feet of descent, there are two or three beaches, the upper one of which is generally strong and has some remarkable peculiarities. This is the Battlefield beach. It is called by this name because it was first observed and is most characteristically developed on the battlefield of August 4, 1814, on northern Mackinac Island. The locality is now a part of the golf links. The beach forms a strong, beautifully shaped, and even-crested crescentic ridge trending west from some rough knolls of limestone.

Though in places it contains much sand and fine gravel, this beach in nearly every locality where it has been identified is characterized by unusual coarseness of composition and steep front and back slopes. In some places it looks as though it was formed partly from stones and bowlders shoved up by the ice into something like an ice rampart. Where cut by the road to British Landing it has an uncommonly coarse composition, being made up largely of stones and small bowlders 5 to 10 inches in diameter. Toward the west its texture is finer, but includes considerable coarse material. In places it stands 6 to 10 feet above the ground back of it. (See Pl. XXVI, *A*.)

[1]Coleman, A. P., Marine and fresh-water beaches of Ontario: Bull. Geol. Soc. America, vol. 12, 1900, pp. 138-143.

At Mackinac Island and St. Ignace, and wherever it has been recognized farther south, this beach seems to lie on a stony, bowldery pavement like that commonly found below strong beaches. Farther south, in fact, it stands on the bowlder pavement of the lowest strand of the upper Algonquin group, but at Mackinac Island it is 40 feet below the lowest of that group. The bowldery belt on which it occurs is in many places wide and flat and very stony, so that the material available for building the ridge was largely coarse, and the situation favored the building of ramparts.

The beach is also peculiar in that, although remarkable for its strength in some localities, it is very weak in other places that seem not unfavorable for its formation. So far as observed, it does not split nor show double or multiple forms. In most places, however, it is accompanied by one or two lighter ridges, which seem to be more closely related to it than to the groups above or below. These may have split off at points farther south. This group of ridges is therefore called the Battlefield group.

From the battlefield on Mackinac Island the beach runs westward across the island and is cut off abruptly at the edge of the great cliff which rises 85 feet from the Nipissing bench below. Another short fragment of the Battlefield beach occurs a few rods northeast of the Grand Hotel as a barrier between two knolls. What seems to be the lowest strand of the Battlefield group appears a little east of the Grand Hotel as a low, gravelly barrier ridge with beautifully crescentic form. It occurs also in fine form about a mile west of St. Ignace as a heavy gravelly ridge running northwest and turning back to the east in a sharply hooked spit.

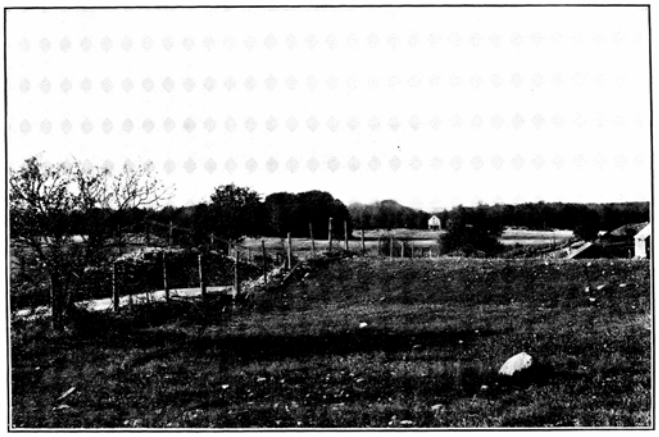
Beaver Island.—On Beaver Island the Battlefield beach is particularly well formed in the western-middle part of the island, where it faces northwest. Its peculiarities of composition and form on Mackinac Island are here even more strongly displayed, suggesting ramparts.

West of Cheboygan.—Except in one locality, the Battlefield beach has not been followed continuously for any considerable distance, but it has been identified satisfactorily at a number of points on the mainland south of the Straits of Mackinac. It was found about 3 miles south of Mackinaw City and was observed in fairly strong development at several places between there and Cheboygan. It was followed almost continuously from south of Mackinaw City south-westward nearly to Cross Village. (See Pl. XXVI, *B*.) It passes about half a mile south of French Farm Lake and wraps around the north side of a morainic knoll 2 miles east of O'Neal Lake, forming a fine crescentic ridge open to the north for 1½ miles to the west. Thence it continues west and southwest around the headland south of Sucker Creek and turns back in a nearly circular loop around Wycamp Lake. It appears again back of Cross Village and extends 2 miles southwest. In this stretch it is generally a well-formed ridge, with the usual stony gravelly composition and bowldery foreslope.

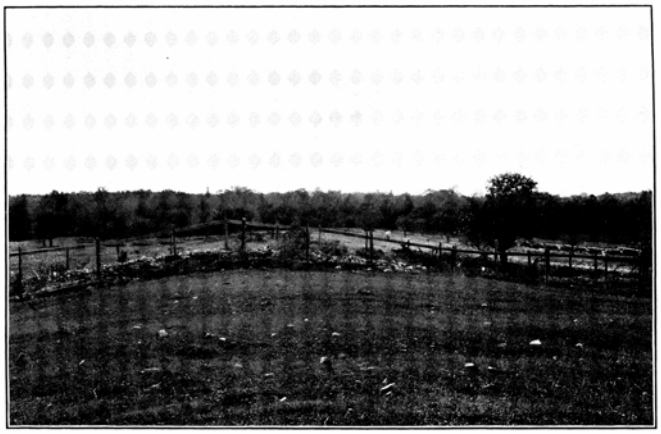
West of Bear Creek in Petoskey, at Burgess, Charlevoix, and Norwood, this beach was recognized. Locally, as near Burgess, it is strong, but in some places it is ill defined. At Northport and Leland a beach ridge that apparently corresponds to it was found, but the distances between points of observation were rather large, and the vertical interval above the Nipissing was so contracted that its identity does not seem certain.

East of Cheboygan.—Between Cheboygan and Alpena most of the writer's observations were made a number of years ago, mainly before particular attention was paid to the weaker beaches below the upper Algonquin group, and although he found some rather weak beach ridges apparently corresponding to the Battlefield beach at several places he did not particularly note their characteristics and relations. At several places Gregory reports a beach or group of beaches which appear to have the place and relations of the Battlefield group, but their identity was not fully determined.

Ontario.—In Ontario, at several places along the south side of Georgian Bay, Goldthwait and the writer found a shore line which appeared to correspond to this beach, but it seemed generally not so well developed as in Michigan and less characteristic. Mr. Leverett found this beach and its associated lighter beaches at several places on the northern peninsula and in Ontario north of Sault Ste. Marie and on St. Josephs Island. It seems certain also that some of Law-son's numerous series on the north side of Lake Superior belong to this group.



A. REAR VIEW.



B. VIEW WEST ALONG CREST OF BEACH.

BATTLEFIELD BEACH, MACKINAC ISLAND, MICH.

[Plate XXVI. Battlefield beach, Mackinac Island, Mich.: *A*, Rear view; *B*, View west along crest of beach]

ALTITUDE.

On Mackinac Island the strongest, most characteristic ridge of the Battlefield group—the one to which the name was originally applied—lies in a plane about 90 feet below the highest and 40 feet below the lowest of the upper Algonquin group. The altitudes of this beach as determined by Goldthwait's spirit leveling are given in the following table. The measurement at Sault Ste. Marie, Ontario, is by Mr. Leverett.

Altitudes of Battlefield beaches on Mackinac Island and in vicinity.

Locality.	Altitude above sea level (in feet).	Altitude below highest Algonquin (in feet).	Altitude of other weaker members of group (in feet).
Sault Ste. Marie, Ontario	790	139	
Hessel, nearly 3 miles north	741(?)	121 (?)	
Mackinac Island, battlefield	719	91	Higher, 726, 729, 732, and 734.
Mackinac Island, northeast of Grand Hotel	715	94	Lower, 703.
Mackinac Island, Benhams road 1 mile south of British Landing	715	94	Higher, 718; lower, 703.
St. Ignace, 1 mile west of courthouse	710	.....	
Mackinaw City, 3 miles south[a]	694	73 (?)	Lower, 693, 691.
Cross Village, three-fourths of a mile east	689	56	Higher, 704, 705.
Beaver Island, west-central part	682	48	Higher, 690.
Petoskey	666(?)	31	Higher, 668.
Burgess	664	33	Higher, 676.
Charlevoix	661(?)	24	Lower, 652.
Norwood	651(?)	22	
Lake Michigan, July and August, 1907	581.6	.....	

[a] The highest beach on the line south from Mackinaw City to Carp Lake has an altitude of 757 feet near north side of Carp Lake. But it is doubtful whether this is the highest Algonquin, for by comparison with other localities near by it seems about 10 feet too low. There is no higher ground near this place.

Gregory's report on his spirit leveling is not yet published, so that identification of the principal Battlefield beach in places is as yet in some doubt, but it seems to be represented by the following beaches:[1]

Location and altitudes of supposed Battlefield beaches.

Locality.	Altitude above sea level.	Altitude below highest Algonquin.
	Feet.	*Feet.*
Rogers	690	50
Crawford's quarry	690	48
Potten	690 ± (?)	48 ± (?)
Alpena, north	690	([a])
Alpena, west	651	37
Ossineke	641	22

[a] Highest Algonquin not reported.

The Battlefield group north of Sault Ste. Marie, Ontario, was found by Mr. Leverett to cover a vertical interval of about 150 feet. Its upper and lower limits, however, have not been determined with entire certainty.

One of the most important results of Goldthwait's survey was the determination of the southward convergence of the Battlefield beach with those above and below. It had been supposed by some geologists, including the writer, that the Battlefield and Fort Brady beaches were each due to a drop in lake level resulting from the opening of an outlet eastward to the Ottawa Valley. This would place these beaches in planes passing southward below the Port Huron and Chicago outlets and would mean that they pass southward below the Nipissing beach, which is of later date and connects with the Port Huron outlet. Goldthwait's measurements, however, show that the Battlefield beach converges with the highest Algonquin beach toward the south and less rapidly with the lower beach of the upper Algonquin group and with the Fort Brady and Nipissing beaches below. Thus it is not parallel to any of the other beaches, as it would be if the lake had been lowered suddenly by the opening of a new outlet.

[1]Gregory, W. M., personal communication.

Although Goldthwait's work does not carry the Battlefield and Fort Brady beaches southward to an absolute union with any of the Algonquin beaches, it carries them so far in that direction that it leaves almost no doubt that they do in fact converge with the lowest member of the upper group. This result seems to preclude the idea of outlets to the Ottawa Valley, except from the last, lowest level of the Fort Brady beaches. In order that the Nipissing Great Lakes could come into existence with full discharge eastward to the Ottawa Valley, there had to be at least a slight drop from the lowest level that could discharge at Port Huron. But that drop was apparently from the lowest Fort Brady to the original Nipissing which is now submerged in all the region south of the isobase of North Bay. There is perhaps some doubt as yet as to whether the lowest beach or two now classed as Fort Brady may in fact belong to this transition to the Nipissing stage. Present facts seem against this view, but they are not conclusive.

The facts seem to show that all but the very last and relatively small increment of the uplift that began during Lake Algonquin turned on a hinge line without the intervention of a drop of lake level by the opening of a lower outlet. Hence, the whole vertical interval from the highest Algonquin down apparently to the lowest Fort Brady measures the vertical uplift during Lake Algonquin.

FORT BRADY GROUP OF ALGONQUIN BEACHES.

DISTRIBUTION.

At Fort Brady, in the southwest part of Sault Ste. Marie, Mr. Leverett found a cut bench and cliff distinctly above the Nipissing and below anything that seemed likely to belong to the Battlefield. He called it the Fort Brady beach. At other places this interval between the Battlefield and Nipissing beaches was found to be occupied by a number of closely set, rather light gravel ridges which seem to constitute a group by themselves. Where typically developed in the north several such beaches, separated by rather small vertical intervals generally less than 10 feet, occupy an interval above the much stronger Nipissing beach and below the Battlefield group, which seems to be distinctly set apart by a barren interval wider than usual.

These beaches are persistent in all the northern region, but like the Battlefield beach, they have nowhere been traced continuously for any considerable distance.

At Mackinac Island they are not very well developed. Just east of the Grand Hotel they occur as a group of very faint, short bars tying knolls of limestone. Four or five short ridges belonging to this group lie in the woods above the Nipissing beach back of British Landing in the northern part of the island and are considerably stronger than those near the Grand Hotel.

At St. Ignace five fairly strong gravelly beach ridges which seem to belong to this group are displayed in best development in the south part of the town. The highest two are strong and beautifully formed ridges, and all are stronger than at any other place observed south of Sault Ste. Marie.

On the road north of Hessel two wave-cut benches between the Nipissing and the Battlefield beaches probably belong to the Fort Brady group. Between Mackinaw City and Carp Lake one strong, gravelly ridge and one faint one represent this group. Two or three ridges of the same set were observed at several points between Mackinaw City and Cheboygan, and two or three were observed between Mackinaw City and Cross Village.

At nearly all of the many places where the Nipissing shore line is developed as a heavily cut terrace with a high lake cliff behind it the Fort Brady beaches have been destroyed. This is the case on the east and west sides of Mackinac Island, at Cross Village, at Harbor Springs, and in the whole interval between these last two. At Petoskey two gravelly ridges appear to stand in the place of this group, but at Burgess they are cut away.

The fullest development of Fort Brady beaches found is on Beaver Island. Seven or eight ridges in the northeast part of this island seem to belong to the Fort Brady. The highest, perhaps, belongs to the Battlefield group, leaving seven ridges, four of them strong and three rather faintly developed. At Charlevoix there are two or three. At Norwood one ridge and possibly two seem to belong to the Fort Brady. Farther south the vertical interval between the lower member of the upper Algonquin group above and the Nipissing below is so narrowed that in the absence of strong individual characteristics it is impossible to distinguish with certainty between the Battlefield and Fort Brady groups. Both groups are crowded into narrower space and are represented by fewer ridges than farther north.

Beaches having moderate strength and now recognized as belonging in all probability to the Fort Brady group were seen by the writer a number of years ago near Rogers and farther south. In Gregory's summary of his leveling operations beaches that probably belong to the Fort Brady group were observed as far south as Alpena, but their identification is not yet certain.

In Ontario the Fort Brady group of beaches is fairly well developed at some localities, especially along the north side of the Penetang Peninsula, but they are generally not strong. They were found also at some places along the south side of Georgian Bay, but are not so well displayed there as farther north.

At North Bay, Ontario, where some of the beaches are well developed a mile north of the town on a terrace overlooking the head of the North Bay outlet channel, the upper and lower limits of the group have not been definitely determined, although the lower limit appears to be at a beach about 50 feet above the Nipissing. At this place four beaches, including the lowest and covering a vertical interval of 31 feet, appear to belong to the Fort Brady group. In all probability there are higher ones and perhaps lower ones, although several fairly favorable localities near North Bay did not appear to show them.

Mr. Leverett reports this group of beaches from several places on the northern peninsula. In 1893 the writer found them faintly developed at several places on the south side of Lake Superior, and subsequently Mr. Leverett found them at other localities. The writer visited several of Lawson's north-shore localities in 1895 and at most of them saw light beaches above the Nipissing which it now seems evident belong to the Fort Brady group.

ALTITUDE.

In the Fort Brady group of beaches no single beach has strength or individual characteristics that make it possible to distinguish it from other members at different localities, and it is not possible to trace the variations of the group in altitude with accuracy. The altitudes given below, compared with the altitude of the Nipissing beach at the same places, show the general relations.

Altitudes of the Fort Brady beaches.

Locality.	Altitude above sea level (in feet).	Altitude of lowest beach above Nipissing (in feet).	Altitude of Nipissing beach (in feet).	Altitude of highest beach above Nipissing (in feet).
North Bay, Ontario	748, 763, 776, 779 (lowest may be cut away)	50	698	77
Sault Ste. Marie, Mich.	699 (higher and lower cut away)	48	651	.....
Mackinac Island, north end	656, 659, 668, 672	15	641	31
Mackinac Island, Benhams road	669, 691 (lowest cut away)	28	641	50
Mackinac Island, south end	639, 653, 661, 681	5	634	47
St. Ignace, west of town	654, 662, 668, 677	26	628	50
St. Ignace, south part	645, 652, 655, 662, 678	17	628	49
Mackinaw City	653, 656	25	628	28
Beaver Island	634, 642, 645, 649, 652, 655, 659	11	623	36
Petoskey	649, 654 (lowest cut away)	36	613	41
Norwood	641 (lowest cut away)	34	607	34

At the south end of Mackinac Island a faint gravel ridge which rises only 5 feet above the Nipissing beach a few yards away may be merely a storm ridge of the Nipissing. Aside from this, both the upper and the lower members, where the latter are not cut away, appear to be somewhat higher in the north than in the south, but it is perhaps an open question whether some of the Fort Brady beaches may not pass southward under the Nipissing beach. South of Charlevoix and Alpena there are in many places one to three beaches between the Nipissing and what seems clearly to be the lowest ridge of the upper Algonquin group, but it has not been found possible so far to tell whether these are all Battlefield or Fort Brady, or are divided between the two. In the stretch between Mackinac Island and St. Ignace on the north and Cross Village on the south, although accurate measurements are not available for the latter place, the impression that the Fort Brady beaches lie in planes sensibly parallel with the Nipissing plane is strong enough to lead to the provisional conclusion that the Fort Brady beaches, or at least the upper ones, do not pass down under the Nipissing plane. This would mean that the opening of the eastward outlet for Lake Algonquin to the Ottawa Valley occurred at the end or very near the end of the Fort Brady substage of the lake.

The convergence of the planes of the lower members of the upper Algonquin group suggests that during that part of the uplift a hinge line may have existed in the vicinity of Traverse City. Similar suggestions of a subsidiary hinge line occur near Tawas City and on the east side of Lake Huron. This line runs parallel with the main Algonquin hinge line and about 25 miles north of it. The uplift related to this line appears to have taken place sometime after the formation of the highest Algonquin beach but before the Nipissing beach, for the latter appears not to have been affected by it. The data in hand at present, however, seem insufficient to settle the questions suggested. (See fig. 8.)

OTTAWA OR CLOSING TRANSITIONAL STAGE.

It seems certain that an outlet for Lake Algonquin to the Ottawa Valley opened before the beginning of the Nipissing Great Lakes and the full eastward discharge over the col at North Bay, but the facts at present available are not decisive. The opening of a lower outlet could hardly have resulted from elevation alone. Something must have given way or have been withdrawn to afford a lower passage.

This early drainage to the Ottawa Valley may have prevailed during all or a part of the formation of the Fort Brady beaches or it may have begun with the abandonment of the last. In any case it marked the last stage of Lake Algonquin and the transition to the Nipissing Great Lakes.

GLACIAL BARRIERS OF LAKE ALGONQUIN.

Although from first to last Lake Algonquin endured for a relatively long time, certainly much longer than did any of the Huron-Erie lakes that preceded it, the precise position of its ice barriers at any of its stages is not known from observation.

The position of the barrier for Early Lake Algonquin, however, seems fairly well determined, only slight uncertainty remaining as to the correlation of the moraines on the two sides of Lake Huron.

In Michigan the main moraine of the Port Huron morainic system turns northwest on the north side of Au Sable River, about 20 miles west of Greenbush in Alcona County. In Bay and Tuscola counties the next later moraine is the Bay City. This passes 5 or 6 miles northwest of Tawas, but it has not been surely identified in the jumbled and broken area northwest of Harrisville. Still, from its lower altitude west of Tawas, it seems certain that it lies lower down on the slope north of Au Sable River. The Tawas moraine passes close along the lake shore at Alabaster and Tawas and seems to be continued in the prominent ridge that passes close west of Greenbush and Harrisville. From Black River it is continued in the chain of knolls that run northwest and along the base of which lies the Algonquin beach. South and west of Rogers the Algonquin beach runs along the inner base of a high morainic mass which rises 40 to 100 feet above it. From the vicinity of Rogers the divide between the drainage basins of Thunder Bay River on the southeast and the Ocqueoc and Black rivers on the northwest runs southwest with no passage across it as low as the Algonquin beach. Hence, the waters of the Lake Huron basin in the time of Early Lake Algonquin, or even after this stage, could not have found open connection with the waters of the Lake Michigan basin until the ice front had withdrawn somewhat from this high morainic mass.

On the Canadian side the continuation of the main moraine of the Port Huron system turns northeast 7 or 8 miles north-northwest of Clinton and the next moraine takes a parallel course northeast from Goderich. The latter moraine appears to be the precise equivalent of the Bay City moraine in Michigan. Following this, five light moraines set close together run northeast from the brow of the Algonquin cliff between Clark and Douglas points, the first one terminating a little south of Clark Point. These are slender ridges, and at present are known only as fragments near the shore. Their courses inland have not yet been worked out, but the characters mentioned suggest that they are deployed ridges of a single moraine, and their places in the series suggest that taken together they may be equivalents of the Taw as moraine in Michigan. Next comes a strong moraine that begins near the shore about 8 miles south of Port Elgin and runs northeast to Hepworth, where it turns back to the southeast around the head of the Owen Sound embayment. It passes close east of Port Elgin

and may be called the Port Elgin moraine. If the five light ridges south of this moraine are equivalents of the Tawas moraine, then this one may be regarded, at least tentatively, as the equivalent of the Cheboygan moraine in Michigan. From the relations of several morainic fragments observed by the writer, it seems probable that at this halt the ice front extended eastward along the base of the high escarpment between Owen Sound and Collingwood and only a little above the Algonquin beach, and that after swinging east and north across the Nottawasaga and Severn valleys, it made a deep northward reentrant toward the highlands of Algonquin Park, returning south and southwest along the northern margin of the lobe that projected into the basin of Lake Ontario.

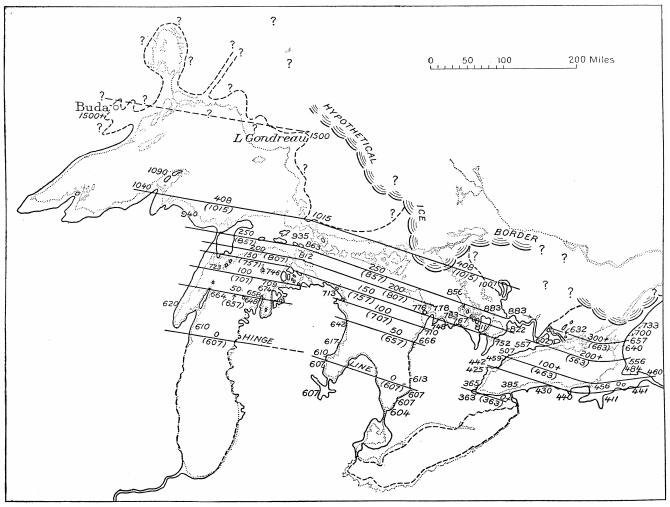


FIGURE 8.—Map showing isobases of Lake Algonquin at its highest stage and isobases of Lake Iroquois as represented by Goldthwait. The numbers above the isobases are altitudes above the horizontal or unaffected part of the beach south of the hinge line; the numbers in parentheses below the isobases are altitudes above sea level.

In the bed of Lake Huron a well-marked escarpment, now submerged and shown on the charts by the 50-fathom line, runs northwest from near Kincardine. North and east of this line lies the deep trough of Lake Huron; south and west of it the lake is much shallower. The general movement of the ice was southwestward across Georgian Bay and the deep trough. The form of the lobation which the ice assumed under the influence of the deep trough and the surrounding lands seems to find normal expression in the moraines described; that is to say, the moraines are disposed about as would be expected under the laws governing the movement of the ice over such a surface. The Port Elgin moraine rises only a little above the Algonquin beach east of Port Elgin and Southampton, and in this respect stands in about the same relation to the Algonquin beach as the Cheboygan moraine near Rogers, in Michigan.

With the ice front resting on this moraine, the waters in the south part of the Lake Huron basin would necessarily discharge southward at Port Huron and the lake in that relation would answer perfectly to the description Early Lake Algonquin. At the next step of ice retreat, however, passages were opened possibly both to the west and east, and the discharge may have passed partly, though for only a very brief time, to Chicago; almost immediately, however, the whole discharge passed to Kirkfield.

At this stage the ice barrier rested largely in the lakes and rested on land only in Canadian territory. If the recession of the ice front after as before the formation of the Port Elgin moraine was marked by a series of halts, the moraines formed must be found mainly in the country, east and north of Georgian Bay and north of the North Channel of Lake Huron. The writer has explored along certain lines in those wild, rough regions and has observed six or seven moraines that may be members of such a series, but they are all short fragments and their connections and relations are not known. Ice tongues pushed southward in two or three deep valleys that enter the Ottawa Valley from the north, impinging heavily against the high south side and forming effectual dams for the waters west of them.[1] These mark, it is believed, the last position in which the ice sheet acted as a retaining barrier for the waters of Lake Algonquin. But in the wide stretch of country between these tongues and the Port Elgin moraine there is room for a number of moraines. If rhythmical halts or oscillations of the ice front occurred in this interval, as they did farther south, they will ultimately afford a good basis for the measurement of the relative duration of Lake Algonquin and of the time and rate of the uplifting movements which deformed its shores.

CORRELATIVES OF LAKE ALGONQUIN.

COMPLEXITY OF RELATIONS.

Lake Algonquin endured for a relatively long time, during the latter part of which the most profound earth movements that have affected the Great Lakes region since the time of the ice sheet took place. For this reason it might be expected that the correlatives of Lake Algonquin, especially in the basins of Lakes Erie and Ontario, would have somewhat complex histories, as indeed they have. The chief correlatives of Lake Algonquin were Lake Erie and glacial Lake Iroquois. Other correlatives existed in the basins of Lake St. Clair and Rouge River.

LAKE ST. CLAIR.

During the time of Early Lake Algonquin the waters in the basin of Lake St. Clair stood 8 or 10 feet lower than in the basin of Lake Huron. Along its western side a well-defined, though not very strong, old shore line, which may be called the first St. Clair beach, is 595 feet above sea level at all points where it has been measured. The altitude of the Algonquin beach near Port Huron is 605 to 607 feet, and therefore, in strict sense, the first St. Clair beach is not the early Algonquin beach but a correlative of that beach, made at a lower

level in a basin connected with Early Lake Algonquin by a river that descended 8 or 10 feet.

[1]Taylor, F. B., Notes on the Quaternary geology of the Mattawa and Ottawa valleys: Am. Geologist, vol. 18, 1896, pp. 108-120.

The first St. Clair beach is scarcely traceable along the river front in Detroit, but it crosses Jefferson Avenue about a quarter of a mile west of the waterworks as a faint wave-cut bench with no noticeable cliff and then turns away inland. It runs thence a little east of north to Mount Clemens and thence northeast for about 10 miles and fades into an ill-defined sandy belt on the clay plain north of Anchor Bay. It lies 2 to 4 miles back from the present shore of the lake for its whole course except 2 or 3 miles along the bay north of Mount Clemens, where it is not over 1 mile back. In this part it is stronger than common and has a well-defined lake cliff at its back 3 to 7 feet high. An island which at the time of this beach reached northeast for about 2 miles from Grosse Pointe is about half a mile wide and, in a small area on the Moran road at its western edge, rises to 620 feet above sea level and is capped with gravel which, from its altitude, appears to belong to the Lundy beach. The first St. Clair beach runs through the village, generally an eighth to a quarter of a mile from the shore, in the form of a low beach ridge of gravel. A gravel spit rising a little above the general level of the beach runs 70 or 80 rods southwest from the southwest end.

Grosse Pointe Island was separated from the mainland to the west by a trough the lower part of which is half a mile wide and swampy. This runs through from Milk River at the north to the flats of Fox Creek a mile southwest of the village and is now only 5 or 6 feet above the lake. It is floored with several feet of lake clay and was therefore originally somewhat deeper.

The island is distinctly morainic and the shore all along its front is paved with bowlders. Three miles to the south the lighthouse at Windmill Point stands on a small isolated fragment of bowldery till, probably part of the same moraine.

On the south shore of the lake 25 miles east of Windsor, Ontario, the land projects into the lake in a wide blunt cape called Stony Point. Its shore is bowldery and suggests morainic ground, but the flat land of that vicinity does not indicate its course and no detailed studies have yet been made in that region.

On the Canadian side the first St. Clair beach has not been traced. The country surface is very low and flat to the south and east, indicating a much wider interval between the old beach and the present shore. The altitude given on the Canadian official topographic maps indicate a line passing east from Walkerville 2 to 3 miles back from the shore, the distance increasing eastward. It passes a mile north of Comer and 2 miles south of Tilbury. Five miles east of Tilbury this line is slightly nearer to Lake Erie than to Lake St. Clair. Along this line nearly all the streams show jogs indicating some diverting influence, such as would be exerted by a beach. Thence the probable course, as indicated by the altitudes, passes a few miles west of Chatham and a little east of Wallaceburg and to St. Clair River a few miles south of Courtright. On such flat ground the beach would be likely to be merely a low belt of fine sand. Several fragments of this sort have been observed west of Chatham and toward Wallaceburg but have not been traced connectedly.

The basin of Lake St. Clair is simply an intermorainic trough or original depression in the drift lying between the main moraine of the Port Huron system on the north and another moraine which passes through Detroit and Windsor and along the north side of Lake Erie from near Leamington. It is probably accidental that the lowest point on the Detroit moraine was at Detroit instead of at some point farther east, as near Tilbury, where it would be more centrally located with reference to the axis of the Lake Huron glacial lobe.

The greatest depth in Lake St. Clair is 22 feet. Its surface at present has an altitude of 575 feet above sea level. At the time of the highest Algonquin beach (Early Lake Algonquin), its altitude was 595 feet, or 20 feet above its present level, and at the time of the Nipissing beach its altitude was 587 feet, or 12 feet above its present level. Lake St. Clair came into existence at the same time as Early Lake Algonquin.

LAKE ROUGE.

With the beginning of Lake St. Clair and the fall of the waters in the Lake Erie basin Lake Rouge was formed between Detroit and the barrier at Limekiln crossing by an expansion of Detroit River. The lake spread some distance over low ground on the Canadian side, but its larger part was over the flats of Rouge River west and southwest of Detroit.

Rouge Lake was small, but during the time of Lake Algonquin its waves formed a faint beach which belongs to it alone and does not lie in the plane of any other beach. This beach appears as a distinct wave-cut notch on the gently sloping clay plain west and southwest of Wyandotte and as a distinct low beach ridge of gravel on the north and northeast sides of Grosse Isle, especially near the lighthouse and for a mile or two to the south. Its altitude is 589 feet.

At the lower level of the Nipissing waters Lake Rouge was so reduced in area that it was almost obliterated and probably had no waves of any importance. No distinctly wave-made features were found for this level, but low, sandy ridges at Wyandotte and Ecorse, 6 or 8 feet above Detroit River, probably mark its position.

LAKE ERIE.

SEPARATION FROM GLACIAL LAKES.

Until its separation from Early Lake Algonquin Lake Erie was a part of the Huron-Erie glacial waters described above, Lake Lundy being the last stage. Immediately following its separation from Early Lake Algonquin Lake

Erie was also separated from the glacial waters of the Lake Ontario basin, and ceased to be a glacial lake. After this separation the only changes which affected it were slight uplifts of the land and large changes of volume in the water which it received and discharged. The largest uplift which affected the Lake Erie basin occurred before the lake became independent—during the time of Lake Lundy. The span of Lake Erie's existence as an independent lake is the precise time equivalent of the duration of Niagara River and the Falls.

SEQUENCE OF STAGES DURING LAKE ALGONQUIN.

During Early Lake Algonquin Lake Erie stood at a somewhat lower level than now, and received a large volume of inflow through Detroit River, which of course gave it a large outflow at Buffalo. The Buffalo outlet, however, was on a rock sill with only very slight fall, and it remained firm and the lake was held steadily at one level. This was Lake Erie's first high stage, and its beach in the western part of its basin was probably 20 to 30 feet lower than the present surface.

Soon, however, an outlet was opened at Kirkfield, Ontario, and this took the whole discharge of the upper three lakes away from Lake Erie, causing a reduction of outflow at Buffalo amounting to about 85 per cent and lowering the level of Lake Erie 10 to 15 feet. This first low stage of Lake Erie lasted throughout the Kirkfield stage of Lake Algonquin. It therefore occurred before the Algonquin uplift, and its beach was probably 10 or 12 feet lower than in the preceding (Early Lake Algonquin) high stage.

The first low stage of Lake Erie was ended by the uplift which raised Kirkfield, closing the outlet there and sending the discharge of the upper lakes back to Port Huron and Chicago. The uplift affected the outlet of Lake Erie at Buffalo much less than it did that at Kirkfield, raising the former probably only 20 or 30 feet and backing the water up this much in the west end of the lake. The closing of the Kirkfield outlet gave Lake Erie a large volume of discharge and a high stage on its shores, and this condition lasted until the retreating ice opened a lower outlet in the Ottawa Valley and Lake Algonquin came to an end.

EFFECTS OF ALGONQUIN UPLIFT.

In the Lake Erie basin the area of horizontality for the Whittlesey beach extends about to Ashtabula, Ohio, and for the Warren beach about to the Ohio-Pennsylvania line. The hinge line for the Algonquin water plane, if produced as a straight line from the southern part of Lake Huron, passes about halfway between Dunkirk and Silver Creek, N. Y., and about 30 miles southwest of Buffalo. On the "thumb" in Michigan the Warren beach at this line has an altitude of about 755 feet, or about 75 feet above its horizontal, undisturbed part. Two miles northeast of Sheridan, N. Y., on the same line produced, the Warren beach has an altitude of about 760 feet, or about 80 feet above its horizontal part; that is to say, it is uplifted about the same amount as at the Algonquin hinge on the "thumb." It is not known, however, that the Algonquin hinge line touches this point in New York; and on the other hand, it is not known that all the uplift at this place is of pre-Algonquin age. If the Algonquin hinge line produced to the southeast bends out of a straight course before reaching Sheridan, it is more likely to bend to the north, in harmony with the isobases of the Iroquois water plane, than to the south.[1] This would indicate a slightly larger pre-Algonquin uplift along the hinge line in New York than on the "thumb," but the difference is probably small. Fairchild finds the uplift farther northeast to be about 2 feet to the mile. This, if continued to the 80 feet of uplift near Sheridan, would make 140 feet in all at Buffalo. This is only approximate, but it is the best estimate now available for the amount of uplift at Buffalo before the beginning of Lake Algonquin. It would give the Warren beach at Buffalo an altitude of about 820 feet. At Alden, 20 miles east of Buffalo, however, it is 845 to 850 feet, the direction of greatest rise being only a few degrees east of north.

Facts in two areas bear indirectly on the amount of uplift at Buffalo during and after the existence of Lake Algonquin. On the west side of Saginaw Bay the Algonquin beach rises about 18 feet in 30 miles up the tilted water plane from the hinge line. This represents the combined Algonquin and post-Algonquin uplifts. The rate is slightly less for the same distance north from the hinge line on the two sides of Lake Michigan, and it is slightly greater on the east side of Lake Huron, the rate apparently increasing gradually eastward. Data derived from the Iroquois beach in the basin of Lake Ontario will probably be helpful in the future, but are not now available. If the assumed position of the hinge line in New York is not wide of the truth, and if the rate of rise is about the same or slightly greater than on Saginaw Bay, it may be said that at the beginning of the Algonquin uplift the outlet at Buffalo was somewhere between 15 and 25 feet lower than now, and that the uplift caused this much drowning in the western part of Lake Erie. This seems to show that the greater part of the deformation of the basin of Lake Erie, say 110 or 120 feet of uplift at Buffalo, was before the time of Lake Algonquin, and before the independent stage of Lake Erie. Hence, only a little additional uplift during and after the existence of Lake Algonquin was required to bring the waters nearly to the present level of Lake Erie and very nearly to the plane of the drowned shore described by Moseley. (See p. 462.) By the best estimate now available this amounted to 20 or 30 feet.

FORT ERIE BEACH.

In 1907 the writer found a strong old shore line, the Fort Erie beach, extending westward along the Lake Erie shore from Fort Erie, Ontario. It is a gravel ridge in Fort Erie and is strong at intervals as far west as Lowbanks, beyond which it has not been traced. It is nearly horizontal, standing 14 to 15 feet above the lake in Fort Erie and only 4 or 5 feet lower at Lowbanks, 28 miles to the west. This beach is distinctly old, is considerably weathered, and is generally preserved only on rocky

parts of the shore, where it could not be undercut by later wave action at lower levels. At Lowbanks it is a little lower than the modern storm beach. This beach confirms Fairchild's conclusion that the direction of tilting in the eastern part of the Lake Erie basin is more nearly north than it is farther west.

The Fort Erie beach has not yet been identified farther west or southwest, but it seems probable that near the Algonquin hinge line, about 30 miles southwest of Buffalo, it becomes horizontal 15 to 25 feet below the present lake level and so continues westward. It is perhaps possible that the Fort Erie beach corresponds to the submerged shore line found by Moseley at the west end of the lake, but it is probably more deeply drowned. This beach is almost certainly the correlative of the Port Huron-Chicago stage of Lake Algonquin, and perhaps also of Early Lake Algonquin when the volume of discharge at Buffalo was large and Lake Erie stood at high stage.

[1]See Goldthwait's isobase map: Bull. Geol. Soc. America, vol. 21, 1910, p. 233.

TRANSITION TO LAKE IROQUOIS.

After the separation of Lakes Erie and Ontario into two independent lakes conditions changed rapidly. The ice front rested against the hills south of Syracuse, N. Y., and the outlet was eastward along its front. Several of the old cataract sites and outlet channels on the hills south of Syracuse are related to this shifting outlet river, though in all probability some of them are older than the Wisconsin glaciation. In fact, it has been shown by Fairchild[1] that the whole front of the escarpment from the Mohawk Valley to Ohio is marked with similar channels of drainage along the border of the ice. The slope is relatively steep, so that every movement of the ice front forward or back was exceptionally effective in raising or lowering the level of the lake waters to the west. This unstable condition was probably most marked while the waters were finally settling down to the Iroquois level during and after separation from Lake Erie. The transition stages and the lower stages confined to the Lake Ontario basin must have undergone many changes of level, and these probably account in part for the alternations of glacial and lacustrine formations which Spencer[2] describes as occurring in the Whirlpool-St. David gorge at Niagara.

