Document Name:
THE GLACIAL HIST. & DEV. OF MI

Requestor's ID:
GSSTG02

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Document Comments:
Jennifer Daniels - Manuscript by S.G. Bergquist

P. 6A
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THE GLACIAL HISTORY
and
DEVELOPMENT OF MICHIGAN

(Manuscript by S.G. Bergquist)

THE GLACIAL HISTORY AND DEVELOPMENT OF MICHIGAN

Although hundreds of millions of years of marine activity were involved in laying the sediments which formed the foundational rocks out of which Michigan was developed, the actual sculpturing of the surface and the delineation of the state into a definite physical unit as we know it today was not accomplished until late in the Pleistocene or glacial epoch, - only yesterday in geologic time.

During this rather recent event, vast sheets of ice in the form of glaciers gathered in the snowfields of Canada and slowly deployed over the surface of the northern half of the North American continent burying its surface to an average depth of over 6,000 feet. There were four major centers of refrigeration and ice accumulation, and several of minor importance in North America during this epoch. One of these centers, the Labradorean, occupied the plateau east of James Bay. From this area the greatest extent of movement was to the southwest where the ice advanced 1,600 miles beyond the center. In its climax of expansion, this ice sheet extended southward to the approximate position of the Ohio River whose course was more or less definitely established along its border. Locally it advanced slightly into southern Illinois, and

Kentucky. It was this ice mass that deployed over Michigan in several invasions and was responsible for the development of its present configuration.

The Keewatin center developed on the low, flat lying plains to the west of Hudson Bay. It was the greatest of the three ice fields and in its maximum activity extended southward for a distance of 1,500 miles. The ice from this center spread southward to the position of the Missouri River, whose course was unquestionably defined along its margin.

The third center, the Cordilleran, occupied the basin-like plateau lying between the Selkirk Mountains and the Cascade Range. Its activity was confined largely to the lofty mountains of western North America with little or no movement into the surrounding lower regions.

A center of accumulation was established also in Greenland. Here the ice spilled over the borders of the continent into the surrounding areas but did not become confluent with the main ice mass of the North American Mainland.

During the climax of ice activity in the Pleistocene epoch the continental glaciers covered approximately

4,000,000 square miles of surface in North America,

2,000,000 square miles in Europe,
another 2,000,000 square miles in Asia,
5,000,000 square miles in Antarctica,
and 800,000 square miles in Greenland.

Today, the ice sheets have largely retired from North America, Europe and Asia, but Antarctica and Greenland lie still practically buried.

In spite of varied controversies regarding certain details of activity, glacialists are generally agreed that there were several invasions of the ice sheets during the Pleistocene epoch. These invasions were separated from each other by long intervals of interglacial activity during which the glaciers shrank back into the accumulation centers.

The earliest of the invasions, commonly referred to as the Nebraskan, occurred approximately a million years ago or about the time that Pithecanthropus erectus, the Ape-man of Java, came upon the scene. This glaciation was undoubtedly the most extensive as well as the most protracted of the several stages.

The Nebraskan was followed by the Aftonian interglacial stage during which the glaciers melted back to near the centers of accumulation. With the wastage of the ice from the land areas, the Nebraskan till surface became subjected to profound weathering

with the resultant development of a tenaceous, gummy soil commonly referred to as gumbotil. Leverett, in his studies of the gumbotils, has found that the old eroded Nebraskan Surface shows leaching of its calcareous content to a depth of eight and more feet.

The second invasion of the ice sheets occurred in the Kansan stage of the Pleistocene which, according to Leverett, dates back some 450,000 to 600,000 years ago. During this stage the ice reached southward as far as the northeastern part of Kansas and covered all but the marginal borders of the Nebraskan gumboltils in the region to the west of the Mississippi River. The ice of this invasion advanced from the Keewatin center and passed over Manitoba, Minnesota, Iowa and Missouri and encroached broadly on the Dakotas, Nebraska and Kansas.

Then followed another interval of deglaciation, the Yarmouth interglacial, which exposed the Kansan drift surface to pronounced weathering. Deposits of peat, and forest beds 15 feet thick lying between the Kansan and the overlying Illinoian drifts give evidence of a relatively long interval of ice removal. Gumbotils, widely exposed outside of the limits of the Illinoian drift, show leaching of calcareous material to a depth of six to eight feet. Basing his conclusions on the amount of leaching in the Kansan drift and the extent of accumulation of organic matter on the surface before the

following invasion, Leverett estimates that the duration of the Yarmouth interglacial stage was probably as long as all of the time since Illinoian. The Yarmouth interglacial dates the approximate time of the appearance of the Heidelberg man in Europe.

The third invasion, the Illinoian, occurred between 150,000 and 200,000 years ago. It was marked by a decided advance of the ice from the Labradorean center. In this activity, the ice deployed across the district of the Great Lakes, westward as far as the Mississippi and southward approximately to the line of the Ohio River. The Illinoian drift is exposed in southern Ohio and northern Kentucky where it shows leaching to a depth of two to five feet. In Michigan and Wisconsin it is almost completely buried under later drift of the Wisconsin invasion. The Illinoian drift is exposed in the bed of the Raisin River at Monroe and in numerous stream gulleys along the shore of Lake Huron in the Thumb region. Wells drilled through the glacial drift usually encounter the hard, indurated, blue clay of the Illinoian directly beneath the brownish surface till and immediately above bed rock in many portions of the state.

The Sangamon interglacial stage followed the Illinoian invasion. The Sangamon soil, composed of a dark colored gumbotil contains much organic matter and is usually buried under deposits of wind

drifted loess. The Sangamon gumbotil, ranging in thickness from three to five feet where best preserved, seems to bear evidence of having been developed under conditions which suggest a cool, damp climate.

G.F. Kay, of Iowa introduces a fourth invasional stage and calls it the Iowan. The deposits of this invasion are confined to the region west of the Mississippi River where they are composed largely of wind deposited loess which has been leached to a depth of several feet below the surface. Leverett is inclined to consider the Iowan as having been derived from an invasion of the Keewatin ice sheet and classes it as a correlative of the Illinoian. Leighton of Illinois places the Iowan in early Wisconsin.

If we accept Kay's interpretation of the so-called Iowan drift then we must give consideration to the presence of an interglacial stage, the Peorian, between the Iowan and the Wisconsin which followed. This interval was sufficiently long to allow the wind blown loess to become somewhat leached and weathered. If, on the other hand, we accept Leverett's point of view, that the Iowan is a western correlative of the Illinoian to the east of the Mississippi River, then the Sangamon interval directly precedes the invasion of the last or Wisconsin stage. This interval, whatever may be its position, represents the time of the appearance of the Neanderthal man in Europe.

