which have inhabited the earth in the past. Geology is not directly concerned with life which is existant upon the earth at the present time, since that is the field of study for the botanist and the zoologist. Geology is concerned, however, with the remains of plants and animals when they become buried and preserved in the rocks of the earth, as the shells, skeletons, casts, impressions, etc., are an aid to the geologist in determining the age of rock formations and enable him to form a picture of the land surface, climate, and oceans at the time the animals or plants were living. The remains of living things found in the rocks also give us a record of the developments of life from the very earliest forms down to those of the present time.

As geological knowledge increased it was found that the subject of geology actually consisted of a number of different branches, each of which was large enough for detailed study in itself. As a result several of these branches such as Mineralogy (the study of minerals) and Paleontology (the study of fossils) have become practically separate sciences; and Physical Geology, Historical Geology, and Economic Geology are recognized as major divisions of geology. A general knowledge of the above subjects as applied to Michigan is necessary for an understanding of the geology of the state. In this booklet attempt has been made to describe as briefly as possible the minerals and rocks which are found at the surface or penetrated by drills, together with a history of their deposition, fossils contained, and mineral products of commercial value. Various land forms or features which have resulted from the action of geologic agencies such as running water, waves, wind, glaciers, volcanic activity, etc., are also mentioned or briefly described.

As an introduction to Michigan geology it is believed advisable to start from the very beginning and outline the theories pertaining to the origin of the earth, followed by a brief discussion of the composition of the earth, minerals and rocks, the geologic time scale, fossils, unconformities, and other information necessary to an understanding of the geology of the State.

CHAPTER III

ORIGIN OF THE EARTH AND SOLAR SYSTEM

Several theories have been advanced by scientists to explain the origin of the earth. One of these theories, known as the Nebular Hypothesis, advanced by Kant and LaPlace, assumes that in the beginning there was an infinitely large mass or nebula of luminous gas revolving about a central core or nucleus. It is assumed that by processes of cooling and contraction, rings were separated off, perhaps to form in appearance a body somewhat similar to the planet Saturn with its rings, and that enough rings were separated off in succession to form the nine planets. These rings of gas are supposed to have broken apart and the gas formed into a rough sphere which upon cooling changed first to a liquid and finally to a solid form. It is supposed that the spheres of gas thus formed separated off rings by the same process as the parent body while still in a gaseous state, and these formed secondary planets or satellites, such as our moon. The planet Saturn may be considered as such a body of gas, the rings of which have not yet broken apart.

The nebular hypothesis would serve excellently to account for the belief formerly held that the interior of the earth is in a molten condition. Volcanic eruptions of molten rock or lava through cracks in the outer cooled crust of the earth gave support to this theory.

The nebular hypothesis was pretty generally accepted as a satisfactory explanation of the origin of the sun and planets, until the latter part of the nineteenth century, when certain objections to this theory led to the formulating of a new theory by Professors Chamberlain and Moulton. This theory is known as the Planetesimal Hypothesis, which takes for its beginning an ancestral sun composed of finely divided solid particles, long streamers of which were pulled out by the attraction of a star passing at close range. Rotation of the sun caused the streamers or arms to wrap themselves around a central core forming a Spiral Nebula. Among these particles comprising the spiral arms were some larger in size which acted as nuclei or centers of attraction for the smaller particles which collected about the larger knots, and by continual falling in of the meteoric particles the earth and the other planets were gradually built up. The planets so formed remained in their original positions in the spiral arms, revolving about the central sun in the paths described by the arms, except that these latter had largely disappeared because of the attraction of the planetesimals to the larger nuclei.

The sun of our universe is but a star similar in character to the 100,000,000 or more stars recorded by astronomers. Each of these stars has a solar system like our own, but billions and trillions of miles distant. Our sun is one of the smallest of these stars, having a diameter of 866,400 miles, in contrast to a diameter of millions of miles for some of the more remote suns. The earth, which ranks fifth in size among the nine planets, has a diameter of slightly less than 8,000 miles, in contrast to that of Jupiter, the largest of the planets, which has a diameter of 86,500 miles. The moon is sometimes considered as a planet, but since it revolves around the earth as well as the sun it is more generally considered as a secondary planet or a satellite of the earth. The moon is a little more than one-fourth the size of the earth, and is about 240,000 miles distant.

Planets differ from stars in that they revolve about a sun, while the stars represent other suns or solar systems, each with its central sun and accompanying planets.

A modification of the Planetesimal Hypothesis known as the Gaseous-Tidal Hypothesis has been recently developed by Jeans and Jeffreys. This hypothesis has its beginning the same as the Planetisimal Hypothesis but it assumes the disruption of a vast streamer or filament of intensely hot gas instead of the spirals composed of solid particles. The filament thus formed is presumed to have broken into segments which contracted into spheres. These gaseous spheres then gradually cooled to at first a liquid and then to a solid state as in the case of the Nebular Hypothesis. The Gaseous Tidal Hypothesis therefore combines features of both the Nebular and Planetesimal Hypotheses and serves to explain the apparent increase in density of the rocks toward the center of the earth with a probable core of metallic iron. The metallic core has been strongly suggested by scientific observations but is difficult to explain under the Planetesimal Hypothesis. In cooling from a gas to a solid the heavier minerals would sink by gravity toward the center of the mass. There are several other observed conditions of the earth and planetary systems which are also more satisfactorily explained by the Gaseous Tidal Hypothesis. The oceans are presumed to have been formed after the earth had cooled sufficiently by condensation of water vapor from an enormously thick atmosphere consisting largely of oxygen but with ample amounts of hydrogen to form water, which fell in endless torrents, eventually filling the low places in the original crust of the earth.

CHAPTER IV

COMPOSITION OF THE EARTH'S CORE

It has been determined by scientific methods that the earth as a whole is $5\frac{1}{2}$ times heavier than an equal volume of water. In other words its specific gravity is said to be 5.5. However, the surface rocks and those which we have been able to study in the deep mines and from wells drilled for oil have an average specific gravity of only about half as much or 2.7. Therefore in order to raise the specific gravity of the earth as a whole to 5.5, it is necessary to assume a considerably higher specific gravity for the materials forming the central core of the earth. There are a number of observations which suggest something as to the probable composition of the earth's core. We all know that the earth is a great magnet, the northern pole of which is in northern Canada, and the southern pole in Antartica. The only magnetic elements known are iron, nickel, and cobalt, the specific gravities of which are respectively 7.15, 7.8, and 7.5. These values would raise the average specific gravity of the rocks of the earth's crust to approximately 5.5 for the entire globe. A study of meteorites or "shooting stars" throws additional light on the problem. Meteorites are of two general kinds; iron meteorites and stony meteorites. The iron meteorites are composed almost entirely of metallic iron and nickel, while the stony meteorites are made up of silicates of magnesium, iron and călcium. No meteorites have been found, however, which have a composition similar to granite and other rocks containing free quartz and silicates of aluminum, potassium, and sodium, which form most of the earth's crust. Vice versa no combinations of metallic iron, nickel, or cobalt have been found on the earth, although material somewhat similar to this has been found on an island west of Greenland. No chemical element has been found in either meteorites or in the earth's crust which has not been found in the other, although as shown above certain <u>combinations</u> of elements occur in each which have not been found in the other groups.

CHAPTER V

COMPOSITION OF THE EARTH'S CRUST

All known matter is made up of 92 chemical elements grouped into various combinations. An individual element may occur singly or uncombined, such as gold, silver, copper, carbon, etc. Only a few of the elements, however, occur free, or native, most of them entering into chemical combinations to form the various minerals, plants, and animals. Living things, such as plants and animals, are made up chiefly of carbon, hydrogen, oxygen, and nitrogen in various forms, and are said to be organic in nature. These and the remainder of the chemical elements form inorganic substances known as minerals which compose the earth, sun, planets, and the stars. Of all the 92 elements, however, only eight occur in very large quantities. Strange to say oxygen, a gas without which life as known to us is impossible, is in chemical combinations with other elements to the extent that 50 percent of the mass of the earth's crust is composed of oxygen. The next most important element is silicon, which comprises more than one-quarter of the crust, and the bulk of the remaining one-fourth is composed of aluminum, iron, calcium, magnesium, sodium, and potassium. None of these eight elements occurs free, but they combine with one another in characteristic proportions to produce the crystalline substances referred to above as minerals.

CHAPTER VI

MINERALS AND ROCKS

Minerals

There are about 2000 known minerals, but a list of approximately 100 will include all of those which are common ones, and of these about 25 constitute more than 99 percent of all the rocks making the earth. Illustrations of rock-forming minerals are: feldspar, a combination of potassium, sodium, aluminum, silicon, oxygen, and sometimes calcium. The chemical symbol for feldspar is written thus - Na (K) $AlSi_3O_8$. Quartz (SiO_2) is a combination of silicon and oxygen. It is a clear glassy mineral which makes up the majority of sand grains and many of the pebbles found in gravel pits and through the soil. Calcite ($CaCO_3$) is composed of calcium, carbon, and oxygen. The extensive limestone deposits of the earth's surface are composed chiefly of calcite.

Other important minerals are mica, hornblende, augite, olivine, epidote, chlorite, serpentine, dolomite, hematite, limonite, magnetite, tourmaline, corundum, apatite, pyrite, garnet, gypsum, halite, anhydrite.

Rocks

The combinations of minerals which form the earth's crust are known as rocks. A rock may consist chiefly of a single mineral, as for instance limestone or rock salt (halite), or it may consist of several minerals as in the case of granite, which contains mica, feldspar, and quartz. A mine or quarry may be operated to secure a single mineral of value, as for instance copper, gold, or silver, in which case the containing rocks are valueless and are wasted, or the entire rock may be wanted, as in the case of granite for building purposes, and limestone for chemical or building purposes.

The principal kinds of rock found in Michigan are limestone, dolomite, sandstone, shale, conglomerate, granite, slate, mica schist, gneiss, quartzite, basalt or trap rock, and marble. There are many other varieties and gradations from one type to another, but a knowledge of all of these is not important for a general understanding of Michigan geology.

Formation of Rocks and Minerals

Minerals are formed by crystallization from molten lavas, by deposition from liquid or gaseous solution, and by metamorphism or change caused by extreme heat or pressure, or both. Rocks are classified under three heads, depending upon the manner of their formation.

1. Igneous rocks are those which have crystallized from a molten condition. This is the same process as that mentioned under formation of minerals, since a rock is simply an aggregate or group of minerals. An illustration is granite, which contains crystallized quartz, feldspar, and mica. Another type of igneous rock is basalt, a rock much darker in color and finer grained than granite. Basalt is a lava poured out or extruded on the surface by volcanic action; hence it cools rapidly and is fine grained. Granite, on the other hand, wells up deep down in the earth and hence cools slowly; therefore the individual mineral grains are larger.

2. Sedimentary rocks are formed as a result of the breaking up of igneous, metamorphic, or other sedimentary rocks by the action of rain, heat or cold, running water, plant growth, etc. The rock and soil particles thus formed are washed away by rivers and deposited along their course, or in lakes, bays, or in the ocean. Great thicknesses of these materials were laid down under water in the course of thousands and millions of years of geologic history and later by uplift of the sea coast or withdrawal of the

water became land areas. Sedimentary rocks are arranged in distinct layers or beds as a result of variation in the kind of material washed down by the transporting streams. Examples of sedimentary rocks are sandstone, limestone and dolomite, shale, and conglomerate.

3. Metamorphic rocks are those formed from igneous and sedimentary rocks by great heat or pressure. The process is the same as that described under formation of minerals. Examples of metamorphic rocks are gneiss, mica schist, and quartzite.

The definitions of the three classes of rocks indicate that only the first class is of primary origin, the other two classes having been formed from pre-existing rocks by means of the geologic processes described. A cycle of events can be described which would show that even the igneous rocks could possibly not be considered as of primary origin, but this would simply be confusing and is not necessary for the purposes of this booklet. It is more convenient that some point or process be taken as the ultimate source or beginning of things in order that later events may be based upon these earlier happenings. We shall therefore proceed on the assumption that igneous rocks are of primary origin as a result of crystallization from a molten condition, and that the original crust of the earth's surface was composed of rocks of this type formed during the period in which the earth was being built up under the planetesimal or gaseous-tidal hypotheses.

Oldest Known Rocks

For a long time it was believed that the vast area of granites and gneisses in the region about Hudson Bay, in the Lake Superior district, and in various other places on the North American Continent, as well as on other parts of the earth, represented the original crust of the earth because they everywhere underlie what were thought to be younger rocks.

It has since been shown, however, that the granitic rocks of the "Canadian Shield," as geologists call all of the area about Hudson Bay, are not the oldest known rocks on the surface of the earth, but are younger than and intrusive into the rocks which they seemingly overlie. In other words, the present granites and gneisses welled up from below as molten magmas which intruded, domed up, wrapped themselves around, and otherwise profoundly altered the pre-existing rocks which originally appeared to consist of carbonaceous shales, conglomerates, limestones, and basaltic lava flows. These rocks have now been altered to mica schists, greenstone schists, slate, marble, and graywacke, and are the oldest rocks exposed at the surface of the earth. They still, however, may not be considered as the original crust of the earth since they are for the most part altered or metamorphosed sedimentary rocks; whereas the original crust of the earth would necessarily be composed of igneous or volcanic material.

It may therefore be stated that nowhere on the earth can there be any rocks positively identified as constituting the original crust of the earth.

The major portion of the western half of the Upper Peninsula of Michigan is composed of rocks of the above described character which are among the most ancient on the earth. From Marquette westward the geologic history goes back to the earliest happenings on our planet and tells a story of volcanic eruptions and upheavals of the strata and profound changes in the character of the rocks. From Marquette eastward the rock formations become progressively younger and undisturbed except for a gentle dip of the beds to the southeast. It may be said that Michigan offers one of the best areas for geologic study on the entire continent, since the exposed rocks cover practically the entire range of the earth's history from the ancient crystalline eruptives to the deposits laid down by the great ice sheet of the "Glacial Epoch."

CHAPTER VII

GEOLOGIC TIME SCALE

The Geologic Time Scale is the geologist's method of recording the passing of events in the earth's history. In modern life we have our calendar to record the passing of the larger divisions of time, and our clock to record the passing of the smaller units. In earth history, however, the week, month, or year are much too small compared to the age of the earth to be of value in recording the passing events of its history. The geologist instead of years, months, or weeks and days, makes use of the term era, period, epoch, and age, which are in the same relation to one another except that they represent vastly greater periods of time. These terms refer to no definite number of our years, nor are all eras of the same duration of time, nor all periods, epochs, etc. A single era may equal to 100,000,000 of our years, another era 200,000,000 or possibly only 50,000,000 years. For the sake of comparison with our divisions of time an era may be said to cover hundreds of millions of years, periods tens of millions, and the smaller divisions in proportion.

The total age of the earth has been variously estimated from 100,000,000 to 2,000,000,000 years. The latter figure is based on the rate of decomposition of radio-active substances and probably represents more nearly the magnitude of time we are dealing with than the smaller figure.

Layers of rock having more or less the same character and containing certain kinds of fossils are called <u>formations</u>, and a number of formations are known as a <u>series</u>. Formations are sometimes subdivided into <u>members</u>.

Geologic history is divided into five eras, namely; <u>Archeozoic</u>, <u>Proterozoic</u>, <u>Paleozoic</u>, <u>Mesozoic</u>, and <u>Cenozoic</u>. Sometimes a sixth, <u>Azoic</u>, is placed below the Archeozoic, and a seventh, Psychozoic, is sometimes placed after the Cenozoic. The above names assigned to the different eras are of Greek origin and refer to stages in the development of life. Archeozoic means archaic or first life; Proterozoic, primitive life; Paleozoic, ancient life; Mesozoic, medieval life; and Cenozoic refers to modern life.

The term Azoic, when used, covers the period between the time of formation of the earth, its oceans and atmosphere, to the time of the appearance of the first forms of life. It refers to the period in the earth's history when there was no life of any description. The term Psychozoic is sometimes used to cover the period of mental domination and world civilization in which we are now living. Previous eras are characterized by domination of so-called progressively lower forms of life, namely mammals and birds in the Cenozoic; dinosaurs and other reptiles in the Mesozoic; amphibians, fishes, and shelled animals in the Paleozoic, with primitive invertebrates and unicellular life, characterizing the Proterozoic and Archeozoic eras. The era or period to which a certain group or series of rocks belongs is determined by the fossils found intombed in the rocks. Fossils are the petrified skeletons or shells of animals or plants or the casts or impressions of the shells, which, upon the death of the animal, are preserved by burial in sand or mud which later is formed into stone through pressure exerted by accumulated thicknesses of sediment or by action of circulating water in depositing cementing material. The remains of sea organisms are much more likely to be preserved than those of land plants or animals, inasmuch as it is necessary for the land forms to be covered soon after death in order to prevent decomposition. For this reason the history of life on the land is not nearly so complete as that of life in the oceans.