GLACIAL LAKE IROQUOIS.

After the separation of Lake Erie the waters in the Lake Ontario basin became independent, except as they received the overflow of the upper lakes through rivers or were for a brief time merged in open connection with the sea. In the present state of knowledge the establishment of synchronous events in the history of these waters and those of the upper lakes is no easy task, for while much is now known concerning Lake Iroquois and Gilbert Gulf, much also remains to be learned. The critical areas of Lake Iroquois showing the correlation of its beaches with positions of the retreating front of the Lake Ontario ice lobe have not yet been studied. Since the time of the earlier studies by Spencer, Gilbert, and the writer, Coleman's investigations of the Iroquois and marine beaches have brought out many important facts showing the effects of the great uplift in deforming and warping all of the beaches and in splitting the Iroquois into a number of vertically diverging strands in the northeastern part of the basin. But the data on some of the critical points are still too few to yield satisfactory numerical values for altitude and time relations.

Most important in its relations to these water bodies is the ancient Algonquin outlet channel. Near Kirkfield and at Fenelon Falls this channel is a mile wide, and its scoured floor and faint shore markings show that the water in it was 20 to 35 feet deep. It is well developed and shows no sign of delta formation from its head at Kirkfield to Peterboro, where the extensive gravelly plain seems to mark its delta in Lake Iroquois. Coleman[3] shows that the delta is in a restricted tributary valley and in all probability marks a level slightly above that of Lake Iroquois, but no serious doubt has been cast upon its general correlative relation to that lake. This delta and the absence of other deltas above it show that Lake Iroquois was already in existence when Algonquin River began to flow, and the strength and magnitude of the delta show that the land in the region of Lake Iroquois was stable and unaffected by uplifts for a relatively long time. This was in the Kirkfield stage before the Algonquin uplift.

In 1894 Gilbert found that the Algonquin outlet channel does not stop at Peterboro, but "continues with undiminished strength" down Trent River to the present level of Lake Ontario at Trenton. The writer made the same observation in the fall of 1893, except that the channel near Trenton seemed to him somewhat smaller and less capacious than that at Fenelon Falls and less thoroughly scoured; this, however, may be an error. If the old channel really extends to present lake level at Trenton, without any indication of stopping there, it may pass 30 feet or more below that level and out to the east along the Bay of Quinte.

[1]Fairchild, H. L., Glacial waters in the Lake Erie basin: Bull. New York State Mus. No. 106, 1907; Glacial waters in central New York: Bull. New York State Mus. No. 129, 1909.

[2]Bull. Geol. Soc. America, vol. 21, 1910, pp. 433-434.

[3]Coleman, A. P., The Iroquois beach in Ontario: Bull. Geol. Soc. America, vol. 15, 1903, pp. 357-358.

The great uplift which deformed the shore lines of Lakes Algonquin and Iroquois began a long time after the establishment of the Kirkfield outlet—at least long enough after to allow for the building of the Peterboro delta and for the making of strong shore lines over a large area of the upper lakes. Coleman[1] confirmed Gilbert's earlier observation that the Iroquois beach splits up into a number of strands, and he found that they diverge in altitude in a direction N. 20° E. from a line passing about through Quays, 6 miles north of Port

Hope. Coleman considers that south of this line the same strands diverge southward in reverse order and that all but the last were submerged and obliterated. The line through Quays was therefore a nodal line, and it is very significant to find that when produced parallel with the other isobases it passes into the former outlet of Lake Iroquois at Rome, N. Y. But at present the Iroquois beach at Quays is 97 feet higher than the same beach at Rome, apparently showing that the post-Iroquois uplifts have had a stronger northward component than the earlier uplifts, for their isobases run more nearly east and west.

GLACIAL LAKE FRONTENAC.

When the ice sheet had retreated in the St. Lawrence Valley to the northern angle of the Adirondacks it opened a new outlet somewhat lower than that at Rome, N. Y. A strip along the mountain side on the slope toward Lake Champlain was scoured bare by that outlet river and is now known as "The Rock." This scoured channel ends in a sort of coarse delta formation 3 miles west of West Chazy. This stage of the lake waters was rather brief, and since the ice barrier which supported it rested on the Frontenac axis of pre-Cambrian rocks, it may be called glacial Lake Frontenac. A definite shore line has not yet been identified with this lake stage.

GILBERT GULF.

After the withdrawal of the ice barrier and the fall of Lake Frontenac the sea entered the basin of Lake Ontario. The duration of the marine occupation was probably short, and the connection was through a shallow strait 25 or 30 miles wide. Gilbert traced the marine beach on the south side of the St. Lawrence more than 25 years ago, following it from Covey Hill, Quebec, near the international boundary, southwestward to Oswego, N. Y., where it passes under the present level of Lake Ontario. Fairchild[2] named the marine waters in the Lake Ontario basin Gilbert Gulf.

On the Canadian side Coleman traced the marine beach from a few miles west of Prescott, where he found the last of the Pleistocene marine shells, westward into the basin of Lake Ontario.[3] Near Prescott the altitude of this beach is given as 350 feet above sea level. In 1896 what appeared to be the same upper marine limit was observed by the writer at Welch's siding, 3 miles north of Smith Falls, at 460 feet. At Brighton, 6 miles southwest of Trenton, Coleman gives it as 309 feet. From Brighton to Prescott the beach rises 41 feet in about 120 miles, or about one-third foot to the mile. But this is nearly on the line of its isobase, for from Prescott to Welch's siding it rises 110 feet in about 35 miles, or more than 3 feet to the mile. The direction of most rapid rise for the plane of the marine beach is therefore nearly due north in this area. At Belleville the altitude of the marine beach is given as 323 feet, and it is calculated that at Trenton it is close to 320 feet. Thus, if it reached present lake level at Trenton, Algonquin River must have descended 74 feet or more below the marine beach.

At first glance it seems hard to believe that the waters of the Lake Ontario basin could have fallen so far while Algonquin River was still flowing. But during the later part of the Kirkfield stage of Lake Algonquin the retreating ice was uncovering critical ground at the northern angle of the Adirondacks, and large and relatively sudden lowerings of the water level were inevitable. The duration of the Kirkfield stage was relatively long and the uplifts were spasmodic and not steady and even. From the beginning of Early Lake Algonquin to near the close of the Kirkfield stage no uplift occurred, so far as known. As the facts now stand, no satisfactory interpretation of the Algonquin channel between Peterboro and Trenton has been found.

[1]Bull. Geol. Soc. America, vol. 15, 1903, pp. 359, 363.

[2]Fairchild, H. L., Gilbert Gulf (marine waters in Ontario basin): Bull. Geol. Soc. America, vol. 17, 1907, p. 112.

[3]Marine and fresh-water beaches of Ontario: Bull. Geol. Soc. America, vol. 12, 1901, map, p. 130.

If the supposed extension of the channel to Trenton is correct, it introduces a problem of much difficulty and seems to suggest an oscillation of the ice front even greater than that which preceded the building of the Port Huron morainic system. It does not seem possible that this episode of the lake history can be settled until more field studies are made.

Coleman's conclusion that the waters were backed up on the southern and western shores of Lake Iroquois by the uplift is confirmed by well-defined remains of an early Iroquois strand found by the writer north of Lockport and 32 feet below the main Iroquois beach.[1]

[1]Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913, p. 12 and surficial-geology map.

CHAPTER XXII.
THE NIPISSING GREAT LAKES.

By FRANK B. TAYLOR.

LOCATION AND AREA.

The term "Nipissing Great Lakes" is applied to the waters of the upper three Great Lakes during the stage immediately following the final disappearance of the ice. The name is used in the plural form, because the Lakes at that stage were almost as distinctly separated as they are to-day. Lake Superior was connected with Lake Huron by a narrow strait or sluggish river without falls. Lake Michigan was connected with Lake Huron by the same strait that connects them now, except that the water stood about 50 feet higher, and also by a much narrower, shallower passage eastward from Little Traverse Bay. (See Pl. XXVII.) The outlet of the lakes, however, was eastward from the northeast angle of Georgian Bay instead of through Lakes Erie and Ontario, as now.

The area covered by the Nipissing Great Lakes was not very different from that now covered by Lakes Superior, Michigan, and Huron, including Georgian Bay. The reason for this lies mainly in the facts that the water plane of the Nipissing Lakes lay little above that of the present lakes and that the lands bordering their northern parts then, as now, were high and had relatively steep lake ward slopes.

Knowledge concerning the beginning of the Nipissing Great Lakes and the transition to them from Lake Algonquin is rather meager, but the condition of the lakes themselves and the transition from them to the present lakes is clearly recorded in the beaches.

EARLY LITERATURE.

As a distinctly recognized feature the Nipissing beach did not make its appearance in the literature of the lake region until a comparatively recent date. Only one or two of the references of the early writers to the "lake ridges" in New York, Ohio, Michigan, and Ontario appear to apply to the Nipissing beach. Whittlesey seems to have seen it in the Green Bay region, and early explorers in the northern parts of the area occasionally referred to "terraces" on the shores of Lake Superior that may have belonged to it.

In his discussion of the relation of the Great Lakes to Niagara Falls, Gilbert presented a map showing the supposed outlines of the upper lakes at the time of their discharge past North Bay to Ottawa River.[1] Gilbert visited North Bay in 1889 and went down the course of the old outlet river as far as Talon Lake. He clearly inferred the existence of such a beach as the Nipissing, but he estimated its deformation as being much greater than that which has actually been found. He identified the beach now known as the Nipissing only at the head of the outlet at North Bay, his outlines for other parts of the lake being wholly different from the true ones.

Wright visited North Bay and Mattawa in 1892 and saw the beach at the former place and evidences of the outlet river at the latter.[2]

In his earlier writings and even in his description of Lake Algonquin Spencer makes no more definite mention of the Nipissing beach than the general statement that along the south side of Georgian Bay there is "a numerous series of beaches extending from 28 feet down to the water level." Not until a later time did he recognize the existence of the outlet at North Bay.[3]

[1]Gilbert, G. K., The history of the Niagara River: Sixth Ann. Rept. Commission of State Reservation at Niagara, 1890, p. 72 and Pl. IV.

[2]Wright, G. F., The supposed postglacial outlet of the Great Lakes through Lake Nipissing and the Mattawa River: Bull. Geol. Soc. America, vol. 4, 1892, pp. 423-427.

[3]Spencer, J. W., Deformation of the Algonquin beach and birth of Lake Huron: Am. Jour. Sci., 3d ser., vol. 41,1891, p. 16.

The correlation of a particular beach in the Lake Superior and Lake Michigan basins with the outlet at North Bay was made in 1893 by the writer on an excursion in company with Dr. F. S. Pierce, of Philadelphia, and was published in 1894.[1] Since that time the beach has been studied by several students of the lake history who have worked in the upper lake region, and it has been mapped in considerable detail on all shores except those north and east of Lake Superior, north of Lake Huron, and north and east of Georgian Bay.

OUTLET.

The outlet of the Nipissing Great Lakes was at North Bay, Ontario, on the northeast shore of the modern Lake Nipissing. Later, differential uplift raised North Bay and gradually drove the waters back to Port Huron, inaugurating a transitional two-outlet stage which ended with the closing of the North Bay outlet and the transfer of the entire discharge to Port Huron, thus terminating the existence of the Nipissing Great Lakes.

The North Bay outlet river, or "Nipissing-Mattawa River,"[2] after passing a swampy col, amid glaciated bosses of crystalline rock, chiefly gneiss, passed down Mattawa River to Mattawa, where it joined Ottawa River and followed it, at first to glacial lakes and later to the sea, which occupied the St. Lawrence and Ottawa valleys at that time.

Mattawa River is composed mainly of a chain of lakes connected by short, rapid streams. Some of the lakes are long, narrow, and deep, lying in canyon-like valleys 200 to 300 feet wide, with water 100 to 300 feet deep, bordered by precipitous walls 100 feet or more high.[3]

The Nipissing beach is strongly marked along the north side of the col a mile north of the Canadian Pacific Railway station in North Bay[4] but is poorly developed along the south side, which was an archipelago of crystalline islands largely bare. The col swamp extends eastward to the head of Trout Lake, beyond which the outlet river leads through Turtle Lake, descends rapidly northward to the head of Tolon Lake, leaves the latter by a cascade of 30 or 40 feet, and passes through several lakes below. The lake beds show no clear evidence of the outlet river, but some of the intervening stretches record the scour of a great river. In some places the cross section of the scoured bed and the indicated velocity of the current show the river to have had about the same volume as St. Clair River of to-day; and this would be expected if this outlet carried the discharge of the same lakes after the ice sheet had ceased to contribute to them. The writer made a canoe trip down Mattawa River from North Bay to its junction with the Ottawa in 1896 and later published an account of some of the evidences of the presence of the outlet river.[5]

Though the erosion in the outlet channel is too slight to signify by itself that the river endured for a great length of time, other features indicate that its life was by no means short. It is to be remembered that its waters were drawn from clear lakes, that they had passed through the long channel of French River and through the basin of the modern Lake Nipissing before they

reached the col at North Bay, and that for much more than half the length of Mattawa River they had flowed through deep narrow lakes. It is certain, therefore, that they were free from the coarser grades of sediment that might otherwise have been most efficient tools of erosion. Probably, therefore, the amount of erosion accomplished by this river is relatively small for the time it flowed.

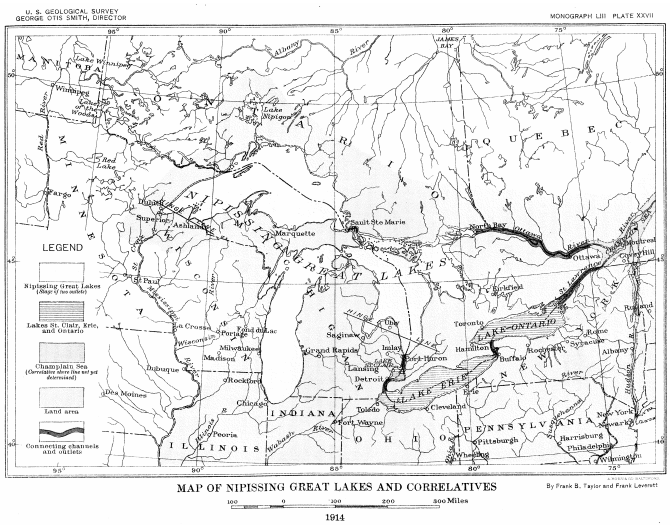
[1]Taylor, F. B., A reconnaissance of the abandoned shore lines of the south coast of Lake Superior: Am. Geologist, vol. 13, 1894, pp. 366-371.

[2]Taylor, F. B., The Nipissing-Mattawa River, the outlet of the Nipissing Great Lakes: Am. Geologist, vol. 20, f897, pp. 65-66.

[3]Much detailed information concerning Mattawa River and its lakes may be found in the report of R. W. Ells and A. E. Barlow in The physical features and geology of the route of the proposed Ottawa Canal between the St. Lawrence River and Lake Huron: Trans. Royal Soc. Canada, 1895. The report gives table of altitudes and many soundings.

[4]In the writer's early paper (The ancient strait at Nipissing: Bull. Geol. Soc. America, vol. 5, 1893, pp. 620-626) an error was in some unaccountable way made both in the map and the text. The name "Nipissing beach" is there attached to a beach lying north of the water tower and having an altitude of 743 feet, whereas the real Nipissing beach lies along the base of the bluff south of the water tower and has an altitude of 698 to 700 feet. Unfortunately this error was repeated in a later paper (The second Lake Algonquin: Am. Geologist, vol. 15, 1895, p. 166).

[5]The scoured bowlders of the Mattawa Valley: Am. Jour. Sci., 4th ser., vol. 3, 1897, pp. 208-218. The Nipissing-Mattawa River, the outlet of the Nipissing Great Lakes (abstract): Jour. Geology, vol. 5, 1897, p. 220; Science, Jan. 15, 1897, p. 90.



[Plate XXVII. Map of Nipissing Great Lakes and correlatives]

The relatively strong Nipissing beach at the head of the outlet and on the shores of modern Lake Nipissing is also significant of the time involved, for at the time of the full discharge through this outlet the expanse of the waters in the basin of the modern Lake Nipissing was very little greater than it is now and was much too small for the generation of powerful waves like those of the Great Lakes. The strong beach in this basin is therefore an indication that wave action lasted for a considerable time. Account must also be taken of the great strength of the Nipissing beach near the isobase of North Bay on the north shore of Lake Superior, which seems to indicate that the water plane of the Nipissing Lakes lasted considerably longer than that of the succeeding transitional two-outlet stage.

In the early part of this closing two-outlet stage a very small discharge probably went by way of Illinois River at Chicago, for the col there is only 8 feet and the Nipissing beach about 15 feet above the modern lake. The latter measurement, however, is the top of the beach ridge, and the water surface was probably 3 or 4 feet lower. This small discharge at Chicago ceased as soon as the outlet at Port Huron had cut down 3 or 4 feet.

NIPISSING BEACH.

NAME.

The name "Nipissing beach" has from the first been applied to the shore line now known to have been formed during the two-outlet stage of the lakes, when the discharge was deserting North Bay and returning to Port Huron and the Nipissing Great Lakes were coming to an end. This shore line is therefore, in reality, the beach of a transition stage, but it is so strongly developed and is so prominent around all the shores of the upper lakes that it has become firmly known as the Nipissing beach, in spite of the fact that this name properly belongs to the slightly older beach made by the Nipissing Great Lakes when their whole discharge passed eastward to Ottawa River.

After the formation of the true Nipissing beach the whole region was differentially elevated, depressing the water plane to the north and raising it to the south of the isobase of the North Bay outlet. This isobase runs about west-northwest, and only a little of the Lake Superior of that time lay north of it. The whole area of the Nipissing Great Lakes south of this line was flooded by the backing up of the water, and the original Nipissing beach and its successors, up to the time when the Port Huron outlet equally divided the flow with the North Bay outlet, were submerged and probably to a large degree destroyed. Hence the original Nipissing beach in unmodified form is to be seen, if anywhere, only in a small area in the northeast corner of Lake Superior, and it seems easier to qualify the name of that beach by calling it the "first" or "original" Nipissing beach than to try to change the name by which the beach of the transition or two-outlet stage has come to be known. Accordingly, the established usage is followed here.

DISCRIMINATION FROM ALGONQUIN BEACHES.

The differential elevation which affected the Nipissing beach appears to have hinged on the same line as that which affected the highest Algonquin beach.[1] South of this line, therefore, in the basins of Lakes Huron and Michigan lies the area of horizontality, so far as relates to this beach. Within this area in both basins

measurements of the altitude of the Nipissing beach vary between 14 and 16 feet above present lake level, the mean being in general about 15 feet.

In the area of horizontality the relation of this beach to the Algonquin shore line is such that for short distances in many places it is impossible to distinguish the two. Both lie in horizontal planes, the Nipissing being 10 to 12 feet below the Algonquin. Where the Algonquin is represented by several strong ridges descending by short steps toward the lake, the Nipissing beach may appear as one of these ridges without any distinguishing characteristics.

This relation, however, obtains for only relatively short distances. Within a mile or two from nearly all such places some distinguishing characteristic or evidence of discordance that shows unconformity will be found. Where any considerable width of beach deposits intervenes between the Nipissing and the present shore it is likely to be occupied by rather light beach ridges set very close together, with the Nipissing beach as the uppermost. Where the Algonquin is represented by several ridges, they are as a rule heavier and less sandy than those below the Nipissing. Only where the Nipissing derived fresh material from the cutting of some great bluff or from outcrops of limestone or shale is it likely to be as pebbly or gravelly as the Algonquin.

[1]This relation seems clearly established in the basin of Lake Michigan, but owing to the difficulty of determining the Nipissing beach, it remains somewhat uncertain in the basin of Lake Huron. In the basin of Lake Superior the two hinge lines may be separated by a considerable interval.

On certain shores the Nipissing beach has been largely and in places almost wholly cut away at present lake level. This is notably the case along the east side of the "thumb" north of Port Huron, on both sides of Lake Michigan, and on the east side of Lake Huron.

DISTRIBUTION IN MICHIGAN.

Port Huron to Port Austin.—The shallow embayment between Port Huron and Lakeport has a faint Algonquin beach at its back and a stronger one a mile farther out. Outside of these the Nipissing and lower beaches complete the filling of the old bay and bring the shore to a straight line.

About a mile north of Fort Gratiot a sandy bench appears in front of the Algonquin. It extends north, widening within 2 miles to a mile and continuing with this width for about 3 miles, to about half a mile south of Lakeport, where the present lake has cut it away. The outer part of this bench is mostly slightly below Nipissing level, but back from the lake it rises gradually to the base of the Algonquin ridge. So much of it is close to the Nipissing level that it is presumably mainly of that age. Almost the whole bench is covered with fine sand, much of it wind blown and heaped into small dunes.

Northward from Lakeport the Nipissing beach has been cut away for many miles. What is possibly a very small remnant of it appears just south of Stevens Landing, 6 miles to the north; but from there northward it is gone for over 40 miles, or to a mile north of White Rock. From its beginning north of White Rock to the mouth of Cooper Creek, 3 miles north, the Algonquin beach has been cut away by the Nipissing waves, but beyond that both beaches are generally present and the Nipissing beach is substantially continuous around the remainder of the "thumb" and Saginaw Bay to Au Sable River.

Throughout this stretch the Nipissing beach is conspicuously developed in few places. For short distances it cuts into the Algonquin beaches and thus shows distinct discordance, and for a few very short distances it is cut away by the present lake. One such cutting appears about 3 miles southeast of Huron on the outer part of the "thumb." Farther on, near Grindstone City, at Pointe aux Barques, and near Port Austin it is cut away for short distances.

Port Austin to Bay City.—Between Port Austin and Caseville the Nipissing beach is so much obscured by dunes that it is not easily distinguished. Between Caseville and Bayport it is mainly sandy, but at some points is a ridge of pebbles and shingles. From Bayport past Sebewaing to Quanicassee it is generally a gravel ridge or group of ridges of nearly the same height. For several miles east of Essexville also it is gravelly.

Bay City to Au Sable River.—From Bay City northward past Lengsville to Saganing, where the hinge line of the Algonquin and Nipissing beaches crosses the west shore of Saginaw Bay, the Nipissing beach is a belt of sandy ridges half a mile to a mile from the lake shore. A mile or two north of Alabaster the cliff back of the beach is 60 to 70 feet high and the bench a quarter of a mile wide. The beach is a wave-cut bench that carries ridges to the mouth of Tawas River. Thence through Tawas and East Tawas and beyond to Au Sable River it is a low, broad ridge or belt of sandy, gravelly ridges half a mile to a mile wide. From East Tawas it lies generally about a mile back from the shore. An extensive swamp behind it stretches 6 or 7 miles northeast from Tawas Lake.

Au Sable River to Mackinaw City.—At Alabaster and Tawas the vertical separation of the Algonquin and Nipissing beaches has noticeably increased, and it continues to increase slowly northward to Alcona. Between Devil Lake and Presque Isle it increases more rapidly. The strength of the Nipissing as an individual beach becomes more and more apparent farther north as it becomes more widely separated from the Algonquin.

From Au Sable River northward the Nipissing beach runs for about 11 miles, or nearly to Greenbush, as a belt of sandy, gravelly ridges. This beach forms the retaining barrier at the southeast end of Van Etten Lake, and two of its prominent ridges inclose the long, narrow lagoon of Cedar Lake.

At Harrisville the Nipissing is cut away for a short distance, but it is well formed toward Sturgeon Point and at Alcona. Between Alcona and Ossineke the beach

carries the highway for much of the distance through a great swamp. It is strongly developed as a heavy gravelly spit a little back from the point that projects halfway between Alcona and Ossineke.

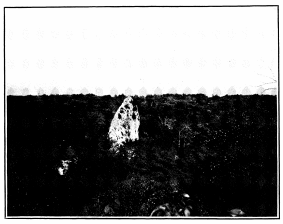
U. S. GEOLOGICAL SURVEY MONOGRAPH LIII PLATE XXVIII

A. NIPISSING BEACH GRAVELS SOUTHEAST OF ROGERS, MICH.

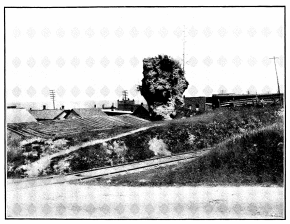
B. SLEEPING BEAR POINT, LEELANAU COUNTY, MICH.

[Plate XXVIII. *A*, Nipissing beach gravels southeast of Rogers, Mich.; *B*, Sleeping Bear Point, Leelanau County, Mich]

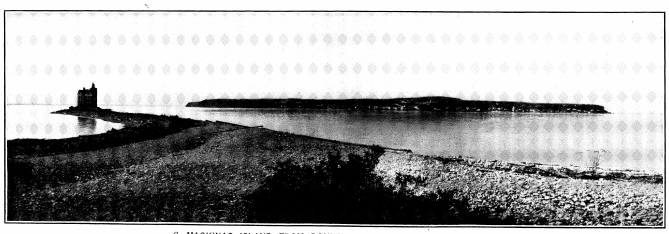
U. S. GEOLOGICAL SURVEY MONOGRAPH LIII PLATE XXIX



A. SUGAR LOAF ROCK, MACKINAC ISLAND, MICH.
A remnant of wave erosion at the Algonquin level.



B. STACK IN ST. IGNACE, MICH.
A remnant of wave erosion at the Nipissing level.



C. MACKINAC ISLAND FROM ROUND ISLAND, LOOKING NORTHWEST.

[Plate XXIX. *A*, Sugar Loaf Rock, Mackinac Island, Mich.; *B*, Stack in St. Ignace, Mich.; *C*, Mackinac Island from Round Island, looking northwest]

From Ossineke to Alpena the Nipissing shore line is a great belt of sandy ridges. The sand is mainly fine and is considerably modified by wind but forms no large dunes. It is as distinct as along the front of the Au Sable delta. South of Alpena it incloses Devil and Mud lakes. Just east of Alpena it passes off the belt of sand and enters a region of limestone thinly covered with drift, where it becomes predominantly a pebbly, gravelly ridge or belt of ridges, in some places changing to a wave-cut bench with more or less of a cliff behind it and in a few places becoming simply a wave-washed rocky slope.

At Alpena the Nipissing beach stands over 30 feet above the lake, more than twice as high as in the area of horizontality. This widening of the vertical interval below it permits better expression for the so-called post-Nipissing raised beaches below, which were formed by lakes that bore the same relations to each other and had the same outlet as those of to-day, the only difference being that the earlier lakes were somewhat more intimately connected and that the water stood higher in the Straits of Mackinac and at Sault Ste. Marie than it does now.

East of Alpena the Nipissing beach appears as a gravelly ridge lying about a mile back from the shore north of Whitefish Bay. Fragments of it extend for some distance south onto the peninsula. At El Cajon Beach, 6 miles east of Alpena, the Nipissing shore line is a strong finely formed gravel ridge at the base of a rather low wave-cut cliff. A mile farther north it forms a high gravelly barrier which shuts off Grass Lake from Lake Huron. Thence northwest to the south end of Grand Lake it runs in great strength, in places as a heavy gravel ridge at the base of a low cliff and in places as a strong wave-cut bench with only a bowldery or rocky slope for some distance below the notch. Near Bell it turns west past the south end of Grand Lake and ends against a vertical cliff of limestone which forms the west side of this lake for several miles.

On the peninsula of Presque Isle along the east side of Grand Lake the Nipissing beach is finely developed at several localities. Both north and south of Presque Isle post office there are areas over a mile wide and 2 to 4 miles long around which the beach is strongly developed as a prominent gravel ridge. It is particularly strong as a great spit or deep-water bar projecting southeast to Presque Isle from a larger island a mile or two northwest. The quantity of coarse, clean gravel in these deposits is enormous. The body of the peninsula is limestone with very little drift upon it, and this rock has been the principal source of the gravel. Beach gravels are also finely developed on the outer part of the narrow peninsula which extends to Presque Isle lighthouse, but are below the Nipissing level.

From the north end of Grand Lake the beach extends to Little Trout River mainly as a wave-cut bench and cliff, but in some places as a barrier ridge inclosing swampy land. Beyond the river it lies farther back from the shore and is chiefly a wave-cut cliff at the back of a sandy belt as far as Crawford's quarry, but between that place and

Rogers it is a wave-cut cliff with a wide bench covered with gravelly beach ridges. This accumulation of gravel is one of the finest developments of the Nipissing beach on the southern peninsula of Michigan. (See Pl. XXVIII, *A*.)

From Rogers for 7 or 8 miles northwest the cliff marking the Nipissing beach is about 40 feet high. It turns westward at Fortymile Point, from which it continues as a cliff to the east side of Hammonds Bay, where it once more becomes a broad belt of sandy and gravelly ridges which separate three or four small lakes from Lake Huron. This sandy belt terminates near Grace Harbor, beyond which cliffs freshly eroded by the present lake extend northwest and west to Cheboygan lighthouse. This part of the shore was seen only at Greens Landing, where only a narrow strip of the Nipissing bench remains. It seems probable that the Nipissing beach has been cut away by the present lake in much of this interval. A mile east of the Cheboygan lighthouse the beach turns inland and runs southwest to Cheboygan River. A great sandy flat, the west half of which is swampy, stretches 4 miles east from Cheboygan.

At Cheboygan the Nipissing shore line makes a considerable excursion inland, forming an irregular strait reaching through to the head of Little Traverse Bay. It extends up Cheboygan and Black rivers to or very nearly to Black Lake. This lake appears to stand almost exactly at the level of the beach, but the precise relationship has not been determined. The waters of Lake Huron at the time of the Nipissing Great Lakes extended as a narrow strait into the basin of Mullet Lake, around which the Nipissing beach is strong, mainly as a cut bench with a lake cliff back of it and light sandy ridges below. From the west side of the lake a narrow, swampy trough extends 5 miles northwest toward Douglas Lake. Up this the waters at that time extended for several miles.

Again contracting to a narrow strait, the waters extended up Indian River to Burt Lake, and around its steep shores the Nipissing beach is nearly everywhere distinct though not strong. Extending westward over a great swamp these waters filled the basins of Pickerel and Crooked lakes and passed through to Little Traverse Bay. At Conway the strait was a little more than a mile wide, but it broadened to 2 miles at Kegomic. The relatively great strength and sharpness of this beach on the shores of these small lakes indicate a relatively long pause of the waters at this level.

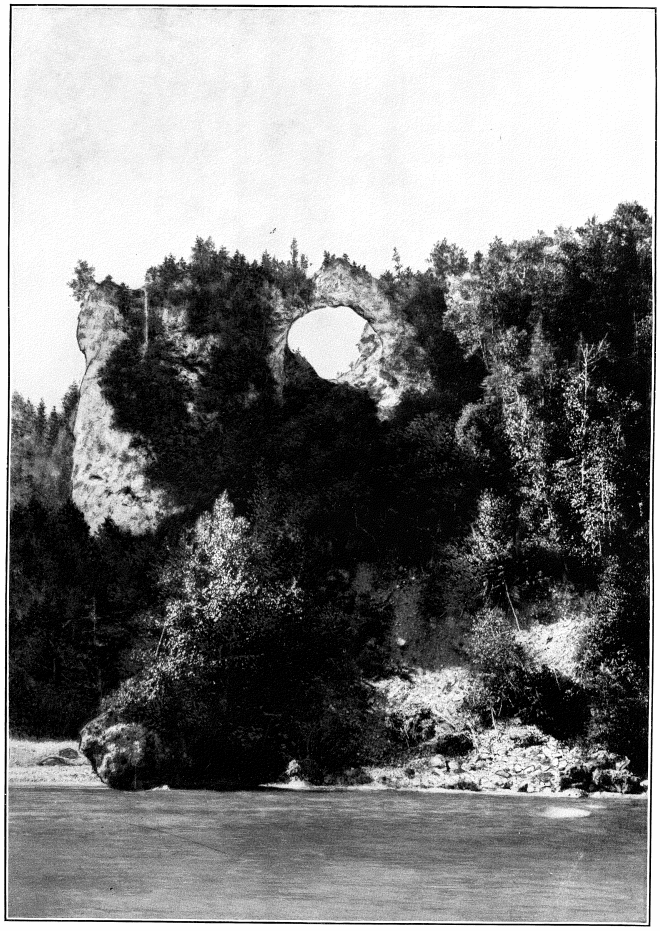
About a mile south of Cheboygan on the east side of the river many fossil shells were found a little below the level of the Nipissing beach. The following forms were identified by W. H. Dall, two or three others being too fragmentary for certain recognition: *Sphærium striatinum* Lamarck, *Unio luteolus* Lamarck, *Limnæa elodis* Say, and *Goniobasis depygis* Say.

In the western part of Cheboygan the Nipissing beach is a wide sandy bench with a cliff 10 or 15 feet high at its back. It weakens considerably southward in the narrow passage to Mullet Lake, but is still distinct. Between Cheboygan and Mackinaw City the Nipissing beach is a bench carrying strong, gravelly, and sandy beach ridges, backed by a lake cliff 10 to 40 feet high and in one or two places 70 or 80 feet high. The Michigan Central Railroad follows the beach rather closely and lies most of the way on its bench. The present lake has cut heavily into this shore and at Lakeside has cut back to the Nipissing beach. At Freedom the beach is composed of heavy sandy and gravelly ridges. A mile south of Mackinaw City it is a wave-cut bench and bluff.

Islands.—The shores of Bois Blanc Island are rather low, but the interior rises above the level of the Nipissing beach, which encircles it about a mile inland. It has not been explored above the Nipissing level, but it certainly rises high enough to record the Fort Brady and probably the Battlefield beaches, though perhaps not high enough to record any of the upper Algonquin group. The Nipissing beach is well developed on Round Island as heavy gravel ridges and a low cliff.

On Mackinac Island the Nipissing beach is well developed on the northwest part and at the southeast end in the vicinity of the village. (See Pl. XXIX, *C*.) On the east side of the island and on the southwest side along the line of the great cliffs the beach has been almost entirely cut away. From Robinsons Folly to the Episcopal Church the beach is a strongly cut bench with a cliff 40 to 70 feet high at its back. Gravelly beach ridges run at the base of the cliffy but the drift is thin over the bedrock and the ridges are rather faint. The Mission House is on the highest beach ridge at that point and the wave-cut notch is just back of the hotel at a slightly higher level. This notch runs along the base of the bluff back of the Island House, the public school, and the Marquette Monument. This beach is cut away below Arch Rock. (See Pl. XXX.)

At the Episcopal Church the beach leaves the cliff and runs southwest as a great deep-water gravelly bar. The church is on the bar near where it leaves the cliff. Back of the Astor House and the city hall the clean coarse gravels of this bar are exposed to a depth of 20 feet or more, and excavations have shown that they extend at least 10 feet deeper. Back of the village there is a considerable body of marl and fine lake clay, along the top of which the great bar extends to the southwest corner of the Government pasture field. From the direction of the Grand Hotel another lighter gravel bar extends out from the bluff at a slightly lower level and joins the one mentioned above. Behind this cuspate bar, in the Government field, lies a depression about 30 feet deep and of considerable extent, which receives much water from several large springs that issue from the bluff. In wet seasons a small pond is formed, but in dry seasons it disappears, being drained by seepage through the gravel. A little east of the Grand Hotel the beach returns again to the bluff and runs along its base as a wave-cut bench. Northwest of the hotel the bench grows narrower and is finally cut away by the modern lake.



ARCH ROCK, MACKINAC ISLAND, MICH., FROM THE LAKE.

[Plate XXX. Arch Rock, Mackinac Island, from the lake]

On the northwest part of the island, back of British Landing and for about a mile to the south, the beach is very strong. Back of the landing it forms a great deep-water barrier which runs south across a depression of considerable extent, above which it rises about 25 feet. A small swamp behind this barrier is drained by seepage through the gravel. At its south end the barrier joins a great cliff, and for nearly a mile to the south forms a wave-cut bench bearing many gravelly ridges and backed by a steep shale cliff 70 to 100 feet high. The barrier bar appears to have derived most of its material from the north by southward drifting along the shore. Around the north end of the island north from British Landing and for a mile down its east side the beach appears as a cliff 20 to 100 feet high with numerous gravel ridges on the slope below it. Pulpit Rock and Scotts Cave are developments associated with this beach.

All around the sides of the St. Ignace Peninsula the Nipissing beach is remarkably strong. Just north of the town one of the most remarkable gravel beds of this part of the country formerly stretched as a great deep-water barrier across a depression which runs westward across the peninsula. The gravel was rather coarse and very clean and white, being composed almost entirely of limestone pebbles. Most of the deposit has now been taken away and used for railroad ballast. On the west side of the peninsula from Point Labarbe to Gros Cap the beach is particularly fine. Two or three chimneys or stacks here and one in St. Ignace are relics of the shore erosion at the time of the Nipissing beach. (See Pl. XXIX, *B*.)