GLACIAL AND INTERGLACIAL STAGES OF THE PLEISTOCENE EPOCH

Va. GLACIO-LACUSTRINE Substage.

Development of the Glacial Great Lakes.

V. WISCONSIN - 5th Invasion.

IVa. PEORIAN INTERGLACIAL. (Kay)

IV. IONAN - 4th Invasion.

IIIa. SANGAMON INTERGLACIAL

III. ILLINOIAN - 3rd Invasion (150,000-200,000 years ago)

IIa. YARMOUTH INTERGLACIAL

II. KANSAN - 2nd Invasion (450,000-600,000 years ago)

Ia. AFTONIAN INTERGLACIAL

I. NEBRASKAN (JERSEYAN) 1st Invasion (1,000,000 years ago)

The last invasion of the ice sheets from the centers of refrigeration is related to Wisconsin ice activity. In the early part of this stage the ice radiated from the Labradorean center and deployed southwestwardly across the Great Lakes region, into central Illinois and Indiana. In the later Wisconsin stage the ice from the Keewatin center deployed over Minnesota, Iowa and the Dakotas and laid down a considerable volume of gray drift which in places overlaps the brown drift of earlier date.

On the basis of the amount of weathering developed in the surface of the latest drift, Leverett estimates that the last remnants of the Wisconsin ice sheet left the southern tier of counties in Michigan not more than 35,000 years ago. By the same measure it is probable that the final vestiges of the ice were removed from the basin of Lake Superior some 10,000 years ago, or about the time that Cromagnon civilization was spreading in Europe.

Throughout the vast expanse of time which followed the removal of the Paleozoic seas from Michigan and up to the beginning of the glacial epoch about a million years ago, the exposed bed rock surface of the state was subjected to widespread and prolonged erosional activity. The pre-glacial relief was reduced to the condition of a vast peneplain scored by old rivers which had carved their valleys deeply into the rock floor. Owing to the thick cover of glacial drift which now mantles the bed rock surface it is difficult to

accurately reproduce the pre-glacial drainage expression of the Great Lakes region. Scattered deep well records, however, seem to indicate that previous to glacial activity there were a number of well defined, deeply cut river troughs following in part the lines which now are occupied by the Laurentian Great Lakes. Speculation is rife among glacialists and hydrologists as to the direction of drainage of the pre-glacial rivers. One school of investigators seems to favor a southward drainage into the Mississippi River. Another group is equally convinced that the St. Lawrence Valley was then, as now, the major line of discharge into the Atlantic. Still a third group would have the waters draining northward through some of the major waterways into Canada, with an outflow into the Artic Ocean. Much more subsurface research is necessary to conclusively prove this perplexing problem. In spite of the differences of opinion concerning pre-glacial drainage outlets, there is still a general concensus that the major lines of river development were concentrated in troughs which were aligned, at least generally, in trends parallel to the longer axes of the present basins of the larger lakes.

In the Wisconsin stage of glaciation, the Labradorean ice sheet readvanced southward across the region of the present Great Lakes. As it encountered the free drainage ways of the area, the deeper

valleys served as natural thoroughfares for ice flow. Several large lobes were thus induced in the ice front and moved forward under control of the river courses. One of the largest of the ice lobes ploughed through the valley in which the basin of Lake Michigan was eventually sculptured. This tongue is referred to as the Lake Michigan lobe and in its maximum extension it completely filled the basin and overflowed its rim. It expanded also southward beyond the site of Chicago to form the extension referred to as the Illinois lobe.

A second important tongue of ice, the Huron-Erie lobe, was directed through a series of valleys which were later sculptured into the basins of lakes Huron and Erie. A third tongue of smaller dimension was pushed out from the Huron-Erie extension into the basin of Lake Saginaw and became active as the Saginaw lobe. As this ice mass moved southward it nosed gradually out of the Saginaw drainage depression and onto the upland where it spread out as a relatively thin sheet which eventually extended into the valley of the Kankakee River in northern Indiana.

Later still, after the glacier had left the surface of the southern Peninsula, a large lobe became centered in the Lake Superior basin. To the activities of this lobe, the northern Peninsula owes most of its glaciated characters.

The Saginaw lobe was initiated in the Saginaw valley as a definite tongue extending out from the much larger Huron ice mass. In its greatest expansion during the Pleistocene epoch this body of ice reached down into the northeastern part of Indiana where evidences of its activity may be traced to a point somewhat south of South Bend. The Saginaw lobe moved through and beyond the present Saginaw Bay and, in the climax of its development, was confined between the Michigan and Huron-Erie lobes with which it coalesced during the culmination of the Wisconsin stage.

A study of the morainic systems distributed over the surface of northern Indiana and southern Michigan, seems to point to the fact that the ice of the Saginaw lobe melted back from the basin of the Kankakee River, disappeared completely from northern Indiana and withdrew into southern Michigan, while the Michigan and Huron-Erie lobes still filled to overflowing their respective basins.

According to Leverett, the more rapid retreat of the Saginaw lobe may be accounted for in several ways. In the first place, after the ice had passed through the immediate basin of Saginaw Bay it pushed up onto the upland and continued to move across more

elevated country. In the meantime, the Michigan and Huron-Erie lobes were definitely keeled in deeply scored basins which directed their movement and thus allowed far greater thickening of the ice masses. The Saginaw ice, by virtue of its upland position, was restricted in its ability to thicken and hence moved across the surface as a relatively thin sheet.

Until the Saginaw ice began to melt back in the early Wisconsin stage, the three lobes were welded into a more or less undifferentiated mass. The early retreat of the ice in this tongue, however, allowed the various lobes to acquire distinctive and individual characters. Secondly, it appears that the Saginaw lobe because of its thinner ice was not able to transport as large a load of drift at the bordering basin filled lobes, a factor which was doubtlessly inducive to faster melting. Clean ice, or ice containing a small amount of drift material, melts faster than dirty ice where the included debris acts in the capacity to promote thermal insolation.

SUCCESSIVE ICE FRONT POSITIONS MARKED BY MORAINES

The various stops made by the Saginaw lobe as it retreated across Michigan are evidenced by a succession of more or less parallel moraines which form festoons of ridges of glacial drift closing in on Saginaw Bay from the south. The earliest of these ridges to be

formed in southern Michigan is represented by the Sturgis moraine which passes through Sturgis. When the Saginaw ice front was building this moraine a very small portion of Michigan, including four or five townships in St. Joseph and Cass counties, was all that was uncovered. It has been established on good authority that the Sturgis moraine was constructed not more than 35,000 years ago.