Correlation of Formations

The Geologic Time Scale is a summary of the geologic history of Michigan. The names assigned to the eras and periods are the same as those used for the entire North American Continent, but the formation names, with few exceptions, are taken from localities in Michigan or adjoining states. This is due to the fact that it is generally difficult or impossible to trace a single formation over long distances unless its geologic position, mineral character, and fossils are so characteristic as to make the beds easily identifiable. For example the Trenton formation is named from the town of Trenton in New York state. The time of deposition of the Trenton limestone formation was one in which conditions were fairly uniform over most of the eastern and central portions of the United States. This region was submerged by a shallow sea which remained for such a long period of time that a great thickness of limestone was built up in the sea from the remains of lime-secreting organisms. The continuity of this formation over much of the eastern United States permits the general use of the name "Trenton" throughout most of this area. Few formations, however, are as easily correlated in different parts of the country as the Trenton, since conditions of deposition were not so universally uniform as in that case, nor maintained over such a long period of time. Shifting seas and variation in the character of materials of rock weathering available at different places of deposition resulted in formations laid down at the same time, which were often very different in mineralogical character. Long distance correlation of beds to determine if belonging to the same geologic period is generally attempted by means of a study of the fossils contained in the beds.

Several Michigan formations, such as the Berea, Bedford, Sunbury, Cataract, Salina, Richmond, and Utica are considered equivalent to similar formations in Ohio, Indiana, and New York; but in the case of the majority of the Michigan formations no such correlation is possible; hence the formations are given names corresponding to localities at which the rocks outcrop and the age determined by means of fossils present.

Unconformities

In the geologic time scale the youngest formations (Recent and Pleistocene) are placed at the top of the page, followed below by successively older rocks with the oldest known rocks,--the Archeozoic--at the bottom of the list. At intervals in the time scale the work "Unconformity" will be noted. This term is used for the intervals during which the land area that is now Michigan was not covered by a sea; hence was subject to the ordinary processes of erosion or wearing down of the land which we can observe today. The sand, mud, and silt derived from wearing away of the land would be carried away by streams and deposited elsewhere in the seas, with the result that deposits would be built up in those water covered areas which would not have equivalent formations in Michigan. In other words, during the interval that Michigan was above water we have no geologic record or history of events. In addition a large portion of the formations constituting the land surface was destroyed and washed away. An unconformity therefore sometimes represents exceedingly long periods of time (millions of our years) of which the history is completely lost.

Later burial under water of the eroded surface and renewed deposition of sediment results in the new beds being laid down upon the irregular surface or dipping beds of the old land; hence the new sediments are said to be unconformable with the older. Where conditions have made it possible to observe such contacts the lack of conformity between the old and the new beds may be clearly seen.

CHAPTER VIII

BRANCHES OF GEOLOGIC STUDY IN MICHIGAN

There are three widely different divisions of geology represented in Michigan, the study of which has engaged the attention of specialists in each of the three divisions. The lowest of these divisions comprises the Archeozoic and Proterozoic or Algonkian, which are commonly referred to as the "Pre-Cambrian." The Pre-Cambrian is characterized chiefly by igneous and metamorphic processes represented by corresponding types of rocks, although deposition of sediments was profound and long continued. The second division, the Paleozoic represents an enormously long period of time in which sedimentation was the dominant process with no igneous or volcanic activity or large disturbances of the rocks in Michigan.

The Pleistocene or Ice Age covers a short period ŏf time in comparison with the Pre-Cambrian and Paleozoic, but it represents an entirely different type of geology and one which has determined to a marked extent the topography, soils, and timber growth of the State, as well as the place of settlement, occupations, and activities of the people.

Michigan is one of few states in which these very different records of geologic processes may be studied. The diversified geologic history of the State has also resulted in a variety of mineral products of economic value, probably not equaled by any other state.

Discudsion of Geologic Formations

The discussion of the rock formations in Michigan commences with the lowest and oldest formations and proceeds to successively younger and higher beds. The formation of the earth, its crust, oceans, and atmosphere have been previously described; hence the first formations to be discussed are made up of the oldest known rocks on the surface of the globe.

CHAPTER IX

THE PRE-CAMBRIAN

Archeozoic and Algonkian

It has been previously stated that nowhere has the original cooled crust of the earth been positively identified. It was formerly thought that the granitic rocks of the Hudson Bay and Lake Superior districts represented the original crust, but it was later proved that these rocks are younger than the formations which they underlie, having been intruded into these latter by volcanic eruptions.

The oldest rocks in Michigan are those of the Keewatin series, so named from a station in the Lake of the Woods region, Canada. These are composed chiefly of greenstones and greenstone schists which represent altered basalts and other lava flows, of similar type, with some sediments metamorphosed to slate and a banded rock of hematite and jasper known as jaspilite. There is an older series of rocks known as Coutchiching which occurs in the Rainy Lake region of Canada, but which does not occur in Michigan. The Coutchiching is composed of mica schists and dolomite and is the oldest group of rocks known on the earth. The fact that these oldest rocks known are composed of metamorphosed sediments again shows that the original crust of the earth is nowhere visible. It is possible that the rocks of the Coutchiching may have been formed from the original solidified crust of the earth, but the earliest history of our planet is too shrouded in obscurity to offer proof of such a theory.

Keewatin rocks occur in two areas of the Upper Peninsula. One of these is located west and northwest of Marquette, and the second is located near Wakefield, Gogebic County. The rocks of this series are generally dark greenish in color and very hard. Owing to their altered character the mineral constituents are difficult to determine, but hornblende and chlorite predominate. The rocks are generally known as "greenstones" or "greenstone schists."

Laurentian Series

The Laurentian Series which is named from the Laurentian Mountains of Canada, consists chiefly of granites and granite gneisses, with lesser amounts of syenite and syenitic gneisses, which have been intruded into the overlying but older Keewatin and Coutchiching rocks. This igneous activity occurred all over the "Canadian Shield" in the Lake Superior region and as in other parts of the world. The intrusions took place at great depths below the surface, but later deep erosion removed thousands of feet of overlying and exposed the intursive masses of granite and related rocks over vast areas in the Hudson Bay and Lake Superior regions. In Michigan the Laurentian Series of granites cover relatively large areas in Marquette County, a smaller area near Ironwood in western Gogebic County, and several similar areas in Dickinson County.

Economic Products of the Archean

The Archean rocks in Northern Michigan have not produced minerals of great commercial value. The greenstones, schists, granites, and gneisses are not well adapted for use as crushed stone for road metal and concrete aggregates in the type of roads required for modern traffic. It is very probable, however, that granite for building purposes, as attractive as much of the stone produced in other parts of the country, could be found in some of the granite areas in Marquette, Gogebic, and Dickinson Counties. Some feldspar suitable for pottery has been produced from Archean rocks near Republic and Iron Mountain, and there is a possibility that kaolin (china clay), mica, and asbestos may be found in commercial quantities.

Probably the most valuable resource of the Archean rocks is to be found in the range of peridotite hills just northwest of Ishpeming. Peridotite is an igneous rock consisting chiefly of the minerals olivine and pyroxene which are compounds of silica with iron, calcium, and magnesium. The peridotite occurs as dikes of Laurentian age forced into cracks in the Keewatin schists. Later alteration of the peridotite dike rocks produced secondary chemical combinations to form magnesium silicates and carbonate minerals namely serpentine, talc, dolomite, and magnesite. The complex rock thus formed is known commercially as <u>verde antique</u> and when polished produces a beautiful green surface with streaks, veins, and mottlings of white. It is in great demand for decorative purposes such as store fronts, baseboards, and other interior trim.

Quarries have been in operation in the serpentine hills of Marquette County for a number of years, but the material produced was marketed in a crushed form chiefly for terrazzo floors owing to the fact that large blocks free from fractures and suitable for cutting into slabs were not obtainable at that time. In recent years it has been proved by test drilling that blocks suitable for this latter purpose can be obtained. This development should enable the Michigan verde antique to compete favorably with stone from the New England states.

Gold is another constituent of the Archean rocks which has been produced in commercial amounts. The gold occurs in veins of quartz which cut through the peridotite dikes northwest of Ishpeming and in some cases through granite and other rocks. Several mines, among them the Ropes, Michigan, Gold Lake, Superior, Peninsula, and Fire Center, produced nearly three-quarters of a million dollars worth of gold during the years from 1880 to 1898, but due to lack of capital, inexperienced management, pinching out of veins, etc., all operations ceased near the end of the last century.

The idea is still prevalent among many that one may prospect for gold and stake claims in Michigan in the same manner as in the "gold rush" days of the western states. It should be pointed out that most of the land is now privately owned, although the State has a large acreage in state forests, parks, and tax-delinquent farms and timber lands. Considerable areas are also owned and set aside by the Federal Government for National forests. The amount of unsurveyed Government land in the State is now so small as to be almost negligible. It may be obtained from the Federal Government only by homestead or purchase and then the mineral rights are subject to reservation by the Government. Certain State owned lands may be purchased, homesteaded, or traded, but mineral rights are always reserved by the State. The mineral rights to a property may, however, be leased from the State, and the property developed by paying a specified royalty on the minerals produced.

In spite of the fact that pyrite (fool's gold) and mica have been mistaken for gold all through the ages, large numbers of people continue to become excited upon finding these materials. Pyrite is distinguished from gold in several ways. It is not a true golden yellow color but is more the color of brass. Pyrite commonly occurs as well developed crystals in the form of cubes or figures which have five sided faces. Generally fine parallel lines can be seen upon the cube faces. Pyrite is attacked by dilute nitric acid while gold is not.

Mica often is of a more truly golden yellow color than pyrite. It is a flaky mineral which can be split into very thin scales which will float on water. Gold, on the other hand, is nineteen times as heavy as water and sinks readily to the bottom. Gold is malleable and can be hammered into sheets, while mica, being of a non-metallic nature, simply breaks into pieces.

CHAPTER X

PROTEROZOIC
(Algonkian)

Huronian - Keweenawan Periods

The term Algonkian is derived from Algonquin after the Algonquin Indian nation which inhabited the Lake Superior country. This era differs from preceding Archean in that the rocks are chiefly sedimentary instead of being dominantly igneous in character. The Algonkian is also less highly altered and the order of the individual beds is much more easily determined. During the later stages of the Archeozoic profound deep seated igneous activity domed up the earlier sedimentary formations into mountains or highly elevated tracts which were then subjected to long periods of erosion which produced generally rough land surfaces. The low-lying portions of the Archean land masses were then submerged by shallow seas and a long period of deposition of gravel, sand, and mud from the bordering lands followed. The lowest formations of the Huronian in Northern Michigan consist of a basal conglomerate overlying unconformably the Archean or ancient land mass, above this a quartzite, which in turn is overlain by a limestone now locally altered to a dolomitic marble. The geology of Upper Michigan and the Lake Superior Region has been studied and described by districts or "ranges." This is because of the fact that iron mining very early brought certain areas to public attention and the opening up of mines facilitated the study of the geology of those particular areas. Thus we have the Marquette range, the Iron River district, Menominee range, Gogebic range, Crystall Falls district.

Lower Huronian

The type locality for the Huronian is found north of Lake Huron in Canada where the rocks have long been studied. In Michigan the lowest Huronian formations are the Mesnard, Sturgeon, and Sunday quartzites and conglomerates.

These formations are considered as equivalent but have been assigned different names on the different ranges; thus the term Mesnard is used on the Marquette range, Sturgeon in the Menominee district, and Sunday formation on the Gogebic range.

Similarly the Kona dolomite overlies the Mesnard quartzite on the Marquette range, but on the Gogebic range the equivalent formation is known as the Bad River limestone, and on the Menominee range as the Randville dolomite. At Iron River the Sturgeon quartzite and Randville dolomite cannot be positively identified but there is a succession of interbedded cherty dolomites, quartzites, and slate known as the Saunders formation, which is believed to be equivalent to the Sturgeon and Randville. On the Marquette range the Kona dolomite is conformably overlain by the Wewe slate into which it gradually changes. However this slate is not present in the other Michigan districts. It may have been removed from the Gogebic range by the deep erosion which the unconformity at the top of the Bad River limestone indicates. An unconformity at the top of the Wewe slate on the Marquette range indicates that the land was above water and being worn or eroded away. Erosional unconformities at the top of the Wewe slate, Bad River and Randville limestones therefore places the dividing line between the Lower and Middle Huronian formations at this point. In the Crystal Falls district it appears that conditions were somewhat different and the presence of a basaltic lava flow known as the Hemlock formation, interbedded with cherty slates, and lenses of iron formation and limestone indicates that during the period between the Lower and Middle Huronian when the Gogebic and Marquette renges were being eroded, the Crystal Falls area was under wqter and sedimentation interrupted by submarine lava flows was occurring. The Hemlock formation conformably overlies the Randville and is in turn conformably underlain by the Middle Huronian slates.

Middle Huronian

The lowest formation of the Middle Huronian is the Ajibik quartzite, which rest unconformably upon the tilted truncated edges of formations ranging from the Wewe slate to rocks of Keewatin age. The ajibik quartzite grades upward into the Siamo formation which consists chiefly of graywacke and fine grained slate containing a considerable quantity of iron oxide (hematite and magnetite) in its upper and lower horizons. This iron bearing or ferruginous character becomes more pronounced as the Siamo grades into the overlying Negaunee iron bearing formation which is the chief source of iron ore on the Marquette range. In the southern part of the district, however, the Siamo is absent and the Negaunee grades into the Ajibik quartzite.

On the Gogebic range there is no formation equivalent to the Ajibik, the lowest of the Middle Huronian group being the Palms formation, which is correlated with the Siamo slate of the Marquette range. The Palms formation consists of conglomerates, clayey slate and quartzite, and rest unconformably upon the Bad River limestone, and also upon the Archean rocks, indicating that in those areas the intervening formations have been removed by deep erosion. The Palms is overlain by the Ironwood iron bearing formation which is equivalent to the Negaunee iron bearing formation of the Marquette range. The change from the upper quartzite of the Palms formation to the iron bearing formation is abrupt, there being only minor transitional stages. The Ironwood is the main productive formation on the Gogebic range. On the Menominee range the iron bearing formation is known as the Vulcan, and at Crystall Falls as the Amasa.

Upper Huronian

The contact between the Upper and Middle Huronian is marked by the presence of an unconformity. On the Marquette range the Goodrich quartzite, generally with a conglomerate at the base, rests on the discordantly dipping beds of the Negaunee iron formation, or on older formations where the Negaunee has been eroded through. The Goodrich formation grades upward into the Greenwood Iron Formation, which consists chiefly of slaty iron ore and slaty quartzites overlaid by the Clarksburg lava flows which began to be extruded at the time the Goodrich formation was being deposited. Since the rocks are very similar in character to those of the Hemlock, the Clarksburg may represent a continuation of the same volcanic activity but occurring at a different vent in the surface. The flows were in part poured out into water, while the muds which later formed the Michigamme slate were being washed in. This volcanic activity subsided before the end of Michigamme time, but deposition of mud continued, with the result that the volcanic rocks grade above into the Michigamme slates and are interbedded with them.

The Michigamme slate consists of slates, mica schists, chlorite schists, gneisses, and graywackes, some of the beds bearing iron ore. The iron bearing portion is known as the Bijiki schist. Metamorphism has been extreme in some portions of the Michigamme formation, with the development of characteristic minerals of advanced metamorphic processes, such as garnet, staurolite, and andalusite. The Bijiki schist, which is interbedded between the lower and upper parts of the Michigamme slate, contains commercial iron ore beds in the form of ferruginous slate, ferruginous chert, and grunerite-magnetite schist. The ore thus produced is in striking contrast with the soft hematite ore of the Negaunee formation.

In the Menominee district there are a series of schists and intrusive rocks of about the same age as the Clarksburg of the Marquette range. The schists include greenstone, chlorite, amphibolite, felsite, sericite, and gneiss, which have resulted from the action of metamorphic processes upon basalt, diorite, gabbro, diabase, granite, and other igneous rocks with which the schists are associated. No equivalent of the Goodrich quartzite is present in the Gogebic or Menominee districts. In the Menominee district the Michigamme slate rests conformably upon the Vulcan formation, and in the Gogebic district the Tyler slate, which is correlated as the equivalent of the Michigamme, is conformable on the Ironwood iron bearing formation.