Mackinaw City to Traverse City.—West of Mackinaw City the Nipissing beach is a strongly cut bench and bluff on the north and west sides of McGulpin Point. On the east side of Cecil Bay the Nipissing beach runs for a short distance along the base of a cliff of limestone, but for most of the way it appears as a heavy belt of sandy ridges which forms the west barrier of French Farm Lake and continues thence west-southwest past Oneil Lake nearly to the shore of Sturgeon Bay. Here it turns south and looping around Wycamp Lake runs southwest to about 3 miles beyond Cross Village. North of Wycamp Lake it is a heavy belt of sand, but west of the lake toward Cross Village it is a high lake cliff. At Cross Village and for about 2 miles southwest it is a wide wave-cut bench with a cliff 80 or 90 feet high. Beyond this for 2 miles it has been cut away by the modern lake, the bluff, rising more than 100 feet nearly vertical from the present shore. From 2 miles north of Middle Village it runs south as a high cliff for about 5 miles, to a point 2 miles north of Appleton, where it is again cut away by the modern lake for about 1 mile, the cliff on the present shore being unusually high. About a mile northwest of Appleton it reappears with a high bluff at its back and it continues in this form along all the north side of Little Traverse Bay past Harbor Springs and Wequetonsing and with a somewhat lower cliff past Conway to the vicinity of Oden. For 2 miles, southeast of Appleton the Nipissing has cut away the Algonquin beach and has penetrated into morainic ground that rises considerably higher, producing a bluff over 125 feet high—probably the highest wave-cut bluff in, this region. The beach and cliff are also finely developed in Harbor Springs and eastward. The bench of the Nipissing beach from Cross Village to the head of Little Traverse Bay is nearly everywhere heavily paved with bowlders and stones derived from the cliff cutting and afford a rough measure of the amount of cutting accomplished. The passage eastward from little Traverse Bay is now closed by a great belt of dunes that stretches across the head of the bay, but it was not closed by the gravels of the Nipissing beach.

At Bay View the Nipissing beach is considerably obscured by wind-blown sand. In the eastern part of the village a sharp bluff rises from a wave-cut bench covered by many low ridges of sandy gravel. But here as in some other places the old shore features are deceptive, because later wave work at a slightly lower level removed the Nipissing shore line. Between Bay View and Petoskey the beach is partly obscured by dunes and partly cut away by the present lake. In Petoskey and for some distance to the west the bluff continues with its base lower than the Nipissing level. At Bay Shore and at several points to the east small fragments of the Nipissing shore line occur, but for about

3 miles west of Bay Shore the beach is again cut away by the present lake. North of Burgess it reappears as a cliff and heavy sandy and gravelly ridges, which extend for 3 miles, to about a mile north of Charlevoix, where it is again cut away by the present lake.

On Beaver Island the Nipissing beach is finely developed around all sides, except the southern, on which for a mile or two it has been cut away by the present lake. Along nearly all the western side the beach is a tremendously strong, wide, bowldery, wave-cut bench with a steep cliff 50 to 100 feet high. On the east side the bluffs are much lower and the ridges along its' base are gravelly and sandy. It is a fine gravelly bar at the old site of Cable's dock and constitutes the barrier which separates Lake Genesareth from Lake Michigan. About 3 miles north of Cable's dock it is cut away by the present lake for nearly a mile. At the north end of the island it is finely developed at Indian Point, and bars belonging to it inclose Faunt Lake on its west side. The gravel bars near the lighthouse, a mile east of St. James, are massive and finely developed.

On High Island the Nipissing beach is well developed and forms a barrier inclosing a small pond on its east side. It occurs also on Garden Island and probably on Hog Island.

The waters of the Nipissing Lakes entered Pine Lake at Charlevoix and left a light but very distinct shore fine all around its shores. For 4 miles southwest of Charlevoix the present lake has cut away the Nipissing beach. From this on to a point a little south of Norwood it is a narrow bench and cliff. At Norwood it is marked by a wide bench and a high bluff. For 3 or 4 miles beyond it is again cut away, but from a point northwest of Eastport it is part of a sandy belt that skirts the shore as far as Elk Rapids. In this vicinity the Nipissing beach lies so little above Lake Michigan and so little below the Algonquin beach that it is less conspicuous and it is more generally cut away by the present lake.

The waters of this stage entered Elk, Round, Torchlight, and probably Clam and Grass Lakes also. From Elk Rapids to the head of East Bay the beach is cut away for much of the distance, but where it remains it is mainly a narrow cut bench with a low cliff at its back. In some places, however, it is a gravelly bar. Across the south end of East Bay it is a low sandy belt.

The east side of the Old Mission Peninsula is high and steep and the water is deep near shore. It has not all been explored, but so far as seen the Nipissing beach appears to be present along the greater part of it as a narrow bench and low cliff. In some places it has been cut away by the present lake. It runs around Old Mission Harbor as a belt of low, crescentic ridges inclosing two small ponds. Along the west side of the peninsula there are more stretches of low ground, although in general the shore is rather steep. From the Mission Point lighthouse for about 3 miles southwest the Nipissing beach is well defined along the back edge of the low, sandy shore. It is also formed in moderate strength around Bowers Harbor and on Marion Island and at most places along the shore southward to Traverse City. The sandy flat which forms the neck of the peninsula just east of Traverse City is mainly an accumulation of the Nipissing beach. But for this sand the peninsula would be an island.

Traverse City to Manistee.—In Traverse City the Nipissing beach encircles the head of the bay about a quarter of a mile from the shore and passes through the south part of the business section. It appears to deflect Boardman River to the west after it leaves Boardman Lake. The beach is not seen to advantage in the city, but in the suburbs both east and west it appears as a belt of sandy ridges. Northward on the west side of the bay it is well defined for several miles and forms the principal part of the barrier that incloses the small lake behind Traverse Beach. Two or three miles north of this small lake both the Nipissing and Algonquin beaches are cut away for two intervals of half a mile each. At Lees Point the deposits of this beach form the principal parts of the projecting cusp. At Suttons Bay the Nipissing beach is a belt of low sandy gravel ridges. Toward Omena it is a well-defined storm bar which ties the headland to the mainland. Thence to Northport it is a gravelly bench and low bluff.

Although generally well defined on the shores of Grand Traverse Bay, the Nipissing beach is considerably weaker than on the more exposed shores outside. In the two arms of the bay it is clearly developed in some places, but it is generally weak, especially toward their heads.

In the vicinity of Northport the beach increases in strength, especially on Lighthouse Point. Around Cathead Bay it is probably covered by dunes. Two small ponds, Mud and Leg lakes, have been shut off by barrier bars.

Southward from Cathead Point the Nipissing beach on the west side of the peninsula has been cut away everywhere except in fragmentary embayments that now remain between truncated headlands. From the point to Leland it is gone. On Lake Leelanau it is faintly marked on both sides of the inlet and is the wide sandy terrace on which the lower part of the village of Leland is built.

The Fox Islands were not visited, but the low altitude of the beach makes it practically certain it is present unless it has been cut away. On North Manitou Island it is a fairly strong sandy, gravelly bench with a low cliff back of it along most of the east shore, but it has been cut away on most of the remaining sides. On South Manitou Island it is recorded on the east side as a belt of gravelly ridges around the harbor, but it is probably cut away at most places on the other sides.

The beach reappears 3 miles south of Leland and extends around Good Harbor Bay to within a mile of Pyramid Point. Between Good Harbor and North Unity it is a great crescentic belt of sandy gravel ridges half a mile or more wide. The barrier formed by this belt incloses Traverse Lake and a small lake west of North

Unity and has diverted the outlet of Traverse Lake 2 miles to the west.

On Sleeping Bear Bay the beach reappears about a mile north of Glen Arbor and forms well-defined sandy gravelly ridges to half a mile west of Glen Haven. Around Sleeping Bear Point and for 5 miles south the Nipissing beach is entirely removed. (See Pl. XXVIII, B.) In an embayment which begins 3 miles north of Empire and extends to that place it lies about a mile back from the shore as a belt of gravelly ridges not far below the Algonquin. Two small ponds in front of the Nipissing beach have been inclosed by modern shore drift and by dunes.

Along the bluffs at Empire the beach is entirely removed, but it begins again at Aral and runs around Platte Bay as a great belt of sandy ridges a quarter to half a mile from the shore. Around the west end of Crystal Lake the beach has been cut away.

Some low sandy ridges at Frankfort seem to belong to the Nipissing stage, but the embayment is small and wave action seems to have been weak. For 2 miles south of Frankfort the beach has been cut away, but in the small embayment at Herring Lake it occurs in faint development as sandy ridges. Beyond, it has been cut away for 2 miles, but for a mile or so north of Arcadia it is present in moderate strength as a gravelly ridge.

From Arcadia to a mile south of Portage Lake the Nipissing beach is gone. It is gone also for 3 miles north of the inlet at Manistee. Around Portage and Bar lakes, however, it is quite distinct, though not strong. Around both of these lakes the Algonquin appears to be absent. (See p. 428.)

The hinge line for the Nipissing beach on this shore appears to be at or near Herring Lake, so that places south of Herring Lake are within the area of horizontality. The identity of the beach with one farther south in Michigan, as described by Mr. Leverett; and with its extension around the south and west sides of Lake Michigan, as observed by Leverett, Alden, and Goldthwait, seems to be beyond reasonable doubt. In these latter regions it stands in the same relation to the present lake and to the Algonquin beach as does the beach described above in the south part of Lake Huron. (See p. 357.)

NIPISSING BEACH IN OTHER PARTS OF THE UPPER GREAT LAKES BASINS.

Since the writer's reconnaissance of 1893 the Nipissing beach has been studied in considerable detail on the shores of Green Bay in Wisconsin and Michigan by Goldthwait and by Hobbs. The beach is strong on those shores and is generally easy to recognize. Goldthwait measured its altitude instrument ally at many places in Wisconsin and Hobbs at several in Michigan.

In Ontario the Nipissing beach was not particularly noted by Spencer in his early work. The writer's early investigations in Ontario included this beach at numerous localities, but the more detailed work and the instrumental measurements of its altitude were made by Goldthwait and the writer in 1908. The beach is developed in great strength along the southern shores of Georgian Bay, especially on the eastern shore of the Saugeen Peninsula and the north shore of the Penetang Peninsula. The region of Lake Simcoe was elevated before the time of the Nipissing beach and was much too high to record it. The beach extends a few miles above Coldwater from the head of Matchedash Bay, but at this village it lies 83 feet below the surface plane of Lake Simcoe.

The writer's early reconnaissance included observations on the Nipissing beach at many points on the northern peninsula of Michigan and on the south shore of Lake Superior. Since that time Russell and Lane have made some further studies and Mr. Leverett in particular has made a much more thorough investigation. The beach has been found in strong development along the entire stretch of the south shore, except at the west end near Duluth, in which vicinity it appears to pass under the level of the present lake. Mr. Leverett finds it apparently passing beneath the present lake about at Washburn, Wis., on Ashland Bay, and again on the west slope of the Bayfield Peninsula, the greater part of the peninsula showing the mark of this beach.

In the area of horizontality in the basins of Lakes Huron and Michigan the Nipissing beach is about 15 feet above present lake level. The uplift which deformed this beach raised the barrier at Sault Ste. Marie so as to place Lake Superior 20 feet above Lake Huron or about 5 feet above the level of the beach in the area of horizontality to the south. From this it may be inferred that if the area of horizontality reaches any part of Lake Superior (and it is obvious that it could do so only at the west end of the lake, where the Nipissing beach descends to or passes below the present lake level), the beach made there before the barrier at Sault Ste. Marie was raised to its present height, supposing open connection at that time with Lake Huron, would now be submerged about 5 feet. This, apparently, is the present condition at the west end of the lake. But, as with the hinge lines in the Lake Huron and Lake Michigan basins, the apparent line here is determined by the backing up of the water, the real hinge being now submerged and lying a few miles farther south.

During the time of the full discharge of the Nipissing Great Lakes at North Bay a low stage prevailed in the region of horizontality, and the beach made then is below the two-outlet Nipissing beach and is now submerged. The same low stage affected the west end of Lake Superior, the lake surface at Duluth being probably 50 to 60 feet lower then than now, as indicated by the old bed of St. Louis River, now drowned in the bay west of Duluth. In all probability Lake Superior was then separated from Lake Huron by a sluggish river, which was later turned into a strait by drowning during the two-outlet stage, the deformation or tilting now seen in the Nipissing or two-outlet beach comprising only that

part of the uplift which occurred after the two-outlet stage had been established. It was therefore this later uplift which produced the drowning of the Nipissing or two-outlet beach at Duluth and raised Lake Superior to a position 20 feet above Lake Huron.

The Nipissing beach is everywhere so little above the water surfaces of the present lakes that it is almost always near the present shore, and hence is easily reached. In the northeast corner of Lake Superior it is 110 feet above the lake, but that shore is a high coast with steep slopes, so that even there it is near the present shore. It is only in the labyrinth of islands along the east side of Georgian Bay and the North Channel of Lake Huron and especially up the valley of French River to Lake Nipissing and North Bay that the Nipissing beach lies any distance inland. All of these northern regions are still in a wild forested state, and it is practically impossible to trace any of their beaches continuously.

Excepting Coleman's observations on the high beaches, the east coast of Lake Superior, between Peninsula Harbor and Sault Ste. Marie has not been explored. But Lawson and the writer have observed this beach at many-places on the north and northwest shores. It was found also at Sault Ste. Marie, at Thessalon, at Algoma Mills on the North Channel of Lake Huron, and at North Bay.

Although these observations of the Nipissing beach on the northern shores are widely scattered, some of them being separated by intervals of more than 100 miles, yet this beach is so distinguished from all others by its great strength and individual characteristics that its identity seems to be beyond doubt at every locality where it has been reported. From these scattered observations some interesting facts have been deduced, the most important being that the strength of the Nipissing beach increases very perceptibly toward the north, attaining its greatest development in the most northerly part of the Lake Superior basin. This is significant when it is noted that the isobase of North Bay passes only a few miles south of the extreme northeast corner of Lake Superior, and that the original Nipissing beach was submerged in all the region south of the isobase of North Bay by the uplift that shifted the discharge to Port Huron. Along the isobase of North Bay the waves were at work not only during the beach of the two-outlet stage (known as the Nipissing beach), but before that, from the very beginning of the discharge eastward by North Bay. The character of the outlet channel in the Mattawa Valley shows that the whole discharge passed that way for a considerable time. South of the isobase of North Bay the only beach of this stage of the lakes now to be seen is that of the closing two-outlet stage. North of the isobase the beach of the two-outlet stage lies below the original beach of the North Bay outlet, but the isobase passes so near the northeast corner that the area to the north, in which the beaches are exposed, is very small, probably too small to show the relations clearly. Nevertheless, the greater strength and distinctness of the beach in the region of the isobase afford substantial proof of the correctness of this interpretation.

ALTITUDE.

In the Michigan and Huron basins the deformed portion of the Nipissing beach appears, as already stated (p. 449), to hinge on the same line as the Algonquin. South of the hinge line in both basins the Nipissing beach has an altitude of 595 to 597 feet, the average being about 596 feet. The observed variations in altitude are entirely within the normal variations in the height of a beach ridge made by the waves of a lake subject only to climatic and wind variations. The altitude of the Nipissing beach where measured instrumentally en the north and west of the southern peninsula of Michigan is given in the following tables, to which are added altitudes at North Bay, Ontario, and Sault Ste. Marie. The altitude of Lake Huron is taken as 581 feet.

Altitudes of Nipissing beach on the north and east of Lake Michigan.

Locality.	Altitude above sea level.	Height above Lake Huron.	Authority.
	Feet.	*Feet.*	
Sault Ste. Marie	[a] 651	70	Leverett.
Detour	[a] 632	51	Russell.
Mackinac Island (storm bar)	634	53	Goldthwait.
Mackinac Island (average normal bars)	631	50	Goldthwait and Taylor.
St. Ignace	628	47	Goldthwait.
Mackinaw City	629	48	Do.
Beaver Island (north)	623	42	Do.
Beaver Island (south)	616	35	Do.
Harbor Springs	615	34	Do.
Burgess	613	32	Do.
Charlevoix	611	30	Do.
Norwood	608	27	Do.
Northport	606	25	Do.
Omena (storm bar)	609	28	Do.
Leland	604	23	Do.
Suttons Bay	607	26	Do.
Elk Rapids	606	25	Do.
Acme	601	20	Do.
Traverse City	602	21	Do.
Aral	600	19	Do.
Frankfort	599	18	Do.
Herring Lake (gravel belt)	595	14	Do.
Arcadia	595	14	Do.
Onekama	597	16	Do.
Bar Lake	597	16	Do.

[a] By aneroid barometer.

The differences in the measurements on Mackinac Island are so great as to leave some doubt as to the height of the normal beach. Estimated from all the forms that seem normal and excluding the extra high storm beaches, the height is about 50 feet above the lake.

The beach at Omena is also a high storm bar. The measurements at Frankfort and Herring Lake are both on ridges that are strong but are not sharply defined.

On the west side of Lake Huron the altitude of the Nipissing beach was determined instrumentally only by Gregory and Cooper. The other readings are by either aneroid or hand level. The altitudes are given in the following table:

Altitudes of Nipissing beach on the north and west of Lake Huron.

Locality.	Altitude above sea level.	Height above Lake Huron.	Authority.
	Feet.	*Feet.*	
Cheboygan [a]	626	45	Taylor.
Hammonds Bay [a]	626	45	Do.
Rogers	621	40	Gregory.
Crawford's quarry	619	38	Do.
Thompson Harbor (storm bar)	(?) 635	54	Do.
Alpena [b]	613	32	Taylor.
Ossineke	(?) 614	33	Gregory.
Harrisville [a]	604	23	Taylor.
Greenbush [a]	603	22	Do.
Oscoda [a]	601	20	Do.
Tawas [a]	599	18	Do.
Alabaster [a]	599	18	Do.
Au Gres [a]	597	16	Do.
Kawkawlin [a]	595	14	Do.
St. Charles	597	16	Cooper.
Sebewaing [a]	597	16	Taylor.
Bayport [a]	596	15	Do.
Grindstone City [a]	598	17	Do.
White Rock [a]	595	14	Lane.
Port Huron [a]	595	14	Taylor.

[a] By hand level. [b] By aneroid barometer.

On the west side of Lake Michigan the Nipissing beach north of the hinge line was determined instrumentally at a number of places by Goldthwait and at a few on the Garden Peninsula by Hobbs. Some determinations

were made by Russell and the writer by aneroid and hand level.

Altitudes of Nipissing beach on west side of Lake Michigan.

Locality.	Altitude above sea level.	Height above Lake Michigan.	Authority.
	Feet.	*Feet.*	
Rapid River	613	32	Hobbs.
Garden Bay	613	32	Do.
Burnt Bluff [a]	611	30	Russell.
Escanaba	609	28	Hobbs.
St. Martins Island	605	24	Do.
Washington Island	603	22	Goldthwait.
Detroit Harbor	602	21	Do.
Hedgehog Harbor	603	22	Do.
Ellisons Bay	602	21	Do.
Sister Bay	599	18	Do.
Ephraim	602	21	Do.
Fish Creek	602	21	Do.
Juddville	598	17	Do.
Egg Harbor	601	20	Do.
Baileys Harbor	602	21	Do.
Jacksonport	600	19	Do.
Graceport	600	19	Do.
Sturgeon Bay	598	17	Do.
Clay Banks	599	18	Do.
Algoma (4 miles north)	597	16	Do.

[a] By hand level.

The hinge line appears to be about at Algoma. South of this is the area of horizontality, in which measurements of the height of the Nipissing around the south end of Lake Michigan vary from 13 to 17 feet above the present lake level.

In Ontario the altitude of the Nipissing beach has been measured instrumentally by Goldthwait at numerous localities. One hand-level measurement by the writer is included.

Altitudes of Nipissing beach in Ontario.

Locality.	Altitude above sea level.	Height above Lake Huron.	Authority.
	Feet.	*Feet.*	
North Bay	698	117	Goldthwait.
Algoma Mills [a]	666	85	Taylor.
Coldwater	635	54	Goldthwait.
Wyebridge	637	56	Do.
Penetang	638	57	Do.
Collingwood	631	50	Do.
Thornbury	631	50	Do.
Meaford	629	48	Do.
Hogg	625	44	Do.
Presque Isle	625	44	Do.
Owen Sound	626	45	Do.
Wiarton	634	53	Do.
Hope Bay	635	54	Do.
Lions Head	636	55	Do.
Dyers Bay	640	59	Do
Southampton	617	36	Do.
Port Elgin	614	33	Do.
Inver Huron	608	27	Do.
Kincardine	600	19	Do.
Kettle Point [b]	596	15	Do.
Sarnia [b]	597	16	Do.

[a] By hand level. [b] In the area of horizontality.

On the south shore of Lake Superior the altitude of the Nipissing beach has been determined by hand level by Mr. Leverett and the writer as follows:

Altitudes of Nipissing beach on the south.

[By hand level except as indicated.]

Locality.	Altitude above sea level.	Height above Lake Superior.	Authority.
	Feet.	*Feet.*	
Sault Ste. Marie	651	51	Leverett.
Iroquois Point	645	45	Do.
Grand Marais	635	35	Do.
Munising	629	29	Do.
Marquette	628	28	Do.
L'Anse	620	20	Do.
Lac la Belle	635	35	Taylor.
Eagle Harbor	640	40	Do.
Copper Harbor	640	40	Leverett.
Houghton	626	26	Taylor.
Portage Canal, north end [a]	630	30	Do.
Ontonagon	616	16	Leverett.
Bayfield, Wis	606	6	Do.

[a] By aneroid.

On the north shore Lawson measured the altitude of the Nipissing instrumentally in many places, but did not recognize the beach from place to place. Nevertheless, by the characters which he described it is possible to identify it with a fair degree of accuracy at most of his localities.[1] The writer afterward visited a number of Lawson's localities and verified previous interpretations by further studies of the characteristics of the beaches between Fort William and Peninsula Harbor which had been judged to be the Nipissing.[2] The beach seems well identified at the following places, some of which were determined by Mr. Leverett in 1911:

Altitudes of Nipissing beach on north shore of Lake Superior.

Locality.	Altitude above sea level.	Height above Lake Superior.	Authority.
	Feet.	*Feet.*	
Beaver Point, ordinary beach [a]	606	6	Leverett.
Engles Cove, storm beach [a]	611.5	11.5	Do.
Cove near Baptism River, storm beach [a]	616	16	Do.
Keinedys Cove, ordinary beach [a]	609.5	9.5	Do.
Little Marais, ordinary beach [a]	612	12	Do.
Little Marais, storm beach [a]	618	18	Do.
Pork Bay, ordinary beach [a]	612	12	Do.
Thomasville, ordinary beach [a]	615	15	Do.
Thomasville, storm beach [a]	620	20	Do.
Cross River, ordinary beach [a]	618	18	Do.
Cross River, storm beach [a]	623	23	Do.
Lutzen by Poplar River, ordinary beach [a]	623.5	23.5	Do.
Lutzen, storm beach [a]	627.5–629	27.5–29	Do.
Carbon Point, ordinary beach [a]	622.5	22.5	Do.
Carbon Point, storm beach [a]	628	28	Do.
Good Harbor Bay, ordinary beach [a]	627	27	Do.
Grand Marais, ordinary beach [a]	630	30	Do.
Grand Marais, storm beach [a]	638	38	Do.
Red Cliff camp, ordinary beach [a]	634	34	Do.
Horseshoe Bay	639	39	Lawson.
Chicago Bay, ordinary beach [a]	638	38	Leverett.
Chicago Bay, storm beach [a]	644	44	Do.
Grand Portage	638	38	Lawson.
Mount Josephine	643	43	Do.
Wauswaugoning Bay	644	44	Do.
McKellars Point	648	48	Do.
Carp River	652	52	Do.
Pigeon Point	657	57	Do.
Port Arthur	661	61	Do.
Mazokama	698	98	Do.
Simpson Island	693	93	Do.
Terrace Bay	696	96	Do.
Jackfish Bay	703	103	Do.
Peninsula Harbor [b]	710	110	Taylor.

[a] By hand level. [b] By aneroid.

[1] Taylor, F. B., The Nipissing beach on the north Superior shore: Am. Geologist, vol. 15, 1895, pp. 304-314. This is a study of Lawson's results as set forth in his paper referred to above.

[2] Notes on the abandoned beaches of the north coast of Lake Superior: Am. Geologist, vol. 20, 1897, pp. 111-128.

If rightly identified the altitude of the Nipissing beach is the same at Mazokama as at North Bay, and is therefore on the isobase at the former place. The nearest strand to the Nipissing at Nipigon, as indicated by the production of its plane from other places where it is better identified on this shore, is 8 or 10 feet lower than would be expected and lacks distinctive character. It is therefore rejected here, though given a probable place of identification in the review of Lawson's paper. Peninsula Harbor lies about 13 miles north of the isobase of North Bay, and the extreme reach of the lake waters northeastward from that line is 14 to 15 miles. The isobase runs about N. 65° W. to S. 65° E., and the tilt line or line of greatest rise therefore runs about N. 25° E.

POST-NIPISSING UPLIFTS OF NORTHERN LANDS.

From the northward rise of the Nipissing beach it appears that uplift of the northern lands did not cease with Lake Algonquin, but continued, though perhaps with less rapidity, for some time after the beginning of the Nipissing Great Lakes. It affected the lands bordering Lake Superior, the northern third of Lake Michigan, and all of Georgian Bay and Lake Huron except Saginaw Bay and the south half of the south arm of Lake Huron. (See fig. 9.)

Goldthwait's measurements on the two sides of Lake Michigan seem to show that the hinge of the uplift that deformed the Nipissing beach is there on the same line as that which deformed the Algonquin beach. In the basin of Lake Huron this relation has not yet been so clearly made out and some doubt remains as to whether the hinge line of the Nipissing beach is not a few miles farther north than the Algonquin. In a small area at the west end of Lake Superior the plane of the Nipissing beach appears to pass below the level of the lake. In the basins of Lakes Michigan and Huron the Nipissing or two-outlet beach comes to an attitude of horizontality at about 596 feet above sea level. This level in the basin of

Lake Superior is 4 or 5 feet below the water surface. Agreeing with this interpretation, Mr. Leverett found that the plane of the Nipissing beach is only 6 feet above present lake surface 4 miles south of Bayfield and that, declining southwestward, it intersects the surface at the head of Ashland Bay. A line drawn from this intersection parallel with the isobases of the Nipissing beach (about N. 65° W.) intersects the north shore about 15 miles east of Duluth. (See also p. 456.)

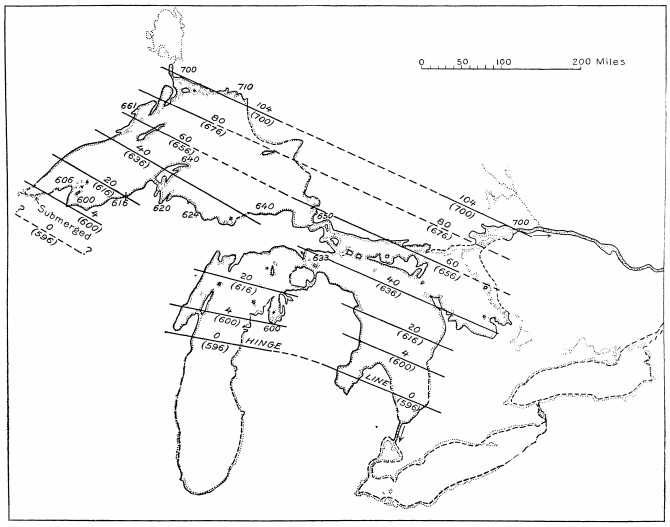


FIGURE 9.—Map of the isobases of the Nipissing Great Lakes at the two-outlet stage. The numbers above the isobases are altitudes above the horizontal or unaffected part of the beach south of the hinge line; the numbers in parentheses below the isobases are altitudes above sea level.

The hinge line of the Algonquin beach at the west end of Lake Superior appears to be located at an undetermined distance south of Duluth and does not appear to fall within the basin of the lake unless the descent of the Algonquin plane southward is much more rapid than has been supposed. The south slope of the Lake Superior basin south of Duluth is largely covered with pebbleless lake clays which bear poor records of the beaches, showing only as wave-cut benches with low cliffs and narrow sloping terraces. For this reason, and on account of the forested condition of most of the country, the Algonquin beach has not yet been surely determined. If the beach runs westward from the region of the Keweenaw Peninsula without notable turning (and such northward bending is not suggested by the isobases of the beaches of Lake Duluth as determined by Mr. Leverett[1]) then the Algonquin beach 12 to 15 miles south of Duluth should have an altitude of something more than 700 feet above sea level or more than 100 feet above the lake, indicating a relatively wide separation of the hinge lines of the Algonquin and Nipissing beaches, amounting perhaps to as much as 100 miles.

A characteristic of the Nipissing beach is the remarkable evenness of its plane over the whole area over which it has been uplifted and tilted. Its variations from a true plane inclined slightly southwestward are, so far as now known, few and small. At North Bay the plane has been uplifted 102 to 104 feet from the horizontal and at Peninsula Harbor, at the extreme northeast angle of Lake Superior, 115 feet (aneroid); and the uplift has produced the effect of simple tilting of a rigid plane and with little irregularity or warping.

CORRELATIVES OF THE NIPISSING GREAT LAKES.

LAKE ST. CLAIR.

During the time of the Nipissing Great Lakes Lake St. Clair was at low stage; in fact, it was almost if not wholly abandoned as a lake. Only a sluggish, relatively small stream with locally expanded ponds or swampy parts remained. (See p. 496.)

LAKE ERIE.

The height of the water in a lake is in some degree dependent upon the volume of discharge at its outlet, especially where the variation of volume is as great as 700 per cent. (See p. 496.) The effect is also largely dependent upon the shape of the outlet; if this is broad and shallow the effects of variation in volume will be slight, but if it is deep and narrow they will be relatively large. Where Niagara River passes over the ledges of the Onondaga limestone at Black Rock, its channel contains a narrow and rather deep passage which probably carried the whole of the stream at the low stages, and this resulted in a lowering of the lake level more than if the rock sill had been broad and even. Lake Erie alone furnishes about 15 per cent (nearly one-seventh) of the whole volume of Niagara River, and the conditions on the sill at the outlet are such that a variation of 700 per cent in volume would markedly affect the level of the lake. This variation is therefore, in all probability, the chief explanation of the drowning which Moseley[2] found at Sandusky, Ohio, and on the islands in Lake Erie. He describes an old land surface with stumps of trees and other vegetable remains now submerged 10 to 12 feet, and also narrow creek beds which are sharply trenched into the bottom of Sandusky Bay and are traceable across its whole width.

[1]Outline of history of the Great Lakes: Twelfth Rept. Michigan Acad. Sci., 1910, map on p. 27.

[2]Moseley, E. L., Lake Erie enlarging; the islands separated from the mainland in recent times: Lakeside Magazine, Lakeside, Ohio, vol. 1, 1898. pp. 14-17. Also Formation of Sandusky Bay and Cedar Point: Proc. Ohio State Acad. Sci., vol. 4, 1904, pt. 5, pp. 179-238.

Thus Lake Erie was at low stage during all the time of the Nipissing Great Lakes, and if, as seems certain, the Fort Erie beach had been made previously (during the time of Lake Algonquin) with the waters at high stage, then the outlet, with the level of the lake at low stage, was probably not less than 10 or 15 feet below the Fort Erie beach. This beach is now 13 or 14 feet above lake level at Fort Erie. It declines in altitude very gradually westward, but the nodal point where it passes below lake level is not yet known. The lake is now at high

stage and Moseley's submerged land, drowned 10 to 12 feet, is almost certainly the low-stage correlative of the Nipissing beach in the upper lakes. If this be true, no recent uplift of the land at Buffalo is required to explain the amount of drowning which Moseley finds around the west end of the lake, but only a change from the low stage during the Nipissing Great Lakes to the present high stage. The status of the Fort Erie beach in the west end of the lake has not yet been determined. It seems probable that it is somewhat lower than the recent low-stage beach of Lake Erie, though the relation of the earlier beaches to the Algonquin and earlier hinge lines (pp. 442-443) indicates that it is probably not more than 10 to 15 feet lower.

It was stated above (p. 442) that after Lake Erie had become an independent nonglacial lake it had three stages, the, third ending with the end of Lake Algonquin. Later, it had a fourth stage, which resulted from the opening of the outlet at North Bay, Ontario, by the retreat of the ice sheet. This took the whole discharge of the upper lakes away from Lake Erie and established its second low stage, which was 10 to 12 feet lower than present lake level and which lasted throughout the time of the Nipissing Great Lakes.

CHAMPLAIN SEA.

The channel of the Algonquin outlet river appears to descend to or possibly below present lake level at Trenton. (See p. 444.) This river ceased to flow when the Kirkfield outlet was abandoned, and the northward splitting of the Algonquin beaches shows that the greater part of the uplift occurred not long after this event, or during the Port Huron-Chicago stage of Lake Algonquin. Thus, if the Algonquin River is rightly interpreted as extending to Trenton, Lake Iroquois, Lake Frontenac, and Gilbert Gulf seem to have disappeared before the beginning of the Nipissing Great Lakes, and the greater part of the elevation of the land at Prescott and Trenton, Ontario, occurred before that time. Indeed, it is not certain but that the Champlain Sea had nearly disappeared and all the uplift, except perhaps about 20 feet, had been accomplished. It seems probable that the marine correlative of the Nipissing beach of the upper Great Lakes is not far above present sea level and might be looked for along the lower tidal St. Lawrence.

Goldthwait[2] found a heavily developed shore line, which he calls the Micmac beach, extending for 200 miles below Quebec along the south side of the lower St. Lawrence. In 1912 this beach was seen by the writer at many points on the north side between Quebec and Tadousac. It is strong and continuous between Quebec and Ste. Anne de Beaupre. It is 20 feet above the level of the Gulf of St. Lawrence and is horizontal so far as seen. Wave action at this level was evidently powerful and prolonged, for the sea cliff is in places 100 feet high, cut in shale, and the wave-cut bench is everywhere unusually wide. The Micmac beach resembles nothing in the Great Lakes region so much as the Nipissing beach, but its actual correlative in the lakes region is not yet known. Further studies in the field will be necessary before the later marine shore lines of the St. Lawrence Valley can be safely correlated with beaches in the region of the Great Lakes.

[2]Goldthwait, J. W., The 20-foot terrace and sea cliff of the lower St. Lawrence: Bull. Geol. Soc. America, vol. 22, 1911. pp. 723-724.

CHAPTER XXIII. POST-NIPISSING GREAT LAKES AND SUMMARY OF GLACIAL AND NONGLACIAL LAKES.

By FRANK B. TAYLOR.

POST-NIPISSING GREAT LAKES.

POST-NIPISSING BEACHES.

The Nipissing beach of the two-outlet stage was the last shore line of the Nipissing Great Lakes. It was a transition beach, and when the discharge of the upper lakes abandoned North Bay entirely and had returned to Port Huron the Nipissing Great Lakes as here defined ceased to exist and the post-Nipissing or present stage of the upper lakes was inaugurated. Since that time there has been no change of outlet, but only a slow uplift in the north and a gradual lowering by erosion of the outlet. There was probably at first a very small overflow at Chicago, but it soon ceased as St. Clair River deepened its channel. The whole deepening since the time of the Nipissing beach has lowered Lakes Michigan and Huron 11 or 12 feet, and by the time the lowering had reached 3 or 4 feet the discharge at Chicago had ceased entirely.

The existence of beaches later than the Nipissing is due to the continuance of differential uplift, by which the Nipissing beach at North Bay has been raised to an altitude of 698 or 700 feet, while in the area of horizontality it has remained at an average altitude of about 596 feet. Thus, since the upper lakes attained their present arrangement the uplift of the land at North Bay has amounted to 102 to 104 feet, and it is to be remembered that while this amount of uplift was going on in the north, Lakes Huron and Michigan south of the hinge line were lowered by erosion 11 or 12 feet, allowing 3 feet for the height of the beach above the water.

For some distance north of the hinge line the beaches due to this uplift are not well displayed, being compactly set over the whole slope below the Nipissing beach, and being therefore difficult to recognize individually for more than a short distance. Farther north, at Mackinac Island, however, the uplift has been 38 or 39 feet, and the beaches begin to be distinctly separated. Still farther north they are still more distinct, especially near Sault Ste. Marie and along the north channel of Lake Huron.

At present, however, the data accumulated do not warrant any detailed description of these beaches. In fact, nearly all of them are of about the same strength, and none offers any certain clue by which it can be followed and identified from place to place. Nevertheless, in all probability, careful study of these youngest raised beaches would yield results of great value in the study of the most recent earth movements that have affected the Great Lakes region.

Among the beaches below the Nipissing is the Algoma, which has been somewhat doubtfully identified at many localities. It was first observed by the writer at Algoma Mills on the north channel of Lake Huron in 1893. At that place its altitude by aneroid was made about 630 feet or about 50 feet above Lake Huron. This beach is probably represented at Sault Ste. Marie by a beach at 620 feet, observed by Mr. Leverett. At Mackinac Island a beach which seems to correspond to this has an altitude of 605 feet, and at a number of places farther south it seems to be satisfactorily identified. Hobbs reports a beach corresponding to the Algoma at 599 feet at Clamshell Harbor, on the Garden Peninsula, northern Michigan. In the area of horizontality a beach among the several light ridges below the Nipissing and having an altitude of 591 to 592 feet (10 or 11 feet above the lake) is generally a little stronger than the rest and is regarded as the Algoma beach. The only basis of its identification, however, is the fact that it is a trifle stronger than the others above and below it.

A beach below the Nipissing and bearing about the same relation to it as the Algoma beach in the Lake Huron basin was found by the writer in 1895 at a few places on the north shore of Lake Superior.[1] It was thought at the time that this beach hinged on the outlet at Sault Ste. Marie and that it marked the first establishment of that outlet and its isobase as the controlling or nodal line for the tilting in that basin. For this reason the beach was called the Sault beach. This correlation, however, now seems somewhat uncertain, because all the points where the beach was observed are on the north shore far away from Sault Ste. Marie, where Mr. Leverett has since found the Algoma beach at an altitude of 620 feet, or only 20 feet above the level of Lake Superior. It seems not improbable, therefore, that the shore line which the writer called the Sault beach is in fact the Algoma beach extending through a narrow strait into the basin of Lake Superior. If it were permissible to suppose that the sill at Sault Ste. Marie has been cut down 20 feet since it first became functional, it would at first have held the water at about the level of the Sault beach. The coincidence of the two beach planes would then be accidental. It does not seem probable, however, that Lake Superior could have been held 20 feet above its present level for any length of time by the barrier of drift at Sault Ste. Marie. The present barrier is of bedrock and affords no evidence of having been perceptibly lowered by the river in postglacial time. The drift that rested on the bedrock must have been quickly removed, and it seems probable, therefore, that the Sault beach is in reality identical with the Algoma.