When the retreating Saginaw ice front finally came to rest on the position of the Kalamazoo moraine, it halted for an interval sufficiently long to build up an extensive ridge. This moraine, extends from near Hastings south and eastwardly through Marshall, and thence to Devils Lake in Lenawee county where it connects up with the Mississinawa moraine which outlines the outermost position of the Erie lobe in southeastern Michigan. On the west side of the state, a limb of the Kalamazoo moraine, extending from Hastings southward through Kalamazoo and Cassopolis marks the eastern margin of the Lake Michigan lobe.

Renewed melting in the Saginaw lobe caused the ice front to recede to the position of the Charlotte moraine. This ridge may be traced from near Milford in Oakland county westward through Brighton, Mason and Charlotte to the vicinity of Grand Rapids were it ties in with another morainic system, the Valparaiso,

which was formed along the edge of the retreating Michigan lobe. On the east side of the state near Pontiac, the Charlotte moraine connects with the Fort Wayne-Wabash morainic systems which were formed at the same time by the Huron-Erie lobes.

Following the formation of the Charlotte moraine and it correlatives, the Valparaiso and Fort Wayne-Wabash morainic systems, the ice along all fronts began another decided retreat. The next important stop of the Lake Michigan lobe and the final one made by it south of Manistee, before it retreated into the Lake Michigan basin, is marked by the Lake Border morainic system, the low ridges of which follow closely the margin of the lake. The West Branch and Gladwin moraines north of the Grand River valley thread out into a group of slender moraines to the south of the river and are correlative with the Lake Border moraine. They mark the changing position of the Saginaw ice front during this stage.

Named in order of development from the vicinity of Lansing northward, the moraines of the deployed slender group are: Lansing, Grand Ledge, Ionia, Portland, Lyons, Fowler, St. Johns, Flint, and Owosso. They are arranged in more or less concentric bands around Saginaw Bay and mark positions of successive halts of the Saginaw lobe as it back stepped into the Bay. The Huron-Erie correlative

of the Lake Border moraine includes the Defiance, Birmingham, Mt. Clemens and Emmett ridges which lie scattered through the lake plain area north of Detroit.

A further retreat and subsequent long halt of the Michigan and Saginaw-Huron lobes was responsible for the construction of the Port Huron Morainic system. This is one of the strongest and most persistent systems in Michigan and was formed during a rather long interval when the ice fronts remained more or less stationary. It may be traced from near Port Huron into the Saginaw Bay region and then north and westwardly across the state into the Grand Traverse Bay county. The last stand of the ice in the southern Peninsula, before it retreated into the Straits of Mackinac, is marked by the slender ridges of the Cheboygan moraine which follows the shore of Lake Huron from Cheboygan to Mackinaw City.

The various glacial features expressed in the surface of the northern Peninsula were formed in large part by the activities of the extensive lobe which was centered in the basin of Lake Superior. This mass of ice was directed into the basin, along the course of a pre-glacial valley, from the northeast. In its maximum extension the ice spread out beyond the rim of the basin and covered the greater portion of the northern Peninsula. Upon retreat by melting, the Superior lobe left in its wake a series of moraines which mark the position of the ice front during successive halts.

By the time the Superior basin was completely freed of ice and the Labradorean sheet had retired to the uplands in Canada, a great lake of glacial waters spread out in front of it to form Lake Algonquin. In its greatest development this lake covered most of the eastern half of the northern Peninsula and inundated or flooded completely all but the highest morainic ridges of the glacial surface. The last vestiges of Pleistocene ice left the Superior basin about 10,000 years ago. Since then the Pleistocene ice sheets have completely disappeared from the continent.

RECORDS OF GLACIATION

In its retreat across Michigan the continental glacier left many records which geologists have learned to interpret and by means of which important events may be read. The vast amount of rock debris carried by the ice was deposited in the form of glacial drift when, during intervals of warming climates, the ice front was forced to melt. However, much of the drift, dumped directly out of the ice, was never sorted by the activities of water. This material, devoid of stratification and consisting of an admixture of clay, silt, and sand, with variable amounts of gravel, cobble and boulders, is commonly referred to as boulder clay or "till". The melt waters issuing from the waning ice front, carried out a great deal of sediment which was subsequently sorted into various sizes such as cobble,

gravel, pebble, sand, silt and clay. This material was deposited in layers or stratified beds in river ways, in ponded basins, and in lakes to form what the geologist calls glacio-fluvial and glacio-lacustrine formations.

The bed rock surface of Michigan is largely mantled with glacial drift whose thickness varies from merely a few inches where the rock structures are high to a maximum of twelve hundred feet in the region of high moraines about six miles southeast of Cadillac. It is estimated that the average thickness of glacial deposits over the entire state is somewhere in the vicinity of three hundred feet. Because of the almost universal cover of drift, rock outcrops are relatively scarce, and somewhat scattered. They occur for the most part in belted arrangement along the borders of the state where the rims of the various rock platters mark the shores of former ocean basins. Bed rock is exposed also in certain areas where rivers have succeeded in cutting their valleys through the mantle of glacial debris.

UNSTRATIFIED GLACIAL DEPOSITS

The features formed by dumping of unstratified drift or till when the ice retreated may be classed as moraines, till plains and drumlins. These formations can be recognized in the field by distinctive

characteristics which are easily identified.

MORAINES are long lines of ridges and festoons of hills composed essentially of boulder-clay or till which was dumped from the ice front during relatively long intervals when the backward melting was equal to the forward advance. The rock debris which the ice had scooped off the land in its steady push out from the various centers was piled up along the more or less stationary glacier fronts. Moraines mark the borders of the ice lobes and are characterized by rugged topography and often high relief. The bulkiness of the ridges was determined largely by the amount of material that was available for deposition and also upon the length of time that the ice front remained stationary.

Frequently, in the construction of the morainic areas, blocks of ice broken off from the ice front were temporarily buried under glacial debris. When these blocks finally melted they left depressions in the moraines which became filled with water to form so-called "kettles". Where basins of this type are abundantly scattered through the morainal areas as is the case in the famous Irish Hills south and east of Jackson, the topography is usually described as kettle morainic.

In certain areas, were several ice fronts combined their activities to build up interlobate tracts, the morainic features are

strongly developed and the resulting topography is unusually rough. The excessive melt water contributed from the adjacent ice masses swirled into the depressions of the moraines and sorted out the material to form knobs or "kames" of rudely stratified gravel and sand.