Presque Isle Granite

On the Gogebic range in the vicinity of Marenisco and occupying smaller areas near Watersmeet and Gogebic Station there are masses of granite and granite gneiss with some syenite and diorite, which were formerly considered as of Archean Age because of their position below the Huronian sediments. It was later shown[1], however, that these granites have pushed up from below or intruded the Huronian formations; hence are of Upper Huronian or possibly of Keweenawan Age. It is believed that they represent offshoots from a great granite mass which underlies the sandy area from Iron River to Marenisco and extending southward into Wisconsin. This area, because of the lack of outcrops and resulting difficulty in study, had previously been mapped as "undifferentiated pre-Cambrian."

Economic Products of the Huronian

Iron Ore

As indicated under the descriptions of the Huronian formations this is the time of deposition of the great iron ore bearing formations of Michigan, Wisconsin, and Minnesota.

Iron ore was first discovered in 1844 near the present site of Negaunee by a party of Government surveyors in charge of William A. Burt working under the direction of Douglass Houghton, first State Geologist of Michigan. The first mines were opened in 1848 and small amounts of ore smelted locally until the opening of the "Soo" locks in 1855 permitted shipments to the lower lake industrial centers. Opening up of the Menominee Range in 1872, the Crystal Falls and Iron River districts in 1880, and the Gogebic range in 1884, brought Michigan into prominence as the leading iron producing State, which position was held until about 1900, when development of the larger deposits of Minnesota reached a stage of production surpassing that of the Michigan ranges.

Nature of the Ores

The Michigan iron ores are composed chiefly of the mineral known as hematite, which is an oxide of iron, the chemical formula of which is written Fe_2O_3. Small amounts of limonite ($Fe_2O_3.X\ H_2O$) and magnetite (Fe_3O_4) are also included with the hematite. The ore varies considerably in its physical character, the bulk of it consisting of soft dark red hematite, but some is harder and blue to black in color.

On the Marquette range a variety of hard ore known as specularite or specular hematite is found. This consists of compacted scales, plates, or grains of hematite having a splendent metallic luster. Most of the hard ore comes from the upper portions of the Negaunee formation in the Marquette region.

Origin of the Ores

Since the iron formations occur as deposits interbedded with slates, quartzites, and other types of rocks of sedimentary origin, we must conclude that the ore bodies were laid down under water in the same general manner as the enclosing formations. It was formerly believed that the beds of iron ore were formed by the ordinary processes of erosion and sedimentation, that is by the weathering of land areas composed of igneous rocks, from which the iron was dissolved out, carried away by streams, and deposited in seas. It was later concluded that the types of igneous rocks which formed the bulk of the land surface were inadequate to furnish sufficient iron bearing minerals, to account for the depth and extent of the iron formation. In place of this theory it has been suggested that basaltic lavas extruded under water might react with salt water to furnish iron salts later chemically precipitated chiefly as cherty iron carbonate and iron silicate, which appears to have been the original state of deposition of the ores. We are reminded that the Hemlock, Clarksburg, and other lava flows were more or less contemporaneous with ore deposition and that they were lavas of the basaltic iron bearing type necessary in this theory. The iron formation as originally deposited probably contained very little hematite or magnetite.

The iron ore as mined at the present time as indicated under "nature of the ores" does not consist of iron carbonate (siderite) and iron silicate (greenalite), nor do these minerals constitute the bulk of the iron formation at the present time. The iron formation now consists chiefly of a flinty mass of chert, iron oxide and jaspillite, with comparatively small bodies of iron ore, ferruginous slate, greenalite, iron carbonate, and magnetite-grunerite rock.

Processes which can be observed at the present time indicate that the iron formation has undergone chemical changes due to action of the various agents of weathering over a long period of time. It is therefore believed that most of the bodies of high grade ore mined at the present time are the result of chemical changes in the iron formation induced by the action of circulating waters, together with secondary enrichment of the ore by means of solution and redeposition. Oxidation of cherty iron carbonate and greenalite to hematite and limonite and subsequent solution of chert by alkaline waters to cause residual enrichment of portions of the iron formation, is considered the most important process in the formation of the ore bodies. Another important process is the solution of a portion of the iron during the early stages of alteration of the iron formation, transporting of the material downward, and precipitation in troughs formed by the folding or warping of the rocks, or at the intersections of dikes with impervious rocks such as slate and quartzite. Mingling of the iron bearing solutions with oxygen bearing waters more direct from the surface is necessary to assume in order to convert the soluble or ferrous compounds of iron in solution to the relatively insoluble ferric oxide and cause its deposition at the favorable points.

Reserves of Iron Ore in Michigan

Large scale production of iron ore, due chiefly to the new market developed with the coming of the automobile and the increased use of steel in building construction, has raised the question "How long will the deposits of iron ore in the Lake Superior region last?" Iron mining companies attempt to prove up new ore to take the place of that mined out by carrying on exploration work as a regular part of their operations. In 1920 the Tax Commission report showed a reserve of iron ore in Michigan of 199,092,855 long tons of ore.[(2)] In 1930 the total reserve of proved ore for all the companies was listed as 168,349,823 tons, a decrease of only 30,000,000 tons of ore in spite of the fact that 135,000,000 tons were shipped from the mines during the ten-year period. This means that nearly four-fifths as much additional ore was proved by explorations as was mined during the period. Based upon the ten-year period from 1920 to 1930 it has been estimated that iron mining may continue for 100 years or more in the Lake Superior region.

There are many factors, however, which may tend to change this estimate. There is no question but that it is becoming increasingly difficult to prove up reserves of high grade ore in Michigan and all of the Lake Superior district. On the other hand advances in metallurgical practice, utilization of scrap, and other economies make a ton of ore go much farther in the steel industry than formerly.

In addition there are vast reserves of low grade ore represented by the iron formations, which are not taken into account at the present time, but which may form an important source of iron ore when the deposits of high grade ore are nearing exhaustion.

Other Economic Products of the Huronian

At Randville and Felch, Dickinson County, the Randville dolomite is quarried for making granules for stucco, and for art stone and ornamental concrete. Near Arvon and L'Anse, Barage County, there are valuable slate and graphite deposits. Quartz has been produced near Ishpeming for wood filler, paint, and polish; and trap rock (basalt) is produced in the same area for roofing granules. Crushed stone for road metal is produced at various places from Huronian rocks. Resources of all of these materials are very large.

Keweenawan Series

The Keweenawan series of rocks derives its name from the Keweenaw Peninsula of Michigan where the entire succession of formations is present. The Keweenawan differs from the Huronian in that it is practically a continuous unit with few of the correlation problems of the Huronian. It forms a belt varying in width from approximately six miles at the end of the Keweenaw Peninsula to approximately 18 miles in the vicinity of the Porcupine Mountains. The belt extends from the Keweenaw Peninsula along the south shore of Lake Superior into Wisconsin and Minnesota. In Michigan the beds are tilted to the northwest and dip under Lake Superior, rising again at Isle Royale and on the north shore of the lake. The eastern side of the Keweenaw belt is terminated by a great fault bringing the lower beds of the Keweenawan into contact with the Cambrian sandstones.

The Keweenawan series consist for the most part of coarse fragmental sediments interbedded with various types of lava flows. The Keweenawan was a time of profound volcanic activity over a large area in contrast to the local lava flows of the Huronian. The lava flows of the Keweenawan differ further from those of the Huronian in that they appear to have been extruded for the most part on the land rather than under water as in the case of the Hemlock-Clarksburg formations. The rocks of the Keweenawan have not been altered nearly so extensively as have those of the Huronian, most of which is constituted by rocks representing an advanced stage of metamorphism. The changes which have occurred in the Keweenawan are largely those which are the result of circulating waters and atmospheric agencies, although intrusive rocks which occur at Mount Bohemia near the north end of the Peninsula, in the Porcupine Mountains, and near the Wisconsin border have undoubtedly produced extreme changes in the rocks. In some instances the intrusive rocks appear to be related to the Great Keweenawan fault and may be offshoots from a great intrusive mass known as the Duluth gabbro.

Three distinct phases of deposition are recognizable in the Keweenawan, a lower sedimentary phase, a middle portion dominantly volcanic, and an upper thick sedimentary phase.

The lowest beds of the Keweenawan rest unconformably upon the Huronian and older formations. They consist of conglomerate and sandstone, the materials for which were derived from erosion of the Huronian and Archean rocks. After about 1500 feet of these materials had been deposited volcanic activity began and numerous flows of basaltic lava followed, interrupted by short intervening periods of sedimentation when beds of conglomerate were formed. Some flows were of the acid or rhyolite type, high in silica, sodium, and potassiu, and low in iron, magnesium, and calcium.

The character of the sediments of the Middle Keweenawan volcanic period, together with the apparent fact that volcanic activity and sedimentation alternated in rapid succession, has led to the belief that these sediments were not deposited in continental seas as were those of the Huronian, but were formed either on the land or in shallow bodies of water.

The extrusion of the lava flows forming the Eagle River group marked the waning of the Keweenawan vulcanism, although a series of thin flows - the Lake Shore traps - followed the deposition of the Great Conglomerate. The outpouring of the Lake Shore traps marked the end of igneous activity in Michigan insofar as known. The succeeding formations, the Outer Conglomerate, Nonesuch Shale, and Freda Sandstone, constitute the Upper Keweenawan and represent a period in which great thicknesses of gravel, sand, and clay were being deposited in a shallow sea.

Economic Products of the Keweenawan

Native Copper

The Keweenawan Peninsula has long ranked as one of the world's most famous copper mining districts. It is unique in that the copper occurs free and uncombined or "native", and requires only stamping to remove it from the rock, and refining to remove impurities, in order to prepare it for the market. This is in contrast to the copper ores of the Western states, which occur as copper oxides and copper sulphides, - very different in character and appearance from the Michigan ores and requiring smelting processes to remove the copper from the ore.

Lode copper was discovered in 1830 ? by Douglass Houghton and mining began in 1845. Since that time Michigan has produced 8,500,000,000 pounds of copper, more than any other district in the world except the Butte Montana district. Increasing depth of the ore, and low prices of copper in recent years, have, however, greatly reduced the importance of Michigan as a copper producing state. Some of the mines are more than one mile in vertical depth. Houghton, Hancock, and Calumet are the centers of the copper mining industry.

Nature of Occurrence and Origin of the Copper Deposits

The copper ore of the Keweenaw Peninsula is of two main types. The most important is the amygdaloid in which the copper is found in small cavities or amygdules in basaltic lava along with other minerals such as prehnite, chlorite, calcite, and quartz. The cavities or amygdules were formed as a result of escaping gases from the molten lavas and the filling and replacement with copper and other minerals took place after the lava had cooled.

The second most important type of ore is the conglomerate where the copper occurs chiefly as replacements of pebbles forming the conglomerate and as a cementing material between the pebbles which are chiefly acid lava known as rhyolite porphyry because of the rather large grains of quartz which it contains. Calcite, epidote, and chlorite are also important cementing materials of secondary origin. Although the conglomerate ores as a whole are second in importance to the amygdaloid types, the Calumet and Hecla conglomerate is the richest and largest single copper lode in the district and one of the largest copper lodes in the world.

In addition to the amygdaloid and conglomerate ores, native copper also occurs in veins or sheets representing fillings and replacements along fissures cutting across the beds. Bedded deposits parallel to the dip of the rocks also occur. Some very large masses and sheets of copper weighing many tons have been removed from fissures and bedding planes, but as a whole these are relatively unimportant in comparison with the amygdaloid and conglomerate types of ore. Native copper also occurs as a cementing material in sandstone and in the Nonesuch shale in the Porcupine Mountain district.

Several theories have been advanced to explain the origin of the deposits of native copper. Although slightly different in the exact mechanics of deposition, a number of the earlier theories advanced by different investigators all point to the solution of copper from the associated basaltic lava flows by downward circulating waters and deposition and concentration of ore by contact with ferrous oxide and other minerals of a reducing nature.

A more recent theory(3) considers the Duluth Gabbro as the source of the copper which would be transported by hot solutions assending from the molten mass and deposited by oxidation through contact with abundant iron oxide present in the rocks. This theory points out that the iron contained in the rocks with which copper is associated, was probably in a ferric or exidizing state long before the copper solutions were introduced. It is further pointed out that if this oxidizing condition had not been present the copper would have been deposited as sulphide ore similar in character to some of the copper ores of the western states. The association of certain aluminum silicates and minerals containing boron and fluorine, together with the nature of the alteration of the wall rock in the copper veins, lends support to the theory of hot ascending solutions.

Other Mineral Products of the Keweenawan

Recoverable amounts of native silver are present in many of the vein deposits associated with the mass copper. Silver is particularly characteristic of the Eagle River and Ontonagon areas. Native silver practically free from copper was mined near Ontonagon as early as 1873. The total value of silver produced in connection with the mining of copper from Michigan mines from 1887 to 1932 inclusive amounts to $5,743,899.

Aside from copper and silver, the only other product of the Keweenawan rocks of commercial value at the present time is crushed stone for road metal and roofing granules. A quarry in the amygdaloid near Wakefield, Gogebic County, has been in operation for a number of years. The "stamp sand" produced in the extraction of copper was formerly used extensively for road surfacing in the copper country and adjacent portions of the Northern Peninsula. The copper mines are very prolific in minerals and many fine museum specimens have been found. About 70 different minerals have been identified in association with the native copper, the principal ones being calcite, quartz, prehnite, laumontite, analcite, apophyllite, natrolite, orthoclase, datolite, epidote, and chlorite.

Life in the Pre-Cambrian

The first direct evidences of life on the earth are found in the Proterozoic. These consist of the remains of microscopic animals known as Radiolaria and Foraminifera, and the fossilized secretions of certain calcareous algae known as Cryptozoon. Casts of worm trails and burrows indicate the existence of other forms of life fairly high in the evolutionary line. No fossils have been found, however, in the Algonkian of Michigan. There are no direct evidences of life in the Archean. In the Grenville limestones of Canada globular masses consisting of thin calcite bands and dark green serpentine are regarded as probably of organic origin. The great quantities of carbon in the form of graphite in the Archean rocks are considered as additional evidence of the presence of low forms of plant life.

Scenic Beauty of the Pre-Cambrian

The area of Pre-Cambrian rocks forming the western half of the Northern Peninsula of Michigan comprises a region the scenic beauty of which is surpassed at few places in the eastern United States. Among the scenic spots may be mentioned the Copper Range and the Great Keweenawan fault near Ahmeek, Eagle Harbor, and other points: Mt. Bohemia, Mt. Houghton, and Mt. Horace Greeley (927 feet above Lake Superior) in Keweenaw County; the Porcupine Mountains in Ontonagon County, 2023 feet above sea level and the highest point in Michigan, as well as one of the highest in the middle West; the granite hills (Presque Isle granite) near Marenisco and the ancient granites (Laurentian) forming the Huron Mountains (1800 feet above sea level) northwest of Marquette; Presque Isle Park at Marquette where the Cambrian sandstone overlies the Archean in a picturesque wave-cut bluff rising high above Lake Superior. The Freda sandstone is tilted almost vertically and forms a very rocky shore line known locally as the "Irish Coast". The unspoiled beauty of Isle Royale has been recognized in its designation as a National Park site.

Pre-Cambrian in Lower Michigan

The Pre-Cambrian rocks in Lower Michigan are buried beneath thousands of feet of sediments. The deepest drilled well in the State is more than 6500 feet in depth but this does not penetrate to the crystalline rocks. Newcombe estimates a thickness of from 12,000 to 15,000 feet[(4)] for the Paleozoic sediments in Michigan. Whether there are Pre-Cambrian sediments underlying the Paleozoic of Lower Michigan, or whether the latter formations rest directly on granite is something which is purely a matter of conjecture.

CHAPTER X

PALEOZOIC ERA

Cambrian Period

The Cambrian system of rocks derives its name from Cambria, the Roman name for northern Wales, where the deposits were first studied. Several of the succeeding periods likewise have been named from localities in the British Isles. Cambrian time marks the beginning of the more or less tranquil events of the Paleozoic insofar as Michigan is concerned. We have seen how the Pre-Cambrian was a period of crustal unrest and vulcanism, folding and faulting of the earth's crust resulting in profound changes in the character and structure of the rocks. The Pre-Cambrian is also characterized by the absence of any except the most primitive forms of life.