LAKE ERIE.

At the beginning of the present lake stage Lake Erie had become an independent body and had passed through four stages. At the beginning of the present stage renewed uplift of northern lands had raised North Bay, closed the outlet at that place, and brought the Nipissing Great Lakes to an end. This sent the whole discharge of the upper lakes back to Port Huron and Lake Erie, gave Lake- Erie a large-volume discharge at Buffalo, and established its fifth stage (third high stage). The uplift which produced this change had little or no effect at Buffalo and probably produced no drowning in the western part of the lake, for its hinge line appears to have passed a little to the north of the outlet.

Through all the changes that have affected Lake Erie since it became an independent body the rock sill at Buffalo has lowered not more than 10 feet. This lowering was probably accomplished mainly during the two low stages, which lasted longer than the high stages and made more effective attacks on the sill, for during the high stages the volume of water was so great that the stream glided over the sill as a smooth rapids, whereas at the low stages a low cascade or waterfall came into being and attacked the rock ledge more effectively. The narrow, deep channel through the ledge was probably made in this way. The crest of the Fort Erie beach ridge, which marks the first stage (a high stage) of Lake Erie after its separation from Lake Ontario, is now 13 to 14 feet above the lake at Fort Erie, Ontario. Assuming the average height of the beach ridge to have been 3 or 4 feet above the water surface and storm beaches somewhat higher, it is evident that the lake level at the outlet has lowered not more than 10 feet since the time of separation.

RECENT UPLIFT AND PRESENT STABILITY OF THE LAND.

GENERAL EVIDENCES OF PROGRESSING OR VERY RECENT UPLIFT.

It used to be thought that the uplifts which have deformed the old water planes of the Great Lakes progressed at a substantially uniform rate and hence were distributed more or less evenly throughout the whole existence of the lakes. This conclusion, however, is not justified by the facts now known. Although some slight uplift took place before the time of Lake Algonquin, the great movement did not begin until a short time before the abandonment of the Kirk-field outlet. Its greatest activity was during the construction of the Battlefield beaches, for most of these are rather weak and are separated by wider barren or only faintly wave-washed vertical intervals than are those of any other group. The movement of elevation was much slower during the making of the upper group of Algonquin beaches, and it was also slower during the making of the

Fort Brady group. It seems again to have been very much slower, if indeed it did not entirely cease for a time, during the making of the original Nipissing and the Nipissing two-outlet beaches. It was slow also after the time of the two-outlet Nipissing beach.

[1]Notes on the abandoned beaches of the north coast of Lake Superior: Am. Geologist, vol. 20, 1897, p. 127.

Judgment as to the rate of recent or progressing uplift, however, depends much on the place of observation. At Mackinac Island and farther south recent close-set, well-developed beaches give the impression that the uplift was very slow and that the beaches had a long time to form. But on the north shore of Lake Superior the beaches below the Nipissing are not well developed and might be supposed to indicate that the land rose too rapidly for the making of beaches of any strength. Locally, however, this is due largely to poor supply of materials. The Nipissing beach itself is well developed only in recesses of the rocky shore, for the hard rocks of this coast were not much affected by the waves and many stretches were bare of drift.

It has been assumed by some that uplift has gone on in recent times at a substantially uniform rate and that it is still progressing. The spasmodic movements in the past cast some doubt on this assumption, although it is of course possible that both spasmodic and slow movements took place. On the other hand, the unbroken series of rather light beach ridges between the Nipissing beach and the present shore seems to show very recent and possibly still continuing uplift in the northern part of the basins. There are some reasons, however, for believing that uplift of the land is not now in progress and has not been for at least 100 or 200 years. If differential uplift, like that which tilted the Nipissing beach, is now in progress it would affect the north sides of the lake basins most and would die out at the hinge line.

Indirect effects, however, would tend to extend over the area south of the hinge line, for those lakes which have their outlets located north of the hinge would have their waters backed up on their southern shores. If the outlets were near the hinge line the uplift would be slight and the drowning effects might be negligible, but at distances of 100 to 200 miles north the effects, if uplift is now in progress, ought to be perceptible in a few centuries, even if not certainly measureable in 50 or 60 years. It is significant that some of the strongest evidences suggesting progressing or very recent uplift have been found on the northerly shores, most notably at the mouth and on the lower course of Nipigon River and of certain streams on the north shore of Lake Huron.[1] These evidences seem to show very recent or progressing emergence of the land, but, like the indirect evidences derived from the drowning of southwestern shores, they give no definite time relations nor rates of uplift. It should be noted that the distribution and character of possible recent and progressing uplifts in this region are distinctly limited, for the uniformity of the tilted water plane marked by the Nipissing beach shows conclusively the absence of notable warping or locally restricted uplifts; if any measurable movement has occurred recently or is now in progress it must be of the character of widespread tilting, affecting as a unit an extensive area north of the hinge line.

Indirect evidence derived from features indicating recent or progressing drowning of southwestern shores is more ample in amount but perhaps less definite in its significance. Great barrier bars and spits like Minnesota Point, at Duluth, Minn.; Chaquamegon Point, near Ashland, Wis.; Cedar Point, near Sandusky, Ohio; the point at Rondeau, Ontario; Presque Isle, at Erie, Pa.; Long Point, at Port Rowan, Ontario; Burlington Beach, near Hamilton, Ontario; and Toronto Island, at Toronto, Ontario, seem surely to indicate either relative permanence of water level or only very slow drowning. The bars at Duluth, Sandusky, Rondeau, Erie, and Port Rowan are in the area of horizontality for the later uplifts, but those near Ashland, Hamilton, and Toronto are north of the hinge line but not far from it, Toronto being the farthest at a distance of about 60 miles. All of these places would be subjected to drowning by northern uplifts affecting the outlets of the lakes in which they occur, and it is a notable fact that all of the great bars mentioned are on those lakes which have northerly outlets. The outlet of Lake Erie probably lies near the hinge line of the most recent uplifts, but the position of the line in that region is not definitely known. The outlets of Lakes Superior and Ontario are well within the area of the recent uplifts.

[1]Taylor, F. B., Notes on the abandoned beaches of the north coast of Lake Superior: Am. Geologist, vol. 20, 1897, pp. 120-122.

Lake Michigan-Huron (regarded as one lake) has its outlet toward the south in the area of horizontally, and for this reason the northern uplifts have not backed the waters up on its southern shores. Since the end of the Nipissing Great Lakes the water level south of the hinge line in this lake has been permanent, except for lowering due to wearing down of the outlet. The recent uplifts merely raised the northern shores and caused them to emerge without producing drowning at the south. During the early part of the present post-Nipissing lake stage Lake Superior and Lake Michigan-Huron were united by a strait and had the same southern outlet. About 50 feet of uplift occurred at Sault Ste. Marie while this relation lasted. It is only during the last 20 feet of uplift at Sault Ste. Marie that Lake Superior has been an independent lake and has had its outlet in the area of uplift north of the hinge line. The emergence effects on the lower Nipigon are due to the latest movement, whether now progressing or only of recent date.

On theoretical grounds it seems certain that very slow drowning would favor the growth of great barriers and spits like those mentioned, for it would greatly facilitate the erosion of all exposed shores and enormously augment the supply of beach-making material. But so also would a rise of lake level due to increased volume of discharge, like that which affected Lakes Erie and Ontario at the beginning of the present lake stage, and

this might be accompanied by no warping or uplifting whatever. In this case there would be sudden drowning of small amount (10 or 12 feet) and a permanent lake level thereafter. Reasons have already been given (p. 465) for believing that Lake Erie was not appreciably affected by the post-Nipissing uplifts. The last drowning that affected it was due to increased volume and rise of lake level following a long low stage. The modern great bars of Lake Erie seem therefore to be due to relatively long permanence of lake level following a sudden rise of small amount.

The spits on the shore of Lake Ontario seem to indicate the same general conditions of formation as those of Lake Erie, both in distribution and in strength of development (including duration of time involved). It seems impossible to reconcile the great spits at Toronto and Hamilton with an uplift of appreciable rate now in progress or with a very recent uplift of more than 10 or 15 feet. It seems more probable that a large increase in the volume of discharge without concurrent or subsequent uplifting of the land has been the chief factor. In this connection it should be noted that the extent of the post-Nipissing uplift east of Lake Huron and Georgian Bay has not yet been determined by observation. It seems almost certain, however, that the isobases bend gradually to the east in southwestern Ontario so as to leave the outlet of Lake Erie at or south of the hinge line, and it is a question whether in passing farther eastward they do not curve still more, turning to courses somewhat north of east, so as to leave the outlet of Lake Ontario likewise at or near the hinge line. In this case the outlet of Lake Ontario may have been affected little if any by the post-Nipissing uplift and the spits of this lake may also be due to a rise in lake level caused by increased volume of discharge.

From the Niagara gorge it is learned that the whole of the post-Nipissing uplift, amounting to about 104 feet at North Bay, Ontario, has taken place in the last 3,000 or 3,500 years. It seems probable that the greater part of it occurred in the early part of this period and very little in the last few hundred years, but the facts now available do not appear to afford a satisfactory basis for determining whether uplift is now in progress and what its rate is if it is going on.

GAGE READINGS AND PROGRESSING UPLIFT.

Some years ago Gilbert investigated the question of progressing uplift by collecting and critically examining and comparing the records of changes of lake level at selected points where gages have been kept by the United States Lake Survey.[1] The result showed a very small differential elevation or tilting for several of the more northerly stations as compared with stations farther south. The mean result on the assumptions made indicates an uplift of 0.42 foot per 100 miles in a century on a line running N. 27° E.

[1]Gilbert, G. K., Modification of the Great Lakes by earth movement: Nat. Geog. Mag., vol. 8, 1897, pp. 233-247. Also more fully in Recent earth movement in the Great Lakes region: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1897, pp. 595-647.

The stations chosen were Milwaukee and Escanaba on Lake Michigan, Port Austin on Lake Huron, Cleveland and Port Colborne on Lake Erie, and Charlotte and Sacketts Harbor on Lake Ontario.

Unfortunately, when Gilbert finished his investigations (1896) the position and attitude of the Nipissing plane in the southern parts of the basins of Lakes Huron and Michigan had not been correctly determined. It was then supposed that both the Algonquin and Nipissing beaches passed under the present lake level southward, the Nipissing being about 20 feet beneath it at Port Huron and about 100 feet beneath it at Chicago. These, however, were estimates based chiefly on the planes of the beaches produced from the north and partly on erroneous determinations of the places where the planes cut the lake surface. The responsibility for these errors is shared by Spencer and the writer.

Since that time it has been found that, instead of passing under the lake surface southward both beaches become horizontal, the Algonquin at about 25 feet above the present lake level and the Nipissing at about 15 feet. The hinge lines, where the planes pass from an inclined to a horizontal attitude, are thought to be very nearly coincident across the southern peninsula of Michigan. (See fig. 8, p. 439, and fig. 9, p. 461.)

These newly found facts throw fresh light on the problem of recent earth movement in the Great Lakes region, introducing important changes in Gilbert's assumptions and modifying his interpretation of some of the data. The relations of his chosen stations to the area of horizontality becomes a matter of much importance. Of these, Chicago and Cleveland are far within the area of horizontality in which no recent earth movement is known. Port Austin and Port Colborne are both close to the hinge line of latest uplift and maybe on it or slightly south of it; at most they are not far north of it and have been affected very little by recent uplifts. Only Escanaba, Charlotte, and Sacketts Harbor are well within the area of uplift. Of the four pairs of stations considered only the pair on Lake Ontario is wholly within the deformed region. This makes it necessary to modify Gilbert's result for three of the pairs, and leaves it unchanged for only one—Charlotte and Sacketts Harbor.

If the movement indicated between Milwaukee and Escanaba is really caused by uplift at Escanaba, its rate is more than twice that obtained by Gilbert, if his determination is numerically accurate, for the hinge line of the movement is probably more than halfway north from Milwaukee to Escanaba. The last movement recorded by the beaches appears to have hinged on this line.

It seems doubtful whether Gilbert's investigation proves that uplift of the land is now in progress. But, on the other hand, a demonstration that Gilbert's conclusions are not well founded does not constitute proof of the truth of the contrary proposition, namely, that uplift of the land is not now in progress. The author is inclined to the belief that the movements of uplift are spasmodic in

character and occur rather suddenly at intervals separated by long periods of rest, during which movements do not occur. It may be doubted whether a measurable movement of uplift has occurred within the last 100 or 150 years. The old beaches in many places suggest sudden uplift, and the place in the Niagara gorge which marks the last increase of volume (just above the railroad bridges) shows a change in gorge characters so abrupt as to be consistent only with a relatively sudden great increase of volume. This change was due to uplift at North Bay, Ontario, closing the outlet there and sending the discharge back to Niagara.

The lack of water-gage stations on the northern shores, especially on those of Georgian Bay and Lake Superior, seems to necessitate postponement of further efforts to solve this problem by this method until observations shall have been collected for many years from stations that still remain to be established. The need of such stations is urgent and immediate. The most desirable places are at the mouth of French River at the north end of Georgian Bay, and at Peninsula Harbor at the extreme northeast angle of Lake Superior. Stations at these two places would afford the longest possible lines in the direction of recent tilting.

SUMMARY OF GLACIAL AND NONGLACIAL LAKES IN THE HURON-ERIE AND MICHIGAN BASINS.

The table below presents a condensed summary of information concerning the Huron-Erie and Michigan glacial lakes and the nonglacial lakes that followed in the same basins.

Glacial and nonglacial lakes of the Huron-Erie and Michigan basins.

Lake names.	Number of stages.	Beach names.	Elevation of beach (south of hinge).	Location of ice dam.	Place of outlet.	Remarks.
Glacial Lake Chicago. (Data given at bottom of table.)						
Maumee.	Three.	Highest (first).	*Feet.* 800–805	Defiance and Birmingham moraines.	Fort Wayne channel.	Discharge at Fort Wayne during middle beach was small and temporary. The lowest beach was drowned during making of the middle beach. Outlet for lowest overridden.
		Middle.	775–785	Imlay to Yale moraine.	Imlay channel (and Fort Wayne ?).	
		Lowest.	760±	?	Near Imlay (?).	
Arkona (and Saginaw basin).	Three.	First Second Third	708–710< 698–702 690–694	(About 25 miles northeast of Bad Axe and same distance north of Alden, N. Y.	Grand River channel.	Except where protected in Black River valley, beaches submerged and destroyed during Lake Whittlesey; overridden on "thumb;" not submerged in Saginaw Valley. Only two west from Flushing.
Whittlesey.	Two.	Whittlesey (Belmore). Beach "A"	735–740 ?	Port Huron moraine.	Ubly channel.	During the time of Lakes Maumee and Whittlesey Lake Saginaw was a separate lake.
Wayne (and Saginaw basin).	One.	Wayne (Lower Forest).	650–657	? Nearly same as for Lake Arkona.	Near (south of) Syracuse, N. Y.	Beach submerged during Lake Warren.
Warren (and Saginaw basin).	One.	Warren (Forest).	675–680	A little west of Alpena, Mich., and Niagara Falls moraine.	Grand River channel.	The Wayne and Warren beaches were upwarped on the "thumb" during the life of Lake Lundy.
Lundy (and Saginaw basin).	Two.	Grassmere.	655–640	A little farther north than for Lake Warren.	Near (south of) Syracuse, N. Y.	The Grassmere and Lundy beaches show remarkable splittings northward in Sanilac and Huron counties, Mich.
		Lundy (Elkton or Dana).	615–620			
Algonquin.	Many, divided into four groups.	(1) Beach of Early Lake Algonquin; theoretical; not yet distinguished.	?	? About at Alpena, Mich., and Port Elgin, Ontario.	Port Huron.	Early Lake Algonquin was confined to south half of Lake Huron, with tributary lakes from east. Main lake covered three upper basins. Upper group possibly absent in north part of Huron and Superior basins. Most rapid uplift during construction of Battlefield group. Beaches in Lakes St. Clair and Rouge basins are correlatives of the Algonquin and Nipissing, not identical.
		(2) Main upper Algonquin group.	603–607	Several positions between Alpena and Mattawa Valley.	Kirkfield, Ontario; later at Port Huron and Chicago.	
		(3) Battlefield beach and group.	? Main ridge 714 feet on Mackinac Island.	In Mattawa Valley (?).	Port Huron (and Chicago ?).	
		(4) Fort Brady beaches and group.	? (640–690 feet on Mackinac Island).	In Ottawa Valley (?).	Port Huron (and Chicago ?).	
Nipissing.	Two.	Original Nipissing. Nipissing (two-outlet stage).	530± 594–597	None None	North Bay, Ontario. North Bay and Port Huron.	The original Nipissing beach (theoretical) is now all submerged south of isobase of North Bay. The well-known Nipissing beach marks a later two-outlet stage.
Post-Nipissing Great Lakes.	Many.	Algoma.	589–591	None.	Port Huron.	Lies a little above the middle of the series below the Nipissing.
(Chicago).[1]	Three.	Glenwood Calumet Tolleston	640 620 607	Retreating positions in Lake Michigan basin.	Chicago.	Correlative of Lake Maumee to Early Lake Algonquin, inclusive. Probably joined with waters of Lake Superior before those of Huron.

[1] The chronological place of Lake Chicago is shown above.

CHAPTER XXIV. POSTGLACIAL DEVELOPMENT OF CONNECTING RIVERS OF THE GREAT LAKES.

By Frank B. Taylor.

RELATIONS OF RIVERS.

At its maximum extent the last ice sheet covered not only all the Great Lake basins, but also the sites of all the rivers which now connect the lakes with each other and with the sea. Special interest attaches to the development of these connecting rivers, not only because of the intimate relation between their histories and lake history in general, but also because of the processes and stages of development which they show and the remarkable youth or new ness which characterizes their beds.

The Great Lake basins are certainly very old and were probably more or less connected by channels in preglacial times. But the vicissitudes of several successive glacial invasions, the lake and river developments of the intervening warm periods, and the differential uplifts which have affected the land have probably obliterated and reestablished the main connecting channels several times over. What is said here relates only to the reestablishment since the obliteration caused by the last ice sheet.

Of all the different facts that show the relative recentness of the postglacial changes which have brought the Great Lakes to their present state none perhaps are so clear and convincing as those pertaining to the rivers which connect the basins. Nipigon River is sometimes called the upper St. Lawrence from the fact that it is much the largest tributary of Lake Superior. In the same sense all the connecting rivers—St. Marys, St. Clair, Detroit, and Niagara—are parts of the St. Lawrence system. The St. Lawrence proper, connecting Lake Ontario with the sea, should be included in any comprehensive view of the development of this river system, for it has had the same general history as the other parts and displays the same striking evidences of newness.

However, only St. Clair and Detroit rivers lie within the region discussed, and only these will be considered in detail. The St. Clair and the Detroit are the oldest of the system; then come the Niagara, the Nipigon, the St. Lawrence, and the St. Marys. The relative ages of the Nipigon and the St. Lawrence are not certainly made out, but their beginnings were probably not far apart in time. The Niagara was distinctly earlier than either of these and the St. Marys was distinctly later. The different lake stages and the separation of the different links of this river system by the intervening lake bodies set uncommonly sharp limits to the beginning and duration of the different links.

EARLY INVESTIGATIONS.

The literature bearing particularly on St. Clair and Detroit rivers and Lake St. Clair, which alone lie within the field covered by this monograph, is not extensive. Much has been written about Niagara River, especially about Niagara Falls and the gorge, but this is outside of the range of the present inquiry.[1]

[1]The development and history of Niagara River and the Falls are discussed in Niagara folio (No. 190), Geol. Atlas U. S., U. S. Geol. Survey, 1913. 470

In one or two of his earlier papers Spencer speaks of the waters which preceded the Great Lakes as "lakes," and he found the outlet of one stage to be "southeast of Georgian Bay by way of the Trent Valley to Lake Ontario." At that time he attributed the change of outlet to the later uplifting of the Trent region, whereby the overflow passed southward to Lake Erie. He called the outlet river in the Trent Valley the Algonquin River.[1] He was the first to trace the Iroquois and Algonquin beaches for long distances and to measure accurately their northward rise. In his later papers, however, he abandons these views and interpretations and appears to regard all the ancestral waters of the Great Lakes as marine with open connection with the sea. He combats the idea of continental ice sheets and ice dams and rejects all of the earlier glacial lake outlets, although he was first to describe two of them—the Trent River outlet at Kirkfield, Ontario, and the Imlay channel in Michigan—attributing the first discharge from Lake Huron to Lake Erie to the uplifting of the land in the region of Lake Nipissing northeast of Georgian Bay, and admitting no earlier activity for the Port Huron outlet. In 1891 Spencer rejected the Mohawk River outlet for Lake Iroquois and the Trent River outlet for Lake Algonquin and calculated the Algonquin beach to pass 20 feet below the present lake level at Port Huron, thus allowing for no southward outlet of Lake Algonquin at that place, nor for any eastward outlet at Kirkfield.[2] In 1894 he reaffirmed that the first discharge of the upper lakes southward to Lake Erie was due to uplift at Lake Nipissing.[3] In the first publication of his papers he repeatedly used the word "lake" in designating these early waters, but in a reprint in book form in 1895 he generally substituted the word "gulf."[4] In this volume he reaffirms his rejection of the Mohawk and Trent Valley outlets, the assumed submergence of the Algonquin beach at Port Huron, and the recent first opening of the southward outlet.

In a recent, more elaborate volume[5] he repeats the same views respecting the southward outlet for Lake Algonquin, although more than 10 years had intervened since his last publication on that subject and the investigations of others had in the meantime brought out new facts that point clearly to a different history. His earlier conjecture that the Algonquin beach passes 20 feet under Lake Huron at its south end was disproved in 1896 by the finding of the beach strongly developed 25 feet above the lake at Port Huron and Sarnia. But although he recognizes this fact in his recent report, Spencer reaffirms his belief that Lake Algonquin had no southward outlet.[6]

In the same work he discusses St. Clair River and the delta and puts forth views that are novel and in harmony with his hypotheses of Lake Algonquin and Niagara Falls, but not in accord with either the lake history or the features of the connecting river district as set forth in this monograph. He makes the first river in the St. Clair Valley a local stream—necessarily relatively small—and flowing northward. He makes it rise in the south part of the bed of Lake St. Clair, the many tributaries uniting at Algonac and flowing northward to Lake Algonquin, the shore of which, he says, was then 17 miles north of Point Edward and 110 feet below the present level of Lake Huron, or 90 feet deeper than by his earlier estimate. On the elevation of the land at Lake Nipissing, Ontario, he says the discharge of Lake Huron shifted south and for the first time passed to Lake Erie. The coming of the great river in a reverse direction into the bed of the previous small local river caused the drowning of the tributaries of St. Clair River.[7] (See, further, pp. 499-500.)

In discussing the relations between Niagara Falls and the upper Great Lakes, the fact that these lakes had two periods during which they discharged their overflow eastward was first distinctly recognized by Gilbert[8] in 1889, when he showed two hypothetical maps intended to represent the conditions at these periods. He states that during both periods the discharge of the upper lakes abandoned the southward course through St. Clair and Detroit rivers which it had previously taken and that these rivers ran dry. He states also that the gradual uplifting of the land at the north caused the discharge of the upper lakes to shift from northerly to more southerly passes, thus implying a reestablishment of the full volume of discharge southward through St. Clair and Detroit rivers.

[1]Spencer, J. W., Notes on the origin and history of the Great Lakes of North America: Proc. Am. Assoc. Adv. Sci., vol. 37, 1888, pp. 198-199.

[2]Deformation of the Algonquin beach and birth of Lake Huron: Am. Jour. Sci., 3d ser., vol. 41, 1891, pp. 18, 19.

[3]Duration of Niagara Falls: Am. Jour. Sci., 3d ser., vol. 48, 1894, pp. 463, 466.

[4]The duration of Niagara Falls, Humboldt Pub. Co., New York, 1895, pp. 69-71, 73, 108, 111.

[5]Evolution of Niagara Falls, Geol. Survey Canada, 1907, pp. xxxi, 490.

[6]Idem, pp. 299, 303.

[7]Since this monograph was written, Spencer claims to have changed his views, accepting the idea of the land ice sheet and its function as a dam retaining lakes of great extent. But on the Niagara excursion connected with the Twelfth International Geological Congress at Toronto in August, 1913, he ignored the land ice sheet and reaffirmed the explanations given in his report of 1907. The intimate connection between the history of Niagara and the history of the Great Lakes as presented in this monograph is set forth briefly in the Niagara folio (No. 190, Geol. Atlas U. S., U. S. Geol. Survey, 1913).

[8]Gilbert, G. K., The history of the Niagara River: Sixth Ann. Kept. Commissioners State Reservation at Niagara, 1890, pp. 72-73, Pls IV, V.

Gilbert does not go into the details of the history of the connecting rivers in his paper, but the abandonment and reoccupation which he describes were important factors in the development of these great river beds. In a later paper[1] he discusses the Great Lakes history in much the same way, without going into details relative to the other connecting rivers. In an article on recent earth movements in the Great Lakes region,[2] he recognizes the "drowned" character of the lower stream courses around Lakes Ontario and Erie, the southern half of Lake Michigan, and the south side of Lake Superior and attributes it to recent tilting of the land. The connecting rivers seem obviously included, but are not particularly mentioned.

In 1903 Cole[3] made a special study, under the direction of the Michigan State Geological Survey, of the delta of St. Clair River.

In his report on the geology of Monroe County, Mich., Sherzer discusses very briefly some rather exceptional till ridges in Monguagon and Brownstown townships, in Wayne County.[4] These ridges are separated by very well defined and persistent troughs, but Sherzer gives the ridges first importance, regarding them as parts of a moraine which he calls the Detroit moraine, and assigning no unusual quality or origin to the troughs. He gives a good description of the recent drowning of the shores of Lake Erie along the border of Monroe County, but does not discuss the distributaries of the Trenton district, which lie outside of that county.

In two papers published early in 1895 the writer[5] attempted to give the main outlines of the Great Lake history on the hypothesis of marine invasion of the upper three lakes and marine origin for some of the higher beaches of that region. Glacial lakes retained by ice dams were supposed to account for nearly all the beaches in the southern part of the Great Lakes region, but not in the northern. The Trent Valley outlet at Kirkfield, Ontario, had not then been visited by the writer, and Spencer's then recent rejection of it as a thing of importance was accepted. The name Lake Algonquin was applied to two different lake stages, the First Lake Algonquin and the Second Lake Algonquin. An eastward uplift separate from and later than the general northward uplift was postulated. On account of the incompleteness of the data then in hand and on account of the confusion introduced by erroneous postulates and interpretations, these two papers were both seen within a year to have been premature and except for a few passages are now worse than useless. Both include statements and interpretations bearing on the development of St. Clair and Detroit rivers and on Lake St. Clair and on the growth of the St. Clair delta which are almost all wrong.

The larger errors of these two papers were set right by investigation on the north shore of Lake Superior and in the Mattawa and Ottawa valleys in the fall of the year of publication (1895), and the corrected results were published in brief form the next spring.[6] After further studies in 1897 a more detailed though brief account of the features near Detroit was published.[7]

ST. CLAIR-DETROIT VALLEY.

The drainage system of the broad flat valley which lies between the south end of Lake Huron and the west end of Lake Erie must have had a long and complex history in preglacial times and in the times of the earlier ice sheets and interglacial intervals. It is not the purpose, however, to discuss this phase of its history here, but to present an account of the way in which the modern rivers became established after the recession of the last ice sheet. The outlet channels and connecting rivers which are now abandoned have already been described.

[1]Niagara Falls and their history: Nat. Geog. Mon. No. 7, vol. 1, 1895, pp. 227, 229.

[2]Recent earth movements in the Great Lakes region: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1897, pp. 601-647, especially pp. 605-606. Also more briefly in Nat. Geog. Mag., vol. 8, 1897, pp. 233-247.

[3]Cole, L. J., The delta of the St. Clair River: Geol. Survey Michigan, vol. 9, pt. 1, 1903, pp. 1-25.

[4]Sherzer, W. H., Geological report on Monroe County Mich.: Michigan Geol. Survey, vol. 7, pt. 1, 1900, p. 135.

[5]The second Lake Algonquin: Am. Geologist, vol. 15,1895, pp. 100-120, 162-179; Niagara and the Great Lakes: Am. Jour. Sci., 3d ser., vol. 49,1895, pp. 249-270.

[6]Preliminary notes on studies of the Great Lakes made in 1895: Am. Geologist, vol. 17, 1896, pp. 253-257.

[7]Some features of the recent geology around Detroit (abstract): Proc. Am. Assoc. Adv. Sci., 1897, pp. 201-202.

The front of the ice sheet had retreated a considerable distance northward in the basin of Lake Huron before the waters of that basin fell to the level of the first or early stage of Lake Algonquin. In some of the stages just preceding this lake the outlet of the expanded waters was eastward along the northward-sloping escarpment near Syracuse, N. Y., and the pressure of the solid, impervious ice mass against that slope was still controlling the level of the waters in the basin of Lake Huron. At that time a strait, now occupied by St. Clair and Detroit rivers, connected the two lake basins. The flow of the waters through the strait could hardly have produced a perceptible current so long as the passage was wide and deep, but as the lake waters fell away the strait grew narrower and shallower and the current stronger, until it became a great river rather than a strait.

On the wide, flat floor of this connecting valley, transverse to the axis, run three low ridges, which, except where they have been cut through by the river, remain substantially as they were when the ice left them. Two of these ridges are morainic and one is partly moraine and partly bedrock. After the glacial lake waters fell St. Clair-Detroit River began to flow from the Lake Huron to the Lake Erie basin, naturally along the lowest line in the valley. It soon cut through the soft materials of which two of the ridges are composed and cut into the third to a depth of a few feet, below which it met more resistant materials.

In its first work the river produced two elaborate systems of distributary channels, one near the village of St. Clair on St. Clair River and the other near Trenton and Amherstburg on Detroit River. Most of the channels are shallow and must have been of very temporary duration, but they furnish an interesting record of the transition from a strait to a well-established river.

ST. CLAIR RIVER.

EARLY DISTRIBUTARIES.

EROSION OF THE MAIN MORAINE OF THE PORT HURON MORAINIC SYSTEM.

The highest of the transverse ridges and therefore the first to be uncovered and eroded by the newly established river is about 1½ miles north of St. Clair and is the southward water-laid extension of the main moraine of the Port Huron morainic system, here a single, simple ridge. Its crest is almost flat longitudinally, and is relatively broad and smooth. Figure 10 shows the distributaries on this moraine, the old river channel, and the esker on the plain south of it.

The moraine is 3 or 4 miles broad at its base, but it is low and its crest is broad and ill defined. From the end of its land-laid part northwest of Port Huron it runs south, forming the watershed between Pine River on the west and St. Clair River on the east. Near the north edge of St. Clair Township it turns southeast and after crossing the river extends east and northeast in Ontario. The highest points on the crest near the gap cut by the river have an altitude of about 645 feet above sea level or about 65 feet above St. Clair River. Northwest and north along the crest the altitude rises on the average not over 5 or 6 feet to the mile—in the first 4 or 5 miles only about 10 feet. Two or three gravelly knolls, probably outwash from the ice front, rise 10 to 15 feet higher than the general crest, but are not considered in the altitudes given.

On the Canadian side there were apparently no distributaries. A small creek flowing wrest of south from the moraine, about a mile east of Courtright, may possibly have been a small, very temporary distributary, but at the two points where it was visited by the writer it is very narrow and the evidence seemed clearly against this view. The first flow which had sufficient velocity of current to cut into the moraine was confined to a space about 4 miles wide extending southeast to northwest on the crest between Moore on the Canadian side and the southeast corner of sec. 1, St. Clair Township. Thus the overflow was in a general way toward the southwest over the western limb of the moraine. The gentle front slope here descends to the southwest and that direction was taken by the distributary streams. The group as a whole shows a slightly radial arrangement conforming to the curved front of the moraine—the western members running southwest and the eastern ones more nearly south. The present channels on the moraine range in width from nearly half a mile to only a few rods. The divided old river bed south of St. Clair, though resembling a pair of distributary channels, is not in reality of that nature. (See pp. 476-478.)

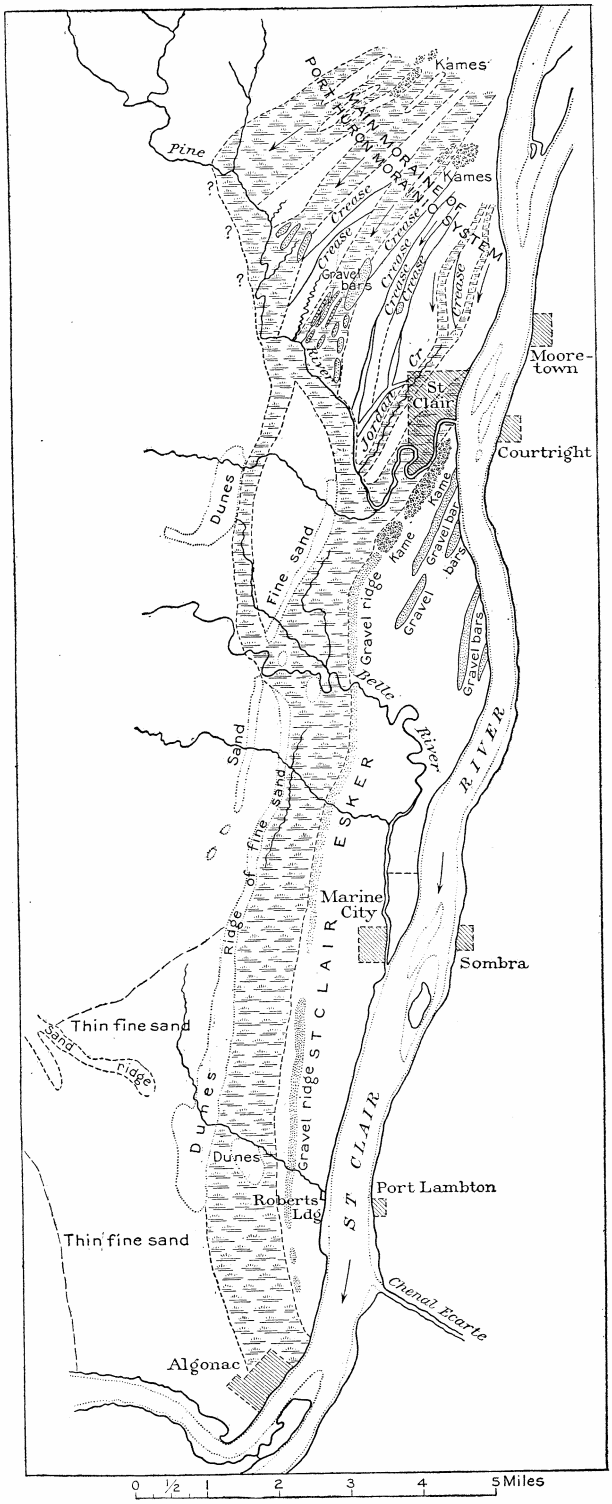


FIGURE 10.—Map of distributaries, gravelly river bars, the St. Clair esker, and other features near St. Clair, Mich. The river occupied both sides of the esker, but the space between the esker and the Canadian bank of the river is not now swampy and shows evidence of such occupation only in the gravelly bars south of St. Clair.

CHANNELS.

The distributary channels north of St. Clair were made at a higher stage of the lake waters than that which made the old river bed in the village, and the streams that made them were shorter lived. They lie in the eastern part of St. Clair Township and run southwesterly to Pine River. Measured by aneroid barometer their heads where they start on the crest of the moraine are 630 to 635 feet above sea level, the moraine crest being 5 to 10 feet higher.

The largest channel starts in southwest sec. 6 (east tier of sections),[1] St. Clair Township, and runs southwest through secs. 7 (east tier), 12, 13, 14, and 23, ending along the east side of sec. 22. It is nearly half a mile wide and is slightly swampy in some parts. It has a thin black soil, with scattered patches of sand and gravel. Toward its lower end it is floored with gravel across its whole width, and it bears two or three conspicuous gravel ridges which were deposited as bars where the current slackened in the Pine River valley. These gravels are best developed in southwest sec. 14 and northwest sec. 23. A prominent gravel bar is crossed by the diagonal road which runs southeast through sec. 23, less than a quarter of a mile east of the northwest corner. Some well-marked banks 5 to 10 feet high along the sides of this channel are in fact residual ridges forming barriers between it and other channels on either side. They are one-quarter to one-half mile wide, are composed of stony clay or till, and are simply parts of the original moraine which remained after the distributary streams had done their work.

Another channel starts in northeast sec. 7 (east tier) and runs southwest through secs. 13, 24, 23, and 26. It is like the channel just described, except that it is only half as wide and runs about a mile farther southwest. It is gravelly toward its lower end and contains gravel and sand bars in southwest sec. 24 and eastern sec. 26. At about mid length, in sec. 13, it grows somewhat indefinite. Little narrow, creaselike channels branch off on its west side, and it splits into a number of such channels toward its south end in secs. 23 and 26. In south sec. 1 two or three small channels start off to the west-southwest, but in south sec. 11 they fade out on a sandy plain.

[1]St. Clair Township is irregular, being made to include a tier of sections east of the regular boundary.