The Irish Hills near Jackson are an example of this type of interlobate moraine formed at the juncture of the Erie-Saginaw lobes. The morainic topography near Pontiac was formed between the Huron-Saginaw ice fronts. The high hills, both north and south of Grand Rapids, were developed by the combined depositional activities of the Michigan and Saginaw lobes while the rugged hills through the region of Clare, Grayling and Gaylord were formed by the Huron and Michigan lobes working together. In all of these areas, kettle lakes, dry basins, and kamic knobs are very prominent features of the landscape.

TILL PLAINS are level to gently undulating plains of unstratified boulder-clay spread out behind the moraines. They were formed when the ice front retreated rapidly from the position of one moraine to the next, and there uncovering the drift floor over which it had advanced. Where these till plains have not been reburied under subsequent glacial outwash, they are commonly referred to as areas of ground moraine. They are constructed largely of unsorted

clay and sand and usually carry an abundance of scattered boulders which are called erratics. They constitute some of the finest agricultural land in the state and because of the smooth character of surface they are easily worked.

DRUMLINS are roughly cigar-shaped ridges developed in areas where the ice readvanced over previously formed till plains. They are elongate in the direction of ice movement and usually have a front or "stoss" slope at the head end which is somewhat steeper than the lee end slope. Because drumlins were sculptured out of ground moraines they are composed of the same type of clayey till material. As a rule, the ridges are arranged in more or less parallel series and are separated from each other by sags or troughs which are usually poorly drained and swampy in character.

There are a number of areas in the southern Peninsula where drumlins constitute the predominant features of the landscape. A section of small drumlins is located in the till plain region of Climax and Union City just outside the Tekonsha moraine. In the lake plain north and slightly west of Alpena is an area of scattered drumlins which was worked over by waters of a former lake. A series of parallel ridges east of Onaway in Presque Isle County has recently been identified as drumlins. One of the most pronounced drumlin areas in the southern Peninsula is associated with the extensive till plain that extends through Antrim and Charlevoix counties

between Little Traverse and Grand Traverse Bays. Along the eastern edge of this plain, near Ellsworth, the ridges have their underpinnings in shale.

In the northern Peninsula, drumlins make up the greater portion of the surface terrain in Menominee County. They are scattered also in the till plain area extending through Iron River and Crystal Falls in Iron County.

No satisfactory explanation has as yet been worked out to account fully for the origin of drumlins. Geologists have accepted the viewpoint, however, that these features were sculptured by active ice which pushed its way over till plain deposits during intervals of readvance.

STRATIFIED GLACIAL DEPOSITS

Features formed by activities of glacial melt water flowing out from the melting ice sheets may be classified into outwash plains, valley trains, eskers and kames. These deposits are composed of material that was carried along, worked over, sorted, and spread out by water, hence they are stratified or layered.

OUTWASH OR OVERWASH PLAINS are level to gently undulating plains composed of sorted and stratified gravel, sand and clay which were spread out over till plains by rivers flowing from the edge of

the melting glacier. They usually rest upon till and are associated in origin with the moraines in front of which they were constructed.

Outwash plains are readily differentiated from till plain features, which they so often resemble, by the character and structure of the material contained. Till plains are composed of till of all sizes even up to large rounded rocks called boulders while outwash plains contain stratified beds of gravel and finer material which is normally boulder free. In the building of outwash plains, however, there was often not sufficient material carried out to completely cover the till plain floor. In such cases boulders from the underlying till plain may protrude into the outwash surface. Again, during the building of the overwash apron, the ice front may have held its position for such a short interval of time as to limit the amount of sedimentation and only a thin veneer of sand and gravel was spread out over the till. Hence the outwash surface may reflect the topography and features of the underlying till plain.

In the process of building up the outwash, ice bergs broken off from the front of the ice resting on the moraine were often carried out into the waters where sedimentation was in progress. Some of these ice blocks became buried under subsequent sediments which prevented their rapid melting. Eventually, however, the debris-covered blocks melted out and left basins which have since been filled up with water to form "pit" lakes. Houghton Lake, the largest inland lake in the state, is an example of such a development. The outwash plain

in which Gull Lake, north of Kalamazoo, is located, is pitted with depressions formed in a similar manner, some of which are now swamp filled or even dry basins.

VALLEY TRAINS are strings of stratified gravel and sand formed in the former spillways and drainage channels which extended out from and along the borders of the ice in places. They are similar to outwash plains in character of material and structure but are usually quite limited in their extent. Many old pre-glacial valleys in the western half of the northern Peninsula were either wholly or partially filled up with valley train deposits carried out from the melting ice front. Like the overwash aprons, these features are important sources for supply of gravel and sand used in highway and general concrete construction.

ESKERS are long, narrow, winding ridges composed of stratified gravel, sand and silt. They are quite generally scattered through the state and furnish a source of the aggregates employed in highway and other construction. In many places eskers are incorrectly called "hogs backs" and "Indian Trails".

The problem involving the origin of eskers is somewhat controversial. Several theories have been advanced to account for the development of the ridges but none seem to fulfill all the requirements necessary to explain adequately the process. The text book explanation

commonly used considers eskers as having been formed by deposition of gravel and sand in subsurface river tunnels in or under the glacier. The mouths of the tunnels became choked with debris causing back water ponding and subsequent sedimentation in the channel. Another theory proposes that eskers are merely chains of kames formed in ice reentrants out of material carried through cracks by melt water and deposited in front of the ice sheet. Upon melting of the ice a succession of kames were built up and eventually became strung together in the form of a winding ridge like a series of beads on a string.

ESKERS are usually found on till plains although some are known to cut through moraines. They vary in length from a fraction of a mile to scores of miles and in height up to several hundred and more feet. The longest esker in Michigan is the so-called Mason esker which may be traced from near south Lansing for a distance of some twenty miles through Holt and slightly beyond Mason. It is confined largely to the extensive till plain that lies between the Lansing and Charlotte moraines. Eskers occupy areas of till plain that were formed under stagnant ice.

KAMES are rudely stratified deposits of cobble, gravel, sand and silt which were sorted out of the ice by rapidly swirling waters whose activity was concentrated largely in depressions or plunge basins where melt waters flowing over the surface of the glacier plunged

over the ice front on to the accumulating moraine. They are recognized by their "knob-like" structure and by their common occurrence in areas of interlobate moraines. It is not surprising that kames should abound in regions where several ice fronts were retreating simultaneously because it was here that pockets were most readily formed to supply the environment in which an excessive supply of melt waters had an opportunity to churn up and deposit the material.

Kames are scattered in various type of moraines and occur frequently in areas of till plains as well. In certain regions of till plains developed under conditions of ice stagnation series of kames were tied into extended chains to form eskers as previously explained.