The Paleozoic, on the other hand, is represented by strata more or less horizontally lying with only relatively minor folds or irregularities of the strata in comparison with those of the Pre-Cambrian. Metamorphic changes due to folding of the strata or igneous intrusions are entirely absent. The deposits of the Paleozoic therefore consist chiefly of sandstones, limestones, and shales, with beds of gypsum, rock salt, and coal, all of which were laid down under water by processes of sedimentation. The earliest Paleozoic rocks also differ markedly from those of the Pre-Cambrian in that they contain abundant fossilized remains of animal life. Furthermore the fossils represent types of life which are far more advanced than the primitive forms of the Archean-Algonkian rocks. This is a very significant fact as it indicates that a gap probably of long duration exists in the geologic record between the Pre-Cambrian and the Cambrian. It means that the Pre-Cambrian formations were above water and were being eroded and the record of the deposits was being written at some other place where it is not accessible for study. That no sedimentary record of the interval between the Algonkian and the Cambrian has been found is explained by the probability that the encroaching seas of the Paleozoic covered the beds so deeply that nowhere have they been exposed by erosion processes.

The Michigan Basin

Geological studies of outcroppings and well records have shown that the Paleozoic rocks of Michigan, while apparently lying in a horizontal position, dip gently (25 to 50 feet per mile) toward the geographical center of the State and rise again at its borders. A formation which outcrops at the margins may therefore be found several thousand feet below the surface in the central part of the State. The Dundee formation, for example, outcrops at Rogers City, Presque Isle County, and south of Detroit, but lies at a depth of approximately 3500 feet in the Central Michigan oil fields. If the surface of the State were reduced to a plane with the glacial drift removed, the appearance of the outcropping layers of rock might be likened to that of an onion cut in half, or a stack of saucers, (See Plate V) but of course not nearly so symmetrical in outline.

Newcombe[(4)] believes that the disturbances which contributed to the formation of the Michigan Basin began very early in geological history and may be connected with those forming the Lake Superior Basin and the Keweenawan Fault.

Cambrian time and the Paleozoic era began with the flooding of continuents by influx of the oceans after vastly long periods of erosion of the Pre-Cambrian land masses. Most of North America, including Michigan, was, however, not covered by water until Middle and Upper Cambrian time. The deposits of the Cambrian and succeeding periods of the Paleozoic were laid down around and over-lapping the ancient land masses and in general dip gently away in all directions, with younger and younger rocks appearing at the surface in going away from the central land mass. This condition may be observed in Northern Michigan where the gently dipping Cambrian sandstones rest unconformably upon the upturned edges or eroded surfaces of Keweenawan, Huronian, or Archean rocks. The Cambrian formations dip to the south and east and are in turn overlain by Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian strata.

In Michigan the Cambrian has been generally known as the Lake Superior Sandstone because of its occurrence along the shore of Lake Superior. There are two divisions of this sandstone, a lower member the sand grains of which are partly cemented by iron oxide, giving it a red color; and an upper light colored portion largely free from iron oxide. The red member is known as the Jacobsville from its occurrence at Jacobsville, Houghton County; and the white member is known as the Munising from the occurrence near Munising in Alger County. Dr. F. T. Thwaites of the Wisconsin Geological Survey has partially correlated the Michigan Cambrian with rocks of that age in Wisconsin.(5)

There are two areas of Cambrian rocks exposed at the surface in Michigan. One of these is a belt varying from 6 to 20 miles in width extending from the western part of Menominee County, north to Marquette, and east along Lake Superior to St. Mary's River. The second area lies in the western part of the Upper Peninsula. It occupies the east one-half of the Keweenaw Peninsula and extends south-westward to the vicinity of Lake Gogebic. From the vicinity of L'Anse south-westward the belt is 20 miles or more in width. Cambrian sandstone also occurs on the east side of Keweenaw Bay and forms a fringe on the Lake Superior shore north of the Huron Mountains. The Cambrian has been penetrated at a depth of 4675 feet in the Lower Peninsula by a single well located in St. Clair County. Due, however, to a rise in the formations caused by the structure of the Michigan "Basin" about 2000 feet less of strata are encountered in St. Clair County than are present in the central part of the State. A well more than 6500 feet in depth located in Newaygo County appears to be about 1000 feet above the Cambrian.

Economic Products of the Cambrian

The lower red sandstone of the Cambrian was in some favor for building purposes during the "brownstone front" era. Many of the houses in a former fashionable residential district on Euclid Avenue, Cleveland, Ohio, are built of red sandstone from Upper Michigan. This stone has also found considerable local usage for business blocks, public buildings, churches, school and college buildings, residences, etc., in Sault Ste. Marie, Munising, Marquette, Houghton, Hancock, Calumet, and Laurium. Quarries are located at Jacobsville, Portage Entry, Marquette, and other places. The stone is known as "Jacobsville Redstone," "Portage Redstone," "Marquette Brownstone," etc. Modern taste for light colored sandstone, limestone, and marble, and competition from the attractive face brick now on the market has decreased the value of redstone deposits for building purposes. Quarries are still in operation in the vicinity of Marquette for producing road metal.

Formation of Sandstone, Shale, Limestone, Dolomite and Conglomerate

Sandstone is formed by the cementation of deposits of sand laid down in shallow water near the shores of seas or oceans and later elevated above water to form land. It is composed largely of quartz grains derived from the weathering of granite and other crystalline rocks. Cementing material is usually silica, calcium carbonate, clay, or iron oxide. In the latter case the stone will be colored red or brown. Metamorphic processes of heat and pressure acting on sandstone give rise to quartzite which is composed entirely of silica, the grains of which interlock to form one of the hardest of all rocks.

Shale is formed in the same manner as sandstone, except that the particles consist of the finer materials derived from the wearing down of the land areas, clay and silt being the chief constituents. These materials being much finer than sand are carried in suspension longer and deposited at some distance from shore. Consolidation of clay beneath great thicknesses of later deposits results in the formation of shale. This type of rock is generally soft and splits readily into thin layers. When shale is acted upon by great heat or pressure a hard dense rock which splits into slabs is formed. This is known as slate.

Limestone is formed for the most part by the action of marine animals and plants which extract calcium carbonate from sea water for building into their shells and bony structures. When the animals die their soft parts decay but their shells and skeletons accumulate on the bottom of the sea. Many limestones consist largely of these remains, but others have a different texture and were probably formed by chemical reactions with sea water or by deposition of limestone flour carried in suspension by the waves. Limestones form in warm seas at some distance from the shore where sand and mud cannot be carried by the currents or undertow, but fluctuations of the shore line may result in the interbedding of shales or sandstones with the limestone beds. Great pressure or igneous intrusions acting upon limestone result in recrystallization and change to a granular form of calcium carbonate known as marble.

Dolomite is difficult to distinguish from limestone by simple inspection. Limestone when pure consists only of calcium carbonate, but dolomite contains 45.65 per cent of magnesium carbonate. It is believed to be formed by chemical replacement of calcium carbonate by magnesium carbonate.

Conglomerate consists of pebbles cemented together. It is formed near the shore owing to inability of the currents to transport the pebbles to any great distance. Conglomerate is very rare in the Paleozoic rocks of Michigan owing to the fact that the shores of the Paleozoic seas were generally outside of the State. It is, however, an extremely common and important type of rock in the Pre-Cambrian of the Upper Peninsula.

Scenic Effects of the Cambrian

The Cambrian sandstone of the Upper Peninsula forms what is probably the most spectacular scenery in the State. The famous Pictured Rocks east of Munising are formed by sandstone bluffs carved by the waves to resemble various objects such as castles, pulpits, battleships, etc. Caves and arches of rock are also common. Many beautiful waterfalls in the vicinity of Munising are sculptured out of Cambrian sandstone capped at the brink of the falls by the hard resistant Hermansville dolomite which has been responsible for the development of the escarpment over which the water falls.(6) The Agate Falls near Trout Creek, Ontonagon County, and other falls of the Ontonagon River are formed by the Cambrian Sandstone. The great Tahquamenon Falls in Luce County are the most spectacular example of this type of formation.(7)

Ordovician Period

It has been mentioned under the discussion of the Cambrian that the Hermansville dolomite caps the Lake Superior sandstone at the various waterfalls in Alger County. This formation consists of sandy limestone and dolomite, with beds of sandstone containing abundant calcium carbonate which acts as the cementing material. It derives its name from the occurrence at Hermansville, Menominee County. Dr. A. C. Lane, former State Geologist of Michigan, gave the name Calciferous to a sandy lime rock occurring in Alger County. The lower portion of this formation is considered to be the same as the Hermansville. In Ontario, Wisconsin, Illinois, and Indiana apparently equivalent formations are known as Beekmantown, Lower Magnesian, or Prairie du Chien. A deep well in Ottawa County shows a thickness of several hundred feet of sandy, cherty dolomite at a depth of 6000 feet, some of which is probably of the same age as the Hermansville. In the southern part of the State this formation is more easily compared with occurrences in adjacent states than in Northern Michigan; hence is called by one of the equivalent names depending upon the location of the well.

St. Peter Formation

The St. Peter formation is of importance in Minnesota, Wisconsin, Illinois, and other adjacent states, but is of doubtful occurrence in Northern Michigan. It does not outcrop anywhere in the State, but several wells drilled in the Upper Peninsula have encountered varying thicknesses of white sandstone which has been called St. Peter. The extreme variation in thicknesses is due to deposition on the unevenly eroded surface of the underlying formation. In some places it may be entirely absent.

In the Lower Peninsula the deep well in Ottawa County passed through 500 feet of mostly sandstone at depths of from 5490 to 5990 feet. This sandstone may be St. Peter.

Trenton Formation
(Trenton - Black River)

The Trenton is the lowest formation in the Geologic Time Scale of which we have ample information as to its character in both the Upper and Lower

Peninsulas. The Trenton out crops in the Upper Peninsula at various places on the west side of Green Bay and Little Bay de Noc, and along the Rapid, Whitefish, Ford, Escanaba, and St. Mary's Rivers.[8] Hussey[9] states that the best exposures are to be found along the Escanaba River. According to Smith the Trenton at these localities consists of low to high magnesian limestones, blue to buff and brown, locally shaly in character and containing oily or bituminous matter. In the Lower Peninsula the Trenton has been penetrated by wells in about twelve counties bordering the southeastern, southern, southwestern, and western portions of the State. It varies in depth from 2130 feet in Monroe County to 6385 feet in Newaygo County. The Trenton is very thick in the southeastern part of the State, the thickness amounting to from 750 to 900 feet. On the west side of the State it is about 400 feet thick. The formation is generally normal limestone in the southern part of the State, although dolomite beds occur. In the extreme southwestern part of the State the beds are practically all dolomitic. In all wells in the Southern Peninsula the Trenton is characterized by a remarkably uniform brown color which makes it easily recognizable.

Economic Products of the Trenton

The Trenton limestone is quarried near Escanaba, Delta County, for road metal, railroad ballast, filter beds, etc. In the Lower Peninsula a small production of oil has been obtained from the Trenton near Deerfield, Lenawee County.

Cincinnatian Series

The Cincinnatian Series includes several formations which are correlated with, and their names derived from the type localities in Ohio, Indiana, and New York. These are the Richmond, Lorraine, Eden, and Utica, formations. The Richmond formation outcrops in the Upper Peninsula on the east side of Little Bay de Noc, Delta County, where it forms bluffs 30 to 50 feet high, and at several other points in the Stonington Peninsula. At the Bay de Noc exposures the upper beds consist of interbedded gray shaly limestone and limy shale, all extremely fossiliferous, with hard, dark gray shaly limestone at the base. At other points light gray to dark brown shales occur, as well as gray to brown shaly and cherty limestones. A detailed study of the Cincinnatian rocks in Michigan has been made by Prof. R. C. Hussey,[10] who divided the Richmond formation into three members based upon the character and relationship of the beds and the fossils present. The Cincinnatian rocks of the Upper Peninsula are all designated as Richmond, but in the Lower Peninsula, Lorraine and Eden beds may be present. The Utica is also an important and easily recognizable formation found in wells in the Lower Peninsula. It consists of dark gray to brown and black shale directly overlying the Trenton limestone. The Richmond-Lorraine beds above the Utica consist chiefly of gray shales with some greenish gray and reddish shales. Beds of limestone may occur locally.

Economic Products of the Cincinnatian

The Cincinnatian rocks have not been utilized for commercial purposes. The shaly limestones and limy shales occurring on the Stonington Peninsula may contain about the right proportions of shale and limestone as to constitute a natural cement rock.

Silurian Period

The lowest formation of the Silurian in Michigan is known as the Cataract, so-called because of its apparent correlation with the Cataract strata occurring below the falls at Niagara Falls, New York. Ehlers[11] found fossils typical of the Cataract in well cuttings from the Lower Peninsula.

The Cataract is divided into two members, the Cabot Head shale member which consists of gray and greenish gray shales with beds of a peculiar reddish purple shale by means of which the top of the formation can generally be determined. The lower part of the formation is predominantly a magnesian limestone of variable character and thickness known as the Manitoulin limestone from the occurrence on Manitoulin Island, Canada. There is no known outcrop of Cataract strata in the Upper Peninsula, but reddish shales similar to those described above are present below the base of the Niagaran in samples from a well drilled at Seul Choix Point, Schoolcraft County.

Niagaran Series

The Niagaran Series is so named from the occurrence at Niagara Falls. The rock forming the brink of the falls is one of the massive resistant beds of the lower part of this series. In Michigan the Niagaran rocks form probably the most nearly continuous series of outcrops of Paleozoic formations in the State. They occur as a belt extending along the north shore of Lakes Michigan and Huron from the Garden Peninsula, Delta County, to Drummond Island, Chippewa County. The conditions under which the Niagaran was deposited in Michigan marked the beginning of a long period of time when the sediments were dominantly limestone and dolomite, with very few beds of shale and sandstone.

A number of different investigators have made studies of the Michigan Niagaran. The continuity of the beds and the excellent exposures with abundant fossils have resulted in probably a better knowledge of the Niagaran than any other group of rocks outcropping within the State.

Prof. G. M. Ehlers of Ann Arbor has been the principal investigator, his work covering several years is embodied in a report entitled "The Stratigraphy of the Niagaran Series of the Northern Peninsula of Michigan.[12] Dr. R.A. Smith, present State Geologist, devoted two field seasons to a study of Michigan limestones,[13] during which time he made a provisional classification of the Niagaran rocks. The writer also spent one season in a study of the geology of Schoolcraft County.[14]

Ehlers divided the Niagaran into four formations and assigned the names Mayville, Burnt Bluff, Manistique, and Engadine, to these formations. The names Engadine and Manistique were first proposed by Smith and are approximately the same as the divisions made by Ehlers. The Mayville is correlated directly with the formation of the same name in Wisconsin, but the other formations are given Michigan names because of the lack of definite correlating evidence. The Niagaran is chiefly magnesian limestone and dolomite, extremely cherty and fossiliferous in some beds (Manistique), but containing locally in the Burnt Bluff, beds of high calcium limestone including one bed (Fiborn) thick enough to be of great commercial importance.

The four part division of the Niagaran recognized in the Upper Peninsula cannot be applied to the Niagaran of the Lower Peninsula as studied in well samples. The upper part is, however, one of the most constant and easily recognized of all Michigan formations. In well samples it is a uniform bluish white to light bluish gray color and is in marked contrast to the darker overlying beds of the Salina. It is probable that portions of this formation correlate with the Engadine; likewise with the Guelph of Ontario and Racine of Wisconsin. On the outcrop the Engadine formation runs more to a light buff color with streaks and mottlings of blue.

Economic Products of the Niagaran

Quarries have been operated in the Fiborn limestone bed in the Hendricks member of the Burnt Bluff formation, at Fiborn and Hendricks, Mackinac County; near Blaney, Schoolcraft County; and near Hunt Spur, Mackinac County, where the Fiborn has a thickness of about 60 feet. The typical Fiborn stone is light brown with a smooth lithographic texture and a fracture something like that of glass or blast furnace slag. The Fiborn stone is of very high purity and well suited for use as blast furnace flux, lime burning, and all chemical uses to which stone is put. West of Blaney quarry the Fiborn grades into a normal dolomite which forms a fairly large area of magnesium limestone north of Manistique.

The Engadine formation is a very pure dolomite and while it has been used chiefly for crushed stone for refractory purposes, railroad ballast, and harbor construction, this stone has a great potential value for its magnesium content. Quarrying conditions and transportation facilities are excellent.

In addition to reserves of stone the Niagaran rocks form an important source of water supply for the region which they underlie. Many flowing wells are present in this area.

Niagaran Scenery

The Niagaran rocks form a bluff rising 235 feet directly above Big Bay de Noc on the west side of the Garden Peninsula, Delta County. This is the type locality for Ehler's "Burnt Bluff" formation. A second bluff about one-half as high as Burn Bluff is located at Fayette about three miles to the north, and there is a third but lower bluff at the entrance to Garden Bay about four miles north of Fayette Bluff. The rock formations of the Garden Peninsula make it one of the scenic attractions of the Upper Peninsula, but owing to its location off the main highway it is little frequented by tourists. A view from Fayette, a peaceful fishing village with its picturesque harbor flanked by a 100-foot wall of rock, along which the road winds to where Burnt Bluff stands sentinal in the distance, affords one of the finest panoramas in the entire State.