Another better-developed channel lies east of those described and nearer St. Clair River. It has two headward branches that start close together, the western one in southeast sec. 18 (east tier) and the other in northeast sec. 19 (east tier). It starts at a lower level, its two heads opening at an altitude of about 620 feet (aneroid), and is more deeply eroded than the others. The eastern branch has a flat floor, swampy in places, and is 10 to 15 feet deep a mile south of its head. The floors are 20 to 40 rods wide above the point of union, which is in southwest sec. 30 (east tier). Throughout its whole length of 4 miles this channel is not over one-third mile from the bank of either the present St. Clair River or that of the old river bed in the village. It passes just west of the village and is the most striking old distributary channel of the locality.

It seems certain that the water flowed longer in this channel than in the others. Its altitude at its head is fully as high as the top of the higher ridge of the Lundy beach in this vicinity, so that it seems hardly probable that it marks the Lundy level, although it lies so near it. It seems rather to have been occupied until the lake level fell almost to the Lundy stage and then to have been left dry. It was on a slightly lower part of the moraine and was probably a little deeper at the start than the others. But although it was cut deeper the stream in it was relatively small.

CREASES.

Several shallow creaselike troughs start in west sec. 18 (east tier) and run southwest, curving south. Such creases are not known to occur except in association with the larger distributaries where St. Clair and Detroit rivers first broke over morainic barriers. They lie closely parallel to each other and 40 to 80 rods apart without branching or uniting. The intervening ridges are sightly convex in cross section and the creases are narrow at their bottom with no perceptible flat floor. Toward their heads some of them fade out on the nearly flat surface, but for most of their length they are 5 feet or more in depth. Three of them are more than 2 miles long. The S. ½ sec. 24 and all of sec. 25 are sprinkled with thin patches of gravel and sand, apparently deposited by water coming from the north over the creased ground. Two other creases, rather more pronounced, start in west sec. 13 and cross secs. 14 and 23 in the broader part of the till ridge between the largest two channels. Another crease crosses secs. 19 (east tier) and 30 (east tier).

It seems certain that the creases and the ridges between them are not original forms, but were produced by the first flow of the river over the moraine, for they are transverse to its crest. They appear to be the earliest recognizable product of erosion produced by the flow and to have been made when the water was flowing over as a thin, even sheet, mainly before any of the other channels had been eroded. Probably at first the whole slope now marked by the channels was creased in this manner. If the creases were made as supposed, by a thin water sheet, the level of which at their heads was gradually falling, then the quantity of water passing through them was diminishing while they were making and in a very short time ceased entirely. The whole process was too brief to permit the development of meanders, so the creases are straight or only slightly curved and have no flat bottoms. The direction of the creases records the direction of flow of the first water sheet as it passed over. On the lower parts of the moraine crest, where the water flowed longer, the creases were apparently cut away by the widening* of the deeper channels. More and larger creases of this kind occur near Trenton. (See p. 489.)

The channels that have been described are all that remain to-day as abandoned distributaries, but at least one other distributary was deepened and became at last the channel of the master stream. This was presumably the largest one at first and as it enlarged and deepened its bed, the level of the waters north of the moraine was lowered and all the other distributaries were abandoned. Thus the largest of the original distributaries became the course of the undivided river. In its enlarged form it may include several originally independent channels.

GRAVELLY RIVER BARS SOUTH OF ST. CLAIR.

The concentration of the river in one channel north of St. Clair led to rapid downcutting through the soft materials of the moraine. At first the water evidently went through the gap with a rush and emerged on the flat plain south of St. Clair, where it spread in a relatively thin sheet 3 or 4 miles wide. Here it slackened and deposited long bars of gravel which it had washed out of the moraine and out of the newly excavated river bed to the north. All the gravel knolls and ridges south of St. Clair, however, are not of this description; a large ridge extending a mile southward from the Pine River bridge and another lying in central sec. 12, China Township, appear to be glacial.

The river bars lie east of the large glacial ridges, mainly in East China Township. They trend a little west of south, several of them being cut off at their heads by St. Clair River, which here runs south-southeast. One bar begins a little south of the Oakland Hotel and another nearly a mile farther south, near where the electric railroad turns west from the river bank. Two others run south from the bluff in sec. 18, East China Township. The bars have long, smooth, tapering forms and are a quarter of a mile to a mile in length, 2 to 6 feet high, and not over 300 feet wide. They are composed of sandy gravel and small pebbles, resting on clay, and are unmistakable river bars. A number of still smaller, shorter swells of sandy gravel of the same origin and trend are too small to be shown on the map. It seems probable that all of the bars were formed mainly during the active cutting of the river through the moraine rather than later when the channel had been completed and rapid cutting had ceased.

OLD RIVER BED SOUTH OF ST. CLAIR.

After quickly cutting through the Port Huron moraine the river reached a relatively stable state as the outlet of Early Lake Algonquin with a descent of about 10 feet from Lake Huron to Lake St. Clair. The Algonquin beach is 605 to 607 feet above sea level or, on the average, about 25 feet above Lake Huron, its level being determined mainly by obstructions in the lower part of Detroit River. (See p. 495.)

St. Clair lies mainly on a bench or terrace 10 to 12 feet above the river. The present river flows almost due south, but a steep bluff at the back of the terrace runs southwest for about a mile from the bank of the river at the north end of the village. The bluff is nearly 40 feet high in the village, but along the river to the north it rises steeply to over 55 feet above the water. Its highest point is about 1½ miles north of the village, just opposite the narrowest, deepest, and swiftest part of the river—the place where the river cuts through the main moraine of the Port Huron morainic system.

On emerging from its constricted passage through the moraine the river of the Early Algonquin stage entered abruptly on a wide, low plain. Evidently a strong current of the spreading river pushed southwest over the site of the village and cut into the moraine, making the conspicuous terrace and the high bluff behind it. The first of the large gravel ridges forms the prominent knoll just south of Pine River and west of the Oakland Hotel, and the flat between this and the bluff in the southwest part of the village is part of the abandoned river bed of that time. This runs southwest through secs. 1, 11, and 12, China Township, turns directly south to the middle of sec. 24, bends a little to the west, and continues in a straight line to west of Roberts Landing, south of which it gradually fades away on the low sand-covered clay plain. In St. Clair it is from one-third to one-half mile wide, but farther south it is three-fourths of a mile to a little more than a mile in width.

On entering the old river bed Pine River turns abruptly from southeast to northeast. A short distance south of the bend the floor is about 15 feet above St. Clair River, and it declines very gradually southward to 3 or 4 feet above the river west of Algonac. The floor was originally nearly all a swamp and a considerable part is so still. The banks are rather peculiar; below Pine River they show very little evidence of scour by the old river. The west bank appears to be a cut bluff in some places, but the cut is now obscured by fine sand which forms a narrow, more or less duny ridge for nearly the whole length. In some places the sand knolls are pronounced, especially toward the south end, where the sand belt broadens. A few dunes have apparently traveled from west of the road northwest of Roberts Landing over into the middle of the swamp. Southward from sec. 10, Cottrellville Township, the sand belt widens to a mile or more.

ST. CLAIR ESKER.

The east bank of the channel is not continuous but is nearly so and is composed in most places of a narrow ridge of gravel. For 2 miles south of St. Clair the large glacial ridge mentioned forms the bank, the gravel in the ridge being fairly coarse. Southward the ridge is lower, almost disappearing in some places. In places where it is low it appears to be partly composed of clay and is generally 30 to 40 rods wide. The cemetery 1½ miles west of Marine City is on this ridge.

The ridge in all is 11 or 12 miles long and its relations and origin are somewhat obscure. It is thought to be a product of glacial drainage and is apparently an esker made in an ice tunnel or canyon when the ice front was somewhere south of Roberts Landing. In one or two

places (for instance, in the bank of Pine River south of St. Clair and where the ridge is cut out by Belle River west of East China) the gravel appears to rest on clay. The ridge is not prominent west of Marine City, but grows stronger a mile or two farther south and is a strong beachlike gravel ridge for about 3 miles to a point southwest of Roberts Landing.

The difficulties in finding a clear and satisfactory explanation for the origin of this ridge are greatly increased by its relations to three other forms of gravel deposit. In its northern part just south of St. Clair it falls in line with the heavier knolls which are regarded as kames and which may possibly be related to an early position of the ice front at the time of the Port Huron morainic system or possibly to a less pronounced halt of an earlier date. In its northern part it is also closely associated with some of the gravelly river bars. It is here fainter and more broken and is rather more sandy and clayey than it is farther south. It may have been modified to some extent by the rushing of the early river over it.

In its stronger southern part its crest happens to lie through much of its length almost exactly at the level of the first St. Clair beach (correlative of the Algonquin beach), faint markings of which, found at and below Courtright, on the Canadian side, show the altitude at which the waves acted. This relation seems to be accidental, for all the shore markings at Courtright and at other points in this part of the basin of Lake St. Clair are extremely faint, consisting merely of a faintly cut notch or a sandy or gravelly belt with scarcely noticeable ridging. The ridge west of Roberts Landing, on the other hand, is composed of fairly coarse gravel and stands 12 to 15 feet above the clay flats on either side. The ridge as seen from either east or west has the appearance of a beach ridge or spit as strong as the Whittlesey and Warren ridges. Its situation, however, is such that it is impossible for it to have been built primarily by wave action. Lake St. Clair is so small a body of water and it was so shallow, even in the time of Early Lake Algonquin, that wave action in it must always have been relatively weak. The gravel ridge widens somewhat toward its southern end in a way that is characteristic of the termination of eskers. Besides, the trend of this ridge is southward along the axis of the St. Clair Valley and not at all what would be expected as a product of wave action from Lake St. Clair, where the most effective waves would come from the south. Hence, though the crest of the ridge appears to have the form of a wave-built deposit and, indeed, has probably been fashioned somewhat by waves, the ridge itself is to be regarded as an esker rather than a beach.

From 2 or 3 miles north of Marine City southward into the St. Clair delta all the low ground on both sides of the gravel ridge is composed to a depth of several feet of lake clay without stones.

In another respect the conditions surrounding this ridge were unfavorable to production by waves. Not only was there no wide deep water to provide waves sufficiently heavy to form such a deposit, but the ridge stands out alone on the flat clay floor of the valley with no visible source of supply for its material. No sea cliffs of stony till and nothing corresponding to a surf-wasted zone lie near, unless buried under the lake clays. Even if such a zone be present, it is more than 20 feet below the ridge crest and can not be accredited to the waves of so small a lake. On the other hand, these characteristics of situation, trend, composition, and height of the ridge with parallel depressions or flats on the two sides are characteristic of eskers. The feeble waves of Lake St. Clair in the time of Lake Algonquin may have in some degree fashioned the gravel along its crest, but they could have done nothing more.

This gravel ridge, as already stated, lies along the central axis of the St. Clair Valley. At the time of Early Lake Algonquin it divided the bed of the river southward from St. Clair into two channels of probably nearly equal capacity. They appear to be troughs associated with the esker. The river at this stage endured through the time of Early Lake Algonquin and the early part of the third or Port Huron-Chicago stage—long enough for Lake St. Clair to build a distinct though not strong shore line and for the river to accomplish a well-defined work of erosion and deposition. It seems certain that during this early stage of the river the part of its bed which lay east of the esker became deeper than that which lay west, so that later, when Lake St. Clair fell to a lower level, the river abandoned the western channel and became concentrated in the eastern one, in which it now flows.

ST. CLAIR DELTA.

SOURCE AND CHARACTER OF MATERIAL.

The delta of St. Clair River in Lake St. Clair is exceptional from the fact that it was built by the outlet river of one of the Great Lakes and by water generally supposed to be clear and free from sediment. (See fig. 11.)

The peculiar relation of St. Clair River to Lake Huron has been the chief cause for the formation of the delta. Storm waves on the south shores of Lake Huron have done and are still doing a tremendous work cutting away the bordering lands, in some places cutting back 5 to 6 feet a year, as established by measurements and surveys.[1]

The storms that do the most effective work on these shores come from northerly directions and tend strongly both by oblique wave action and by wind-driven currents to carry the sediments derived from the cutting toward the south end of the lake. The same thing occurs in Lake Michigan where there is no natural outlet and where the sands have consequently accumulated in enormous quantities as dunes about its south end. Storms make the water of Lake Huron roily all along the shore and for some distance out into the lake. St. Clair River opens from the southern extremity of the lake and the roily water is carried into the river and down to Lake St. Clair. Here, on meeting the still water, the finer

sediments are deposited, and it is mainly through a long continuance of this action that the delta has been built. A considerable amount of sand and some gravel also are rolled along the bottom and are added to the delta deposit.

An excellent detailed study and discussion of the St. Clair delta was made by Cole[2] for the Michigan Geological Survey. His investigations show the delta to be in nearly all respects a normally formed, low-grade (fine sediment) delta, though having some peculiarities and some exceptional features. Cole made 31 borings in the delta and found clay of varying quality to be the main constituent, with considerable quantities of sand and sandy clay. At a certain depth, generally 12 to 17 feet, the borings penetrated a stiff blue clay which in a few feet became soft and waxy and continued uniform in texture to an indefinite depth, in one boring to at least 56 feet. Borings at Algonac and Port Huron show this "bottom clay," as Cole calls it, to be 80 to 100 feet deep at Port Huron and 150 to 200 feet deep at Algonac. In several borings, at a depth of 11 to 12 feet below the level of Lake St. Clair, Cole found beds of muck composed of decayed vegetation resting on the stiff top layer of the "bottom clay."

[1]Gordon, C. H., Wave cutting on west shore of Lake Huron: Ann. Rept. Michigan Geol. Survey, 1901, pp. 283-290, Pls. XI-XV.

[2]Cole, L. J., The delta of the St. Clair River: Michigan Geol. Survey, vol. 9, pt. 1, 1903, pp. 1-25.

As Cole points out, the "bottom clay" fills all the lower parts of the valley between Lake Huron and Detroit, and is hi fact a great deposit of lake clay laid down probably in the large glacial Lakes Arkona, Whittlesey, and Warren. The ice barrier is known to have stood a mile north of St. Clair for Lake Whittlesey, and somewhere in the south part of Lake Huron for Lakes Arkona and Warren.

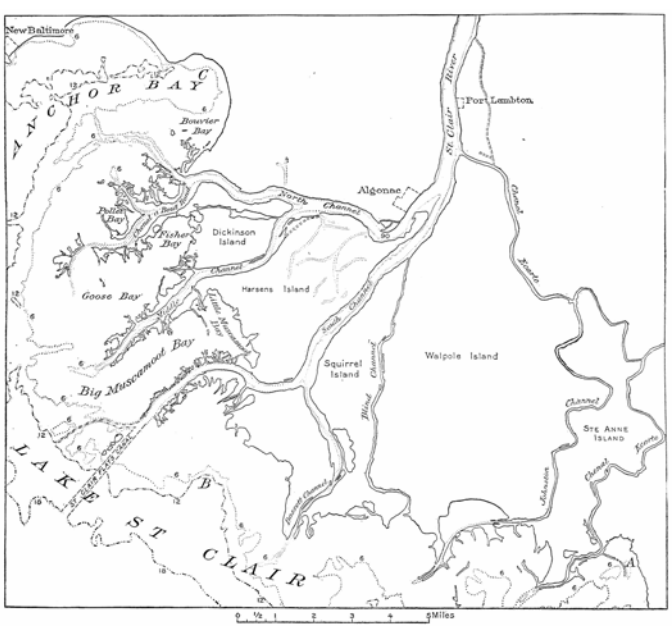


FIGURE 11.—Map of St. Clair delta.

The sediments contributed to the delta are derived from three sources: Streams tributary to St. Clair River bring in moderate quantities of sediment in times of flood; the river itself erodes its banks and bottom, cutting away the banks rapidly in a few localities and carrying the material to the delta; Lake Huron contributes sediments cut away during storms. Cole quotes interesting estimates made by O. B. Wheeler[1] of the United States Lake Survey, on the amount of sediments derived from this last source. The estimates have considerable elements of uncertainty but seem to show that the quantity is at least twice as great as that derived from all other sources.

[1]Rept. Chief of Engineers U. S. Army, 1885, pt. 3, pp. 2199-2202.

CHARACTER OF THE DELTA.

Some of the more important facts stated by Cole and by Lane in an introduction to Cole's report may be summarized as follows: From its head to its front the delta measures nearly 15 miles on a line running south-southwest from the head of Russell Island. Transverse to this line its width is about 20 miles and it is estimated to have filled about one-quarter of Lake St. Clair. The delta is made up of islands separated by somewhat winding distributary channels. It has not all been made with the lake at its present level, for the ground toward its head stands about 6 feet above the mean level of the river. The surface of the delta is extremely flat and slopes very evenly, its front being a submerged flat 2 to 3 miles wide. Its outer edge is fairly well defined at a depth of 6 or 8 feet by a rather definite bank from which the descent is relatively abrupt to the deeper part of the lake. The greatest depth of the lake is 22 feet, with a general depth in the central part of about 20 feet. Thus; the delta surface slopes 12 feet from head to front but slopes a little more rapidly near the submerged edge.

The steepness of the sides of the channels under water is most remarkable, being sometimes almost vertical for a distance, while a greater dip than 45° is probably characteristic. There are nine channels, including Baltimore channel and the ship canal, which have a depth of over 3 fathoms to the bars at their mouths. Throughout the most of their length the main channels have an average depth of about 30 to 40 feet, but the north channel, in the large bend south of Algonac, reaches a depth of 90 feet and is 60 feet and more deep to some distance below the North Channel clubhouse at the junction of the Chenal a Bout Rond. The river above the head of the south channel ranges in depth from 30 to 60 feet.[1]

Toward the head of the delta large areas on Russell, Herson, Squirrel, and Walpole islands are well above mean water level, are partly covered with heavy forests, and partly under cultivation. The height of these islands above mean water level shows that they were built when Lake St. Clair stood higher than now. The fall in the lake level has caused the river to deepen its channels through the older parts of the delta.

A glance at the excellent chart of Lake St. Clair by the United States Lake Survey (edition of August, 1908, or later), which is indispensable for studying the outline of the delta and the width and depth of its various channels, shows that the delta as a whole is divisible

into two main parts, the old and the new. The dividing line is along the east side of the South Channel. Squirrel, Walpole, and Ste. Anne islands and probably the marshy flats west of the Bassett Channel belong to the old part. Russell, Herson, and Dickenson islands, though their higher or northern parts are probably as old as Walpole Island, are associated with the new channels and the newly made part of the delta. There are, however, some evidences that Herson Island is partly of relatively recent date, for irregular shallow sloughs run through its northern half in several directions. The islands east of the South Channel show no such features containing water.

The moving current of the river carries the fine sediments in suspension when the water is roily and rolls the sand along the bottoms of the larger channels. The growth of the delta takes place chiefly in the shallow waters along the sides and around the ends of the channels, where these are active and reach nearly to the delta front. Big and Little Muscamoot, Goose, and Fisher bays are being gradually filled up in this way. Even where the channels are deep to within a mile of the submerged edge of the delta, they end abruptly in the shallows behind a wide flat bar. As the platform of the delta is built out the deep channels follow, but never open directly into the deeper part of the lake.

CHANNELS OF THE NEW DELTA.

The channels now active are the South, which is the principal line of navigation, and the North, which has two branches from its south side, the first of which is called the Middle Channel and the other, farther west, the Chenal a Bout Rond, or locally the Sny. The main line of the North Channel, which runs westward from Algonac, is the largest in cross section, has the swiftest current, and carries the largest volume of water. The upper part of these channels, for 3 to 4 miles below Algonac, are simply deepened passages through the older part of the delta and vary from an eighth of a mile to half a mile in width. The land there is slightly above high water and can hardly be said, to be growing. Farther out, however, the channels pass beyond the dry-land surface and run for 4 or 5 miles out into the shallows of the submerged growing parts of the delta between narrow but very ragged and irregular belts of land barely above the mean level of the lake. These form natural levees, broken by many small crevasses through which the water pours into the very shallow bays along the sides. The moment the roily water leaves the deep channel it slackens and deposits the coarser parts of its sediments. Thus the ragged low levees have been built up by the distributaries themselves, and each little crevasse in these levees tends to build its own smaller levees out into the shallow bay into which it enters. These levees in turn are worn away and destroyed by the feeble action of the waves which run in over the shallow bays.

[1]Cole, L. J., Michigan Geol. Survey, vol. 9, pt. 1, 1903, pp. 6-7.

FRONT OF THE NEW DELTA.

That growth is at present active in the western part of the delta is shown by the long ragged fingers of the South and Middle channels and the Chenal a Bout Rond, each of which projects its levees about 4 miles beyond the general land front of the delta. The whole area between the active channels and for a mile or more beyond their ends has been extensively built up in recent times and is still actively growing.

The limits of the newly built delta are clearly shown by the soundings. The new part, which is about 10 miles long from north to south, has been added to the west side of the older delta and projects into the bed of the lake about 5 miles westward from the ill-defined land margin. The 2-fathom (12-foot) contour shows a well-marked reentrant about halfway between the ship canal and the south end of the Bassett Channel. It runs about 1½ miles northward into the front of the delta and marks the southeast limit of the newly made part. On the north side the same contour shows a narrow unfilled part of the lake running east to the mouth of Swan Creek from the deeper part of Anchor Bay. The wider, deeper part of Anchor Bay defines the western front.

CHANNELS OF THE OLD DELTA.

In the size and character of its channels and in its relatively smooth south front, the old part of the delta east of the South Channel presents a strong contrast to the new part just described. The principal channels in the old part are the Chenal Ecarte and the Johnston Channel, which branches from it, the Blind Channel, and the Bassett Channel.

These channels, especially the Ecarte and Johnston channels, are very crooked and narrow, being generally not over 400 feet wide. The water is generally 20 to 30 feet deep, but is reduced on bars to 15 to 17 feet. The Blind Channel, which branches from the South Channel a mile below the head of Russell Island, is more nearly dead than any other that still carries water. At its head it is only 2 feet deep and is very narrow, and through most of its length it is not over 10 to 15 feet deep. An extinct channel, which leaves the river 2 miles above Port Lambton and runs south to the Ecarte a mile below its head, is the oldest known channel of any length.

The Chenal Ecarte leaves the river 2 miles above Russell Island, and it and the Johnston Channel seem more like artificial canals than natural distributaries. Still, they are of a type common in deltas. They are not intensely active like the North Channel, but seem to have reached a stationary or balanced state, and although half dead and substantially unchanged for a long time, they do not become closed. The Blind Channel has progressed further toward extinction and will probably be closed at a not distant date.

The Bassett Channel, which branches from the South Channel at the great westward bend, is a dying distributary. Its deep part is not wider than the Ecarte, but for 2 miles down from its head it is bordered on one

side or the other by shallows 400 to 800 feet wide. This channel has not progressed so far toward extinction as the Ecarte, which was once large like the South Channel of to-day but has become gradually contracted and now has scarcely any shallows along its sides. Water plants, such as sedges and rushes, are important agents in the con traction of these channels, when once they begin to decline. The plants slacken the roily waters and thus induce deposition of sediment and build up the banks. The Bassett Channel was evidently once of large dimensions and is still in process of contraction.

FRONT OF THE OLD DELTA.

Another evidence of greater age in the eastern part of the delta is its lack of long ragged levees along the outer parts of its old channels. Some ragged points are associated with the Johnston and Ecarte channels, but they appear to be battered fading forms. None accompany the Blind Channel, and only two or three fading remnants border the Bassett Channel. The whole land front of the old delta has been much smoothed as compared with that of the new.

RECENT AND PROGRESSING CHANGES IN THE CHANNELS.

The aging or extinction of the older channels suggests the future of some of the newer ones. The present active channels are not all in the same condition. One is aggressively active, actually enlarging, and others are evidently dwindling.

Throughout its whole length the North Channel seems to have the strongest flow. It is on the average slightly deeper and wider than the South Channel and is the master stream and would be the best route for navigation if it extended in a southwesterly direction. It seems certain that until recently its waters followed the Chenal a Bout Rond, which is lined with ragged levees as large as those of either the Middle or South channels, but which has so dwindled in recent times that its deeper bed is now narrow and is bordered by wide shallows. It is not very long since the bank between Point aux Trembles (where the main line of the North Channel turns northwest) and the North Channel clubhouse was continuous across the present North Channel or was broken by only a small crevasse. But some circumstance, perhaps an ice jam like that which Cole describes as affecting the river higher up, forced a powerful current through it to the northwest and established a new route. This part is so new that it has not yet built any levees along its sides, those on the two sides near the clubhouse being parts of the older levee.

The Middle Channel, which branches from the North Channel 2½ miles west of Algonac, is also dwindling but has not shrunk so much as the Chenal a Bout Rond. The South Channel has also dwindled and is now distinctly second in importance to the North Channel. Under present conditions the North Channel has a decided advantage over the other channels and is evidently gaining on them, for from the head of Russell Island to the open water of Lake St. Clair a quarter of a mile northwest of Point aux Trembles, the distance is 3 miles shorter than to the open water at the Old clubhouse on the South Channel. It is characteristic for delta distributaries to change and shift about, and just now the North Channel seems to be robbing the others.

If the South Channel is to continue to be the main route of navigation steps ought to be taken to prevent its further dwindling if not to enlarge and improve it. This could be done by diversion works above Algonac so arranged as to guide into it a larger proportion of the river.

No doubt there was a small natural crevasse near Point aux Trembles before the main current broke through, and this probably determined in part the course of the scouring current at that time. Artificial cuts through the natural levee, such as have been made at many places in the flats above the ship canal, are a menace to the maintenance of the deep channel. By drawing off the water they slacken the flow in the channel and tend to increase deposition of sediment.

AGE OF THE DELTA.

The muck beds described by Cole appear to rest on the surface of the lake clay which underlies the whole region. The muck evidently dates from one of the times when the upper lakes were discharging eastward by other outlets and St. Clair River ran dry. Under the muck, Cole generally found 2 or 3 feet of tougher clay marking the upper part of the lake clays. This tough stratum appears to be an old land surface and was generally present, even where the muck was absent.

Twenty-nine of Cole's thirty-one borings are on the new delta, and one is on or about on the dividing line between the new and old. Only one is distinctly on the old. Six borings penetrate muck beds, and five of these are on the new delta. One is on the North Channel at Point aux Trembles, three on the Chenal a Bout Rond (two at one place), and one on the Middle Channel. The sixth is on the west side of the Bassett Channel, about half a mile south of its head, or about on the dividing line. The one boring on the old delta is east of the dividing line a little below the head of the Blind Channel. It disclosed deep muck at the surface but no buried muck or hardened lake clay.

It is inferred that all the buried muck beds found, with the possible exception of the one on the Bassett Channel, date from the discharge of the upper lakes through the North Bay outlet. The muck of the boring on the Bassett Channel may be of the same origin. At any rate, it can hardly be taken as sufficient proof that buried muck and an old land surface exist under the old part of the delta, and that the delta holds similar records of the discharge of the upper lakes through the Trent Valley outlet. The boring on the Bassett Channel is offset by that on the Blind Channel, in which no buried muck or hardened clay was found. The substratum of the old delta remains to be investigated.

The flow of St. Clair River before the opening of the Trent Valley outlet was probably too brief for important delta growth. In that event the only important period of delta growth before the present one was during the time of the third or Port Huron-Chicago stage of Lake Algonquin. The level of St. Clair River was at that time higher than now and the delta was built to a s higher level. The old dry distributary which runs south from 2 miles north of Port Lambton suggests a delta head perhaps as far north as Marine City and at a higher level. The delta head near Algonac, with surface 6 feet above the present river, seems related more nearly to the time of the Nipissing beach (transition phase), which was the beginning of the modern lakes. It stands close to that level.

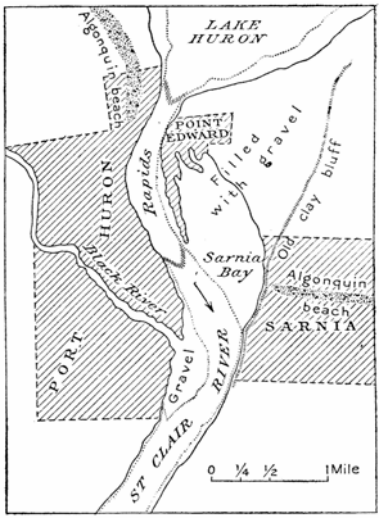


FIGURE 12.—Map of Point Edward spit.

Since the closing of the North Bay outlet St. Clair River has flowed continuously as the outlet of the upper lakes. If the old and new parts of the delta correspond to definite parts of the lake history the new part was probably made since the closing of the North Bay outlet and the old part during the southward discharge (Port Huron-Chicago stage) of Lake Algonquin.

In discussing the history of delta growth, Cole makes use of one factor which has since been eliminated. He estimates the effect of the northward tilting of the land which is supposed to have continued through recent times to the present and to be still progressing and discusses its effect on the supposition that the delta and Lake St. Clair lie within the area of the progressing uplift. The idea is an application of conclusions reached by Gilbert,[1] in a study of recent and present land movements in this region. It has since been found, however (pp. 439, 449), that the hinge line of the uplifted area passes across the "thumb" and the south part of Lake Huron, so that St. Clair River and Lake St. Clair with the delta are not affected by recent deformation or tilting.

GRAVEL SPIT AT HEAD OF ST. CLAIR RIVER.

A gravelly deposit, here called Point Edward spit, lying at the head of St. Clair River, on the Canadian side (see fig. 12), is a distinct correlative of the newer part of the St. Clair delta (p. 484). It has played an important part in the history of the river and has produced a marked effect on the American shore. Studies of this locality still lack much of completeness, but the general relations of the deposits have been determined.

[1]Gilbert, G. K., Recent earth movements in the Great Lakes region: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, pp. 595-647.

Gravel and sand are constantly drifting southwest along the Canadian shore into the head of St. Clair River, where they have been deposited as a southward-pointing spit 1½ miles long. As the gravels were rolled into the opening the strong current swept away the finer particles and dropped only the coarse material, adding layer after layer of coarse gravel to the westward front of the spit, and constantly crowding the river over against its western bank. The current in the rapids flows 4½ miles an hour, and the relations show plainly that the existence of the latter is due to the narrowing of the river caused by the growth of this gravel mass westward.

On the American side there is no spit, but a much smaller bar or shoal appears farther down the river. The west bank of the rapids has no protection against the swift current and is eroded away as fast as the gravels on the east side press westward. Continual adjustment is in progress and has been for a relatively long time, the river at Fort Gratiot having gnawed westward into the clay land about a mile from its original position.

The alignment of the Canadian shore of Lake Huron with reference to the head of the river favors the formation of a spit, and that on the American side does not do so. Gravel carried into the head of the river from the north on the American side is swept along the bottom of the river, and probably added to the shoal off the mouth of Black River. It seems doubtful whether much coarse gravel could be swept through the whole length of the river to the St. Clair delta.

It seems probable, however, that the relative quantity of gravel brought in from the two shores is much more important than their alignment. The Canadian shore faces west and north-west and receives the full force of the heaviest storms. The Michigan shore faces east and is not so severely attacked. Both shores have been heavily eroded in the past and are still receding, but the length of shore tributary to the head of the river is considerably greater on the Canadian side. Cole does not accept this explanation of the rapids in his report, but he looks at the matter from a slightly different point of view.

The gravel mass at Point Edward measures 1½ miles from east to west and about 2 miles from north to south. The deposit appears to be all of modern or post-Nipissing age. At the time of Lake Algonquin the entrance to St. Clair River was a wide tapering bay

opening northward from Corunna; and the gravels of the Algonquin stage, except for one prominent bar upon which the London road enters Sarnia, lie north and northeast of Sarnia and are quite separate from those that have displaced the river at Point Edward. The deposits related to Lake Algonquin have not been fully investigated.

The Point Edward spit is the correlative of the new part of the St. Clair delta. Every north or northwest storm cuts into the great clay cliffs on the Canadian shore, roils the water in the shallows, and stirs up the gravel. The shore current bears the roily waters along and rolls the gravel toward Point Edward. Once there they separate, the coarse materials and gravel being added to the great spit and the fine sediments being carried down to Lake St. Clair and built into the delta. The main part of the spit has been built since the closing of the North Bay outlet. The process has a peculiar international relation; the shores of Lake Huron on the Canadian side are being torn away, and though the coarse material is mainly left at Point Edward on the Canadian side, nearly all the fine sediment is carried down the river and built into the new St. Clair delta on the American side.

LAKE ST. CLAIR.

The body of land which projects into the west side of Lake St. Clair on the two sides of Clinton River looks like a delta on the map but is shown by Cole's investigations to be mainly glacial till carrying bowlders—probably part of the Emmett moraine. Only about 800 acres of it along the outer front is of the nature of a delta, and Black Creek, which flows southward through it, is the only distributary besides Clinton River that crosses it.

Salt Creek, west of New Baltimore, and Swan Creek, west of Fair Haven, have produced only very small salients in the shore line.

DETROIT RIVER.

DETROIT RIVER AT DETROIT.

DISTRIBUTARIES.

The next ridge which obstructed the flow of the new river was the low interlobate moraine which crosses the river at Detroit and upon which the higher parts of that city and of Windsor, Ontario, are built. This ridge is so broad and flat that it is scarcely perceptible to the eye as such, except where seen in cross section along the bank of Detroit River. The bank is noticeably higher along the city front, standing 30 to 35 feet above the river, than it is either east or west of the city, where it falls away to a reedy marsh at the level of the river. From the river bank half a mile east of Woodward Avenue the axis of the ill-defined ridge runs about northwest. In Canada it runs about southeast from Windsor nearly to the shore of Lake Erie, before turning northeast. This moraine has already been fully described (p. 284).

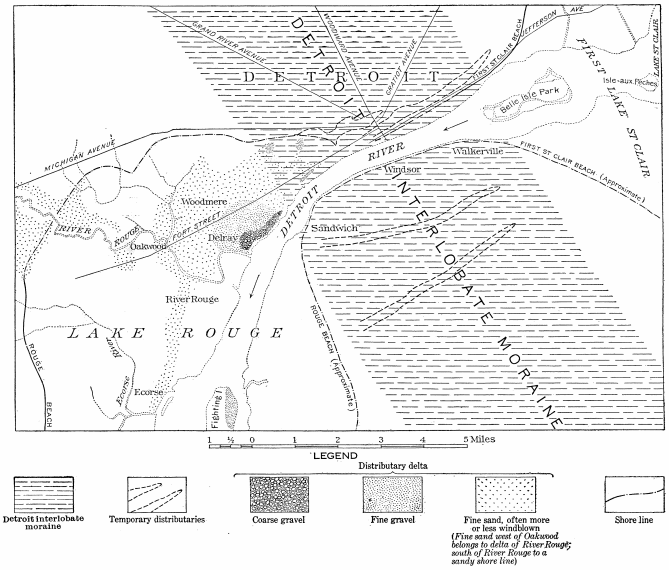


FIGURE 13.—Map showing distributaries of Detroit River at Detroit and delta in Lake Rouge.

There appear to have been two distributaries on the Canadian side, one called the Grand Marais, about a mile back, and another farther out. Both are very shallow and not well developed. Those in Detroit are small and close to the river, the farthest being less than a mile from it. (See fig. 13.) Probably a well-marked depression or sag already existent in the crest of the moraine was followed by the river, for otherwise distributary channels would cover a wider interval on the moraine crest, as they do at both St. Clair and Trenton.

Between the city hall and Jefferson Avenue, which lies on a distinct ridge, Woodward Avenue crosses a well-defined depression running nearly parallel with the river. The Jefferson Avenue ridge extends from about Cass Street eastward along Jefferson Avenue to the vicinity of St. Aubin Avenue. The depression north of the ridge is very distinct for a considerable distance, but it gradually fades away toward Elmwood Cemetery, though it possibly continues in faint form to Champlain Avenue, to the boulevard north of the Belle Isle bridge, and thence about half a mile farther to the vicinity of Kercheval and Burns streets. In this part of the city the contour of 600 feet above sea level bends from the north around to the south and then to the west, showing a long, low point projecting from the vicinity of Burns and St. Paul streets about to Baldwin Street and Champlain Avenue. The depression behind this point lies in such a position as to form a natural continuation of the trough farther west, and may represent a part of the same distributary channel, although this is not certain. The grading and filling connected with the improvement and growth of the city have so altered the original surface that a slight depression might have been obliterated. Congress Street lies about in the trough of this old distributary, at least as far east as St. Aubin Avenue. In its western part this depression was originally much deeper than it is now, and was, in fact, the site of a small drowned creek which in the early days formed the harbor of Detroit for the small craft of that time. The deepening of the creek

and its subsequent drowning are both later than the time of the distributaries. (See pp. 499-500.)

Another irregular depression begins three or four blocks east of Grand Circus Park and extends with some irregularities westward across Woodward Avenue and Washington Park and along Labrosse and Baker streets as far as Tenth Avenue where it fades away on a thin deposit of sand. This was not originally so deep as the other, and is less regular, apparently indicating that it was occupied for a shorter time.

Both of these channels are relatively short and irregular and, in comparison with the more typical examples at St. Clair and Trenton, their identification as distributaries might be regarded as doubtful. But for their position, transverse to the axis of the moraine and parallel to the river, and their relation to sandy deposits made by the river in cutting through the ridge they might be interpreted as merely accidents of morainic deposition. It may be noted that both of them head on the higher part of the ridge and that their bottoms descend toward the west as though they were eroded by currents flowing in that direction. Neither is a quarter of a mile wide, at some points half as much, and probably neither was originally more than 10 to 15 feet deep.

LAKE ROUGE.