It would be futile to attempt to list the many localities in Michigan where kames are found. One of the finest examples of this type of feature is located in the vicinity of Howell where it furnishes the site upon which the Sanatorium is located. The gravelly knobs which surmount the morainic hills in the region of Somerset Center, south and east of Jackson, are also kamic in character.

THE HISTORY OF THE GREAT LAKES DATES BACK TO THE GLACIAL EPOCH

The most recent chapter of Michigan geology was written during

the last tick of the geological time clock and records the events which led to the formation and development of the Great Lakes. Michigan is situated in the plexus of ice activities which were responsible for the initiation and subsequent changes which marked the progress of growth of the lakes. As has been previously mentioned, the Great Lakes basins occupy the sites of pre-glacial rivers, and came into existence during the late Wisconsin stage of the Pleistocene epoch. The present Great Lakes which now drain through the Niagara River and the St. Lawrence are the product of a series of changes and adjustments that took place during the brief interval when the Labradorean ice sheet made its final retreat across the region. It is not certain that the Great Lakes as we know them today will continue to retain their present characters of outline and drainage. If, as many glacialists believe, we are now living in the interglacial stage similar to those of the past which mark merely brief interludes of recession between successive advances, it is quite probable that another refrigeration or cooling of climate may cause renewed invasions of ice in the not too distant future.

No story of the glacial history of the state would be complete without giving some consideration to the development of the Great Lakes. As has already

been stated, the Great Lakes basin occupy the sites of pre-glacial rivers. Into these old and established drainage depressions the continental ice mass sent out its various tongues or lobes whose movement was responsible for deepening and scouring of the valleys into broad troughs.

The Great Lakes had their inception when the margins of the ice sheet retreated by melting across the higher land and in recessive temporary halts built up a succession of terminal moraines. Melt waters coming out from the withdrawing ice borders were prevented from flowing across the natural morainic barriers and hence accumulated in basins between them and the ice front. The basins of melt water accumulation increased in size as the oscillating ice front melted farther and farther back toward the centers of radiation. They attained their normal size only after the ice lobes had completely withdrawn from the basins and drainage adjustments had become fully established.

LAKE MAUMEE

The first lake to develop was related to the withdrawal of the ice front of the Erie lobe from the position of the Fort Wayne moraine. This lake had its early inception in the Maumee basin or northwestern Ohio and neighboring parts of Indiana and is

referred to as Lake Maumee. According to Leverett, this lake came into existence about 30,000 years ago. In its early stages, the lake was confined to a small basin situated between the Fort Wayne moraine and the ice front then standing on the Defiance moraine. The water level of this early basin stood at an altitude of 785 feet or 212 feet above the level of the present Lake Erie. The drainage outlet was through a col in the moraine past Fort Wayne, into the Wabash River and thence south into the Mississippi. A narrow arm of this early lake extended along the border of the ice to the vicinity of Ypsilanti where a remnant of the shore may be traced along Summit Street at an elevation of approximately 800 feet above sea level.

In its early stages, Lake Maumee occupied a relatively small depression, but as the glacier oscillated in retreat the basin was progressively enlarged with the result that the water level was forced to drop. When the area on the "Thumb" near Imlay City was finally uncovered, the waters of the expanded lake found a new outlet through the Imlay channel, at an elevation of 750 feet. From the Imlay channel the drainage water was carried westward down the Flint River valley past Flint and finally into the Grand River near Lyons. Thence by this drainage way, it flowed into an embayment of Chicago, the predecessor of Lake Michigan, near the present site of Grand Rapids.

During the Imlay outlet stage of Lake Maumee, the ice border rested on the Flint-Owosso-Mayville moraines. When the ice of the Saginaw lobe finally melted back into the Saginaw basin sufficiently far to expose a land surface with a general slope toward it, lake waters accumulated to form early Lake Saginaw. This lake found an outlet through Maple River near Maple Rapids from whence it discharged its waters into the Grand River at Lyons and thus westward across the state to Lake Chicago. Shore features in the early Saginaw lake plain show the Maple River outlet to have stood at an elevation of 710 feet or 40 feet below the Imlay outlet of Lake Maumee.

LAKE ARKONA

Lake Arkona came into existence when the ice front withdrew altogether from the "Thumb" of Michigan. When the ice margin had retreated to a position some 25 miles north of Bad Axe, the waters of the expanded lakes fell to the level of Lake Saginaw and gradually merged with it. The drainage waters of the lake went around the "Thumb" and found an outlet through the Maple River into the Grand River. The highest beach of Lake Arkona stands at an elevation of 710 feet at the outlet. Due to cutting in the Grand River channel the water plane was lowered to 694 feet.

Lake Arkona was of short duration. A readvance of the ice over the "Thumb" soon separated the waters of Lakes Arkona and Saginaw, raised the level of the water in the Erie basin to initiate glacial Lake Whittlesey.

LAKE WHITTLESEY

During this stage the ice front maintained a temporary position on the main moraine of the Port Huron system. The section between Vassar and Bentley stood in 50 feet of water. The Erie-Ontario lobe was separated from the Huron lobe by an island of exposed land some fifty miles or more across.

The waters of Lake Whittlesey discharged through the Black River embayment along the outer border of the Port Huron moraine and found an outlet near the village of Ubly. From here the drainage was directed into independent Lake Saginaw where it eventually found its way out to the Grand River by way of Maple River. The highest beaches of Lake Whittlesey stand at an elevation of 740 feet. Before the close of this stage, however, the Maple River channel was deepened by scouring to drop the level to 735 feet.

Lake Chicago, an independent correlative lake in the south end of the Michigan basin, was rather small. The ice still filled the Superior basin but had started to melt slightly in the vicinity

of Duluth. Small fingers of ice extending out from the Ontario lobe in New York, found their way into river valleys which were gradually sculptured into Finger Lakes. These had an independent drainage southward through the Susquehanna River into the Atlantic.

During the Whittlesey stage, at a level of 740 and 735 feet, the lake was too low to maintain the outlet at Imlay. It was forced to find a new passage through the Black River embayment on the outside of the Port Huron moraine. The Ubly outlet in the northern part of the "Thumb" district was opened up with a direct connection into Cass River. The waters of the lake were thus carried into Lake Saginaw where they eventually discharged through the Maple River and then into the Grand to Lake Chicago.

The water of Lake Whittlesey was maintained at the level of the Ubly outlet only while the ice front rested on the Port Huron moraine. That the ice maintained this position for a relatively long interval, is manifested by the strong beaches and distinct shore features which may be traced for miles along the Lake Huron side of the "Thumb" in eastern Michigan. When the glacier retreated beyond the "Thumb" the lake level dropped to a plane so low that the Ubly outlet could no longer function.