On M-94 about five miles north of Manistique the tourist is treated to the sight of a 75 foot wall of rock rising precipitously from a swamp. This is the famous Niagaran escarpment and a continuation of the rocks from Burnt Bluff and the Garden Peninsula.

The Big Spring located on the west side of Indian Lake near Manistique is one of the beauty spots of the State. The water wells up under great pressure from the underlying rocks to form a crystal clear, emerald green pool 175 by 300 feet across, and 40 feet deep, from which a large stream flows to Indian Lake.

Salina Formation (Salt Beds)

Outcrops of the Salina formation have not been positively identified in Michigan. The area of possible outcrop is confined to the St. Ignace peninsula and the nearby islands. Elsewhere the Salina is believed to underlie the basins of Lakes Michigan and Huron since the Niagaran dolomites, which immediately underlie the Saline, wrap themselves almost entirely around the outer shores of the lakes. In fact the lake basins are believed to have been formed in part by the solution of salt by rivers which existed before the formation of the lakes. Outcrops of dolomite, limestone, and gypsum at St. Ignace, St. Martins Island, and Mackinac Island have been thought to be of Salina age, but owing to the similarity of the Salina to the overlying beds of the Monroe, it is impossible to distinguish them by the character of the rocks. The fact that the salt beds of the Salina do not outcrop may be explained by complete surface solution of the salt by the action of rain and streams.

The Salina is, however, well known in the Lower Peninsula where it has been drilled by wells in a dozen or more rather widely separated points in the southern part of the State. Aside from the salt beds the Salina is extremely variable in character. In the Detroit area it consists for the most part of buff, brown, and gray argillaceous dolomites interbedded with gray shales, but at Saginaw and in Monroe County gray and brown dolomites predominate. In Newaygo County gray and brown limestones and dolomites alternate, but in Ottawa County, aside from salt, the formation is composed entirely of gray and brown limestones. At Manistee brown and gray dolomites predominate with brown and buff limestones near the base.

The aggregate thickness of the beds of rock salt amounts to over 800 feet at Onaway, Presque Isle County; 750 feet in Newaygo County; 725 feet in Ottawa County; 550 feet at Manistee; and 550 feet in the Detroit area. In Saginaw County nearly 400 feet of salt was drilled through but the well did not reach the bottom of the formation. At Detroit the total thickness of the Salina is 1245 feet, at Manistee 1235, and at Onaway 1220 feet.

Economic Products - Salt

The production of salt in Michigan dates from about 1860 and the industry has become one of the most stable in the State. For many years Michigan has ranked first among the states in the production of salt. With a thickness of salt beds ranging from 500 to 800 feet underlying most of the Lower Peninsula, the reserves of salt in Michigan are adequate to supply the entire country for a very long period of time. The salt is obtained chiefly by means of wells into which water is pumped to dissolve the salt, which is brought to the surface in the form of brine and the water evaporated.

The chief centers of salt production by this process are at Port Huron, St. Clair, Marine City, and along the Detroit River from Detroit to Wyandotte. At Detroit rock salt is mined by means of a shaft 1100 feet in depth. This is the only salt mine in the State.

Origin of Salt

It is generally believed that the thick deposits of rock salt occurring at various places have been formed by evaporation of sea water. It has been proved, however, that simple evaporation of a body of sea water would not be adequate to account for the hundreds of feet of rock salt which underlie the State as bodies of water vastly deeper than any known depths of our present oceans would be required. A theory which seems to get rid of this difficulty was advanced by Ochsenius and is known as the "Bar Theory." This theory assumes a bay partly separated from the open ocean by means of a bar. Evaporation takes place more rapidly in the bay than in the ocean, with the result that the salt is deposited. Lowering of the surface of the bay by evaporation of the water causes inflow of additional supplies from the open sea and the cycle of evaporation and refilling of the basin continues as long as the bay is in existence and climatic conditions remain the same. Some writers[15], however, hold that the salt deposits of the Salina were formed in shallow lakes such as exist in desert regions today. According to this theory the salt is obtained through erosion of surrounding land masses and deposited during rainy periods in the low-lying parts of the basin.

Monroe Group

The Monroe group consists of three formations, namely the Bass Island or Lower Monroe, the Sylvania or Middle Monroe, and the Detroit River or Upper Monroe formation. The Bass Island formation overlies the Salina and where salt beds are absent cannot be distinguished from the latter. The Bass Island consists chiefly of gray, brown, and buff dolomites, often shaly and containing some beds of gray shale. Limestone is not of common occurrence in the Bass Island. According to Dr. A. C. Lane, former State Geologist of Michigan, a satisfactory division between the Bass Island and Salina can be made where the salt beds are absent by placing the top of the Salina at 400 feet below the base of the Sylvania sandstone, which can be easily recognized. The upper member of the Bass Island, which is known as the Basin River dolomite, outcrops rather extensively in eastern Monroe County, particularly in the valley of the Raisin River.

Devonian Period

Sylvania Formation

The Sylvania sandstone overlies with a slight unconformity the Bass Island formation. The Sylvania is one of the most interesting of Michigan formations because of its unique method of formation and its unusual physical characters. It consists of pure white sandstone, very loosely cemented and resembling granulated sugar. Dr. A. C. Lane described this sand as "white as the driven snow." This pure sandy phase of the Sylvania, however, exists only in the southeastern part of the State, especially in Wayne and Monroe counties. Elsewhere the Sylvania is generally represented by cherty limestones or dolomites, but at Walhalla in Mason County on the opposite side of the State from the occurrence in Wayne and Monroe counties, the Sylvania also consists of sandstone, not so pure, however, as that in the southeastern part of the State. Grabau and Sherzer, who made a detailed study of the Monroe formation,(16) concluded that the Sylvania was formed under conditions which permitted of long continued working over of the sand by winds and waves in order to cause the almost complete removal of all minerals except quartz. The original source of the sand is believed to be the St. Peter sandstone, to which the Sylvania is strikingly similar. The formation is named from the occurrence at Sylvania, just across the State line in Ohio.

Economic Importance

The Sylvania sandstone, because of its high purity, is especially adapted for the manufacture of plate glass and lenses for microscopes and fine telescopes. The stone outcrops or is under shallow cover near Whiteford and Steiner, Monreo County, and near Rockwood, Wayne County, where a quarry is in operation. The thickness of the Sylvania sand in the Wayne-Monroe area varies from 35 feet at the Ohio line to 165 feet at Detroit. It appears to thin out and disappear in Ohio, but thickens to over 300 feet at Ypsilanti, Washtenaw County. Locally the Sylvania yields a hydrogen sulphide or sulphur water. Beautiful crystals of celestite (Strontium sulphate) occur in the Sylvania at Rockwood.

Detroit River Formation
(Upper Monroe)

The Detroit River formation outcrops along the Detroit River and in other parts of Wayne and Monroe counties. Several divisions have been recognized by Grabau and Sherzer, who made detailed geologic studies of Wayne and Monroe counties. These are namely the Flat Rock dolomite, Anderdon limestone, Amherstburg dolomite, and Lucas dolomite. Elsewhere in the State, however, the Detroit River formation can be studied only by means of well samples in which it is not generally possible to separate the different members recognized in the southeastern part of the State. As indicated by the names of the various members, the Detroit River formation consists chiefly of dolomite with one very pure bed of limestone in Monroe and Wayne counties. The Monroe-Wayne exposures, however, represent only a portion of the entire formation and we find from a study of well samples from other points in the southeastern part of the State that the Detroit River formation contains in some areas as much limestone as dolomite. Samples from one St. Clair County well, for instance, show an upper bed of limestone and a dolomitic middle portion, but the lower half of the 400-foot thickness is all limestone. Samples from a Macomb County well are practically all of dolomitic character. In Presque Isle and Montmorency counties in the northern part of the Lower Peninsula two wells show nothing but limestone and the Detroit River cannot be separated from the overlying Dundee Limestone. In the central and western portions of the State the formation is largely of dolomitic character which distinguishes it from the Dundee. Rather thick beds of anhydrite near the top of the formation are also important in distinguishing it from the Dundee in well samples. Chert, which occurs locally, is also helpful in this regard. Celestite associated with native sulphur occurs in the Detroit River formation at Gibralter, Wayne County, and Maybee, Monroe County. Gypsum is also common and there are important beds of rock salt occurring in the Detroit River formation in the north central and northwestern parts of the Lower Peninsula.

Economic Products of the Monroe Group

Aside from the Sylvania formation many quarries have been operated in Monroe County in both the Upper and Lower Monroe beds. Only one, however, is operated at the present time and this is located in the Bass Island beds at Monroe. The stone is quarried chiefly for road metal, concrete aggregate, and railroad ballast. Quarries formerly operated in Monroe County are located at Maybee, Ida, Ottawa Lake, Newport Center, Brest, Plum Creek, Otter Creek, and other places. At some of these quarries stone was burned for lime. A quarry was formerly operated in the Upper Monroe beds at Gibralter, Wayne County. Several unsuccessful attempts have been made to mine gypsum in the vicinity of St. Ignace and some stone was burned for lime.

Salt

The production of salt by the large plants at Manistee and Ludington is from the Detroit River formation. It was formerly thought that the salt wells had penetrated the Salina beds at depths of about 2000 feet, but deeper drilling proved conclusively that the production is from the Upper Monroe.(17)

Salt beds have also been encountered in wells in Muskegon, Roscommon, and Saginaw counties, the thickest beds being found in Roscommon County.

In addition to salt, limestone, and glas sand, valuable brines for medicinal purposes occur very close to the contact between the Detroit River formation and the overlying Dundee. These waters, in addition to containing large quantities of sodium chloride, are heavily charged with hydrogen sulphide gas. They are exploited on a commercial scale notably at Mount Clemens. Bromine is produced from the Detroit River formation at Manistee.

Dundee Formation

The Detroit River formation is unconformably overlain by the Dundee limestone, exposures of which are relatively few. There is a small outcrop south of Detroit at Sibley, and larger exposures in Presque Isle County near Presque Isle and Rogers City, and near Mackinaw City in Cheboygan and Emmet counties. In the central Michigan oil fields the Dundee is encountered at depths of approximately 3500 feet. The Dundee is fairly uniform in character over the State. It is everywhere a pure limestone formation except on the west side of the State, where dolomite beds occur, chiefly at the base. It is generally brown in color on the west side of the State, but elsewhere is of a characteristic buff color. In Muskegon County it is practically impossible to distinguish the drill cuttings of the Dundee from either the Traverse or Detroit River formations. It is possible that the Dundee may be absent in that locality. In the east central part of the Lower Peninsula the Dundee attains its maximum thickness of approximately 300 feet.

Economic Products

The Dundee limestone is one of the most important rock formations of the Michigan Basin. The quarry of the Michigan Limestone and Chemical Company at Rogers City enjoys the reputation of being the largest quarry in the world. Another large quarry is operated near Presque Isle, Presque Isle County, by the Kelley Island Lime and Transport Company. At Sibley, Wayne County, a quarry is operated by the Solvay Process Company. The high purity of the Dundee stone especially adapts it for use in blast furnaces for fluxing iron ore and for lime, paper, and sugar manufacture, calcium carbide, and most other chemical purposes. At Sibley it is quarried chiefly for the manufacture of sodium carbonate, caustic soda, and other products by treatment with brines. At this latter quarry beds belonging to the underlying Detroit River (Anderdon limestone) are quarried with the Dundee stone. Quarries have also been operated in the vicinity of Dundee, Monroe County, from which the formation is named.

Oil and Gas

The Dundee formation is the chief oil and gas producing formation in Michigan. Oil was first discovered in paying quantities in the Dundee formation near Port Huron in 1886. Incidentally this was the first commercial production of oil in the State. About 1900, and again in 1912, a small production was obtained from the Dundee near Allegan, Allegan County. The central Michigan field was discovered by the Pure Oil Company in 1928 with a producing well in the Dundee limestone, and the same year wells in the Muskegon field were deepened to the Dundee, with a resultant increase in production. This field had previously produced oil from the Traverse formation. The Dundee oil is, however, not as high grade as the oil from other producing horizons in the Michigan basin, and requires special refining processes in order to prepare it for the market.

Several distinct oil pools are recognized in the central Michigan fields, namely the Mount Pleasant pool, and its East Extension, the Porter pool, Leaton pool, Vernon pool, Yost-Jasper pool, and Crystal Pool. Considerable quantities of natural gas are found in association with the oil in these pools.

Origin and Occurrence of Petroleum and Natural Gas

A number of theories have been advanced to explain the origin of petroleum and natural gas. The most generally accepted of these states that these substances have been formed by the decomposition of the soft parts of marine plants and animals. The great thicknesses of limestones which have been build up largely by the shells of marine animals, and the thick beds of shale composed largely of the siliceous skeletons of marine plants known as diatoms, prove that the oceans swarmed with life over enormously long periods of time. It is believed that these organisms after death sank to the bottom and that the soft parts upon decomposition formed substances which eventually were transformed into oil or gas. Certain kinds of bacteria are supposed to have played an important part in this transformation. The oily material thus formed was held at the bottom of the sea by muds which were washed in and remained there when the sediments were finally consolidated and uplifted to form land areas.

Nature of the Occurrence of Oil and Gas

The bulk of the world's oil is produced from sandstone formations, although many important fields derive their production from limestone. Oil is found in almost every other kind of rock but these are relatively unimportant in comparison to sandstone and limestone reservoirs. Shales in some localities contain enormous quantities of oil, but the openings in shale are too small to permit recovery of the oil by other than distillation processes. Where oil occurs in sandstone the spaces between the individual grains of sand constitute the reservoir for the oil, but in the case of limestone or dolomite there are no such openings. Reservoir conditions in these rocks are due to bedding planes, joint cracks, and openings which have been enlarged and made continuous by solution of the calcium or magnesium carbonate by circulating waters.

It has long been known that oil and gas accumulate at points of important structural changes in the rocks. The most important of these is the anticline or dome where the rocks have been arched upward to form a trap into which the oil and gas, being lighter than the associated salt water, is forced upward into the high places in the rocks. The locating of a successful oil or gas well depends, therefore, upon the finding of one of these "highs." Large oil companies employ geologists to map the rock structures from the relations of the surface outcrops, or in areas where the rocks are heavily covered by drift deposits, as in Michigan, drill a number of shallow test wells to an easily recognizable "key bed," by means of which they are able to determine the structure over a fairly large area. If the results of the tests indicate favorable structures a deep well is then drilled to the known or conjectured oil bearing formation. The central Michigan fields were discovered as a result of a structural map compiled from records or logs of salt wells furnished by the Dow Chemical Company of Midland.

In addition to accumulation in anticlines or domes, oil may be trapped by faults, unconformities, impervious strata, and other structures or textures in the rocks. Considerable exploration for oil has been conducted in the vicinity of a fault known to exist in southeastern Michigan.

Brines and Mineral Waters

The Dundee limestone also contains valuable brines somewhat similar in character to the Detroit River brines, but generally of lower specific gravity and containing lesser amounts of hydrogen sulphide, calcium magnesium chloride, and bromine. Waters used for medicinal purposes generally represent a mixture of Dundee and Monroe brines as the wells are rarely cased sufficiently to confine the flow to a definite formation.

Well Logs and Samples

Companies and individuals drilling for oil in Michigan are asked to cooperate with the State in furnishing logs of wells and samples of formations penetrated by the drill. Effort is made to secure a sample of rock for every five feet drilled; thus giving a fairly accurate picture of the rock formations from the top to the bottom of the well. The samples are then washed and placed in small bottles, each of which is labeled with the proper depth and arranged in order in small trays. A geologic record of the formations is then made up from the samples, together with the accompanying driller's log, and copies are available for operating companies and anyone desiring the record, providing its release is authorized by the company owning the well. Well records thus compiled are in demand by companies and individuals in search of oil or gas, as a knowledge of the thickness, character, and structure of the formations is of great value in prospecting for a commercial pool of oil, gas, or other mineral product.

Traverse Formation

The Traverse formation is separated from the underlying Dundee by the Bell shale, a blue gray to dark gray soft shale, generally limy and very fossiliferous. The Bell shale varies from 60 to 80 feet in thickness in the central and northern portions of the State, thinning progressively to the west and southwest, but becoming much thicker to the east and southeast. In the Muskegon oil field the Bell shale is generally absent and the Traverse cannot be separated from the lower formations. In the Saginaw Bay region the shale at the base of the Traverse thickens from 100 to 300 feet, but it is probable that some of this thickness correlates with higher up portions of the Traverse, since the entire Traverse in that section of the State is dominantly shale.