The imperfect distributary channels just described were evidently abandoned early in the cutting of the ridge, for, beginning two squares northeast of the fort at Fort Wayne in the southwestern part of the city and extending west for about half a mile, there is a very well marked gravel and sand deposit, apparently a river bar formed at the head of a delta. The fort and the officers' quarters are on this bar. It appears to have originally extended perhaps a quarter of a mile farther northeast but to have been cut away by the modern river. At the fort and in the lots northeast of it these gravels are rather coarse and clean and the deposit is heaped up 6 or 8 feet higher than the surrounding ground. Toward the southwest this deposit spreads rapidly in passing into Delray and at the same time becomes lower and thinner and of finer texture. The gradation within half a mile from coarse gravel to sand fine enough to be blown by the wind is very striking.

Between the fort and West Detroit and in the vicinity of Clark Park there are a number of irregular deposits, some of them of gravel, like that at Twenty-fourth and River streets, at Twenty-first and Standish streets, and at Scotten and Toledo streets; and others of sand, like that west of St. Luke's Hospital and on the boulevard north of Lafayette Street. Thinner deposits of sand cover most of the surface at Woodmere and Delray, and there are a few duny ridges of fine sand, like that which begins a quarter of a mile south of West Detroit and follows the line of Dix Avenue. There is also much thin sand in the vicinity of Woodmere Cemetery, on the west side of Baby Creek and in the western part of Delray. Other duny sand ridges along Rouge River in Springwells Township may have had a different origin, but all the gravels and sands in the southwest part of the city and in Woodmere and Delray were evidently deposited when the river first broke through the moraine. (See fig. 13.)

The cutting through the moraine at that time was evidently not very deep, and the low ground along Rouge River southwest of the city was occupied by a shallow lake or expansion of the river which may be called Lake Rouge. In this lake the gravel and sand derived from the cutting of the distributaries and the main channel were deposited as a scattered thin delta. That this is really the explanation of these gravel and sand deposits seems clear from their relation to the river. The main channel at that time must have been the same as at present, but was not so deep. It was probably not excavated much below the present surface of the river, and southwestward toward the fort, where the river entered Lake Rouge, it was probably not excavating at all, but spreading out widely and depositing gravel and sand. The gravels at the fort stand precisely in line with the cut of the main channel through the moraine and exactly where the spreading, slackening current would drop its load on emerging from the narrow cut. A considerable part of this gravel deposit, the eastern part of the bar especially, has probably been cut away by the modern river. One or two gravel bars were made at the same time on the Canadian side, the largest being on the north part of Fighting Island. The relations of all these features taken together present a very clear record of the river's first cutting through the moraine.

Lake Rouge covered the south half of Springwells Township and nearly all of Ecorse Township, reaching down to the head of Grosse Isle. It was 10 or 12 miles long from north to south and at least 6 or 7 miles wide, but its precise limits on the Canadian side have not yet been determined. So small a body of water could hardly be expected to develop perceptible shore lines, but Lake Rouge did develop a faint but well-defined one on its west side and on the north end of Grosse Isle. From the rear light of the Grosse Isle north channel range lights a faint ridge of gravel runs south for a couple of miles just west of the beach road. Most of the cottages are built upon it. Its altitude at the north end of Grosse Isle is about 13 feet above the water, or about 588 feet above sea level. This is about 7 feet below the first St. Clair beach in the basin of Lake St. Clair. This beach of Lake Rouge, or the first Rouge beach, as it may be called, is also a correlative of the upper Algonquin beach and marks another step in the descent from Early Lake Algonquin to the Lake Erie basin.

DETROIT RIVER NEAR TRENTON AND AMHERSTBURG.

The finest development of abandoned distributaries is in the vicinity of Trenton and Amherstburg. The new river here found obstructing its flow a broad, flat-topped ridge which was composed in part of ordinary till like the ridges already described, in part of a bowlder bed set in very tough till, but in part of limestone in massive beds. As at St. Clair, the crest of the ridge appears to have

extended northwest and southeast, so that, when the river first flowed over it, most of the distributaries tended to flow southwest. Plate XXXI shows the distributaries in the vicinity of Trenton and Amherstburg.

The distributaries of this locality are extremely complex. There are early ones and later ones and others that the river has scarcely left dry. Indeed, the river still occupies a considerable number, though most of those now occupied are merely fragments. There are also a number of distributaries that are now drowned and are seen only in the bed of the river or on the floor of its estuary.

DISTRIBUTARIES NEAR TRENTON.

EARLY DISTRIBUTARIES.

Two very distinct distributaries that head on the higher ground about 2 miles southwest of Wyandotte or 3 to 4 miles north of Trenton are probably the oldest on the American side. The first of these begins in northeast sec. 36, in Ecorse Township, and after running for a mile southwest divides and passes around two sides of a knoll, forming an island more than a quarter of a mile long. The headward part of this channel is comparatively narrow and shallow and from its form appears to have been occupied for a relatively brief time. Its width averages from 200 to 300 feet and its depth from 5 to 10 feet. At the north line of Monguagon Township it turns and runs directly south for about a mile into southeastern Brownstown Township, where it turns southeast for another mile and enters the Detroit River about a mile south of Gibraltar.

For the first 3 miles in Monguagon Township[1] this channel is broader and less sharply defined than it is in its headword part, the plain here being broad and flat. But in the western part of sec. 12 it is joined from the northeast by another distributary, which is better developed and more deeply eroded. The head of this channel opens near the north line of Monguagon Township in the northeast corner of sec. 6 about a quarter of a mile west of the Lake Shore & Michigan Southern Railway. At its head the channel is 12 to 15 feet deep and 50 to 75 feet wide, with steep banks and a narrow flat floor. It is not occupied in this part by a stream, but is wet and swampy. Within a short distance to the southwest a very small creek appears in it, but is lost in the reeds and has no perceptible flow at ordinary stages. In west sec. 12 this channel appears to merge with the channel from the north previously described. Another wide, ill-defined, shallow depression extends from this point southeast through south sec. 12 and east sec. 13, but seems to have been abandoned, for the channel which runs directly south is now followed by the small stream which drains both channels from the north. The tract of ground comprised in western sec. 12, southeastern sec. 11, and northeastern sec, 14 is nearly flat and the channels there have low banks and are ill defined. A small creek that comes into northwestern sec. 11 from the higher ground to the northwest shows no features of a distributary until it reaches the low, flat ground in north sec. 14, beyond which, south through Monguagon Township and southeast in Brownstown Township, distributary characters are fairly well developed.

From these facts it seems certain that this last channel, which lies close to the west fine of Monguagon Township, was not a distributary in its upper part, but received a considerable volume of water while crossing the half mile of flat ground in northeastern sec. 14. Near the middle of sec. 35, Brownstown Township, this channel divides around a low knoll and reunites below in sec. 2. West of this knoll the western branch unites with the second main distributary from the north, and the united channel divides again around a sandy river bar in secs. 1 and 2 in the southeastward extension of Browns town Township. This is a mile west of Gibraltar, a mile south of which the united channels enter Detroit River. A small creek which comes from the northwest through Brownstown Township strikes the divided channel in southwest sec. 35 and turns northward in it to join the creek that occupies the western distributary. A very faint distributary branches southwest in western sec. 26, Monguagon Township, and curves around through the eastern part of secs. 27 and 34 of Brownstown, but beyond this its course is uncertain. It may run through secs. 2 and 12 to Detroit River half a mile south of the distributary previously mentioned. In sec. 12 it is very well defined as a long, narrow marsh perhaps 30 to 40 rods wide. Another channel which runs through the center of sec. 12 is also well developed. The braided forms which the channels take in this locality are too complex for easy interpretation.

[1]Ecorse and Monguagon townships are irregular in plan, each taking two tiers of sections from the east side of the public-land townships next to the west. In each, therefore, sec. 1 lies next west of sec. 6.

The distributaries thus far described have their headward openings at a relatively high level and must therefore have been among the first to be abandoned and were occupied for relatively short times.

The next distributary opens southwest about a mile north of Trenton. At its head the floor is now about 4 feet above the level of the river. It is larger than the distributaries just described, having a width of 400 to 500 feet on its floor. After passing the railroads it curves gradually south, passing about half a mile west of Trenton, and after running about due south through the east half of sec. 24 turns gradually southeast through sec. 25, where, within half a mile of Detroit River, it splits up into several smaller channels, some of which run southeast to the river, and some continue south, the main one to join the previously described channel about a mile west of Gibraltar. From this last two or three narrow, swampy channels turn southeast to Detroit River. This channel heads north of Trenton and may be called the Sibley channel, for the Sibley limestone quarries are near its headward opening.

In southwest Trenton another slight depression, evidently cut by a distributary stream, begins near the

railroad station and extends for half a mile southeast to the channel behind Slocum Island.

CREASES.

Besides the large distributary channels in the vicinity of Trenton, a number of the peculiar crease type appear. (See p. 289.) The best occur between the larger channels near Trenton, particularly between the Sibley channel and Brownstown Creek southwest of Trenton. They may be seen from the train on any of the railroads running southwest from Trenton. These creases show the same peculiarities as those of St. Clair River (pp. 474-475), having narrow bottoms with no flat floors. They run in parallel lines 30 to 40 rods apart, curving gradually from south to southeast. The ground between them lies in long billow-like, smooth ridges with crests generally 10 to 12 feet above the troughs. Their surface is rather bowldery, suggesting moraines, and Sherzer has interpreted them as such.[1] But they are closely related to the general slope of the ground and change their courses with its changes in slope. Besides, they are related to the barrier which obstructed the river at this locality in precisely the same way as the creases near St. Clair; and the latter are certainly not moraines, but are transverse ridges left between early, immature lines of scour made by water currents flowing down the front slope of the main moraine of the Port Huron morainic system at the earliest stage of river flow.

LATE DISTRIBUTARIES.

At the south end of Trenton a remarkable channel a mile long separates Slocum Island from the mainland. It is about 500 feet wide and is floored by a marsh with aquatic plants. Its bottom lies so close to the level of the river that some water formerly passed through in high stages but not in low ones. The channel, which is now obstructed by a railway embankment, was evidently actively occupied for a very long time. Farther down the river a number of islands, evidently fragments of land left between a network of interlacing distributaries, are now at or slightly below lake level. These fragmentary channels and others that are clearly traceable below the present level of Lake Erie were made when the lake stood at least 12 or 15 feet lower than now. (See p. 462.) Many of these later distributaries have been submerged by the recent rise of the lake waters and the fragments of land between them appear now as islands. Humbug Island is one of these; Gibraltar and Snake Island, just west of Gibraltar, are others. Smaller ones are Calf, Horse, Big and Little Cherry, Oak, Sturgeon, and Peabody islands. These are separated from the mainland and from one another mainly by very shallow channels, 300 to 800 feet wide and in few places more than 3 to 4 feet deep. The water passing through them is not now effectively eroding. Indeed, many of these channels, especially those that are choked with reeds, are probably being slowly filled.

[1]Sherzer, W. H., Geological report on Monroe County, Mich.: Michigan Geol. Survey, vol. 7, pt. 1, 1900, pp. 134-135.

A number of channels around the south part of Grosse Isle show the same peculiarities as those along the west side of the river below Trenton. Celeron Island, half a mile southwest of the south end of Grosse Isle, is divided in two by a very distinct old channel 700 or 800 feet wide; now a marsh about at lake level, which starts at the north end of the island and runs south along its east side nearly half the length before turning southwest across it. At an earlier stage. with floor a little higher, this channel ran on to the south end of the island along its east side. Celeron Island stands out alone between channels now carrying 14 to 15 feet of water and this fragment of a distributary, so distinctly developed on the island in this isolated position, shows the remarkable changes that have taken place in this part of the river. This and many of the other distributary fragments lying within half a mile or so of the river are well shown on the newer charts of Detroit River issued by the United States Lake Survey. Hickory Island east of the south end of Grosse Isle is separated from the larger island by a shallow channel over a quarter of a mile wide. Elba Island is separated from Stone Quarry Island by one channel, and Stone Quarry Island from Grosse Isle by another which is now dry.

GROSSE ISLE NATURAL CANALS.

Several channels on Grosse Isle are wholly different from any of those on the mainland, being long and narrow and more like artificial canals than distributaries. The so-called Thorofare is the longest and most characteristic. This heads on the east side near the north end about due west of the south end of Fighting Island and runs south through the middle of the island down to the ferry road near the center, where it turns southwest and enters the Trenton branch of Detroit River at the Michigan Central Railroad bridge. The channel is 200 to 300 feet wide with no perceptible variation of width. It runs in a remarkably even course—nearly a straight line—for its whole length.

Until a few years ago the Thorofare was almost abandoned as a line of flow. It had only 1 to 3 feet of water in it, and Detroit River being a remarkably steady stream with very little variation of volume, the Thorofare became choked with water plants and was a favorite breeding place of mosquitoes. A few years ago the summer residents dredged a channel 4 or 5 feet deep and about 25 feet wide through its whole length and a current now flows through. The Thorofare is trenched 10 to 15 feet below the drift surface of the island.

At a point about a quarter of a mile east of its mouth another similar canal-like channel, called Frenchman Creek, branches from it and runs south to the extreme south end of Grosse Isle. This channel has not yet been dredged, but remains in its natural state, a swampy bayou.

Grosse Isle has also several much shorter channels of the same character. One branches from the west side of Frenchman Creek near its south end; another, half a mile to the northwest, separates Snake Island from

Grosse Isle. The first of these is swampy but almost dry, and the second is still active though very shallow. Each is less than half a mile long. Another channel cuts into the west side of the island opposite Trenton. Except at its north end this one is now dry, but it formerly separated a small half-circular island from Grosse Isle. Another small channel of the same kind and about a mile long cuts across the north end of the island from northeast to southwest, with a branch nearly midway to the northwest. Two more short, narrow northeast-southwest channels cut across Point Hennepin. Those at the north end of Grosse Isle are on low swampy ground. Narrow, canal-like channels like these appear to be found in this vicinity only on Grosse Isle, though one or two short ones are said to have existed on Belle Isle, above Detroit, before the improvement of that island. Some of them seem like deepened creases. (See pp. 474-475, 489.)

When the level of the waters above Grosse Isle was a little higher a small distributary channel apparently led from the mouth of the south branch of Ecorse River to Monguagon Creek, passed close west of Wyandotte and Glenwood, and followed Monguagon Creek back to the river southwest of Wyandotte.

ROCKWOOD DISTRIBUTARIES.

West of the channel which terminates at Peabody Island (also called Sturgeon Bar Island on some maps) and which connects northward with Brownstown Creek several small, shallow, interlacing depressions run southward to Silver and Smith creeks and by their situation and relations to the area marked by distributaries just north of them appear to have been shortlived channels made by water coming from the north over the very low barrier which forms the divide between them and Brownstown Creek. They must have been very short lived because none of them are cut back to that stream; their heads all begin south of the divide along its southern side.

Farther west between these channels and Rockwood several troughs on the north side of Silver Creek and Huron River indicate still more faintly developed lines of flow from the north, but no such features appear west of Rockwood or south of Huron River, unless they lie in the great swamp back of Point Mouille, which has not been examined. The swampy channel which separates Peabody Island appears to extend south a little west of the shore to the swamp at the mouth of Huron River, and another swampy depression a quarter of a mile west of this extends over half a mile north.

These faint Rockwood channels have a very important bearing on the early history of Detroit River and of that part of the Lake Erie shore which formerly spanned it. (See p. 493.)

DISTRIBUTARIES NEAR AMHERSTBURG.

In some respects the most impressive of all the distributaries are those on the Canadian side southeast of Amherstburg. They are strongly developed and are longer and deeper than most others. One or two of them are drowned for long distances back from their mouths, making long estuaries or dead-water bayous. One of the most remarkable opens abruptly through the bank of the present river in the south edge of Amherstburg and may be called the Amherstburg distributary. Its floor was about a foot above the surface of Detroit River at the time of observation. At this point it is not over 200 feet wide, but its floor is wet and becomes a marsh within a quarter of a mile south. The Amherstburg distributary runs south-southeast for about a mile and then turns almost directly south and follows a slightly winding course to the shore of Lake Erie half a mile southeast of Bar Point, where it ends in a swamp which runs along the shore for about a mile behind a low ridge of dunes. From a mile south of Amherstburg the channel has a width of about 500 feet and carries from 6 inches to 4 feet of water.

At Elliott Point, about a mile south of Amherstburg, another small distributary runs southeast. It has two headward branches, one opening near the north range light and the other about 60 rods farther south. These two branches unite within about a quarter of a mile in a channel that crosses the Amherstburg distributary and about 1½ miles beyond unites with still another channel. The Elliott Point distributary is somewhat smaller than the Amherstburg channel and is not so deep.

About a mile east of Bar Point a short distributary heads less than a mile from the lake shore and enters the swamp behind the dune ridge. The general level of the ground is 5 to 6 feet above Lake Erie, and this short channel appears to have gathered its water from the flat area around its head.

The finest of the Canadian distributaries, however, lies about 1½ miles east of Amherstburg and runs south to Lake Erie. The backwater in this channel, giving it the appearance of an estuary, extends northeast of Amherstburg to a point about 5 miles from the lake, but the distributary characters extend to about 1½ miles north of the Michigan Central Railroad. Two headward branches meet about one-quarter of a mile north of the tracks.

This distributary had its headward opening at a level considerably above Detroit River. Its upper part was active only during the early part of the flow over the ridge, but its lower part probably received contributions from the Amherstburg and Elliott Point channels for a much longer time. The channel east of Amherstburg has a sufficient depth of water throughout most of its drowned part to prevent its becoming choked with vegetation, although it generally has a fringe of reeds or lily pads along its margin. The water is said to be 5 or 6 feet deep east of Amherstburg, increasing to 10 or 12 feet toward its mouth.

RELATION OF EARLY DISTRIBUTARIES TO LAKE ROUGE.

It is interesting to note the relation of the earlier distributaries to Lake Rouge. The first two channels

described above, having their heads on the higher ground southwest of Wyandotte, are the only two on the American side which had been abandoned by the time the water fell to the level of Lake Rouge. Indeed, it is not quite certain that the second or lower one, which heads in the northeastern part of sec. 6, Monguagon Township, was then abandoned, for the floor at its head is at about the same level as the beach. On the Canadian side the only one abandoned at that time was the long channel east of Amherstburg having its head on the high ground north of the railroad tracks. The largest channels developed at that time were two corresponding to the present main channels on the two sides of Grosse Isle. Into these the river appears to have sunk at a relatively rapid rate, until it uncovered the rock ledge and bowlder beds which offered effective resistance and held the water at the level of the first Rouge beach.

Running northwest from the Sibley quarry there is a broad, low divide with its crest close to 600 feet above sea level. Slight depressions in it having altitudes above 599 feet showed no enlargement such as result where distributaries were established, but depressions below this altitude did show such enlargements.[1] From this fact it is inferred that the new river first began to cut distributary channels on the obstructing ridge when the water surface north of the barrier had fallen to about 600 feet above sea level or 25 feet above the present river level.

The data for determining the level of the river surface at the time of the first cutting are not so satisfactory for the ridges at Detroit and St. Clair. But as nearly as can be stated the water surface above the ridge at Detroit stood between 605 and 610 feet above sea level and at St. Clair close to 640 feet. It seems certain, therefore, that as the waters fell in the basin of Lake Erie and in the St. Clair-Detroit Valley the ridge at St. Clair was the first obstruction to be uncovered, that at Detroit next, and that at Trenton last. The cutting at St. Clair and Detroit and in the river bed above and below these points did not uncover any bedrock or other resistant material, so that the river cut down at a relatively rapid rate. Near Trenton, however, the river uncovered some resistant limestone and sandstone ledges, but chiefly a tough till thickly set with bowlders, mostly crystalline erratics brought there by the ice sheet. This is the character of most of the material that has been removed from the bed of the river in the recent deepening of the channel of the Limekiln crossing, where the original depth before dredging was 13 feet. The effectiveness with which this material resisted the erosion of the river was greater than present conditions would lead one to expect, for it is certain that the level of Lake Erie fell considerably very soon after Detroit River first began to flow and has only recently come back to its present level. The river must therefore have had more fall, and the rapids in the river, instead of being 2 or 3 miles long as now, must have extended several miles out into what is now Lake Erie. The current was probably more rapid at the crossing than it is now. It was the obstruction at the crossing, however, that determined the level of the water in the rivers above this point and in the basins of Lakes St. Clair and Huron.

DEVELOPMENT OF THE DETROIT RIVER ESTUARY.

DROWNING OF LAKE ERIE SHORE.

The shores of Lake Erie, especially the western shores, are distinctly drowned by the relatively recent backing up of the lake upon them. It seems certain, therefore, that the marshy shores near the mouth of Detroit River and the shallow offshores have not been cut back to any great extent by the lake at its present level. This applies to the west shore of the lake from the mouth of Detroit River to Toledo and to the Canadian shore for at least 4 or 5 miles east from Bar Point. But from Amherstburg south to Bar Point the land has been cut away in recent times. Whether this cutting has been done by lake waves or by river erosion or partly by each is difficult to determine, but for a mile or more south of Amherstburg it seems certain that the cutting has been done almost entirely by the river, for the shore is not much exposed to lake waves and the current is deep and strong. South of Elliott Point the most recent cutting has no doubt been done by the lake waves, but its amount has been slight. Originally the land here was probably cut out by the river when the level of the lake stood lower. When the lake stood 10 to 15 feet lower than now, the soundings indicate that the general shore line off Point Mouille and Bar Point must have been half a mile to a mile farther lake ward on both sides.

[1] At the time this area was being studied the marks of the topographic survey showing the altitude at every road corner were still fresh and afforded accurate measurements at two or three critical points.

If the general trend of the coast line from Toledo to Point Mouille is produced it meets the Canadian shore somewhere near Bar Point, and if the line is curved a little eastward to conform to the general trend of the north shore, it will strike about a mile southeast of Bar Point and will then represent more truly the probable position of the shore line and the configuration of the land as they would have been if not modified by Detroit River.

The mouth or estuary of Detroit River may be defined as covering the area which lies between Grosse Isle and Bois Blanc Island on the north and a line joining Point Mouille and Bar Point on the south. It measures about 4 miles each way. There is much reason to believe that this area was originally land, like that now lying to the east and west, and had a surface substantially of the same character and altitude. In this area only one narrow channel near the east shore (the present line of navigation) is more than 20 feet deep, the depth over the rest of the area averaging about 10 feet. The bordering land is nowhere over 15 feet above the lake and on the west side is mostly under 5 feet. It is certain that at least a large part of the estuary was land, for Grosse Isle and in fact all the islands in this part of the river and also the banks of the mainland on both sides within the estuary are shown by the distributaries and the submerged channel beds to have been carved out of a former land

mass by the river. But even granting this, the assumption that the whole area was formerly land may seem unwarranted.

This conclusion, however, is strongly suggested by the early distributaries. On the east side the distributaries ran away to the south from Amherstburg and one to the southeast from Elliott Point. This they would hardly have done if there had been anything like a deep channel running south from their heads on the course of the present river.

On the west side the distributaries east of Rockwood run south, which they could hardly have done if there had been an available channel between the present shore and Celeron Island. The river soon developed a master stream, or possibly two of them, one between Grosse Isle and Bois Blanc Island and another where the Trenton Channel is now, and these rapidly cut back channels in the relatively soft drift to the resistant rock ledges and bowlder beds. At this time, the level of Lake Erie being somewhat lower than now, the streams on the west side naturally turned southeastward toward it; and those which turned first had the shortest, steepest courses and drew an increasing proportion of the water to themselves, thus causing the Rockwood channels to be abandoned at a very early stage. It seems certain that these channels would not have been made at all, unless, when the water first rushed over the barrier, there was land with no pronounced channel or depression where the estuary now is. (See p. 491.)

In the estuary and along the near-by shores of Lake Erie the bottom is generally stony to a depth of about 15 feet, below which it is mostly sand. Possibly this might be ascribed to the action of the undertow from the surf with the lake standing at its present level, but in the light of other evidence this sand may be regarded as a submerged beach, due to the recent rise of the lake upon the land about all its western shores. Several authors pointed long ago to evidences of such a change, and Moseley (see p. 462) finds that the water has recently risen at least 12 to 15 feet upon the land, thus agreeing very closely with the amount of recent change suggested by the various features of the Detroit River estuary.

DROWNED DISTRIBUTARY CHANNELS.

Besides the distributaries described above, a number of elongated depressions on the floor of the estuary of the Detroit River, evidently the remains of former distributary channels now submerged, are very distinctly marked in several places and are traceable to a depth of 15 to 17 feet below the present surface of Lake Erie.

Southward from the vicinity of Humbug Island two narrow troughs lie in the river floor. One on the east side passes between Calf and Snake islands and Grosse Isle. The other one runs south from Humbug Island and turns gradually southeastward to the deeper water 2 or 3 miles from Horse Island. Another channel not so well defined runs south from the west side of Calf Island and with some breaks seems traceable almost as far as the other and is closely parallel with it. Both of these lead southward out of the present Trenton Channel.

On the east side of Grosse Isle there are several well-marked submerged channels. A very distinct one passes between Sugar and Hickory islands and is traceable for 2 or 3 miles to the south. Another passes just east of Sugar Island and within a half mile appears to branch into two parts which run southwest and southeast around the two sides of an extensive area of bedrock. Another larger channel lies west of Bois Blanc Island, where it divides in two, one branch going south and the other southwest to the channel east of Sugar Island. The main channel also divides north of Bois Blanc Island, one branch passing southwest to the channels just described and the other, which is the present main route of navigation, running south between Bois Blanc Island and the mainland at Amherstburg. A considerable part of these channels north of a line passing through the south ends of Hickory and Bois Blanc islands is more than 18 feet deep; on the west side between Humbug and Celeron islands a number of spots are deeper than 18 feet. All of these and many other details are well shown on recent issues of the United States Lake Survey chart of Detroit River.

The distributaries in the Trenton-Amherstburg district, including those submerged on the floor of the estuary, have been in process of making whenever Detroit River was flowing in full or nearly full volume. Twice, when this great volume was withdrawn, work on the distributaries must have ceased. The channels now submerged were made mainly before the recent rise of the waters of Lake Erie on its western shores, and the making of the estuary is intimately related to this earlier work of the river. The making of the distributaries has been accomplished in three high stages of the river. The first high stage was during the time of Early Lake Algonquin; during this stage all of the older, higher distributaries, including those east of Rockwood, were made and probably abandoned. The second high stage was during the Port Huron-Chicago stage of Lake Algonquin. The Algonquin uplifts occurred chiefly during this stage. The fact that so many clearly defined distributary channels pass 20 feet or more below present lake level and are submerged this much seems to show that the surface of Lake Erie was slightly lower than now during one or both of the earlier high stages, the present being the third high stage. The amount of difference is uncertain. It may have amounted to 20 or 30 feet at first, but toward the close of the Algonquin uplifts in the Port Huron-Chicago stage the water was brought very nearly up to its present level in the west end of the lake.

RECENT AND PROGRESSING CHANGES IN DETROIT RIVER.

Between Stony Island and Amherstburg and in the west channel between Trenton and Grosse Isle the bottom of the river is nearly everywhere stony. Two considerable areas of rock, one south and the other southeast of Stony Island, are covered by not more than 4 or 5 feet of water, and at some points by less. The trend of the main

deep channel from its wider part north of Stony Island strongly suggests very recent change, and this is corroborated by the character and relations of the narrow deep channel between Bois Blanc and Amherstburg. The main channel from the north runs a little east of south to the Limekiln crossing, where it enters a majestic curve which bends around to the southwest and passes by the north end of Bois Blanc Island. West of the island it turns south, apparently in two branching courses. This channel appears to have been developed by a slow shifting eastward by erosion of the eastern bank in comparatively recent times. At the time of Early Lake Algonquin the river could not have had this deep passage and have maintained the water at the level indicated by the Rouge beach, which is now 13 feet above the river at the head of Grosse Isle. But if the relatively deep channel at Limekiln crossing did not then exist, and if the river was held up partly by the ledges of rock in the vicinity of Stony Island, and if the shallow passages west of Stony Island and between Trenton and Grosse Isle were narrower than now, the former high level of the river is explained. At that time the Sibley and Slocum Island channels were no doubt active, but the channel east of Stony Island, now the main channel of the river, was probably not open or was small. The bedrock in the river slopes downward east from Stony Island and from the submerged rock ledges southeast of it. As the channel deepened and shifted eastward, it was pressed over against the Canadian shore and more and more of the river was drawn to it. The great curve which it made by cutting into the Canadian shore is exactly continued in the northeast-southwest line which forms the northern shore of Bois Blanc Island.

It seems certain that this gradual eastward shifting of the channel, with deepening and enlargement, has been the chief cause of the recent, post-Nipissing fall of the river and lake waters to the north. It was here on the Limekiln crossing and on the rocky ledges about Stony Island that the critical point lay. It was this obstruction which held up the waters of the Lake Huron basin during the south-flowing stages of Lake Algonquin.

Among the early distributaries one or two cut across to the south along a line passing a little east of Bois Blanc Island, where the main channel now is. This may have been the Amherstburg distributary (p. 491), and it may have included the north branch of the Elliott Point distributary. For a considerable time after the deepened channel between the Limekiln crossing and the north end of Bois Blanc Island had been established, the channel east of Bois Blanc remained undeveloped. Although much narrower than the passage west of the island and narrower even than the present Trenton Channel, the channel east of Bois Blanc is the deepest of all. That its development must have been relatively recent appears from its greater depth and narrowness, from the steepness of its banks at Amherstburg, and from the abrupt manner in which it departs from the great curve which the river had just previously developed. It seems quite certain, therefore, that its enlargement took place after the development of the great bend.

When the first dredging was undertaken by the United States Government in the shallow rapids at Limekiln crossing the greatest depth was 13 feet. On a line running west from Limekiln crossing the river was wide and shallow, with its deepest part in the newly excavated bend. The opening of the Amherstburg passage, with its greater depth and shorter distance must have increased the eroding power of the river at the Limekiln crossing, and with the deepening of these parts the water was lowered more or less in the shallow rapids to the west and in the Trenton Channel.

It seems probable that at the time of Early Lake Algonquin the channels west of Grosse Isle carried a volume of water as great or possibly greater than those east of it, but that the more effective erosion on the east side has established the main channel in its present course.

Several peculiarities of the present river are certainly very recent. The channel which passes down the east side of Fighting Island is as deep as the main channel west of the island but is much narrower. It appears newer than the main channel, especially from the fact that, although deep, its submerged banks are very steep, much steeper than those of the main channel. This channel is a short cut, and the water in it flows a little more rapidly than in the present main channel, and it will probably be gradually enlarged and eventually become the main channel.

When the river was somewhat higher than now the present Trenton Channel probably received its water in a shallow sheet over the flat grounds of northern Grosse Isle and of the vicinity of Wyandotte. The northern part of the Trenton Channel, which passes in front of the city of Wyandotte, was not then so deep as now. Its submerged bank is very steep, suggesting recent or present bank cutting.

At Ecorse a bend, much like that above Amherstburg, has the same radius and slightly greater length, but is not so easy to explain, though it seems to be partly due to Ecorse River, which enters at this point, and partly to the fact that the undivided stream of Detroit River, since it sank to its present deep and relatively narrow bed, strikes the bank at this point with full force.

It is to be remembered that St. Clair River and the Detroit River above the head of the estuary flow at a slightly lower level to-day than they ever flowed before while carrying the full discharge of the upper lakes. It seems certain from this fact that their beds in the immediate past were not so deeply trenched as they are now, and this is the same as saying that they have been in recent times and almost certainly are still deepening and shaping their channels. These rivers bear many evidences of the fact that they are of recent origin. One is their straightness and the absence of any but very slight curves or meanders, like those of the Mississippi and other great rivers. (It must be remembered,

however, that the Detroit and St. Clair rivers are not subject to floods and do not vary more than 5 or 6 feet between extreme stages, and are thus less likely to develop meanders.) The only features suggesting lateral cuttings and the development of meanders are the bends above Amherstburg, at Ecorse, and in the rapids at the head of the St. Clair River. This latter bend, however, is due to a different cause (p. 483).

The sinking of these rivers into their present narrow, constricted channels in clay is very recent. It is certainly not long since their courses were marked by shallow expansions which have now disappeared. Lake Rouge in particular is of this class and Lake St. Clair was much more expanded, mainly toward the east, south, and north. Almost the entire delta, as known to-day, was submerged when Lake St. Clair stood 3 feet higher. With the exception of the bowldery and partly rocky barrier at Trenton and Amherstburg, the entire course of these rivers is in soft sediments. If the resistant barrier west of Limekiln crossing had been absent the sinking of the rivers into the clay plain would have been more rapid. But the barrier yielded only very slowly and the rivers have in consequence got down into their present beds so recently that they have not had time to develop the normal characters of graded rivers flowing through soft sediments; lateral swing has barely begun to find expression. The cutting of the new Livingstone channel through the rock floor east of Stony Island will tend to lower the surface and increase the rate of flow and also the rate of channel deepening in the rivers above.

FLOODING OF TRIBUTARIES.

CAUSE OF FLOODING.

All the streams—even the very small ones—which are tributary to this connecting river system show certain characters which are abnormal and are not reconcilable with the ordinary course of stream development. Their mouths and lower courses are all drowned in precisely the same way as are the mouths of the streams that enter the western parts of Lakes Ontario and Erie. In the lakes the drowning was formerly supposed to be due entirely to recent uplift at their outlets, causing the water to back up and overflow the southwestern shores. But it is due also in considerable part to large increase in the volume of discharge at the outlet, amounting to 700 per cent, as shown on page 462.

The backing up of the waters in Lake Erie probably deadened the flow of Detroit River a little, but evidently only a very little, for gentle rapids still exist at the Limekiln crossing, and the river is lower and Lake Erie higher than formerly. The drowning in these rivers is due chiefly to the return of large volume after a long period of abandonment and very small volume. During the dry stage the river channels became long, narrow valleys, like the dry coulees of the West, but smaller and shallower, in which the small streams were lost. Meanwhile all the tributaries, great and small, worked away, deepening their beds to the lower base-level, which may be taken as the bottom level of the shallower parts of the great channels. The holes in the great river beds were probably ponds and the intervening stretches were swampy flats. The floor of the whole connecting river system was probably in this condition.

TRIBUTARIES OF DETROIT RIVER.

The evidences for this manner of development on the tributaries of Detroit River are clear. The United States Lake Survey charts show the depths in the lower courses of most of the tributaries on the American side. A few in which the soundings are not shown are well known to be overdeepened in their lower courses, the same as the others.

Ecorse River.—No soundings are given for Ecorse River, but its drowned condition is very evident on inspection and it is said by the inhabitants to be 12 or 15 feet deep for a mile or two above its mouth. The Ecorse is a small stream, its extreme sources lying at the western edge of Romulus Township about 14 miles west of its mouth. Within half a mile of its mouth it branches twice, and all three branches are drowned for half a mile to a mile above the point of junction.

Rouge River and minor creeks.—Rouge River, which is much the largest tributary of Detroit River, shows the effects of drowning nearly up to Dearborn, 9 miles above its mouth. Concerning the Rouge and the smaller drowned creeks where Detroit now stands, the following description was given by the writer[1] in 1897:

> One of the most interesting features in the vicinity of Detroit is found in the drowned condition of the lower courses of all the tributaries of the Detroit River. Even the smallest streams whose whole length is not over 2 miles have deep estuaries—much deeper than could have originated by their own erosion under present conditions. Many of these were navigable naturally and form excellent harbors for the smaller lake craft. There were several drowned streams originally where the city of Detroit now stands; among them were Parent, Savoyard, May, Knagg, and other creeks, while a little to the west of the city is the River Rouge, a larger stream, which shows the effect of drowning for some 8 or 9 miles above its mouth. About 3 miles above its mouth the Rouge receives a tributary from the north called Baby Creek. It is a very small stream, but it has a depth of 8 or 9 feet for nearly a mile from the Rouge, and it was here that Commodore Perry, after his great victory on Lake Erie in 1813, brought his fleet for repairs. Baby Creek itself has a small short tributary from the east which is navigable and a tract of land bordering upon it was set apart at an early day for a shipyard. Another very small tributary of the Rouge, about half a mile farther up, called Campbell Creek, shows drowning in a very marked way. The average midstream depth of the Rouge for at least 4 miles above its mouth is 18 to 20 feet. This is perhaps three or four times the depth that would be expected from erosion of the stream itself. The Savoyard was where the busiest part of the city is now located. There was a bridge across it at Congress Street where the depth of water was about 10 feet. This creek was the harbor of early Detroit, but with the growth of the city it became an open sewer and grew so obnoxious that it was finally covered over. Most of the other estuaries mentioned within the limits of the city have been filled up.

The Lake Survey chart shows depths mostly of 16 feet, with a few of 17 and 18 feet, up to the Michigan Central Railroad bridge 2 miles or more above the mouth of Rouge River. In 1897 the writer sounded from the bridge at Dix Avenue (now removed), 3½ miles above the mouth, and found a depth of 22 feet. At that time no dredging had been done on Rouge River above the River Street bridge, which is less than 2 miles above the mouth. Baby Creek was originally Baubee Creek, and some maps show Campbell Creek entering it from the west about a mile above the Rouge. Other maps, however, show Campbell Creek entering the Rouge just above the former Dix Avenue bridge. Some maps call this small stream Roulo Creek. At present Woodmere Cemetery occupies the western part of the old shipyard tract and the little tributary that received Perry's fleet is a stagnant bayou running through the middle of the cemetery. Above the city Conners and Fox creeks originally showed slight evidence of drowning, but they are both small and have now been straightened artificially.

Riviere aux Canards.—On the Canadian side the Riviere aux Canards is the only creek of importance. It enters about 3 miles above Amherstburg. No measures of its depth have been obtained, but it has the same drowned appearance as the other tributaries.

TRIBUTARIES OF LAKE ST. CLAIR.

Clinton River.—The only important tributary on the American side is Clinton River, which shows the effects of drowning up to Mount Clemens, about 6 miles above its mouth. Its average depth is 9 or 10 feet, with a few depths of 12 to 15 feet. Several small creeks that enter Anchor Bay from the north all show drowning.