LAKE WAYNE

Lake Wayne followed Whittlesey. It formed when the ice of the Ontario lobe in the east melted back to uncover a portion of the Mohawk valley. The Ubly outlet was abandoned and the drainage of

the lake was directed eastward along the edge of the ice past Syracuse, New York, and into the Mohawk to the Hudson River. During this stage, the Finger Lakes of New York were also connected up with the main line of drainage. This is the first occasion in the history of the Great Lakes that the drainage was eastward and the Grand River was not utilized for discharge. A slight readvance of the ice in the east, however, soon blocked the Mohawk outlet and brought the Wayne stage to a close. The water plane of this lake was maintained at a level of 650 feet or 90 feet below the level of the preceding lake.

LAKE WARREN

Lake Warren which followed was formed when the ice barrier stood slightly north of Alpena in Michigan and south of Rochester in New York. Its waters merged with those in the Saginaw basin and gradually expanded to include the water in the Huron-Erie basin as well. The discharge was around the "Thumb", into Lake Saginaw and out through the Maple River. Thence it flowed westward by way of the Grand River drainage line to Lake Chicago. In the area not affected by differential uplift, the warren beach stands at 670 to 680 feet above sea level or merely a few feet higher than the outlet.

LAKE ELKTON (LUNDY)

Lake Elkton which followed Lake Warren was relatively short lived and merely transitional to the succeeding stage Algonquin. In this stage the ice barrier had retreated to a position north of Alpena in Michigan and rested between the Niagara escarpment and Lake Ontario in the region of Niagara. The outlet was similar to that of the Wayne stage. The ice in the east had retreated northward sufficiently far to again open the Mohawk outlet and the drainage was discharged in the direction of the Hudson River. Owing to the opening of a lower outlet, the lake level dropped to between 620 and 640 feet. Later, with the complete withdrawal of the ice sheet from the lowland area south of Lake Ontario, the waters of Lake Elkton were drawn down to a level which allowed Niagara Falls to come into operation. This is the first evidence of discharge through this route.

LAKE ALGONQUIN

The last of the glacial lakes is known as the Algonquin. This stage followed Elkton and represents the greatest expansion of water in the development of the Great Lakes. The various lakes in the different basins were merged into one vast body of water. In the culmination of this stage, the lake extended northward to include the Nipigon basin in Canada. In the eastern lowlands of

the northern Peninsula all but a few small islands were submerged. It was during this stage that the Straits of Mackinac were finally opened up to connect the lakes in the Superior, Huron and Michigan basins.

The Algonquin Lake history passed through several changes in drainage due to differential uplifts which were then in progress. An early outlet of Lake Algonquin was opened up at Kirkfield soon after the ice had withdrawn from the superior basin. The discharge was then carried from Georgian Bay through the Trent Valley to the Ontario basin. As differential uplifts continued, the Kirkfield outlet was raised so high that it soon became abandoned. For a short interval following the closing of the Kirkfield outlet, the discharge of the lake was divided more or less between lower outlets at Chicago and Port Huron respectively. At Chicago, the outlet encountered a sill of resistant limestone which effectively slowed up the process of downcutting. At Port Huron, the drainage waters passed through an area of less resistant clayey material which was readily eroded. Consequently, the Port Huron outlet was soon lowered to the point where the level of the lake was brought below the Chicago outlet and the discharge was diverted wholly into the Port Huron line of drainage.

Throughout the different intervals of Lake Algonquin history, variable volumes of water flowed across the Niagara Falls. At first,

in the Kirkfield outlet phase, the Niagara River carried only the discharge of Lake Erie, amounting to about 15 percent of the present volume. Finally, as the Port Huron outlet assumed control of the drainage, a full volume of flow by this route resulted. The effects of the changes in Lake Algonquin drainage are readily observed in the gorge of the Niagara River in the section between Lewiston on the original escarpment and the whirlpool.

In the area of horizontality to the south of the hinge line which crosses the state approximately from Port Huron to Manistee, the beaches of higher Lake Algonquin stand at a plane of 607 feet. At Kirkfield the shore features find expression at an altitude of 883 feet which means that in the distance from Port Huron to Kirkfield, the land has been raised 276 feet by differential uplift. Farther to the north, in the region of Georgian Bay, and the north shore of Lake Superior, the region was raised by at least 600 to 700 feet. In the high morainic hills south of Munising, the highest Algonquin shore is found at an altitude of 948 feet above sea level while a few miles south of Grand Marais, the morainic bluffs show evidences of Algonquin shore work to an elevation of 890 feet. In the latter place, however, the successive lower Algonquin beaches can readily be traced and show definitely the progressive changes in lake level which have taken place.

LAKE NIPISSING

When the glaciers had retreated to the northward well beyond the border of the Superior basin, the land was raised to the point where the Kirkfield outlet was permanently closed. A new and lower outlet was opened up at North Bay with discharge into the St. Lawrence by way of the Ottawa River. Thus was initiated the post-glacial Nipissing stage of lake history.

The Nipissing Great Lakes occupied the basin of Lakes Huron, Michigan and Superior. Its shore is well formed and may be easily traced along beaches which stand at an altitude of 595 feet. Continued uplift of the land to the north of the hinge line eventually raised the North Bay outlet sufficiently high to close it to further discharge. The water was then directed southward into the St. Clair and Port Huron outlets and the present lake stage with its drainage through the Niagara and St. Lawrence Rivers was introduced. In this stage, Michigan attained her present physiographic complexion.

During the interval of maximum invasion, the millions of cubic miles of ice resting upon the surface of the continent exerted a tremendous weight upon the rock formations below. This pressure was sufficient to cause an isostatic depression of the entire Laurentian plateau with an ultimate downwarping estimated at 800 to 900 feet in the region north of Lake Superior. The downwarping

of the continental block allowed marine water of the Atlantic to invade the Hudson and St. Lawrence Valleys and inundate the basin of Lake Champlain and the upper end of Lake Ontario. This inundation, commonly referred to as the Champlain Marine stage, was responsible for the deposition of a series of clays which contain a small but characteristic sub-arctic fauna. The recent discovery by Dr. E.C. Case, of partial skeletons of two whales in the bogs overlying glacial deposits along the Huron shore in Michigan would suggest a possible open route of migration from the ocean to the fresh water lakes.

The final removal of the vast sheet of continental ice and the consequent release of pressure due to melting has allowed the depressed region to partially recover its original attitude. Differential uplift, which began possibly with the first recession of ice in the Wisconsin stage, is still in progress--a fact which seems to bear out the conclusion that the recovery has not been completed. At present, the land is rising at a rate of 10 inches per hundred years, or one-tenth of an inch per year for each hundred miles of distance to the north of the Algonquin hinge line.