The Traverse is so named because of the exposures along Little Traverse Bay in Charlevoix and Emmet counties. From Little Traverse Bay there are outcrops in a belt extending across Cheboygan County into Presque Isle and Alpena counties where the Traverse limestone is at or near the surface over considerable areas.

The Traverse of the Alpena area has been studied in more detail than any other exposure and three divisions are recognizable: an upper group of beds consisting of shales and siliceous limestone (Thunder Bay series), a middle portion of high calcium limestone (Alpena limestone, Petoskey limestone), and a lower portion (Long Lake Series), consisting of shales and shaly limestones with a bed of pure limestone (Rockport) at the base. These divisions cannot be recognized in other parts of the State. Generally, however, the upper part of the Traverse consists of gray shales and gray shaly limestones. In the Petoskey district limestone greatly predominates over shale, and a similar condition exists in other areas in the northwestern part of the State which have been penetrated by wells. In the south central and southeastern parts of the State shale predominates over limestone. In the north central part of the Lower Peninsula the Traverse is from 700 to over 800 feet thick, but in the southwestern portion of the State it thins to less than 150 feet and is from 200 to 400 feet thick in the extreme southeastern part of the State. At Alpena it is about 600 feet in thickness. The Traverse varies greatly in color, brown and buff variegated layers being probably most characteristic, with beds of gray limestone being quite common. Some limestones are dark brown to almost black, mixed with light colored portions to give a "salt and pepper" appearance. In the southwestern part of the State a very white to light buff color is characteristic.

Economic Products of the Traverse

Limestone - The Traverse is another very important formation commercially. Quarries are in operation at Alpena and Petoskey, Afton, Cheboygan County, and formerly near Charlevoix. The stone is used chiefly for portland cement, lime, alkali, road materials, and concrete aggregates. Several shale beds of the Traverse have been utilized in the vicinity of Alpena for the manufacture of portland cement, brick, and tile.

Water Supplies - In addition to crushed stone, the Traverse is an important source of water supplies for the area it underlies. The water is fairly hard but not salty. In other portions of the State the Traverse carries brine which is utilized in some localities for medicinal purposes.

Oil and Gas - The Traverse is an important producing horizon for oil and gas in the Muskegon field, and smaller amounts have been produced at Saginaw. The depth at which production is obtained at Muskegon ranges from 1620 to 1680 feet, but at Saginaw the Traverse is found about 700 feet lower.

Scenery in the Traverse

The Traverse formation furnishes a type of scenery which is as spectacular as much of that of the Upper Peninsula. In Alpena and Presque Isle counties t e action of underground waters has so dissolved and weakened the strata in some places that cave-ins have resulted and great "Sunken Holes" have been formed. These are often several hundred feet across and from 100 to 200 feet in depth. Many have vertical walls of limestone. The most impressive "Sunken Holes" are to be found in the vicinity of Long Rapids and Leer, Alpena County, near Shoepac Lake, Presque Isle County and in the Pigeon River State Forest, Otsego and Cheboygan Counties. An awe-inspiring sight is to be found in El Cajon (Misery) Bay, Alpena County, where due to a sink hole near the edge of the bay the water drops off abruptly from a depth of one to two feet to a depth of 76 feet. A large part of the outflow of Long Lake, Alpena County, drains through underground channels. Except in the spring and early summer when the volume of water is large, the drainage is entirely underground. This underground drainage is plainly visible at the "narrows" in the late summer or fall. Silver Creek near Millersburg, Presque Isle County flows entirely underground for a short distance in its course, reappearing at the surface several hundred yards downstream.

In addition to the spectacular sink hole development of Alpena and Presque Isle counties, the Traverse adds a milder beauty to the landscape in the form of limestone bluffs along the shores of Little Traverse Bay and Lake Michigan near Petoskey and Charlevoix. At Alpena fossil coral reefs occur in the limestone in the form of mounds or ridges. These are not spectacular to observe but their presence is of interest in that these reefs tell a story of times when conditions in Northern Michigan were similar to those existing off the coast of Australia and other places where coral reefs are forming. The coral rock at Alpena is pure white and of very beautiful and delicate structure. The reefs are generally very high in calcium carbonate content and increase the commercial value of the stohe. The falls of the Ocqueoc and Rainy Rivers near Onaway, Presque Isle County, are the largest and most beautiful falls in the Lower Peninsula.

Antrim Formation

The Antrim Formation definitely marks the end of the long period of dominantly limestone deposition beginning with the Niagaran series and ending with the Traverse. We can see, however, that transitional stages were under way in the Traverse with the formation of rather thick shale beds between the intervals of limestone deposition. No important beds of limestone were formed in Michigan after the end of Traverse time. The sea which covered Michigan became shallower, due to uplift of the land or lowering of the water surface by partial withdrawal of the sea, with the result that conditions became favorable for the deposition of sands and muds which were later consolidated to form several thousand feet of chiefly shales and sandstones with only minor beds of limestone.

The Antrim formation consists of black shale, which has a dark brown appearance on a fresh fracture or when powdered or finely ground. Drillers refer to it as "coffee" shale due to the resemblance of the drill cuttings to coffee grounds. The dark brown or black color is due to the presence of organic matter.

The base of the Antrim shale constitutes one of the best key horizons in the State since it is everywhere present within the limits of the outcrop and the contact with the underlying traverse is very sharp. The Antrim varies in thickness from less than 100 feet in the southwestern part of the

State to more than 500 feet in the north central part of the Lower Peninsula. It is probable, however, that some of this greater thickness correlates with higher beds on the west side of the State where the Antrim is normally from 200 to 250 feet in thickness. In the central Michigan oil fields the black shale runs from 400 to 480 feet in thickness.

The outcrops of Antrim shale are restricted to the northern part of the State. It is exposed at several places in the vicinity of Norwood, Boyne City, and Walloon Lake, Charlevoix County, near Afton, Cheboygan County, and at Paxton, Squaw Bay, and Sulphur Island, Alpena County. At Norwood one can observe a bluff of black Antrim shale along the lake shore just south of the village, while about one mile north of the village the Traverse limestone forms a bluff along the shore, indicating that the contact between the two formations lies near the village of Norwood. Similar contacts can be observed in Alpena County. An interesting feature of the Antrim shale is the presence near the base of the formation of large balls or concretions which range up to six feet in diameter, one to three feet being common. These concretions are generally of three types - (1) consisting entirely of iron carbonate or siderite, (2) composed of a core of bituminous or oil bearing limestone or dolomite, with an outer shell of the same material but having the crystals of bituminous limestone (anthraconite) arranged in parallel fashion, forming a needle-like or columnar structure with the needles radiating toward the center of the concretion, (3) composed of pyrite (iron sulphide). The pyrite concretions are generally much smaller than the other types, ranging from one to three inches in diameter. Pyrite is more or less common through the formation.

Economic Products of the Antrim Shale

A quarry is operated at Paxton, Alpena County, for the production of shale for the manufacture of portland cement. A few tests which have been made show that the Antrim shale contains four to nine gallons of oil per ton of rock, but this is not sufficient to make extraction profitable at the present time. Many pockets of natural gas have been discovered by means of wells in the glacial drift overlying the outcrop of the Antrim shale. Some of these have been large enough to furnish gas for several farm homes over a period of years. In Alpena County the Antrim shale is locally important for fresh water supplies.

Very thin seams of coal have been found in the Paxton quarry. These are of no economic importance since the thickest seam amounts to only 1½ inches, but they are of interest in that they represent the first coal formation in geologic history and may be thought of as a prophecy of the great coal forming period which was to come in the Pennsylvanian period.

Mississippian Period

Berea-Bedford Formations

These formations are considered together since they occupy the same position above the Antrim shale but in different parts of the State, and portions of each are possibly to be correlated with the other. The names are from localities in Ohio where occur the type exposures with which the Michigan beds are correlated. The Berea formation does not outcrop in the State; hence all knowledge of it is derived from well records and samples. These show it to consist chiefly of gray sandstone, generally fine grained but somewhat coarser in the "Thumb" region. White mica and pyrite are characteristic minerals present. Beds of gray shale occur between the sandstone beds, and in the central part of the State a rather thick bed of gray shale occurs below the sandstone.

It is possible that this shale should be correlated with the Bedford.

The Berea is present as a sandstone only on the eastern side of the State; whereas the Bedford is present with certainty only on the west side. There are certain red shales which occur in the southwestern part of the State and red limestones farther north which occupy about the same position in the geologic section and possibly correlate with the Berea.

The Bedford formation outcrops at a number of localities in the northwestern part of the Lower Peninsula. The chief exposures are at Ellsworth, Eastport, Central Lake, and Chestonia, Antrim County, and at Boyne City and East Jordan, Charlevoix County. The shale at these points is generally bluish gray to greenish gray in color, very soft, and free from concretions and other foreign substances. At Boyne City green shale is finely interlaminated with brown and grades into brown shale. In well samples from the western side of the State the Bedford formation is seen to consist chiefly of greenish shale interbedded with very fine grained, light gray sandstone beds. These, however, disappear toward the base of the formation and the green shale becomes interbedded with brown and finally grades into the dark brown Antrim shale. This change is so gradual in some wells that it is almost impossible to separate the two formations. The Bedford ranges from 400 to 600 feet in thickness on the west side of the State. In view of the lack of definite correlating data with the Bedford of Ohio, Newcombe proposes the name Ellsworth[18] for this thick section of greenish sandy shales.

Economic Products of the Berea-Bedford

Oil and Gas - The discovery of oil in the Berea formation at Saginaw was responsible for stimulating recent interest in oil and gas in Michigan with the resultant more important discoveries. The first successful well was completed in 1925 and during the next two years more than 300 wells were drilled. About 190 of these were producing wells which yielded a maximum of about 1400 barrels of high grade oil per day. The structure with which the oil is associated is unfortunately located directly under the city of Saginaw and much town lot drilling resulted, causing the wells to be spaced too closely, which greatly decreased the life of the field. The oil is obtained at a depth of slightly more than 1800 feet.

Brine - In addition to its oil content the Berea contains valuable brines. These were formerly utilized in the "Thumb" district for medicinal purposes and for the manufacture of salt.

Shale - The Bedford formation is the source of shale for the manufacture of portland cement at Petoskey and Newaygo. The quarry is located at Ellsworth in the northwestern part of Antrim County. This shale has also been used for the manufacture of brick and tile at Boyne City and East Jordan. The reserves of shale in Antrim County are very large.

Coldwater-Sunbury Formation

Where the Berea is present as a sandstone it is overlain by the Sunbury shale which is generally from 10 to 30 feet in thickness, but much thicker in some areas. In a well in southwestern Jackson County 200 feet of Sunbury was encountered. The Sunbury shale is dark brown to black and very similar to the Antrim with which it may be confused when present in abnormal thickness. On the west side of the State where the Berea is absent the Sunbury likewise cannot be recognized. There are no outcrops of this shale in the State; hence it is of no economic importance except as a cap rock for preventing the upward migration of oil, gas, and water. The name Sunbury is taken from the occurrence at Sunbury, Ohio, and is used in Michigan because the succession of Bedford, Berea, and Sunbury formations is very similar to that of Ohio.

The Coldwater shale is one of the most persistent and uniform of Michigan formations. It is also one of the thickest. Outcrops are present near Coldwater, Union City, Quincy, and Bronson, all in Branch County, and along the Lake Huron shore, near Richmondville, Sanilac County, Forestville and White Rock, Huron County. The Coldwater is characteristically a soft blue gray shale, but is distinctly sandy in some areas and in others contains beds of limestone or dolomite. In the central Michigan oil fields the Coldwater attains a thickness of slightly more than 1000 feet. Practically the entire thickness is blue gray shale. On the west side of the State the formation is only about 600 feet thick, and there is a thick bed of brown limestone or dolomite about 250 feet from the top. On thd east side of the State sandstone beds become very important and in some areas the entire thickness is dominantly sandy. The sandy portions are very similar to the Berea and have been mistaken for the latter. Near the base of the Coldwater on the west side of the State a red limestone or dolomite occurs. The "red rock" has been found to constitute a satisfactory "key" horizon for determining structure of the rocks in that part of the State. In the southwestern part of the State the red limestone changes to a red shale.

Economic Products

The Coldwater is a source of shale for portland cement at Coldwater and Quincy in Branch County. Some production of mineral waters has also been obtained in the eastern part of the State where sandy beds occur. Bromine has been produced near East Tawas, Iosco County.

Marshall Formation

The Marshall formation overlies the Coldwater and the lower beds are difficult to distinguish from the latter formation in the absence of the red beds which are characteristic of the Lower Marshall. The Marshall is divisible into two parts, an upper sandstone member known as the Napoleon, named from the outcrop at Napoleon in Jackson County, and a lower and generally thicker member composed of white and red sandstones and gray and red sandy shales. In the central and eastern portions of the State the Lower Marshall is generally marked by the presence of a dark red sandstone or red sandy shale at the top and base of the formation, including between these limits 300 to 400 feet of gray and red sandy shales and sandstones. The amount of section between the red beds will, however, vary considerably within a short distance. In Midland county in adjoining townships the thickness of beds which can be positively identified as Lower Marshall varies from less than 50 to nearly 400 feet. The maximum thickness of the Lower Marshall is less toward the western portion of the State, but locally it is greater than that on the eastern side of the State.

The Upper Marshall or Napoleon is entirely a sandstone member ranging in thickness from 60 to 125 feet, between which limits it is fairly constant and there appears to be no definite direction of progressive thickening or thinning. It is a white to light gray medium grained rock, containing a variety of minerals.[19]

In the west central part of the Lower Peninsula the Upper Marshall is tinted a light reddish color and the Lower Marshall is represented by dark red ferruginous sandstones fifty feet or more in thickness.

The Marshall formation outcrops in a belt extending from Ottawa County on the west side of the State, southeastward to Hillsdale County and northeastward to Huron County. Exposures are found in Ottawa, Calhoun, Jackson, Hillsdale, and Huron Counties.

Economic Importance of the Marshall

The Marshall is of chief importance because of the valuable brominiferous brines which it contains and which are produced by the Dow Chemical Company from about 125 wells scattered over Midland, Isabella, and Gratiot counties. The Marshall brine is the raw material from which over 150 chemicals are manufactured at the Midland plant. Some of the more important products are bromine compounds for use in the manufacture of ethyl gasoline, for photography and medicinal purposes, calcium chloride for dust laying, refrigeration and other purposes, metallic magnesium for aircraft and light weight alloys, magnesium sulphate, magnesium chloride, aspirin, and salt. The wells are about 1400 feet in depth.

Origin of the Marshall Brines

The Marshall brines probably represent sea water partially concentrated by evaporation and held in the rocks at the time of their formation. Heavier constituents such as calcium-magnesium chloride and bromine have settled down the dip of the rocks toward the center of the Michigan Basin in such quantities as to be of great commercial value.

Near the outcrops, however, due to this migration, the Marshall carries fresh water suitable for drinking, and is the source of supply for a number of cities. Marshall and Battle Creek derive their supplies from this source, while a part of the municipal supply of Jackson comes from the Marshall.

Sandstone

Many quarries were formerly operated for building stone in the Marshall formation in Jackson, Calhoun, Hillsdale, Huron, and Ottawa counties. For many years the Cleveland Quarries Company has made grindstones from the Marshall sandstones at Grindstone City, Huron County. The stone is composed of sharp angular grains, chiefly quartz, imbedded in a softer clay cement which permits the grains to wear away just fast enough to expose fresh cutting surfaces and to prevent the stone from becoming glazed.

As a building stone the Marshall is of too poor quality to compete with the sandstones and limestones of Indiana and Ohio.

Oil and Gas

Small quantities of oil have been found in the Marshall formation but no commercial occurrences are known. The Marshall is of importance, however, as a key formation in the central Michigan oil fields, the elevation of the first red bed in the Lower Marshall indicating whether or not a well in progress of drilling is "on structure" or not. All oil wells drilled in central Michigan must necessarily penetrate the valuable brine-bearing Marshall formation in order to secure the oil at greater depths. State law requires the protection of the valuable brines against contamination by oil or dilution by fresh water from other formations. This is accomplished by placing well casing to the base of the Marshall and cementing or mudding between the casing and the wall rock, to the top of the formation.

Marshall Scenery

The wave-cut cliffs of Marshall sandstone at Pointe Aux Barques, Huron County, form one of the beauty spots of the Southern Peninsula. Sea caves, arches, chimneys of rock, and other forms have resulted from undercutting of the sandstone ledges which constitute the "Thumb Nail" of Michigan.

Grand Rapids Series

Michigan Formation

The Grand Rapids series is extremely variable in thickness owing to deposition on an uneven surface and later erosion of the top of the formation.