[1]Some features of the recent geology around Detroit: Proc. Am. Assoc. Adv. Sci., 1897, pp. 201-202.

Milk River.—Milk River is a very small stream, but it shows pronounced drowning, as may be seen from the car on the electric line about 4 miles north of Grosse Pointe.

Southern tributaries.—On the Canadian side eight small creeks enter Lake St. Clair from the south, and all of them show drowning very clearly. No data as to their depths were obtained, but their condition is readily seen along the Grand Trunk Railway, which skirts the south shore.

Thames River.—The Thames is the largest tributary of Lake St. Clair. Soundings show depths of 18 to 22 feet for several miles from the lake, and it is navigable for small steamers to Chatham, about 16 miles above the mouth. Baptiste and Jeannette creeks, which enter the Thames on the south side near its mouth, are also plainly drowned.

Sydenham River.—Sydenham River enters the Ecarte Channel of the St. Clair delta about 6 miles above its mouth. At Wallaceburg, about 2½ miles above the channel, the two branches of the Sydenham meet and both show well-marked drowning. The south branch is navigable up to Dresden, 10 miles above Wallaceburg.

TRIBUTARIES OF ST. CLAIR RIVER.

Belle River.—For about 3 miles above its mouth Belle River resembles a deep natural canal. Its value as a harbor for small lake craft determined the location of Marine City at its mouth. Its general depth is 12 feet.

Pine River.—The lower mile or two of Pine River has a general depth of 12 feet and is an excellent harbor for small lake craft. This fact determined the location of St. Clair.

Black River.—Black River is considerably larger than the Pine and the Belle and for about 3 miles above its mouth shows depths of 10 and 16 feet. It is a typical example of an overdeepened and drowned stream.

Canadian tributaries.—On the Canadian side a few very small creeks, such as Talford Creek, a mile above Gorunna, and Clay Creek, 3 miles above Sombra, seem to show (on the Lake Survey chart) slight drowning, but their condition has not been actually observed.

PROGRESS OF OVERDEEPENING AND DROWNING OR FLOODING.

During two periods, after the retreating ice sheet began to uncover the Great Lakes region, the upper three lakes discharged eastward from Georgian Bay, and Detroit and St. Clair rivers ran dry. During these two periods the relatively small local streams worked to a new and lower base-level and deepened their lower courses considerably.

FIRST DEEPENING.

Early Lake Algonquin had a comparatively short life, for the discharge soon left the Port Huron route and went to Kirkfield, Ontario, where it appears to have remained for a relatively long time. (See p. 410.) During this time some deepening at the mouths and in the lower courses of the tributaries may have been accomplished, but it is doubtful whether any recognizable evidence of it now remains. At the close of Early Lake Algonquin, St. Clair and Detroit rivers had probably only cut through the St. Clair and Detroit barriers and the softer parts of the Trenton barrier. They had not sunk into the deep beds in which they now flow.

The upper Algonquin beach and the first St. Clair and first Rouge beaches represent the water levels at that time. The general bottom levels of St. Clair and Detroit rivers were at that time probably not much, if any, below the present water surfaces of these rivers. During the third or Kirkfield stage of Lake Algonquin the beds of St. Clair and Detroit rivers were dry for a relatively long time. The first period of deepening was, therefore, to a higher base-level than the later one, for it was to the abandoned, immature, and only partly developed channel of the outlet of Early Lake Algonquin.

When the discharge of the upper lakes left Kirkfield it was probably divided in unknown proportions between two outlets, Port Huron and Chicago. The return of large volume to Port Huron drowned the lower courses of the channels which the tributary streams had cut to the dry beds, but the drowning effect was probably slight.

CHANNEL MAKING DURING TIME OF LAKE ALGONQUIN.

The later or main period of southward discharge of Lake Algonquin appears to have endured for a relatively long time, during which St. Clair and Detroit rivers must have greatly eroded their beds, probably enough to bring their level down to that now marked by the Nipissing beach at the south end of Lake Huron and to correlative levels descending, as in earlier stages, by steps toward the Trenton barrier and the basin of Lake Erie. During this relatively long period of flow with large volume the connecting channels were probably cut down nearly to their present depths, and the way was prepared for the deepening of the beds of the tributaries in the next period of abandonment.

SECOND OR LAST DEEPENING.

The closing stages of Lake Algonquin were marked by the retreat of the ice and the opening of a passage eastward at North Bay, Ontario, by which the upper lakes discharged through Mattawa and Ottawa rivers to the sea. This event left St. Clair and Detroit rivers dry again, and it was chiefly then that the tributaries accomplished the deepening now shown in the drowning of tributary beds that appear to have been overdeepened. They cut to a base-level about 30 feet lower than that which had controlled them when the great channels were last carrying large volumes. It is to be remembered that at the close of the Port Huron-Chicago stage of Lake Algonquin the level of the waters in the south end of Lake Huron was about 15 feet above present lake level, somewhat less in the basin of Lake St. Clair, and still less in that of Lake Rouge. Cole[1] found buried peat beds in the St. Clair delta 14 or 15 feet below the present level of Lake St. Clair, so that 30 feet or perhaps a little more may be regarded as a close measure of the drop in base-level which affected the tributaries when the great rivers last ran dry.

These facts might afford a basis for a rough estimate of the time which passed between the second abandonment of the outlet at Port Huron and its reestablishment when North Bay was elevated. This interval, whatever it might be, would also measure the time during which the upper lakes discharged past North Bay to Ottawa River—the duration of the Nipissing Great Lakes. But it would hardly measure the transitional or two-outlet phase of those lakes, for in that phase more or less of the discharge had returned to the southward course and the deepening grew less. It is possible that results having considerable value as a check on other means of estimation might be obtained in this way.

During the time of the Nipissing Great Lakes the streams which gathered in the abandoned connecting channels appear to have reversed the direction of flow, going northward to Lake Huron. It seems probable that all the tributaries, including even the Ecorse and the Riviere aux Canards flowed northward to the basin of Lake Huron rather than to that of Lake Erie, which was so much nearer. This stream may be called Algonac River. This direction of flow seems the more probable when it is remembered that the original depth on the Limekiln crossing before dredging was only 13 feet and that that depth had almost certainly been attained only in very recent times. The cutting of the bank on the Canadian side at the Limekiln crossing is still going on. When the bank at this place stood 2,000 feet farther west than now the greatest depth on the crossing, supposing the water surface to remain as it is now with reference to sea level, would be only 8 or 9 feet. In the Trenton Channel the present least depth is 13 feet, about 3,000 feet south of the railroad bridge. The bottom is marked “stony” on the charts, not rocky, so that the depth here has probably been increased in recent time. It may be inferred from these facts that just before the great volume returned the lowest bottom surface on the barrier was at least 5 feet higher than now, and of course the water surface was at first slightly higher.

The only obstacle to the supposition that all these streams flowed northward at that time is the present shallowness of the water at the mouths of the distributaries of the St. Clair delta. But it might easily have happened that one among the several distributaries then existing should have afforded a lower passage than that over the barrier above Amherstburg.

[1]Cole, L. J., Michigan Geol. Survey, vol. 9, pt. 1, 1903.

Spencer notes the depth of 90 feet in the north channel of the St. Clair delta, a little south of Algonac, and takes this as an indication of a northward-flowing stream, and in order to have a northward gradient from this point, supposes the contemporary beach north of Point Edward to be at least 110 feet below present lake level. But, as has been pointed out above, this assumption and the interpretation on which it depends are not justified by sound theory. Some of the deep holes in Mississippi River above New Orleans are 150 feet deep, but to account for this it is not necessary to suppose that the Gulf of Mexico once stood 180 or 200 feet lower than now. Deep holes of this kind in great rivers flowing in alluvial or other soft sediments are common enough and their cause is well known. All of them are in bends where the current is swift and is strongly deflected against the concave bank. The deepest holes in Rouge and Clinton rivers as well as the one south of Algonac stand in this relation. They are not relics of a past condition but are made by the rivers as they are to-day. It is not these exceptional deep holes that constitute evidence of deeper erosion in the past, but the average depth of the lower courses of the tributary streams.

As shown on the charts, the present distributary channels in the St. Clair delta have depths ranging commonly between 25 and 50 feet, and at their extremities the North and South channels have least

depths of 8 and 10 feet, respectively, not counting the artificial canal. It seems -scarcely possible to explain the overdeepening of the tributaries of Detroit River and Lake St. Clair except by northward drainage from the barrier at Amherstburg through some one of the distributaries in the St. Clair delta.

Sydenham River stood in a different relation to the delta, for it enters the Ecarte distributary 6 miles above its mouth and it is only at their mouths that the distributaries grow shallow. It would seem certain therefore that the Sydenham at that time went northward. But this and the other tributaries of St. Clair River show no more effects of drowning than do the streams farther south; indeed, they show less, for a reason given below.

PRESENT DROWNING OR FLOODING.

When the transitional or two-outlet stage of the Nipissing Great Lakes ended and the pass at North Bay was uplifted above that at Port Huron, the great outlet river returned once more to a southward course and the abandoned beds of St. Clair and Detroit rivers and Lake St. Clair were refilled and the enlarged mouths and lower courses of all the tributaries were drowned. That was the beginning of the present condition; there have been no changes of outlet nor any notable change in volume since that time. The level of the lake waters was then about 15 feet above the present level at Port Huron, 9 or 10 feet above Lake St. Clair, and 6 or 7 feet above the present river between Detroit and Grosse Isle. Hence, the drowning effect, as it appeared at the first return of the large river, has been considerably reduced by the lowering of the river surface. This is especially true of the tributaries of St. Clair River, where this lowering has amounted to 12 or 15 feet, but the amount is progressively less in Lake St. Clair and Detroit River. This accounts mainly for the somewhat greater amount of drowning seen now in the Rouge and the Thames as compared with Black River at Port Huron. The lowering of the river surfaces has been due to the recent erosion of the barriers and of the river beds—to the gradual sinking of the great connecting rivers more deeply into the soft sediments of the plain; and, as already said (p. 499), the amount of this deepening (to which drowning now gives the effect of overdeepening) might be taken as a measure of the time during which the southward discharge was absent.

Other factors, however, such as lowering of the river level and silting up or aggradation of the overdeepened parts, operate to reduce the apparent deepening and complicate the calculation. Each tributary has been bringing more or less sediment to its drowned lower course ever since the great volume returned. The finer parts are partly deposited in the estuary and are partly carried into the larger river. Sand and gravel are deposited in the heads of the estuaries, where the first deep water is met, and are gradually accumulating as inset delta deposits. It is interesting to note that the amount of this refilling with sand and gravel is too small to be noticed in the smaller streams, and is smaller than would be expected in most of the larger streams, such as the Rouge, the Clinton, the Thames, and the Sydenham. Black River alone shows a large amount of refilling, but apparently with more reason. The other streams flow through a gently sloping plain for a longer distance, and so have lower gradients and gentler currents for longer distances above their mouths. Black River cuts through the Port Huron morainic system at Wadhams, from near which the refilling extends to within about 3 miles of the mouth of the river. The river flows in a valley trenched deeply in the drift for several miles above and below Wadhams. Its valley is older than the time of Algonac River, but it was deepened at that time up to a point near Wadhams. The deepened part is now floored with a flat gravel deposit or an elongated estuarine delta, which constitutes the present flood plain and is gradually extending downstream. The amount of this refilling might be made the basis of a rough estimate of the time since the discharge of the upper lakes returned to Port Huron. For this, however, other and much better data (Niagara Falls and Gorge) are available, and the amount of refilling would be interesting chiefly in its relation to that better-determined estimate.

A large part of the surface of the St. Clair delta is now above the water; its head near Algonac is about 6 feet above. The water surface in the south end of Lake Huron and in the head of St. Clair River has fallen about 15 feet since the end of the transitional stage from the Nipissing Great Lakes; at Algonac it has fallen slightly less, so that at the beginning of the present stage the water was probably 6 or 7 feet deep over the ground at the head of the delta. Hence, the emergence of the St. Clair delta in this last stage of the lake history is relatively recent, and the development of the present distributary channels in it is nearly as recent, the necessity for their existence arising only when the water began to grow thin over the surface of the delta.

A large part of the westward crowding of the rapids at the head of St. Clair River, causing the erosion of its western bank and the accretion of gravel on its eastern bank, is also relatively recent, and has resulted in a lengthening of the rapids and the bend and a large increase in the gravel deposit at the head of the river.

Six principal changes are now going on: (1) The two great rivers are gradually deepening their channels; (2) they are beginning to develop lateral swinging and bank cutting, as where Detroit River is cutting into the Canadian bank at the Limekiln crossing; (3) the lowering of the river surface is decreasing the area of Lake St. Clair and the effect of drowning in all the tributaries; (4) the tributaries are filling and aggrading their drowned parts with sediments; (5) the St. Clair delta is growing and filling up Lake St. Clair; and (6) the spit gravels at the head of St. Clair River are growing westward and pushing the river farther into the land on the west side.

RELATIVE AGES OF THE CONNECTING RIVERS.

St. Clair River came into existence first and Detroit River almost at the same time; then came the Niagara River; then, in all probability, the upper part of the St. Lawrence below Lake Ontario, extending perhaps down to Cornwall; then the upper part of Nipigon River (the part above the long rapids), and finally, about coincidently, the lower part of the Nipigon, the lower part of the St. Lawrence, and the whole of the St. Marys between Lakes Superior and Huron. The three last-named rivers are very new in their lower courses, and if differential elevation is still in progress it is lifting their mouths out of the water and making their beds shallower and longer.

CHAPTER XXV.
DEFORMATION OF SHORE LINES.

By FRANK B. TAYLOR.

POSSIBLE CAUSES.

Old shore lines may have been deformed in several ways.

1. The water surface may not have been perfectly horizontal while the beaches were being made, as where the water of a lake rested against the front of the ice sheet and was drawn up toward it by the gravitative attraction of the ice. This effect was slight in the Great Lakes region but was always present.

2. Shore lines may be deformed after they are made by elevation or depression of the land arising from one or more causes.

According to the theory of isostasy the larger inequalities of the earth's surf ace express differences of density of segmental parts of the earth, the less dense high or continental parts being balanced against the more dense low or oceanic parts. As a sequence of this theory, erosion from the land surface removes weight from that part and deposition of sediment in the sea adds weight there, and on account of this shifting of weight the equilibrium of the parts affected is progressively disturbed. The deposition of sediments causes the ocean floor to sink and erosion of the land causes the continental areas to rise. De Geer has ascribed the rising of the land and consequent deformation of shore lines of Sweden in part to the erosion of the old (pre-Cambrian) land surface, and he extends the same idea to America.

A popular view, in some sense a corollary of the theory of isostasy, is that the earth movements which raised and deformed the old shore lines were due to resilience of the land following depression by the weight of the ice sheet. There are many reasons for regarding this idea with favor, and it has found more adherents than any other among students of glacial geology.

All forms of earth movement, without regard to cause, may deform old shore lines. This includes the movements involved in continental and mountain growth as well as the more local warpings, sinkings, and upheavals.

3. Eustatic movements, like those described by Suess, tend to raise or lower the whole ocean with reference to the land. Such movements would cause the shore lines to be sub merged as though the land were depressed, or abandoned as though the land were elevated, according as the movement of the sea was positive or negative.

Shore lines may also be in effect raised or depressed (according to Suess) by oscillations of the ocean which may at one time cause an actual excess of water at the poles and an actual deficiency at the equator, and at other times may reverse these conditions, producing the effect of raised and submerged shore lines in both high and low latitudes.

All these possible causes should claim attention in any exhaustive discussion of the subject. In this monograph, however, it will suffice to consider a few of them in a general way.

HINGE LINES AND AREAS OF UPLIFT.

The map (fig. 14) is diagrammatic and is intended to show only the principal facts relating to the ice sheet and the uplifting movements. The boundary of the last or Wisconsin ice sheet at its greatest extent is marked by the heavy line extending entirely across the map, and defines by its sinuous course the outlines of the several strongly marked lobes and reentrant angles of the ice front. The Dakota and the Minnesota-Iowa or Iowa lobes are sharply developed in the west. Between the northeast angle of the Driftless Area in Wisconsin and the reentrant angle at Salamanca, N. Y., a great ice lobe, 600 miles broad at its base, which may be called the Great Lakes lobe, projected 400 miles southward. In it were merged the Lake Erie, Lake Huron, and Lake Michigan lobes and a number of lesser subsidiary lobes, like that of Green Bay in Wisconsin and Grand River valley in eastern Ohio. The remainder of the lobe, projecting south of a line joining Chicago, Ill., and Mansfield, Ohio, was shaped like an inverted cauliflower. East of Salamanca a broad, flat lobe reached the islands south of Cape Cod and had an ill-defined apex in New Jersey just west of New York City. This may be called the Hudson-Ontario lobe, for it was formed chiefly by ice diverging featherwise from the axis of the Hudson-Champlain trough and was augmented on the west by ice spreading southward from the eastern part of the basin of Lake Ontario.

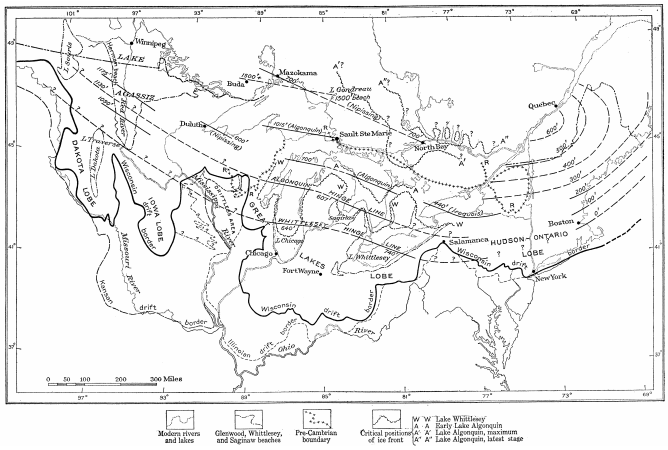


FIGURE 14.—Diagrammatic map showing the relation of the Whittlesey and Algonquin hinge lines to the extreme border of the Wisconsin ice sheet, with three later critical positions of the ice front and several of the isobases. The hinge lines and isobases in the regions east and west of the Great Lakes are added to show the general relation of the deformations in those parts to that in the region discussed.

The region west of the meridian of Duluth is included simply to show how the features there are related to those of the Great Lake region.[1]

No shore lines are shown in the Great Lakes area except the Glenwood or highest beach of Lake Chicago, the Whittlesey beach, and the correlative beach of Lake Saginaw.

Two hinge lines are shown. The first or Whittlesey line crosses Lake Erie from Ashtabula, Ohio, through the middle of Lake St. Clair and thence bends more to the west, crossing Lake Michigan west of Grand Rapids. This line is the isobase of zero for the first or earliest recognized uplift recorded by the beaches. South from this line the Whittlesey and lower beaches and the beaches of Lake Chicago are horizontal and give no evidence of having been uplifted or tilted. But at the hinge line the Whittlesey and Glenwood beaches begin to rise northward. The horizontal part of each successive beach below the Whittlesey reaches a little farther north than that of its predecessor before beginning to rise, but all of them rise before reaching the Algonquin hinge line. The successive positions of the hinge line are shown with approximate accuracy in figure 15.

The Algonquin hinge line is the isobase of zero for the Algonquin beach. South of this line the Algonquin beach in the Lake Huron and Lake Michigan basins is horizontal, but at the line the beach begins to rise northward. On the map the Algonquin hinge line is produced conjecturally eastward across Lake Erie and is made to turn toward the east in harmony with the 440-foot isobase of the Iroquois beach. The conjectural eastward extension of the first hinge line is also bent in the same way and for the same reason, where it crosses the unglaciated reentrant angle south of Salamanca. Both hinge lines are also produced conjecturally northwestward to the region of glacial Lake Agassiz.

The highest or Herman beach of that lake rises northeastward a little, even at the extreme south end of the lake, but Todd found Lake Dakota to be horizontal. The first hinge line is therefore drawn through Traverse Lake parallel with the isobases for 1,090 and 1,175 feet, both of which are based on accurate measurements made by Upham.[2] The Algonquin hinge line is drawn parallel with these isobases and is placed where the earlier uplift is about the same in amount as it is at the Algonquin hinge line on the " thumb" of Michigan. The Algonquin isobases for 700 and 1,015 feet are shown and the general harmony of their trend with the two hinge lines and with the western part of the 440-foot isobase of the Iroquois beach is evident. All the lines run west-northwest over Lakes Huron, Erie, and Ontario, bend more westerly over Lake Michigan and the eastern part of Lake Superior, and return to west-northwest toward Lake Agassiz. The 440-foot isobase of the Iroquois beach bends sharply east near Rochester, N. Y.

Two isobases of the Nipissing beach are shown. This beach comes down to the level of Lake Superior (600 feet above sea level) at the head of Ashland Bay and its nodal line runs about N. 65° W. from this point. The hinge line of this beach is at an altitude of 596 feet in the Lake Huron and Lake Michigan basins, but its place in Lake Superior has not been determined. The isobase of North Bay (700 feet) is the most northerly yet determined. (See p. 460.) In the basin of Lake Superior the trend of the Nipissing isobases is quite different from the Algonquin. In the basins of Lakes Michigan and Huron the Nipissing beach appears to hinge on the same line as the Algonquin, but this is probably not the case at the west end of Lake Superior. The isobases of the Algonquin and Nipissing beaches are shown more completely in figure 8 (p. 439) and figure 9 (p. 461).

[1]The shore lines of the glacial lakes Agassiz, Souris, Dakota, and Minnesota are taken from Warren Upham's maps in his monograph on glacial Lake Agassiz (Mon. U. S. Geol. Survey, vol. 25, 1896).

[2]Op. cit., pp. 278-381.

The beach observed by Coleman at Gondreau Lake north of the east end of Lake Superior has an altitude of about 1;500 feet. A conjectural isobase is drawn from this place to a point north of Buda, 40 miles northwest of Port Arthur, where in 1895 the writer observed a well-defined upper limit to extensive lake sediments.

Besides the extreme border line of the Wisconsin ice, four later positions of the ice front, corresponding closely to critical times in the uplift, are shown in figure 14. The first position, WW, is that of the main moraine of the Port Huron system, and marks the position of the barrier of Lake Whittlesey. The second position, AA, is that of the ice barrier of Early Lake Algonquin. The third position, A'A', which marks the place of the ice front when the lake was at its greatest extent and the upper group of beaches had reached their farthest northward extension, and the fourth position, A"A", which marks the place of the ice front at the last stage of Lake Algonquin (the lower of the Fort Brady beaches) just before the inauguration of the Nipissing Great Lakes, are only

rough approximations, the actual position of the ice front having not yet been well determined.

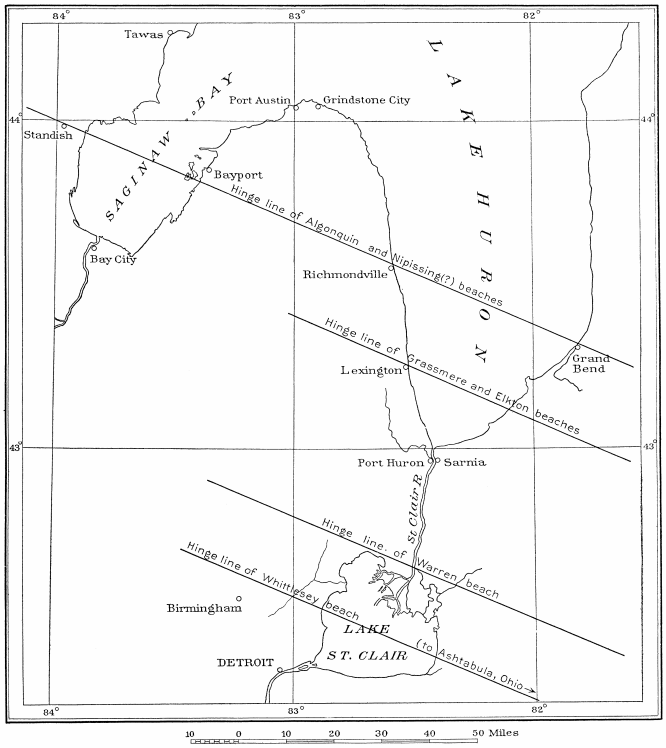


FIGURE 15.—Map showing northward shifting of the hinge lines.

The curved isobases in the region south of St. Lawrence River and east of Lake Ontario show present knowledge concerning the deformation of the marine shore line, as recently represented by Goldthwait.[1] These lines have no connection with the glacial lakes, but relate solely to the marine waters. They are added merely to show the general relation of the deformation in the marine area to that of the Great Lakes region.

ICE ATTRACTION.

The effects of ice attraction in deforming the old beaches are discussed on pages 343-348.

RESILIENCE FOLLOWING DEPRESSION BY ICE WEIGHT.

RELATIONS OF UPLIFT TO RETREAT OF ICE.

The causes that deformed the old shore lines of the Great Lakes region acted within fairly well defined limits of space and time; that is to say, although the deforming causes affected a vast area of the northern and northeastern parts of the continent, they had clearly denned southward limits in the region of the Great Lakes, and the time of their action is recorded in the deformed beaches of a long series of lakes and lake stages covering almost the entire period since the maximum of the last or Wisconsin ice sheet. The areal relations of these limits to the area covered by that ice sheet and the time relations of the uplift to the retreat of the ice are so nearly in accord that to many minds they prove causal relation between the ice sheet and the elevation of the land. The apparent great strength of this explanation is not denied, but serious difficulties, that ought not to be overlooked, stand in its way.

The southern boundary of the uplifted lands, marked by the first or Whittlesey hinge line (see fig. 14), is roughly parallel to the boundary of the Wisconsin ice sheet and is not far north of the mean course of that boundary from northwestern Dakota to the Atlantic coast in Massachusetts. Further, the Algonquin hinge line is substantially parallel with the first, the interval between them, however, being about twice as wide in the west as in the east.

The attitudes of the old shore lines show three distinct periods of land elevation in the Great Lakes region, separated by two fairly well denned times of stability. The relations of the uplifting movements to the retreating ice sheet may be briefly summarized as follows:

1. The first elevation began when the ice front had retreated nearly halfway across the Great Lakes region. Just before this uplift the ice front had been resting on the main moraine of the Port Huron system, which marks the ice barrier of Lake Whittlesey. This position of the ice front (see wavy line WW in fig. 14) has been traced continuously through nearly the whole length shown. The uplifting movement continued in spasmodic fashion until the ice front had retreated nearly to the position marked AA. During this interval the hinge line kept shifting north. This movement deformed all the beaches before the Algonquin, the Maumee to the Lundy, inclusive.

It is entirely possible that uplifts occurred before the formation of the earliest glacial lakes and hence were not recorded in the beaches. The Lum and Rochester channels seem to show a movement occurring just after these channels were abandoned, but the beaches show none that are clearly discernible. The movement, if it took place, must have been relatively slight and could have extended only a few miles, if at all, south of the Whittlesey hinge line.

2. At the position AA the ice barrier was holding up the water of Early Lake Algonquin. But this short-lived stage soon gave place to the longer second stage with outlet at Kirkfield, Ontario, and from the beginning of that stage until the ice front had retreated approximately to the position A'A' no uplift occurred.

[1]Bull. Geol. Soc. America, vol. 22, 1911, pp. 723-724.

This conclusion is supported by the fact that the upper group of Algonquin beaches (see pp. 415, 433) extend to the northern highlands of the lake region, reaching 1,220 feet on the hills north of Trout Creek, Ontario, 25 miles south of North Bay, and about 1,500 feet (as observed by Coleman) at Gondreau Lake, north of Lake Superior. These high beaches have not been continuously traced to the beaches farther south, and their places in the group are not definitely known; but

they are strong and show characteristics that indicate the work of heavy waves of wide waters, and their altitudes agree in a general way with the planes of the upper members of the upper group produced.

3. When the ice front was approximately at the position A'A', the second and greatest period of uplift began. It was this movement that produced the remarkable deformation of the Algonquin beaches and caused the northward splitting that amounted to 365 feet at Sault Ste. Marie to 550 feet near North Bay, and apparently to 850 or 900 feet at Gondreau Lake, 150 miles north of Sault Ste. Marie.

The relative rapidity of the middle part of this uplift is remarkable. By the time the ice front had retreated from the position A'A' (fig. 14, p. 503), approximately to the position A"A" (about 150 miles on the lowest line of retreat), the greater part of the Algonquin uplift had been completed. That for a considerable time the movement must have been relatively slow is shown by the great strength of the beaches of the upper group. That all the movements turned on the Algonquin hinge line shown in figure 8 (p. 439) and figure 14 has been established by the wye-level surveys of the beaches made in 1907 and 1908 by Goldthwait and the writer. From Mackinac Island, Mich., and from Kirkfield, Ontario, all the numerous beach ridges of the Algonquin groups were found to converge southward to this one hinge line.

4. The most characteristic quality of the Nipissing beach is its great strength and relatively mature development, which seem to show stable condition of the land. The beach is stronger near the Mazokama-North Bay isobase than elsewhere, but it is strong for a long distance south of this line; so far south, indeed, that some part of its strength should probably be attributed to the two-outlet stage when the overflow was divided between Port Huron and North Bay. These characters seem to imply either stability or extremely slow uplift. Hence, during the time of the Nipissing Great Lakes and perhaps for a time during their closing two-outlet stage, the elevation of the land had ceased or was extremely slow. This period covered the time of the retreat of the ice from the position A"A" and may have included the entire disappearance of the Labrador ice sheet.

5. Finally, the movement of elevation was renewed and has continued rather slowly and spasmodically to or nearly to the present time. In this time North Bay has been uplifted a trifle more than 100 feet and the lands farther north still more. This period may possibly include the last fading stage of the ice sheet, but in all probability it began after the complete disappearance of the latter.

In the marine area in the east it is not yet possible to divide the time of the uplifting movements into periods corresponding to those so clearly defined in the Great Lakes region. From Boston to Quebec the isobases shown on the map range from zero to 600 feet. It seems significant that the first hinge line of the Great Lakes region, if bent in harmony with the 440-foot isobase of the Iroquois beach and produced eastward, seems naturally continued in the zero line of the marine area. There seems to be no reason to doubt that this apparent relation represents the real relation. It can not be safely inferred, however, that the isobases shown around Quebec record the whole amount of uplift that has affected that region, for, as in the Great Lakes region, the early uplifts raised a large area of the land still covered by ice, along with a part of that which had just been uncovered. Thus, the lands for 100 miles or more south and east of Quebec may have been and probably were elevated several hundred feet while still covered by the ice sheet. It follows that the marine beaches observed near Quebec and along the south side of the St. Lawrence probably belong to a different and later period from those near Boston. It may at some time become possible to recognize stages of uplift and correlative ice fronts and beaches in the marine region, but data for doing so are not yet available.

In the Great Lakes region the first period of uplift raised the Warren beach at Bad Axe, Mich., about 100 feet above the level of that beach in the area of horizontality. Bad Axe was not far outside the front of the ice as it then stood, and it seems certain that the uplift involved much land that was still under the ice sheet. No correlative beaches and moraines found in the deformed area show diminution of uplift on approaching the front of the ice and some of them show increased northward rise, even after allowing for ice attraction. Indeed, it seems probable that the whole area of Lake Algonquin and perhaps much more was uplifted at least 100 to 150 feet by the first movement while still covered by the ice sheet. This occurred before the beginning of Lake Algonquin and requires the addition of some such amount to the total uplift recorded in the Algonquin beach in the northern part of the Great Lakes region.

THEORETICAL PRINCIPLES.

On its theoretical side the relations of ice weight to land depression and resilience present many difficult problems. Some of the most important elements that must enter into any attempt at numerical evaluation have not yet been satisfactorily determined. One such element is the thickness of the ice over a given locality or area at a given time. It seems certain that it will be possible some day to determine this with a close degree of accuracy, but at present all estimates are uncertain.

According to Lane the weight of the ice sheet might depress the land in two ways—by elastic compression and by actual transfer of fluid or plastic molten magma in relatively large quantities from one place to another beneath the earth's crust.

Woodward[1] has shown that one atmosphere of pressure on the earth's surface tends to shorten the earth's radius about 2 meters. This furnishes the required datum for estimating the amount of depression due to elastic compression under the weight of the ice.

On the basis of this hypothesis Lane[2] estimated the proportion of the total depression that might be ascribed

to each of these two modes of adjustment on the assumption of certain conditions of ice thickness which he thought applicable to a particular area in Michigan. He points out that 2 meters of compression by one atmosphere of pressure means that an ice or water load on the surface would tend to compress the earth underneath by about one-fifth as much as the thickness of the water or ice.

On the assumption that the earth's crust is a somewhat flexible sheet resting on a more or less fluid interior, Lane shows that the weight of the ice or water would bend the crust down into this fluid interior and that, neglecting for the time the lateral or shearing stresses, the depression would be accomplished by the displacement of an equal weight of the magma or fluid rock beneath the crust. The density of the rock below being approximately three times that of water, the amount of depression would be about one-third of the thickness of water or ice. The use of this ratio without qualification implies the assumption that the relation is truly and simply hydrostatic, that the interior fluid has no physical quality which prevents it from obeying hydrostatic laws with substantially complete fidelity, and therefore that viscosity in such degree as is allowed for the interior fluid of the earth is no bar to interior readjustments of mass in strict accordance with hydrostatic laws.

Lane's assumption that resilience may be caused by the hydrostatic inflow of a fluid molten magma previously displaced by depression of the earth's crust seems to the present writer out of accord with the best modern conclusions regarding the conditions of the earth's interior. Years ago the physicists gave the geologists reason enough for believing the earth to be solid to its center and to have there its greatest density and a rigidity greater than that of steel; and the more recent records of the propagation of earthquake waves through the deeper parts of the earth seem, through many repetitions, to have fully established its essentially solid, rigid character. Again, though some physical phenomena affecting the earth find no bar to their action in mere vastness of area or of matter involved, the transfer of tremendous volumes of fluid magma through great distances beneath the earth's crust is not of this class. The difficulty of explaining such a transfer is enormously increased when a mass of magma from 1,000 to 4,000 feet thick and underlying about one-third of the continent of North America is involved. The displaced magma could go nowhere without producing effects that would be readily recognized. With the amounts and the distances so great time would be of great importance, especially if the material was more or less viscous. To make readjustment easy would require the whole interior body to be perfectly fluid and responsive to pressure, like water in a water-filled rubber ball when dented. It seems incredible that the interior of the earth can be in any such condition, and if it is not in such condition the difficulties of explaining resilience in this way are incalculably greater. The very vastness of the region affected appears to exclude this cause.

[1]Bull. U. S. Geol. Survey No. 48, 1888, p. 66; Sixth Ann. Rept. U. S. Geol. Survey, 1885, pp. 295-296.

[2]Personal communication, Nov. 9, 1907.

It is also a question whether both modes of depression can be postulated as occurring at once with the values stated, for Woodward's calculation of the effect of elastic compression is based on the assumption that the earth is solid to the center and highly rigid throughout—an idea that is hardly compatible with the postulate of a widespread fluid magma beneath the crust. If the interior is fluid, the elastic compression found by Woodward must reside solely in the rigid crust above the fluid interior. But, assuming for the moment that the two modes of depression can occur together with the values assumed, it becomes possible, on the basis of definite assumptions as to the thickness of the ice, to calculate roughly the amount of resilience which would arise from each of these causes on the removal of the ice weight. Thus, employing the values used by Lane, if the ice be supposed to be 1,250 feet thick, the amount of elastic resilience on its removal would be one-fifth, or about 250 feet. This, presumably, would be instantaneous; that is to say, it would follow the decrease of ice weight at the same rate, but the hydrostatic readjustment of the fluid magma would be much slower, depending upon the degree of viscosity. On this assumption of ice thickness, according to Lane, the hydrostatic relief would give an additional uplift amounting to one-third of the ice thickness, or about 400 feet. This would give a total uplift of about 650 feet. On account of its slowness, however, the hydrostatic relief may be still in progress and not yet fully satisfied.

THEORETICAL AND ACTUAL UPLIFT.

LAKE SUPERIOR REGION.

Lane applies his theory to the region of Lake Superior, where he supposes the Huron Mountains on the south side of the lake to have been barely overtopped by the ice at its greatest thickness. If it be granted for the moment that Lane's assumption on this point is true, the thickness of ice measured from the present water surface of Lake Superior is approximately in accord with the assumed thickness of 1,250 feet in the Lake Superior basin close north of these mountains. The amount of uplift on the Keweenaw Peninsula has been on the least estimate 500 or 600 feet and may have been more. On the assumption made, therefore, the results seem to accord fairly well with expectation.

But although it is true that the Huron Mountains were not covered by a great depth of ice, even at the maximum of the Wisconsin ice sheet, Lane's assumption that they were barely overtopped is at variance with evidence recently found by Mr. Leverett showing clearly that their highest parts were heavily scored by the ice sheet that passed over them. On the most conservative estimate the ice could hardly have been less than 1,500 feet thick and was in all probability 2,000 to 2,500 feet thick on the northern part of the high ground north and northwest of

Champion, for at the maximum the ice moved nearly 150 miles southwest over this high region, nearly all of it more than 1,500 feet above sea level (900 feet above Lake Superior). Allowing for an average slope of only 10 feet to the mile for the surface of the ice back from the extreme front, the depth 150 miles back would be 1,500 feet, as stated above. But in all probability the average slope was nearer 20 feet to the mile, which would give a depth of 3,000 feet. The Keweenaw and Chippewa ice lobes merged on this highland and covered it completely, the front of the ice advancing down to the northern side of the Driftless Area in Wisconsin. Over the middle of the outer part of Keweenaw Bay, say 20 miles directly south of Keweenaw Point, the ice surface, must have been at least 500 or 600 feet higher than on the high ground north of Champion. Thus, by an estimate based on minimum values throughout, the depth of ice at the maximum of the Wisconsin sheet over the present surface of Lake Superior in the central part of Keweenaw Bay was 2,900 to 3,000 feet, or considerably more than twice the depth assumed by Lane. Applying to this depth of ice the ratios used by Lane, the amount of uplift due to elastic resilience would be nearly 600 feet and to this must be added that due to hydrostatic inflow amounting to nearly 1,000 feet, making a total uplift of 1,500 to 1,600 feet in Keweenaw Bay.