The effect of the continued uplifts has been to tilt, and in some places to split, the beaches of the Algonquin and Nipissing Lakes. The amount of tilting to which Michigan has been subjected since

the Algonquin Lake stage may be readily measured by comparing the present altitudes of its beaches in various localities. In the area of horizontality near Manistee on Lake Michigan, the highest Algonquin shore stands at 607 feet. Six miles to the north of the Canadian Soo, the same shore is found at 1015 feet. At Port Huron, on the east side of the state, the highest Algonquin beach stands at an altitude of 606 feet. On Mackinac Island, in the Straits, the same beach rises to 809 feet.

The Nipissing beaches likewise show the affects of differential uplift, but on a much smaller scale. In the area of horizontality near Manistee, the Nipissing shore has an elevation of 595 feet. At Sault Ste. Marie, the same shore stands at 651 feet--which evidences an uplift of 56 feet in a distance of 160 miles. At Port Huron, the altitude of the Nipissing beach is 595 feet, while at Cheboygan it is 31 feet higher, or 626 feet.

NIAGARA FALLS IN RELATION TO LAKE HISTORY

The history of Niagara Falls dates back to the later portion of the Elkton lake stage when an outlet was uncovered at Rome, New York. During the early development of Lake Algonquin, the Niagara River carried a discharge of about 25 percent of the present volume of water. The gorge was cut for a distance of 2,000 feet from the suspension bridge at Queenstown.

The second section of the gorge extends from the south end of the first section for a distance of one and one eighth miles to the bend at Niagara University. This section is remarkably straight and uniformly wide and deep. It was cut during the Kirkfield outlet phase of the Algonquin stage when about 15 percent of the present volume discharged over this route.

The third section, or lower great gorge, extends from the bend of the river at Niagara University for a distance of two miles to the upper end of the Eddy Basin. it does not include the Whirlpool proper, however.

When the Kirkfield outlet was closed, due to differential uplift, the discharge of the upper lakes was sent down past Port Huron, increasing the volume of Niagara Falls about seven-fold. The same uplift raised the outlet at Rome, New York, and backed the water up to the level of the Iroquois beach about 125 feet higher than Lake Ontario. The cataract at this stage tumbled into deep water, which limited the depth to which the falls were scoured.

The fourth or Whirlpool Rapids Gorge section extends from the south end of the Eddy Basin for a distance of three-fourths of a mile to the expansion in the river just above the railroad bridges. This section was cut during the Nipissing stage of lake history,

when the falls carried only the discharge from Lake Erie.

The fifth section which includes the upper great gorge extends from the point of widening of the river just above the railroad bridges up to the Horseshoe Falls, a distance of two and one quarter miles. This section has been cut during the present lake stage, with a full discharge of the upper four lakes passing over Niagara Falls.

LAKE PLAINS MARK SITES OF FORMER INUNDATIONS

In the various changes resulting from differential uplift and retreat of the several ice lobes new and lower outlets were opened up in the basins. With each successive fluctuation in the position of the outlet there was a corresponding change in the water level of the lakes thus developed. The effects of these shifts in level are well marked in the sites previously occupied by water. Extensive areas of level lake bed are distributed over the surface. For the most part, these plains lie close to the present margins of the state but may extend inland for considerable distance where glacial lake inundations were widespread.

The old lake beds are made up of material with a rather wide range of composition. Areas of heavy clay are interspersed with stretches of water washed sand and gravel. Locally, sand and clay have become

intermixed to form patches of good loam soil. In certain areas where fluctuations in water level were pronounced, the lake plains assume the form of terraces which are separated from each other by well defined shore cliffs formed by wave erosion. In other localities, where the water level dropped slowly, the shores are marked by lines of wave-built deposits and bars of sand and gravel.

Lacustrine or lake plains, on a large scale, are now exposed far inland along the borders of Lakes Erie and Huron. Broad expanses of level land in the Saginaw basin were formed under waters which but a short time ago receded from the surface. Many embayments scattered along the shore of Lake Michigan are filled in with stratified gravels and sand deposited in the waters of Lake Chicago as it gradually adjusted itself to the present drainage facilities.

The expansive tracts of marshy lowlands now lying in the watershed areas of the Tahquamenon and Manistique rivers in the northern Peninsula mark the floor of the lake whose water overflowed the basin of Lake Superior during the Algonquin stage. Those who have traveled across the level plain from Seney to Shingleton are familiar with the general character of this broad, level plain.

The city of Munising is located on the plain of an embayment of Lake Nipissing whose south shore was confined by the high bluff of the Munising Moraine.

SAND DUNES

Sand dunes are widely dispersed along the shores of the various lakes which surround Michigan. They make up prominent features of the landscape along the older shores as well as those which now bound the state. The most extensive dunes in the Great Lakes region are distributed along Lake Michigan where they may be traced in almost continuous succession from the Indiana line northward beyond Petoskey.

Many of the larger dunes which line the present shore of Lake Michigan were formed on terraces developed by the ancestral lakes which stood somewhat higher than the present level. Fore dune ridges which flank the windward slopes of these older dunes have been blown up from sand deposited on the more recently formed beaches of the modern lake.

The dunes are composed of wave washed sand that was spread out upon the beaches of the various lakes and blown inland by prevailing winds which moved across Lake Michigan from a generally southwest direction. They are characterized by windward slopes which are gentle and leeward slopes much steeper. In many of the dunes along the west coast of the state, the windward slopes have been greatly modified by wind erosion with the result that

large blowouts are prominent. Old Baldhead near Saugatuck and Rosy Mound south of Grand Haven are examples of the blow-out type.

Some of the dunes, perched high above the level of the present lake, were formed upon bars which since have been raised by uplift. Sleeping Bear near Glen Lake, one of the most famous dunes in the state, is composed of a 125 foot pile of sand perched on the Manistee moraine whose surface stands about 350 feet above the level of Lake Michigan.

It is significant to note that the dunes along Lake Michigan are situated only in those areas where sandy beaches and embayments are present. They are unusually well developed along those sites where rivers empty into the lake. It is quite probable that the larger streams which flow across the uplands have contributed a great deal of sediment which from time to time has been worked over by the waves and processed into material sufficiently fine for the wind to handle. Dunes are conspicuously absent in those tracts where heavy clay ridges of moraines border the lake.

The line of dunes which stretches across the head of Little Traverse Bay from near Petoskey to Harbor Springs in Emmet county in superposed upon a bar which closed the outlet of an old drainage way that extended westward from Cheboygan during the Nipissing Lake stage. The building of the bar and the consequent construction

of the dune upon it were responsible for damming of the drainage way and the ponding of waters into the deeper depressions to form Burt and Mullet Lakes.