Its maximum thickness is over 500 feet but in the southeastern part of the State it has been entirely removed by erosion and the beds of the succeeding Pennsylvanian period rest directly upon the Marshall sandstone. The Lower Grand Rapids, which is known as the Michigan formation, consists chiefly of gray and greenish gray shales with brown beds of limestone and dolomite and relatively thick beds of gypsum and anhydrite. The Michigan is usually separated from the underlying Marshall by a bed of brown, impure dolomite. Sandstone beds occur locally, one important bed being present above the basal dolomite in the central part of the State. Thomas[20] suggests inclusion of this lower sandstone bed with the Marshall formation, making a three-fold division of the latter, namely the Upper Marshall, Napoleon, and Lower Marshall formations.

Bayport Formation

The Bayport or Upper Grand Rapids consists chiefly of a bed of limestone of variable character and thickness. Often it is entirely absent owing to deep erosion at the end of Grand Rapids time. At some localities it may range up to 100 feet in thickness. The Bayport is usually recognized in well samples as a limestone immediately underlying the Parma sandstone. It varies from light buff gray to brown in color and contains sandstone beds and cherty portions. The Bayport usually grades into white sandstone at the base.

Outcrops of the gypsiferous Michigan formation occur near Grand Rapids, Kent County, and in Iosco and Arenac counties. The Bayport outcrops in Eaton, Huron, Arenac, Jackson, Tuscola, and Kent counties.

Economic Products of the Grand Rapids Series

Gypsum (Calcium Sulphate)

The Grand Rapids Series comprises a very important group of rocks commercially. Gypsum, of which Michigan is one of the leading producers, is quarried at Alabaster and National City, Iosco County, and mined at Grand Rapids. It has an important usage in the manufacture of wall board, various kinds of plasters, and insulating and structural material. Gypsum is formed by the same processes of evaporation described under salt. It is, however, deposited before the salt and in Michigan time evaporation did not progress far enough to result in deposition of the more soluble sodium chloride (salt) as in the case of the Salina.

Limestone

The Bayport formation is quarried at Bellevue, Eaton County, for the manufacture of portland cement, and at Bayport, Huron County, for the production of crushed stone for road material, concrete aggregate, etc.

Oil and Gas

The lower sandstone bed of the Michigan formation contains small quantities of heavy oil and large quantities of natural gas. It constitutes the most important source of natural gas discovered in Michigan to date. The principal discoveries have been in Clare, Montcalm, Isabella and Mecosta counties, where the gas sand is found at a depth of about 1400 feet.

Pennsylvanian Period

The Pennsylvanian (Coal Measures) is divided by Kelly[21] into the Parma sandstone, Saginaw group and Grand River group. The Parma is a white sandstone consisting chiefly of quartz grains, medium to coarse in texture, containing in some places small pebbles of milky white quartz which give it a conglomerate appearance. The Parma rests unconformably upon the Bayport or upon the Michigan formation in case the Bayport has been entirely eroded. In the southeastern part of the State the Michigan has also been removed and the Parma rests on the Marshall from which it cannot be distinguished. The thickness of the Parma varies considerably within short distances, owing to the deposition on an irregular surface. It is generally 50 feet or more, but is often 100 feet thick with a maximum known thickenss of over 200 feet. The Parma is named from the type locality at Parma, Jackson County. Exposures also occur at other points in Jackson County and in adjacent portions of Calhoun County.

Saginaw Group

The Saginaw Group consists chiefly of white sandstones, gray and black carbonaceous shales, impure limestone beds, and thin seams of coal. In some localities, as at Lansing, well records show the group to consist almost entirely of sandstones with only minor beds of shale. The maximum thickness of the Saginaw as shown by well records is over 500 feet. Exposures of the Saginaw group are to be found in Arenac, Tuscola, Genesee, Shiawasse, Clinton, Eaton, and Ingham counties. Coal mines in Bay, Saginaw, and other counties have also furnished excellent exposures for study, although the rocks do not outcrop at the surface.

Grand River Group (Woodville formation)

The Woodville formation was so designated by Winchell, a former State Geologist, from exposures of an iron stained sandstone near the old Woodville coal mine in Jackson County. In the mine a thickness of 30 feet of this sandstone was exposed apparently as the uppermost or capping sandstone of the Coal Measures.

Much better exposures of the Woodville or Grand River group are to be found near Ionia and at Grand Ledge,[21] Eaton County. The stone is generally thick bedded, coarse grained, and stained red or brown by iron oxide.

Permian Period

Samples from wells in the central part of the State show up to 180 feet of more or less unconsolidated red sand and clay, containing thin beds or pockets of gypsum. These beds are believed to have been formed at the same time and in a manner similar to the "Red Beds" of the southwestern states which contain thick deposits of gypsum and salt formed under desert conditions existing over a long period of time, with resultant oxidation of iron in the sediments to give them the characteristic red color.

Economic Products of the Pennsylvanian-Permian Periods

The Pennsylvanian Period was the time of greatest coal formation in North America and Europe. The climate of Pennsylvanian time is believed to have been warm and humid and large areas of the land surface were thought to be near sea level which permitted the formation of great coastal swamps similar in character to the Great Dismal Swamp of Virginia and North Carolina. The warm swampy conditions favored the development of the most luxuriant land flora in the history of the earth. Giant rushes, lycopods, and fern-like plants dominated the landscape, and there were thousands of smaller species. The remains of generation upon generation of this profuse growth accumulating on the bottom of the marsh formed great thicknesses of partly decayed plant matter or peat. Deep burial beneath later deposits of sediment resulted in removal of water and gases and very slow change into coal. It has been calculated that on the average 100 years are required to form one foot of well compressed peat, and that three feet of well compressed peat will form one foot of coal. It would therefore require 300 years to form enough peat for one foot of coal and 3000 years to form a ten-foot seam.

Large quantities of peat are being formed today in the cooler, wetter climates and in poorly drained glaciated areas. In the most extensive of the northern Michigan swamps near Seney, Schoolcraft County, peat has accumulated to a known depth of from 10 to 12 feet. In the Chandler marsh near Lansing soundings show a depth of 45 feet of peat and a thickness of 60 feet has been recorded near Six Lakes in Montcalm County.(22)

The principal coal mines in Michigan are located at Saginaw, Bay City, St. Charles, Unionville, and Midland. Mines operated chiefly to supply local trade are operated at Williamston, Grand Ledge, Jackson, Owosso, Mason, Unionville and other places.

Extent and Quality of Michigan Coals(23)

The Michigan "Coal Basin" or the region underlain by the rocks of the Pennsylvanian, comprises an area of about 11,000 square miles.(24) Only a very small part of the basin is, however, underlain by coal beds, and these are very local in character. A single bed may thicken, thin, or pinch out entirely within a few hundred feet. Records of wells drilled for oil show that coal beds are largely absent over most of the central part of the basin. In prospecting for coal it is therefore necessary to test the deposit very carefully by means of drill or test holes in order to accurately determine its character, as the productive area may not consist of more than a few hundred acres. Fourteen different coal seams have been recognized at some places, but these cannot be traced to other parts of the Michigan Basin. The seams range in thickness from a few inches to four feet, but this latter thickness is rare. Most of the commercial seams average about 30 inches in thickness.

Michigan coals are of the bituminous variety, but generally of lower grade than the Eastern coals. They are not generally suitable for gas and coke making, but are satisfactory for general heating purposes and make fairly good steam coals, although owing to the generally lower B.T.U. content some equipment will not operate economically upon Michigan Coal. Most of the coals are characterized by a high moisture content and in many places the ash content is quite high. Coals which have a high sulphur content are not economical to use in the long run, owing to the fact that grates and firepots will be corroded. All Michigan coal breaks and slacks readily so that it is not practical to ship it long distances or permit it to stand in stock piles for any great length of time.

Shale

Shales of the Coal Measures are utilized at Williamston, Ingham County; Grand Ledge, Eaton County; Corunna, Shiawassee County; and at Jackson, Jackson County, for the manufacture of brick and tile and sewer pipe.

Sandstone

The Woodville sandstone is quarried near Ionia for building stone. The stone produced is vari-colored, with shades of red, brown, yellow, purple, and pink, and is known as "Rainbow Valley Stone."

Water Supplies

The sandstones of the Saginaw formation constitute an important source of water supply for cities in the southern part of the State. Lansing and St. Johns derive their supplies from this source, and a portion of the Jackson supply comes from the Coal Measures sandstones.

Salt Brines

The brines of the Parma sandstone constituted a source of evaporated salt in the early days of salt manufacture in the Saginaw valley. They are not used, however, at the present time.

Pennsylvania Scenery

The Woodville sandstone forms picturesque bluffs along Sandstone Creek and the Grand River at Grand Ledge, Eaton County. This is the site of a city park.

CHAPTER XII

LIFE OF THE PALEOZOIC

We have seen how the Pre-Cambrian rocks contain evidence of only very primitive forms of life. The lowest of Paleozoic formations, the Cambrian, on the other hand, contains abundant remains of some of the highest forms of invertebrate life, emphasizing again the great break and loss of record between the Pre-Cambrian and Paleozoic. Trilobites, very complex organisms, dominated the Cambrian seas, but brachiopods and corals were also common. Succeeding geologic periods brought a multitude of new forms with a progressive development of higher types of life. Brachiopods, cephalopods, gastropods, graptolites, bryozoans, corals, crinoids, and trilobites swarmed in the seas during Ordovician and Silurian time. In the Upper Silurian higher forms of life such as nautilids and scorpions appear. The scorpion became the first air-breathing animal in geologic history and these are followed by fishes in the late Silurian and Devonian where they became the dominant form of life as well as the first known vertebrate animals.

The first land plants also made their appearance in the Devonian, impressions of the leaves and stems of which are preserved in the Antrim shale of Michigan.

Mississippian and Pennsylvanian time was marked by the creeping out upon the land of many forms of animal life, with the result that the amphibian, a creature which spends a part of its life in water and the remainder on land, was developed. In Permian time there evolved the reptiles which lived entirely on the land. As these higher and higher forms developed the ancestral forms remained, but many became less prominent. The seas swarmed all through Paleozoic time with the various types of invertebrates, but the end of that era saw the virtual extinction of some of the most important forms. Trilobites became entirely extinct and the older orders of brachiopods disappeared from the seas.

As indicated under the formation of coal, Pennsylvanian time was characterized by the most profuse land flora of all time. The warm moist climate and luxuriant plant growth also favored the development of more than 1000 species of insects most of which were of giant size, varying from two inches in length to more than a foot, with a wing spread in some instances of 29 inches.

Evidences of Paleozoic Life in Michigan

With the exception of the Cambrian period, fossils are abundant throughout the Paleozoic. Fossils are rarely found in the Michigan Cambrian, owing to the fact that the red sandstones are not favorable for the preservation of the remains of animals.

Ordovician brachiopods and other forms are to be found in great abundance along the shore of Little Bay de Noc at Stonington, Deltz County, and at many outcrops of the Trenton limestone along the various rivers in the vicinity of Escanaba, and near Trenary.

Silurian corals and other fossils may be obtained at many exposures of the Niagaran Series from Burnt Bluff, Delta County, to Drummond Island, Chippewa County.

Fertile hunting grounds for Devonian corals, brachiopods, and occasional trilobites are present in the old quarries near Alpena and

Petoskey, in the bluffs along the shore of Little Traverse Bay, and at Partridge Point and El Cajon Beach, Alpena County. Fossil fishes also occur, but the remains of these are generally too poorly preserved to be recognizable by anyone not trained in their identification.

Mississippian fossils are found at Bayport, Huron County; Bellevue, Eaton County; and Coldwater, Branch County; and the dump heaps in the vicinity of coal mines offer possibilities for finding the fossil plants of the Pennsylvanian.

Plates XI and XII show the most common types of fossils occurring in Michigan rocks. Reference to the geological maps, Plates I and IV, will show in what belts or zones one may expect to find the fossils of the different periods. Slabs of fossiliferous limestone are common in the glacial drift and may be found at considerable distance from the zone of outcrop of that particular kind of rock. The nature of the fossils present, however, may give a clue to the formation outcrop from which the slab was transported by the ice.

Post-Paleozoic in Michigan

At the end of Paleozoic time, the greater part of eastern North America was elevated above water and has remained as a continental area to the present time. In western United States, however, millions of years of sedimentation followed the Paleozoic to record the events of the Mesozoic and Cenozoic eras. With the Michigan land area standing high above water throughout these eras, deep erosion occurred with a complete absence of geologic record and loss of much of that which was written during Paleozoic time.

Warping, faulting, settling, and other adjustments of the rock strata were also in progress during the Mesozoic and Cenozoic eras. It is probable that there was abundant life on the land which is now Michigan during the unrecorded eras; possibly even the great dinosaurs known to the Mesozoic of the western states roamed the Michigan hills, swamps, and forests only to have their remains bleached to powder and washed away; or if by chance a more favorable resting place was found beneath river sands or silts the ice sheet of the glacial spoch swept away and destroyed any possible record of the life of those times.

Pleistocene Period

We now come to the third great division of Michigan geology, but one which in point of time was relatively of short duration in comparison to the Pre-Cambrian and the Paleozoic. We have seen how the Pre-Cambrian in Michigan was dominated by profound volcanic activity, although vastly long periods of sedimentation also occurred, and how the Paleozoic was characterized by tranquil events with but few breaks in the long continued deposition of sediments. The Pleistocene is a type of geology found only in the northern portion of the United States. It is a story written in the form of scratched and grooved rock surfaces and thick deposits of sand, clay, and stones, spread over Michigan and adjoining states by the Great Ice sheet which invaded the North American continent in Pleistocene time.

Centers of Accumulation of Ice

A decidedly colder climate than that of the Cenozoic and Mesozoic eras permitted great fields of snow and ice to accumulate on the North American continent. The centers of accumulation were to the east and west of Hudson Bay and were known as the Labrador and Keewatin ice sheets respectively. These ice sheets are believed to have been of the same character as those which exist today upon the continents of Greenland and Antarctica; hence were probably as much as 10,000 feet thick at the centers of accumulation, thinning to probably

4,000 feet at the margins. After the ice had attained sufficient thickness it began to move outward in all directions from the center, probably much in the same fashion as thick syrup spreads out upon a plate. In moving thus it overwhelmed everything in its path as is shown by the smooth and rounded knobs of rock, often with deeply scratched and grooved surfaces, and the gouged-out valleys, now filled with water to form lakes. In its journey southward across the northern part of the United States the glacier carried great quantities of rock and soil particles frozen into its mass, which made it a far more effective grinding agent.

Eventually, however, the ice reached a point in its southward journey where the climate was too mild for further advance of the ice front, which therefore began to melt, dropping the rock and soil particles frozen in the body of the glacier. The ice to the northward was of course pushing forward but could not advance its front beyond the point where the rate of melting exceeded the rate of advance. This balance between forward movement and melting caused a continual supply of soil and rock debris to be brought up from the rear and dropped at the stationary front of the glacier. This resulted in the building up of a hummocky, irregular ridge which marked the point of farthest advance of the ice. These hummocky ridges are known as <u>terminal moraines</u> and are often several hundred feet in height. They are composed of a mixture of sand, clay, boulders, and pebbles, known as <u>till</u>. In the southern part of the State the moraines are dominantly of clay mixed with pebbles and boulders, but in the northern part of the State they are chiefly of sandy texture containing large boulders and pockets of gravel.

The farthest advance of the ice reached to southern Illinois and eastern Kentucky. The Great Lakes were the center of the glaciated region of the United States, although the ice sheet reached westward into the Dakotas and eastward into New York and the New England States. After a period in which the ice front remained stationary at these southern points the climate became sufficiently warm to cause the rate of melting to exceed the rate of forward movement. This condition resulted in the ice front retreating northward, in which case the rock and soil debris, instead of being built up as a ridge, were spread out in a sheet or plain as the ice melted back. These plains of boulder clay or till are referred to as till plains or ground moraines. Where a second balance between advance and melting is established a second balance between advance and melting is established a second moraine was formed and the process was repeated many times before the ice sheet finally withdrew. Periods of colder climate also intervened in which the ice front re-advanced and destroyed the earlier moraines and other features.

Several very prominent morainic systems were developed in Michigan and a number of smaller systems. These moraines conform in ground plan to the several ice lobes which occupied the basins of Lake Michigan, Lake Erie, and Saginaw Bay, and may be traced for hundreds of miles across the country. The outermost moraines in Michigan are found in the southwestern part of the State, the first prominent moraine being known as the Kalamazoo morainic system. The "Irish Hills" in Jackson, Hillsdale, Lenawee, and Washtenaw counties are a part of the Mississinawa Morainic system which was formed by the Huron-Erie ice lobe at about the same time the Michigan-Saginaw lobes formed the Kalamazoo and Charlotte moraines.

From the Kalamazoo moraine the ice front receded to form the Charlotte moraine which enters Michigan from Defiance, Ohio, passes north to Imlay City, swings back to Lansing, and then passes northward to near Cadillac, swinging southward again to round Lake Michigan. Following the Charlotte moraine a series of slender, closely spaced moraines were formed by the Huron, Erie, Saginaw, and Lake Michigan ice lobes. These are best developed in the Saginaw Bay region where there are about ten of these slender moraines grouped concentrically about Saginaw Bay. The next and most eastern of the moraines is the Port Huron system which passes from near Port Huron around Saginaw Bay where it was laid under water, and across the north central part of the Lower Peninsula to near Manistee. The Port Huron moraine was built up as a result of a re-advance of the ice front.

The last stand of the ice in the Lower Peninsula appears to have been near Cheboygan where there is a small, poorly defined moraine.

In the northern part of the Lower Peninsula the succession of glacial formations is not nearly so well defined as in the southern part of the State and the deposits are predominantly of sand. The glacial history in that region has undoubtedly been complicated by conditions not fully understood. In the Northern Peninsula the glacial drift is thin or absent over large portions of the area and no well defined morainic systems such as those of the Southern Peninsula have been worked out. There is a strong moraine, however, in the western part of the Upper Peninsula which forms the divide between Lake Superior and Lake Michigan. This moraine enters Michigan in Gogebic County, passes eastward through Iron and Dickinson counties, then swings southward along the Menominee River into Wisconsin. Upon recession of the ice other prominent moraines were formed in the vicinity of Keweenaw Bay. The eastern half of the Upper Peninsula was practically all covered by the waters of the glacial Great Lakes; hence the moraines are water laid and generally poorly defined.

Other Glacial Features

In addition to the moraine and till plains there are several other features formed by the ice. While the moraines were being built up at the front of the melting ice, great streams of water were flowing from the base of the glacier. These washed out various materials which are not too heavy to be transported by the water and deposited the load in front of the moraine. Since clay and silt are carried in suspension for long distances the deposits in front of the moraine are largely of sand and water-rounded pebbles or gravel. These formations are known as outwash plains and are often very extensive. The University of Michigan is located on an outwash plain. Within the moraine and on the till plain hills and knolls of sand and gravel occur. These are known as kames and appear to represent deposition in a crevice in the ice sheet or where the water was ponded so that the heavier sand and gravel was deposited, while the clay and silt were washed away. Eskers are long winding ridges of sand and gravel, located on the till plains. They have their long direction parallel to the direction of the ice movement and are believed to have been formed in tunnels beneath the ice. They are often several miles in length. The longest esker in the State has its north end at Mount Hope cemetery in Lansing and passes southward through Holt and Mason for a distance of approximately 20 miles. Other prominent eskers are located near Williamston, Webberville, Howell, and Lima. In the northern part of the State there is a prominent esker west of Alpena. This esker is about nine miles long and 60 to 75 feet in height in places. In the Upper Peninsula eskers are numerous, but generally very small in comparison with those of the Southern Peninsula, being usually less than a mile in length and 10 to 15 feet in height. Eskers are common in Menominee County and occur in some parts of Marquette and Gogebic Counties. A very prominent esker is located two miles north of Blaney, in Schoolcraft County. It is about three-quarters of a mile in length and 20 to 40 feet in height.

In Menominee County and adjoining portions of Delta and Marquette counties, and in Iron County, there are conspicuous oval hills of boulder clay which have their long axis more or less parallel to each other and to the direction of the ice movement. These are known as drumlins and they appear to have been formed through shaping by the overriding ice. A prominent drumlin area is located in the northwestern part of the Lower Peninsula in Grand Traverse, Antrim, and Charlevoix counties. A short distance north of Atwood, Antrim County, at the Charlevoix County line, U. S. 31 runs along the top of a drumlin and others can be observed on either side of the road.

Economic Importance of the Pleistocene

Agricultural and Recreational

The glacial formations are of great economic importance to the people of Michigan. The soils of the moraines and till plains are good for general farming purposes and the areas formerly covered by the glacial lakes are especially fertile. In the Upper Peninsula some of the best farming land is located in the drumlinoid area of Menominee County.

The areas of gravelly outwash often make fair farming country as the decomposition of minerals composing the pebbles gives rise to a loamy soil, but the areas of sandy outwash and sandy moraine are not adapted for farming purposes. The large areas of sandy land in northern Michigan have been of great importance, however, in producing one of the world's greatest harvests of white and Norway pine. The sandy lands of Northern Michigan with their multitude of lakes and covering of second growth timber have become one of the great recreational spots of the nation, with the result that the resort and tourist "industry" is now one of the largest in the State.

The poorly drained swamp areas are of great value in regulating the flow of streams. When cleared and drained many of these swamps have been made to yield large returns in the production of celery, onions, peppermint and other crops. The large cedar, balsam, spruce swamps of the North furnish a type of forest scenery which is very beautiful and very impressive to the tourist.

A project now under way would classify Michigan lands according to their adaptability for various uses. Certain lands would be designated as farm lands, others as forest lands, recreational areas, and so on. Governmental agencies would direct the proper uses of the lands so designated.

Sand and Gravel - Clay

Millions of dollars worth of sand and gravel have been produced from the outwash plains, kames, eskers, and old channels of glacial drainage. Some of the large centers of production in the Lower Peninsula are Oxford, Oakland County; Green Oak, Livingston County; Somerset Center and Jonesville, Hillsdale County; Tecumseh and Cement City, Lenawee County; Hersey, Osceola County; Grand Rapids, Kalamazoo, Battle Creek, and Lansing. Normally the volume of sand and gravel used for city construction is equal or greater than that used for roads, but in times of industrial depression road building supported by public funds is more important as regards use of materials than construction in cities. Clay is produced at a number of localities for the manufacture of brick and tile and portland cement.

Water Supplies

The glacial drift forms the source of water supply for most of the smaller cities, villages, and practically all of the rural population. Benton Harbor, Ypsilanti, Pontiac, Holland, Ann Arbor, and Kalamazoo are among the larger cities which derive their municipal supplies from the glacial drift. Michigan is extremely fortunate in this respect and should never lack for adequate water supplies unless a very much drier climate should develop. In some areas water can be obtained by means of shallow dug or driven wells, but in other places a deep drilled well is necessary. For a safe pure water supply the deep well is preferable. In many cases geologic conditions are suitable for obtaining flowing wells.

Thickness of the Drift

Leverett[25] states that the average thickness of the drift in the Southern Peninsula is about 300 feet. Generally it ranges from this figure down to 100 feet, but in Newaygo, Mecosta, Lake, Osceola, and Wexford counties wells have encountered from 600 to over 800 feet of glacial drift. Two wells in Austin township, Mecosta County, reported 851 and 863 feet of drift. Several miles northeast of Cadillac 884 feet were reported. In the northeast corner of Sherman township, Osceola County, the morainic hills rise to an elevation of 1710 feet above se level, the highest point in the Lower Peninsula. It is possible that the thickness of the drift at this point is more than 1000 feet.

Number of Glacial Periods

It is believed that during Pleistocene time the ice came down not once, but from three to six times, due to changes in climate. Evidences of this are found in buried soils, beds of peat, and bones of animals found between sheets of drift. The latter invasions would of course largely destroy the records of the earlier ice sheets so that the surface formations as described are those laid down by the latest or Wisconsin glacier. Exposures of blue unoxidized till believed to belong to an earlier stage of glaciation have been found at a number of localities.

In addition to the Pleistocene glaciation certain characteristics in the rocks of the Permian Period and even so far back as the Huronian indicate that there were intervals of cold climate and glaciation in those periods.

CHAPTER XIII

HISTORY OF THE GREAT LAKES (26)

Inspection of the geologic map of the Northern Peninsula (Plate I) will show that the north shores of Lakes Huron and Michigan are bordered by the Niagaran dolomites, a very resistant series of rocks which form a bold escarpment extending from New York across Ontario, turning northward to pass between Lake Huron and Georgian Bay and across the Upper Peninsula into Wisconsin between Green Bay and Lake Michigan. The geologic map also shows the belt of the Monroe-Salina group lying inside the Niagaran outcrop but the area of outcropping being limited to the St. Ignace Peninsula. It is evident that the remainder of the Monroe-Salina belt lies under Lake Michigan and Lake Huron. The diagramatic cross section of the Lower Peninsula (Plate V) shows the position of the Niagaran and Monroe-Salina outcrops more clearly.

It is believed that the basins of Lakes Michigan, Huron, and Erie were occupied previous to the Ice Age by a great river system which had its valleys largely determined by the outcrop of the resistant Niagaran limestone bordering the softer beds of the Monroe and Salina groups. The Salina we have learned contains thick beds of rock salt and the Upper Monroe contains thinner beds. It is quite probable that solution of rock salt from the beds greatly weakened the strata, made it porous and easily dissolved and broken down. The land surface was probably a thousand or more feet higher than at the present time for the valleys were cut several hundred feet below the present level of the sea. The Lake Superior basin is believed to have had a different history from that of the other lakes as it is a structural basin, the rocks dipping toward the center, which may have existed from the Pre-Cambrian times.

When the ice came down from the North it entered these basins and possibly widened and deepened them to a certain extent and advanced on to its southern terminus. The lake basins, although many hundreds of feet deep, were rather insignificant compared to an ice sheet a mile or more in thickness. When the ice began to melt back, however, it naturally became much thinner and the influence of the lake basins made itself felt in the development of the lobate form, the ice melting off the highlands first and being held in the depressions. When the ice front had reached a position near Fort Wayne, Indiana, a definite lobe lay in the valley of the present Maumee River, which, in pre-glacial times held a tributary to the great Laurentian river which occupied the basins of Lakes Michigan, Huron, and Erie. The ice then retreated to near Defiance, Ohio, and built up the Defiance moraine which is a continuation of the Charlotte moraine in Michigan. The valley from its head near Fort Wayne to the front of the glacier was filled with water from the melting ice and underground seepage. This was known as Lake Maumee, the outlet for which was past Fort Wayne down the Wabash into the Ohio. There were three stages of Lake Maumee. The second stage was brought about by a retreat of the ice which lowered the water 35 feet so that it no longer overflowed at Fort Wayne but formed an outlet northward along the edge of the ice past Imlay City into the early Lake Saginaw, which was forming in front of the Saginaw Lobe. The ice in the meantime had entirely disappeared from the interior of Michigan and a drainage channel for the Lake Saginaw waters was established down the present Maple River valley to the Grand River and down along the edge of the Lake Michigan ice lobe into the first Lake Chicago, then down the Chicago and Illinois Rivers into the Mississippi. These ancient channels of glacial drainage are plainly visible today in the form of great valleys far too large for the rivers which occupy them, as is illustrated by the Grand River Valley at Ionia.

In the third stage the waters of Lake Maumee rose 20 feet, due to a slight re-advance of the ice sheet, but not high enough to overflow at Fort Wayne. The beaches and shore features formed during the second stage were therefore partly destroyed by the rising waters. The shore line of the early lake Maumee is easily traceable from Fort Wayne, Indiana, across the Michigan line, past Adrian, Ypsilanti, and Birmingham, to Imlay City. The highest beach of Lake Maumee has an elevation of 785 feet above sea level or about 208 feet above the present level of Lake Erie.

Following the last stage of Lake Maumee the ice retreated from the Thumb and Lake Maumee merged with Lake Saginaw. This was known as Lake Arkona which formed three beaches within a vertical range of about 10 feet. The ice had melted almost entirely out of the Lake Erie basin by this time and Lake Arkona was considerably larger than the present Lake Erie. Following Lake Arkona the ice re-advanced in the Thumb region to near Port Huron and Ubly and formed the Port Huron moraine. The water level was raised 28 feet above the highest Arkona beach and Lake Whittlesey, as the resulting lake in the Erie basin is called, was connected to Lake Saginaw only by a narrow arm or drainage channel which was known as the Ubly outlet. The Lake Whittlesey beaches are very prominent ridges 10 to 15 feet in height and one-eighth mile in width in many places. Many gravel pits have been opened in these beaches for road materials. East of Cleveland, Ohio, an important highway runs along the crest of this beach.

Following Lake Whittlesey, the waters lowered to Lake Wayne which had an outlet along the edge of the Lake Ontario ice lobe to Syracuse, New York, and down the Mohawk valley to the Hudson. Great cataracts existed in the hills southeast of Syracuse at this time. A re-advance of the ice, however, closed this outlet and sent the waters back to the Grand River channel. This was known as Lake Warren, which was followed by Lake Lundy, in which the conditions were much the same as in the case of Lake Wayne except that the water was lower.

Meantime lakes in the Michigan and Superior lobe (Lake Duluth) were enlarging and a final withdrawal of the ice merged Lakes Superior, Michigan, and Erie. The history of Lakes Chicago and Duluth, while similar to that of the lakes in the Erie Basin in fluctuations of the water level, was not as complicated, owing to the fact that the shores were higher and the lakes were largely confined to the present basins with overlaps of only a few miles on each side. The enlarged lake was known as Lake Algonquin and it submerged most of the eastern half of the Upper Peninsula. Meantime the ice withdrew from the Ontario basin, forming Lake Iroquois, and Niagara Falls came into existence. Lake Algonquin found an outlet past Kirkfield, Ontario, down the Trent River valley to Lake Iroquois, and the outlet at Port Huron became dry, or nearly so, with the result that Lake Erie dropped to a lower level than at the present time. An uplift of the land in the Kirkfield region closed the Trent outlet and sent the flow back to Port Huron, but the removal of an ice barrier at North Bay, Ontario, furnished a lower outlet down the Ottawa River to the Champlain sea, as the early St. Lawrence River was called. This was known as the Lake Nipissing stage, and Lake Erie was again low, but the final removal of the ice from the region resulted in uplift in the North Bay region, sending the flow back to Port Huron, establishing the modern Great Lakes and marking the beginning of recent geologic history.

CHAPTER XIV

UPLIFT OF THE LAND AT THE END OF THE ICE AGE

The highest Maumee beach has an elevation above sea level of 785 feet at Fort Wayne, but at the Michigan-Ohio line it is 800 feet and near Imlay City 850. The Whittlesey beach is 735 to 740 feet in Ohio, reaching 800 feet at the Ubly outlet. The Algonkian beach is 607 feet in the southern part of the Lower Peninsula, but is 812 feet at Mackinac Island and 1090 feet in the Keweenaw Peninsula. Beaches of the same lake should be nearly horizontal, with but slight irregularities, so that the progressive rise to the north means that the country was gradually uplifted as the ice moved off, due possibly to the relief of the load of ice which had weighted down the land along certain lines of weakness. The lines north of which successive uplifts occurred are known as <u>hinge lines</u>. Mackinac Island constitutes an excellent record of lake history and subsequent uplift. The highest point in the island is about 320 feet above the present lake level, but all except the top 80 feet was covered by Lake Algonquin. Since that time, however, the island has been uplifted over 200 feet. The wave-cut terraces of Lakes Algonquin and Nipissing are plainly visible from Mackinaw City or St. Ignace. Arch Rock, Sugar Loaf Rock, Castle Rock, Rabbit's Back Peak, and other rock formations at Mackinac Island and St. Ignace are the result of wave erosion by Lake Algonquin.

CHAPTER XV

RECENT GEOLOGIC HISTORY

Recent history begins with the final and complete withdrawal of the ice from the North American continent. The duration of time since this occurred has been computed from the measured rate of recession of Niagara Falls from its original position at Lewiston, New York. Figures thus obtained range from 10,000 to 20,000 years. Recent geologic history is being made today, and by observing the processes now in progress on the earth the geologist theorizes on what has gone on in the past.

Economic Products of the Recent

Marl, peat, and sand are the most important products formed into deposits since the ice age. Peat bogs have already been discussed under coal. No extensive market for peat has been discovered to date but it used to some extent for fertilizer. Marl is a deposit of calcium carbonate formed in lakes and swamps. The beds are often several feet or more in thickness and are valuable for fertilizer and for the manufacture of portland cement.

The great sand dunes of Lake Michigan and the Grand Sauble Banks of Lake Superior were formed in Recent Geologic time by the prevailing southwesterly winds which pick up the sand washed in by the waves and heap it into ridges. The dunes constitute scenic playgrounds and in addition are exploited at Muskegon, Manistee, and Ludington for foundry sands and other purposes.

The most spectacular dunes are located near Sawyer, Berrien County; Glen Haven, Leelaneu County (Sleeping Bear); and near Grand Marais, Alger County.

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