Dunes are widely distributed also along the Lake Michigan shore of the northern Peninsula. In the region of Manistique the main row of dunes may be traced to the base of the Nipissing bluff just east of the city. These dunes were formed out of sand blown up from the beach of Lake Nipissing and may definitely be correlated with that stage of lake history.

On the Superior shore of the northern Peninsula there are dunes which range in age from Algonquin to present. The most extensive pile of sand in this area is to be found in the Grand Sable dunes, a few miles west of Grand Marais in Alger County. The dunes in this region are perched upon a gravelly bar that was deposited in an embayment of Lake Algonquin. The sand which comprises the dunes was whipped up from a beach that stood five feet higher than the present level of Lake Superior. Differential uplifts have raised the bar and its perched dunes about 283 feet to the present elevation of 890 feet. The construction of the bar and the development of the dunes upon it were responsible for cutting off the waters of the embayment to form Sable Lake.

Sand dunes are widely scattered over the old Saginaw lake plain and also on the higher terraces along the Huron shore. Thousands of dune ridges are spread out over the Algonquin plain of the Tahquamenon-Manistee drainage basin. Most of these dunes were formed along the shores of retreating lakes and mark the position of the water level during successive temporary halts while drainage adjustments were being established.

The sand in many of the dunes, especially on the west coast of Michigan, is now being moved inland by the winds which blow across the lake. In the process of transportation, arable land is being covered with sand in places and transformed into barren waste lands. Man, in his meager attempts to control wind erosion and transportation, has constructed artificial barriers to reduce the turbulent activity of the wind. Plantings of beach grass and trees have recently been made in an effort to hold the sand in place and to prevent its widespread movement from the dune areas. Despite his desperate attempts to control the dunes man has found that somehow the forces of nature have outplayed his hand and continue in wanton destruction.

MODIFICATION OF DRAINAGE

In the 35,000 years since the ice front of the Saginaw lobe rested on the Sturgis moraine in the southwest portion of Michigan, many

changes have occurred to modify the expression of its surface. The major streams which now control the drainage of the state started out largely as border channels along the various ice fronts and carried melt waters from the retreating glaciers. In each back step of the ice border to a new position, the headwaters of the glacial rivers were extended ice-ward. Gradually, the major spillways were connected up to form permanent rivers and the tributary channels became adjusted to their control. Many of the glacial drainways were robbed of their waters and thus were turned into strings of marshy lowlands, the traces of which may readily be followed across the surface.

The present drainage facilities in Michigan are haphazard and poorly developed. Sufficient time has not elapsed since the final melting of the ice to have allowed the tributaries to extend their headwaters back to the outer limits of the watershed areas. The numerous water filled basins which make up the network of over 5,000 lakes in the state remain as testimony to inadequate drainage control. In many areas, tributary streams have tapped some of the glacial lakes with the result that their waters have been partially run out and they have given way to swampy depressions which became sites for the accumulation of organic matter which, by compaction, has in part been transformed into peat.

That these old peat filled bogs and marshes were deep lake basins before drainage adjustments robbed them of their waters may be attested by boring into them with the peat rod. In many of the water logged basins the peat attains a thickness of 25 to 75 feet and rests upon bottoms of clay, sand or gravel. It has been determined by various authorities that in this climate some 300 years are required to lay down the organic material necessary to form one foot of peat. Thus in a deposit where 50 feet of peat is present it may be assumed that not less than 15,000 years of time were involved in its accumulation.

In many areas throughout the state, open basins of accumulation are surrounded by uplands of glacial deposits containing an abundance of pulverized limestone flour. Ground waters moving through these formations have taken the soluble salts of calcium carbonate into solution and moved them into the depressions where they have been precipitated to form deposits of marl. Marl beds scattered over the surface of the state contribute a considerable supply of lime carbonate which is now being used as an amendment to sweeten and improve sour soil.

In the early beginnings of the cement industry, marl was used extensively in the manufacture of this product. Later, as cheap sources of limestone became available, the use of marl for this purpose was gradually abandoned. At present there are but three

cement plants in the state which operate wholly on marl and they are located respectively at Coldwater, Fenton and Cement City. In the area of Cement City in Lenawee County marl is being taken from a chain of kettle lakes nestled in the moraines which make up the Irish Hills. Soundings made in some of the deeper deposits show the marl beds to have a total thickness up to 75 or more feet.

GLACIAL LAKES

The abundance of peat filled bogs scattered over the surface of Michigan is significant. It tends to show that glacial lakes are ephemeral in character and disappear when facilities for drainage are extended to them. It is well to expect then that, as drainage adjustments continue and the rivers sink their channels deeper into the easily eroded glacial surface, the water logged swamps will in turn become permanently dry. Thousands of years of geologic activity will undoubtedly be required to produce these changes, but they will eventually be accomplished in spite of anything man may do to control them.

RIVERS RELATED TO GROUND WATER SUPPLY

The rivers which make up the major drainage ways of the surface receive much of their water from ground water supply. Ground water

is that water which fills in the spaces and openings of the regolith and the basement rock below. The upper level of ground water is called the water table and may roughly be considered as the water surface in our lakes and permanent streams. As rivers become older they cut their channels deeper into the earth crust and tap greater and greater supplies of ground water. Thus as streams advance in their cycle of development they become more permanent. The position of the water table is controlled by the amount of rainfall available. In protracted periods of drought the upper level of ground water may be depressed below the floor of the stream and the channel then becomes temporarily dry. In order for a river to flow water permanently it must have its bed cut below the dry season water table.

Running water is the most important agent of erosion. It has caused more changes in the surface expression of the earth than all of the other forces of erosion combined. By its activities mountains have been leveled down to their roots and reduced to almost level plains. The same force has been responsible for sweeping the weathered material from the land to the sea. Erosion is nothing new. It has been in operation through two billion years of geologic time. Man can control erosional activities and delay them to a certain extent but he does not have it in his power to stop

them. So long as land areas are exposed to the elements of water, wind and temperature variations erosion will continue to produce changes in surface expression of the earth.

The past twenty-five-thousand years have witnessed numerous and varied modifications in the surface expression of the state. But twenty-five-thousand years is as but a few seconds in geologic time and the panorama of change still goes on and will continue thus so long as a single square foot of land surface remains exposed to the mighty onslaught of slowly grinding geologic forces. An exposure of merely a few short seconds of geologic time has produced a state framed by the largest bodies of inland freshwater in the world. The present reproduction is merely temporary - ere another day in geologic time has passed, the scene will have shifted many times over - geologic progress goes on to the end.

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