The total amount of uplift actually determined by observation near Calumet on the Keweenaw Peninsula is only a little over 500 feet, this amount being recorded in the Algonquin beach. To this may be added by inference 150 to 200 feet for the first period of uplift, which is recorded in the Michigan, Huron, and Erie basins, but which is not shown by the beaches of Lake Superior. The absence of such evidence in the Lake Superior basin is not, however, a safe reason for inferring that the early uplift did not affect that basin, because the basin lies well within the uplifted region and none of its old shore lines extend south of the Algonquin hinge line, or even near to it. Thus the total uplift, recorded and inferred, was 650 to 700 feet, agreeing closely with Lane's estimate on the assumptions which he made, but amounting to less than half that which would correspond to the revised estimate of the thickness of the ice.

The selection of the Lake Superior region, however, as a place for testing the hypotheses of elastic resilience and hydrostatic readjustment appears to be unfortunate, in the light of recent investigations. Studies by Leverett and Sardeson in 1910, the results of which were announced in a paper presented by Sardeson at the Minneapolis meeting of the American Association for the Advancement of Science, indicate that the region west and north of the west end of Lake Superior became free of ice in an early part of the Wisconsin stage of glaciation. It was open territory at the time the Keewatin ice field had its greatest eastward extent in northern Minnesota, for the Superior lobe at that time extended but little beyond the western end of the basin. The only glaciation which this region experienced in the Wisconsin stage seems to have been from a weak ice advance southward from the high country between the Superior and Winnipeg basins. At the height of the Wisconsin stage of glaciation this country seems to have had a covering of ice which was thin in comparison with that in the basins on either side, and before the earliest uplift recorded in the Huron-Erie basin it seems to have been free from ice. It is not yet known how far northeast this ice-free region extended, but it seems to widen toward the Canadian border. The existence of this area along the north side of the western part of the Lake Superior basin changes the glacial status of that whole region and puts the ice lobe of the western arm of Lake Superior into the category of strongly protruding marginal lobes, like the others farther south. The deep basin of the western arm of the lake was near the ice border toward the northwest as well as toward the south. And yet this whole region is well within the area of Algonquin uplift and both of the hinge lines shown in figure 14 (p. 503) pass far south of it.

ICE LOBES AND DRIFTLESS REENTRANTS.

If the problem be considered in connection with another differently situated ice lobe, a more certain and a very different light is thrown on the relations of uplift to ice weight. The best subject is the Great Lakes lobe. The base line of this lobe is 600 miles long and extends from the northeast angle of the Driftless Area in Wisconsin to the reentrant angle at Salamanca, N. Y. It happens that this base line is almost exactly coincident with the Algonquin hinge line in the Lake Huron basin. It lies only a few miles south of this line and has almost the same trend. Within the area of this lobe there is no evidence whatever of either depression or elevation of the land in Wisconsin glacial time before the movement which raised the land north of the first or Whittlesey hinge line. The whole lobe, therefore, the part north of the first hinge line alone excepted, lies within the area of horizontality, and as the base line of the lobe is substantially coincident with the Algonquin hinge line, it may be said that only that part of the lobe which covered the area between the two hinge lines was affected by depression and resilience, and further, that the movements affecting it were all of the first period and had ceased before the beginning of Lake Algonquin. It may therefore be said that the whole lobe lies within the area of horizontality when considered with reference to the Algonquin period of elevation.

From the front of this great lobe back to its base line the surface of the ice sheet must have risen in the usual way. The data for determining the rate, however, are meager. The present land surface at both ends of the base line is something above 1,500 feet above sea level. Both of these points, however, were about 100 feet lower than now before the beginning of the first period of uplift. The rim of the Lake Erie basin rises gradually eastward from 760 feet above sea level at Fort Wayne, Ind., to above 1,000 feet across most of northern Ohio and to above 1,500 feet at Salamanca, N. Y. Northward from Fort Wayne the rim rises to over 1,000 feet above

sea level in northeastern Indiana. The rim of the Lake Michigan basin rises from 590 feet at Chicago to over 1,000 feet above sea level in northeastern Indiana and gradually to 1,000 feet in southern Wisconsin and to over 1,500 feet at the northeast corner of the Driftless Area. The present surface of Lake Erie is 573 feet and of Lakes Huron and Michigan 581 feet above sea level.

The ice surface must also have risen along the base line from the two ends toward the middle as well as backward along the central axis from the apex. At an average of 10 feet per mile for 400 miles the surface would rise 4,000 feet from the apex to the base. This would allow for a rise of 2,000 to 2,500 feet in 300 miles from the ends of the base line to the middle. This average rate seems low enough. If the rise be divided into sections with a higher rate at the front diminishing toward the base any estimate that seems tenable leads to a rise of at least 4,000 feet. For example, if the rate averaged 50 feet per mile for the first 10 miles, 20 feet per mile for the next 90 miles, 10 feet per mile for 100 miles, and then 5 feet per mile for 200 miles, the total rise to the base line would be 4,300 feet. A rise of 4,000 feet in 400 miles on the central axis and of 2,000 to 2,500 feet in 300 miles on the transverse axis at the base fine does not seem excessive—certainly not in comparison with the Greenland and Antarctic ice sheets as now known. Indeed, it is almost certainly an underestimate, rather than the reverse. This would mean a depth of ice of something near 4,000 feet over the head of Saginaw Bay and the south end of Lake Huron. In the Huron-Erie basin the Whittlesey hinge line lies about 75 miles south of the Algonquin hinge fine, and the surface of the ice over Lake St. Clair and for 100 miles or more to the west along the former hinge line may be supposed to have been between 500 and 700 feet lower than at the base line. Even if the thickness of the ice on the middle of the base line was as little as 3,000 feet, this is equal to the thickness found by the revision of the estimate for Keweenaw Bay in Lake Superior and is more than twice the thickness which Lane found so closely accordant with his results for elastic resilience and hydrostatic readjustments in that region. He found that 1,250 feet of the ice there produced depression followed by 650 feet of resilience (combining both causes), but on the Whittlesey hinge line, 75 miles south of the base line of the Great Lakes lobe, there was probably fully 3,000 feet of ice, possibly even 4,000 feet, and yet there is no evidence whatever of either depression during ice occupancy or of resilience following its removal.

RELATION OF ICE WEIGHT AND HINGE LINES TO ICE MARGIN.

EFFECT OF DRIFTLESS AREAS.

In Wisconsin the first hinge line passes through the central part of the Driftless Area, which was at the time of the Wisconsin ice sheet simply a large reentrant angle, and it passes also across the central part of the driftless reentrant south of Salamanca. Neither of these areas was covered by the Wisconsin ice sheet at its maximum, nor were they covered by any of the earlier ice sheets. Yet the hinge lines keep their courses with scarcely any deviation across the Great Lakes ice lobe, the Driftless Area, and the Salamanca reentrant angle. Indeed, looking at the details a little more closely, it appears that the only place where the first hinge line is concave, even very slightly, toward the south is in the central part of the Great Lakes lobe, 100 miles or more west of Lake St. Clair (see fig. 14), and that the only places, within the area here discussed, where the first hinge line is convex toward the south are in the Driftless Area of Wisconsin and the Salamanca reentrant angle. In the Great Lakes lobe the southward concavity of the line looks as though the uplifting forces had met some resistance there which had prevented them from reaching as far south as they otherwise would. On the contrary, the southward convexities in the Driftless Area and the Salamanca reentrant look as though the uplifting forces had found less resistance there and had reached a little farther south than the mean. The relations of these details certainly present problems of great difficulty for those who believe the uplifts to be due solely to depression by ice weight and resilience following its removal.

These facts and relations raise a number of important questions. What was the order of magnitude of the uplifting force? How much pressure and how large an area were required to produce the initial effect of depression? On the one hand, it was manifestly of such an order of magnitude that the weight of 3,000 or 4,000 feet of ice fell a trifle short of being critical; that is to say, it did not produce appreciable depression, for the removal of ice of that thickness did not produce resilience at the first hinge fine, although at points a little farther north, where the ice was thicker, there was a slight uplift following removal of the ice. Yet the removal of less than this thickness of ice over the central part of the ice field north of the hinge fine was apparently followed by relatively rapid uplift of 100 to 200 feet throughout a large part if not all of the region still covered by ice. In this movement the ice load then remaining was uplifted along with the land. On the best interpretation now available it is assumed that the removal of 3,000 or 4,000 feet of ice at the hinge line by melting and the retreat of the ice front, including the marginal belt with its relatively steep surface gradient, would be accompanied by a lowering of the central area of the ice field, not in like amount but in a considerably less amount, perhaps half as much or less. The surface gradient near the central area would be low, even if gravity were the only cause of the radial movement of the ice. If radial movement of snow by the action of powerful and permanent anticyclonic winds upon it before its consolidation into ice is an important factor, the surface gradient would be likely to be still lower.

On the assumption that the removal of the weight of the ice was the cause of the uplift, these considerations lead to the conclusion that at the hinge line the superposition of 3,000 or 4,000 feet of ice on the land did not add

weight enough to start a movement of depression, not even by elastic compression, and consequently its removal was not followed by resilience, but that in the central part of the ice field the accumulation of 10,000 to 15,000 feet of ice did produce depression, and the subsequent removal of say 1,500 to 2,000 feet (considerably less than the maximum thickness at the hinge line) did cause resilience with resultant uplift. Whether such a conclusion is tenable or not in the light of known physical and dynamic laws is a problem for the geophysicist.

On the other hand, the first hinge line takes a direct course across driftless reentrants as well as across great ice lobes, as if the uplifting movement had had nothing whatever to do with such ice weight as affected the land under the basal part of the Great Lakes lobe. Apparently, a variation of surface load ranging from zero to the weight of 3,000 or 4,000 feet of ice was not enough to cause marked deviation in the hinge line. Indeed, the very slight deviation observed is in the wrong direction to have any significance with regard to ice weight. If ice weight produced depression it seems certain that it was confined chiefly to an area much farther north, where the ice was much thicker than at the base line of the Great Lakes lobe. In order to fit the facts, it seems necessary to suppose that marked depression by ice weight occurred only where the ice was two or three times as thick as at the base line. If, as seems probable, there was a large area of ice of great thickness farther north and northeast, strong depression may be supposed to have taken place there. It seems probable that the area of depression would not be limited by a sharp boundary with vertical sides or with a very steep gradient, for since the surface of the ice rose gradually from the edge back to the highest point, the amount of depression would diminish gradually from the central area out toward the ice margin. But it might fall considerably short of reaching the extreme margin or even the mean line of the lob ate margin. If depression depended on a central ice mass of great thickness and was not influenced by the relatively thin ice of the marginal part with its lobes, it might be expected that the outer boundary or hinge line of depression and of subsequent resilience would lie within the marginal belt of the ice field and would follow a straight or gently curved line substantially parallel with the isobases of the uplifted region to the north and largely if not entirely independent of the marginal lobes and reentrants. Thus, the elevation of the land for probably 100 to 150 miles north of the first hinge line was in all probability due not to depression by the weight of the ice that rested directly upon that land (at the maximum of the ice) but to the greater weight of the much thicker ice farther north, the depression under which died out gradually southward into the marginal area, where the weight of the thinner ice failed to produce depression.

As the retreat of the ice front progressed from the maximum boundary, the height of the entire ice surface to the north and hence the thickness of the ice and the weight with which it pressed upon the lands beneath it were reduced, and it was presumably this reduction of weight in the central, thickest part of the ice field that caused resilience, and not the uncovering of the marginal belt by the shrinkage of the lobes. In view of the independence of the hinge lines in relation to the irregularities of the ice margin it seems certain that only a small part, if any, of the uplift in the region discussed by Lane (Huron Mountains and Keweenaw Bay, Lake Superior) could have been caused by the removal of the weight of the ice mass of that immediate vicinity, and that the uplift, if due at all to the removal of ice weight, was due mainly or wholly to the removal of the much thicker ice farther north or northeast.

The area of marked depression under the central mass of the ice sheet may be regarded theoretically as a saucer-shaped basin, its outer margin sloping gently upward and dying out to a hinge line in the marginal belt, where the ice weight was not sufficient to produce depression. Questions arise here as to the probable breadth of the inclined rim of the depressed basin, the distance to which depression may have extended beyond the area of effective ice weight, and the size of the area that might be left bare of ice without markedly modifying the courses of the hinge lines and isobases.

The boundary of the light and short-lived glaciation around the west end of Lake Superior appears to widen toward the northeast in northeastern Minnesota, as though extending across into Canada. This it may do, and it may include a large part of the high region which lies north of the western arm of Lake Superior and west and northwest of Lake Nipigon. As may be seen on the relief map of the Dominion of Canada,[1] this area is occupied by a high plateau covering about 100,000 square miles. The widening toward this plateau indicates that it was not a region of strong glacial growth and dispersion and hence of thick ice, but that it was in the marginal belt and was covered, if at all, at the Wisconsin maximum only thinly and that for a relatively short time. If this area extends into Canada, as seems probable, it reaches so far back from the hinge line, as determined by the Lake Agassiz beaches in Minnesota, that it seems to call for too great a width of the propagated marginal belt of the ice-depressed basin.

Suppose a nunatak, or rather, a flat island in the ice field, like that which existed for a time in the southwestern peninsula of Ontario, surrounded by thick ice at some distance, but with the ice thinning toward it on all sides. If the island were of small area it is easy to believe that it would be carried down along with the depression of the surrounding heavily weighted lands, although it was itself not covered or only thinly covered, and that it would come up again when the ice disappeared and the surrounding lands were affected by resilience. How large such an island must be to be exempt from the influence of conditions directly affecting only the surrounding lands and not the island itself is a question. Even if the island itself be relatively small, 200 or 300 miles of relatively thin ice must be allowed for in the margin around it. The area in Canada exempt from

direct depression by ice weight may have been larger than the whole of the high plateau; and, if so, the northernmost boundary of the nonweighted land would be at least 400 or 500 miles back from the hinge line at Traverse Lake, Minn. This region of light and short-lived glaciation, therefore, is set back so far into the area of uplift that if it is as large as seems likely (including the marginal belt of relatively thin ice) it seems to constitute a serious obstacle to the hypothesis of depression by ice weight.

[1]White, James, Dictionary of altitudes in Canada, Ottawa, 1904, map.

The greatest amount of uplift yet recorded is that found by Coleman at Gondreau Lake, northeast of Lake Superior. Lake Kaministiquia, supposed by the writer to have been a local ice-dammed lake, seems likely from Mr. Leverett's recent results to be merely a bay of Lake Duluth, or possibly of Lake Algonquin,[1] with an upper limit more than 1,500 feet above sea level. These shore lines suggest that 900 to 1,000 feet of uplift has affected the northern part of the plateau referred to, and this inference will have to stand, unless facts are found that disprove it, which now seems decidedly unlikely, especially in view of Coleman's recent account of Lake Ojibway.[2] Coleman presents many facts relating mainly to high-level lake clays overlying the drift north of Height of Land between Lake Nipigon and Lake Abitibi and to terraces, belts of sand, and gravel at higher levels. He finds higher old water levels passing above the cols across Height of Land and regards them as temporary arms of Lake Algonquin reaching across to the Hudson Bay slope and covering narrow belts of this slope in front of the retreating ice sheet. They are not so high as the beach at Gondreau Lake, but they appear to mark levels not far below it, and though as yet they can not be positively proved to belong to Lake Algonquin, they indicate the great uplift suggested for the plateau west of Lake Nipigon. The plateau corresponds to the supposed island in the preceding discussion.

These old lake levels are several hundred feet above the upper limit of marine submergence (about 450 feet above Hudson Bay) as marked by beds of fossil marine shells farther north on the same slope. The fossil-shell beds could not have been deposited until after the ice sheet had disappeared from the region where they are found, and the movement by which they were elevated consequently came still later. The withdrawal of the ice from the southwest slope of the James Bay basin could hardly have been earlier than the later stages of Lake Algonquin and was probably considerably later. Yet, if the plane of the Nipissing beach in the northern part of the upper lake region be produced northward to the shell bed on Albany River, it would indicate an uplift of only 200 to 250 feet. This suggests that the shells may have been raised 150 to 200 feet before the uplift recorded in the Nipissing beach. The data are still too few to permit final conclusions, but they seem thus far to be in accord with the conclusions reached from the study of the Great Lakes.

SHIFTING OF THE HINGE LINE.

For such difficulties as these, which seem strongly unfavorable to resilience following depression by ice weight, the northward shifting of the hinge line and the time relations of the uplifting movements to the retreat of the ice seem to be partial if not equal offsets. The ice front rested close north of the line WW (fig. 14, p. 503) when the first period of uplift began, and the hinge line shifted almost to the Algonquin hinge while the ice retreated to the position AA.

The northward shifting of the hinge line during the retreat of the ice is shown diagrammatically in figure 15 (p. 505), the positions of the lines being only roughly determined. The movements appear to have been spasmodic, and they cover altogether the retreat of the ice from the late phase of Lake Maumee, not far from the time of the Yale moraine, nearly to the time of the Port Elgin moraine (AA, fig. 14). The Warren hinge line is 15 to 17 miles north of the Whittlesey hinge line, the Grassmere and Lundy about 40 miles north of the Warren, and the Algonquin 15 to 17 miles north of the Grassmere and Lundy. A more pronounced rise begins about 40 miles north of the Algonquin line and appears to correspond to the time of the Battlefield beaches, when the rate of uplift was most rapid.

The retreat of the ice front from the extreme limit to the line WW was synchronous with the lowering of the entire ice surface in the north by probably 1,500 to 2,000 feet, and this much ice removed from the top of the sheet where it was probably at least 10,000 to 15,000 feet thick may be supposed to have reduced the ice weight and inaugurated the uplifting movement. Later, when the ice front had retreated 150 to 200 miles farther, and another ice layer probably 1,000 feet or more in thickness had been removed, the great Algonquin uplift began. This, again, continued while the ice retreated 150 miles farther, and after a second pause during the time of the Nipissing Great Lakes, the uplift was resumed and has continued to or nearly to the present time. The natural significance of such relations as these seems suggestive and strongly favors resilience following depression by ice weight. Still, the adverse factors mentioned above appear to be of equal or greater strength.

[1]Notes on the abandoned beaches of the north coast of Lake Superior: Am. Geologist, vol. 20, 1897, pp. 117-119.

[2]Coleman, A. P., Lake Ojibway, the last of the great glacial lakes: Eighteenth Ann. Rept. Bur. Mines, Ontario, 1909, pp. 284-293, particularly pp. 286-287.

ABSENCE OF RECENT FAULTS.

Another thing that seems strongly favorable to the hypothesis of depression by ice weight is the fact that only a few very small step faults have been found in all the region recently uplifted. The greater number of the faults so far observed run north and south in New York and Vermont east of Hudson River.[1] Others have been found in Nova Scotia and elsewhere. Small anticlinal

folds of recent date are common in the shale around the western end of Lake Ontario. Depression by ice weight would be unlikely to produce faults, because the movement would take place beneath the heavy ice load, which would be in its effects equivalent to the overlying load of strata that contributed to some of the strongly folded parts of the Appalachian Mountains, where folding is conspicuous and faults rare. Resilience following the removal of the ice would also be unlikely to produce faults, because much of it occurred beneath considerable thickness of ice, because the upward force was widely and evenly spread over a great area and was lacking in concentration at any particular place or along any particular line, and because the forces both of depression and resilience increased with extreme slowness. The phenomena of the uplifted region seem as a whole distinct and different in kind from those that would be expected as normal results of the usual processes of mountain making and continental growth. Still, it is not certain that faulting need be strong in the initial stages of folding in mountain making.

PRE-WISCONSIN DEPRESSION AND RESILIENCE.

The question naturally arises whether any evidence exists of depression and resilience in the older glacial and interglacial epochs.

A few phenomena, such as the interglacial lake beds and the buried old land surfaces at Toronto, suggest episodes of pre-Wisconsin glacial and lake history closely resembling some of those associated with the Wisconsin ice sheet and the lakes of its waning phase. It seems certain that if the basin of Lake Ontario in pre-Wisconsin interglacial times had been continuously as much depressed with reference to sea level as it was at the maximum of the Wisconsin glaciation there could have been no lake beds nor any old land surfaces where those at Toronto have been found, but only glacial and marine beds.

RELATION OF ISOBASES TO THE PRE-CAMBRIAN BOUNDARY.

The partial parallelism of the isobases to the pre-Cambrian boundary is interesting and probably deeply significant, but its meaning is not yet clear. De Geer[2] found that the isobases of the uplifted marine shore lines in Sweden maintain a close parallelism with the boundary of the pre-Cambrian rocks, conforming even to relatively small details of that boundary. In the region of the Great Lakes the isobases appear to have the same parallelism to the pre-Cambrian boundary (line RR, fig. 14, p. 503) from the southeast end of Lake Superior to the east end of Lake Ontario, running in a nearly straight fine between these points. The relations to minor details have not yet been fully worked out, but so far as observed the parallelism does not appear to be so close as in Sweden. Outside of the interval mentioned the isobases appear to show only a very general

[1]Woodworth, J. B., Postglacial faults of eastern New York: Bull. New York State Mus. No. 107, 1907, pp. 5-28.

[2]De Geer, Gerard, Quaternary changes of level in Scandinavia: Bull. Geol. Soc. America, vol. 3, 1892, pp. 65-66; also, On Pleistocene changes of level in eastern North America: Proc. Boston Soc. Nat. Hist., vol. 25,1892, pp. 454-477. The important passages are quoted by Goldthwait in Bull. Geol. Soc. America, vol. 21, 1910, pp. 245-246.

tendency to parallel the Azoic boundary. Near this boundary, however, as pointed out some years ago by Chalmers,[1] the northward rise abruptly increases. Whether this is merely an expression of differential effects of elasticity or of slight effects of overthrusting or underthrusting or of some other cause has not been determined. The existence of this increased rise has recently been verified by Goldthwait, Johnston, and the writer near Kirkfield and Orillia, Ontario,[2] and by Mr. Leverett on St. Joseph Island.[3]

EUSTATIC AND OSCILLATORY MOVEMENTS.

Eustatic and oscillatory movements, such as have been described by Suess, are of little import in the present discussion, for neither principle appears to have acted perceptibly in the Great Lakes region. The land in the area of horizontality appears to have been a “steady mass,” remaining unmoved throughout the elevation of the lands to the north. It is not improbable, however, that both of these kinds of deformation have been operative to a slight but recognizable degree along the borders of the continent, where the shore lines of the sea were involved. If such effects have operated there they must also have acted in the region of the Great Lakes at the same time and in the same direction, but they appear to have been too small in amount to be detected.

TECTONIC EARTH MOVEMENTS.

WIDE RANGE OF PHENOMENA.

Although the hypothesis of resilience following depression by ice weight appears to have much strength, perhaps this strength seems greater than it really is, because the phenomena contemplated are confined to a somewhat restricted field. Beyond the region of the Great Lakes a vast stretch of the earth’s surface, comprising almost the whole of northeastern North America, including Hudson Bay and all the lands for 400 to 500 miles around it and reaching from New England and Labrador on the southeast to the Arctic Ocean and Bering Sea on the northwest, was affected at the same time and in the same way as the Great Lakes region. The very vastness of this area operates to exclude certain hypotheses that have been suggested. The limitations which it imposes seem particularly applicable to all hypotheses that depend on the transfer of subcrustal molten magmas, unless the modern conception of an essentially solid, rigid interior for the earth is wrong, and the old idea of a molten, highly fluid,

essentially non-viscous interior, moving under hydrostatic laws, is right. The writer is disposed to accept the newer view. But this would exclude the transfer of molten magmas as a cause of resilience and place the whole burden on elasticity, which is calculated to account at most for less than two-fifths of the total uplift. Moreover, the failure of the uplifts to act instantaneously or pari passu with the removal of ice weight casts a further doubt upon the relation of the uplifts to elasticity.

In the present unsettled state of knowledge concerning the ultimate fundamental principles of geology, and especially of the primary forces involved in dynamic geology, it is not possible to specify with certainty how and in what particular manner the old shore lines may have been deformed by geotectonic processes. Geologists have so long been accustomed to speak of "upheavals" and "subsidences," without having any definite or adequate conception of the cause of such movements, except so far as based on vague ideas of cooling and contraction of a molten globe, that explanations by the use of these terms are indefinite and of comparatively little value. Even now there is no generally accepted explanation of the growth or formation of continents by dynamic processes, and hence there is no genetic classification of the characteristic features of continents. Substantial progress along the lines of any contraction hypothesis seems unlikely, and real progress seems more likely, at least in the opinion of the writer, along two or three of the newer lines of thought, probably by a combination and modification of the planetesimal hypothesis of Chamberlin and that of continental crustal creep with peripheral folding as formulated by Suess.

[1]Chalmers, R., The geomorphic origin and development of the raised shore lines of the St. Lawrence Valley and Great Lakes: Am. Jour. Sci., 4th ser., vol. 18, 1904, p. 175.

[2]Summary Rept. Canadian Geol. Survey for 1909, 1910, p. 104.

[3]Personal communication, 1912.

CRUSTAL CREEP.

The greatest earth movements involved in the formation of continents and mountains are mainly horizontal or tangential creeping and thrusting movements, the associated movements of elevation and subsidence being mainly incidental or secondary. Hence deformations due to tangential or nearly horizontal creeping movements, such as Suess found to be involved in the formation of the mountain ranges of Asia and in the growth of the continent itself, are fully competent to be the cause of elevation and warping of old shore lines.

The writer has endeavored to apply to North America the principles evolved by Suess in Asia[1] and has found two widely separated sets of phenomena that clearly indicate a crustal movement of the continent toward the southwest. One of these is the mountain knot of Alaska, the highest mountain mass in North America, located at the angle where the Aleutian and Cordilleran mountain ranges come together on converging lines. The mountain ranges and the knot are mainly of Tertiary age. The other feature is the rift valley on the northwest and west sides of Greenland, probably mainly of Tertiary age also. The bearing of these two features on the direction of crustal movement of the continent is clear and single in its meaning and is not susceptible to two opposite interpretations. In this respect they stand in strong contrast with the usual explanations of overthrusts and folds, and even a group of folds showing diminishing intensity from one side to the other, which are nearly always susceptible to two opposite interpretations as to the direction of the main deep-seated folding force. This arises from the difficulty of distinguishing relative from actual movements. In the Rocky Mountain region what have generally been called northeastward overthrusts may just as truly be described as south westward underthrusts with northeastward overthrusts as secondary results. Suess found the most intense folding at the front of the southward creeping crustal sheet in Asia, where this sheet met a resistant obstacle—either a foreign mass, like India, or more often the upturned, metamorphosed, basal layers of the crustal sheet itself. On the other hand, the mountain knot of Alaska and the Greenland rifts are neither of them open to two opposite interpretations; they are facts of two different classes and relate to distant and opposite sides of the continental sheet, and yet they indicate the same direction of crustal creep. It is perhaps worth while to point out that the recently uplifted and tilted region of the Great Lakes and the extension of this deformed region to the northwest across the continent follows a course substantially parallel with the great disjunctive line or rift on the west side of Greenland and is also in part subparallel with the Tertiary mountain belt of the Pacific coast. All of the region east of this belt has been affected by the same recent uplifting movement, and its southwestern border, passing through the Great Lakes region and far to the northwest, appears to stand either in the relation of a broad, low swell or anticline or else a broad, low monocline with gentle dip to the southwest. It occupies a medial position between the Greenland rift and the Cordilleran range, and its axis is transverse to the direction of the southwestward crustal creep which these two features indicate. Its position is therefore natural for a fold produced by crustal movement in the direction indicated, and such movement seems to the writer to be the only one that would explain the uplift as part of a definite, systematic process of continental development.

The recurving of the marine isobases south and east of Quebec (fig. 14) suggests that a broad, low anticlinal fold is there pitching downward to the east. This may or may not be true, for, as was pointed out above, the raised beaches near Quebec probably do not record all of the recent uplift in that region, and the complete record might show a different configuration of the isobases. But from the eastern end of Lake Ontario the isobases run west-northwest at least to some point beyond Manitoba,

and if an anticlinal fold exists its axis lies, in all probability, north of the Great Lakes and parallel with the isobases now determined. A broad belt west and northwest of Hudson Bay, including the region of the Archean rocks and the chain of lakes along the Paleozoic margin, and extending from the Arctic Ocean through Alaska to Bering Sea, has been elevated 300 to 400 feet out of the sea since the disappearance of the last ice sheet. It is perhaps somewhat significant that in Alaska this belt includes a large region which has not been glaciated, and hence where direct depression by ice weight did not occur. No great ice sheet was near to that region.

[1]Bearing of the Tertiary mountain belt upon the origin of the earth's plan: Bull. Geol. Soc. America, vol. 21, No. 2, 1910, pp. 179-226.

If the crustal creeping movement of Tertiary time had not entirely ceased at the time of the glacial period it is easy to see that a slight crustal movement toward the southwest might be the cause of the observed uplifting and tilting. It would not require much horizontal movement of a crustal sheet 5 to 10 miles thick to produce the relatively slight arching recorded in the beaches. It may well be that the ice sheet influenced this movement to some extent and contributed in some degree to the determination of its place and limits, although it is at present hard to see just what effect it would have and how it would act. The general course of the margin of the uplifted belt is broadly parallel with the limits of the crystalline rocks for a great distance but appears to turn away westward across Alaska to the Bering Sea. Even if the uplifted belt is some sort of fold or upswelling produced by recent crustal creep from the northeast, it is not possible to say at present to what extent, if any, ice weight and geologic structure may have influenced the result.

Orogenic movements of no small amount have occurred in the region of the Cordilleran mountain belt within the Quaternary period, and these seem to imply a continuance, at least in some slight degree, of the creeping movement of the continental crustal sheet.

CONCLUSIONS.

Although the uplifts were spasmodic in character, the time relations are so intimate that it is hard to resist the impression that the land rose simply because the ice and its weight disappeared. And yet there is no reason why tectonic movements in the earth's crust may not have occurred with just these time and place relations to the retreating ice sheet. Perhaps the truth lies in a middle course and both causes may have contributed to the result. If the uplifting movements were to any large extent tectonic or epeirogenic and independent of resilience after depression by ice weight, then the undeviating course of the hinge line across large ice lobes and unglaciated reentrants is not a matter of surprise nor of special difficulty.

However, it is not intended here to attempt to reach final conclusions as to the cause of the uplifts but merely to point out some of the limitations established by the known facts. Ice weight may have been an important contributory factor in the great Quaternary regional uplifts but probably did not have the values nor act in the simple and complete way supposed by many. The limitations seem to carry the problem suggestively near to the realm of another class of earth movements due to entirely different causes.

There appears to be no reason to question the validity of Woodward's result in his determination of the elastic compressibility of the earth, nor of Lane's quantitative application of the same to the concrete case assumed by him. But the facts fall so far short of agreeing with these theories that the whole matter becomes uncertain.

In conclusion it may be said that while the preponderance of evidence may appear at the present time to be slightly in favor of resilience following depression by ice weight as the main cause of the uplifting of the land and the deformation of the shore lines in the region of the Great Lakes, the difficulties in the way of a complete demonstration of this as the main cause seem well-nigh insuperable. It seems certain that some new basis of physical principles better adapted to a quantitative analysis of the problem will have to be found before the ice-weight hypothesis can be firmly established.

Standing as a close second to the hypothesis of deformation by ice weight is that of deformation by uplifts of the land incidental to crustal creeping movements, which are simply the latest or most recent impulses in a process of continental growth reaching back into Tertiary time. Both causes may have acted, but if certain evidences which are now supposed to indicate relatively recent crustal creep toward the southwest are substantiated by future investigations the hypothesis of resilience following depression by ice weight seems likely to become of secondary importance.

CHAPTER XXVI.
ECONOMIC RESOURCES.

By Frank Leverett.

Only deposits of economic value connected with or developed upon the formations which form the theme of this monograph are discussed in this chapter, and as special reports have been published by this Survey and by the State surveys on the more important of these economic resources, the discussion aims merely to direct attention to these reports and to set forth in a very general way the relations of the resources to the glacial formations.

ERRATICS IN THE DRIFT.

In the drift are incorporated metals and ores such as copper, iron, and gold, precious gems like the diamond, and blocks of coal, whose sources are in the rock formations passed over by the ice sheet. (See pp. 64,

249.) All these are so rare and so irregularly distributed that they can not be profitably worked on any commercial scale, but are to be classed as "finds." Gold washing has, it is true, been attempted at a number of places in Indiana and neighboring States, but has scarcely ever yielded a fair day's wage and can be said to pay only when the miners have leisure time to spend. Before the character and origin of the glacial deposits were understood the finding of these metals and gems led to erroneous conclusions as to their occurrence in paying quantities in the near vicinity, and conclusions of this sort are drawn nowadays by many uninformed persons.

In some localities, where the rock formations are completely covered, the glacial deposits contain sufficient amounts of certain kinds of building stone in the form of bowlders to constitute a valuable economic resource, which, though becoming scarce in many localities, will not be exhausted for some time. Such stone is especially plentiful along most of the moraines. In other places masses of limestone have been, so abundant in the drift or on its surface that they have supplied limekilns for years and have been very useful, especially in the early days of settlement.

MARL OR BOG LIME.

Marl deposits of great depth, sufficient to warrant the erection of large cement mills, exist on the borders of many lakes of Indiana and Michigan. These deposits were drawn on by early settlers for lime and to some extent for land plaster. Their use was so extensive and their value so great that in the earliest surveys of both States data were collected as to their distribution. It was not, however, until they began to be used on a large scale in the manufacture of Portland cement that special reports on them were prepared. In Indiana the State Geological Survey has made systematic investigation of nearly all the lakes and basins which formerly held lakes but are now filled with marl and peat. The published report sets forth not only the extent of workable but also of what are classed as unworkable deposits, the latter term being applied where the quantity seems insufficient to justify the erection of a cement mill.

In Michigan the investigations have been less complete. The field, however, is much more extensive than in Indiana, for marl lakes are scattered over the whole of Michigan and they occupy only a small area in the northern part of Indiana. The mills for the manufacture of Portland cement in Michigan, however, are nearly all located in the populous southern part, where a strong demand for the product exists, where transportation facilities are good, and where the clay or shale needed in the manufacture of cement can be had within convenient distances.

Since cement making became an important business, reports on the production of cement in the United States have been published annually by the United States Geological Survey in Mineral Resources. These papers are largely statistical and are based on correspondence rather than on field investigations. Several important special reports and papers dealing with the origin, distribution, and utilization of the marl of Michigan and Indiana have also been published, as follows:

BLATCHLEY, W. S., and ASHLEY, G. H., The lakes of northern Indiana and their associated marl deposits: Twenty-fifth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1901, pp. 31-321.

BLATCHLEY, W. S., Cement resources: Thirty-first Ann. Rept. Indiana Dept. Geology and Nat. Res., 1906, pp. 50-61.

DAVIS, C. A., A contribution to the natural history of marl: Jour. Geology, vol. 8, 1900, pp. 485-497; vol. 9, 1901, pp. 491-506; Michigan Geol. Survey, vol. 8, pt. 3,1903, pp. 65-96.

——— A remarkable marl lake: Jour. Geology, vol. 8, 1909, pp. 498-503.

FALL, DELOS, Marls and clays in Michigan: Michigan Miner, vol. 3,1901, No. 11, pp. 11-14; Michigan Geol. Survey, vol. 8, pt. 3, 1903, pp. 343-353.

HALE, D. J., and others, Marl (bog lime) and its application to the manufacture of Portland cement: Michigan Geol. Survey, vol. 8, pt. 3, 1903, 386 pp.

RUSSELL, I. C., The Portland cement industry in Michigan: Twenty-second Ann. Rept. U. S, Geol. Survey, pt. 3, 1902, pp. 629-685.

——— Marl or bog lime: Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908, pp. 12-13.

PEAT.

Peat is very extensive in northern Indiana and in Michigan on the borders of lakes and in poorly drained situations. It has been made a subject of special investigation by Charles A. Davis[1] and by Arthur E. Taylor.[2] Taylor's report contains the results of numerous borings in a large number of extensive peat bogs of northern Indiana, and includes maps showing the extent of the bogs and their situation in reference to railway transportation lines. Davis's report contains fewer data concerning the thickness of peat in the bogs of Michigan but goes more fully into the origin and the ecology of peat. He discusses also the use of peat as fuel, arguing that though peat is unlikely to be utilized to more than a slight extent in competition with coal, peat bogs will yield quick and sure returns if they are developed in a small way for local markets rather than on a large scale in competition with better-known and more widely used fuels. "A relatively small bog, a small investment, and a local market, with a limited requirement in quantity should make a combination which should be satisfactory to the owner and the investor, who could then afford to give his customers a fair price, which should run considerably below that paid for ordinary fuel, and still give good profits." Davis's report also describes peat-working machinery in considerable detail.

In addition to these two large reports Taylor[3] and Davis[4] have each published short papers on this subject.

CLAY.

The extensive till sheets of Indiana and Michigan are utilized to some extent for brick and tile, but are in most places too full of stony and sandy material to be suitable even for these products. The clay of chief commercial value in these States is a water deposit laid down either in lakes or in slack drainage. Loess deposits laid down by wind are important in southern Indiana, where also much of the alluvial material, being derived by wash from bordering loess, is suitable for use in some of the clay industries.

The thickest deposits of clay on the beds of the great glacial lakes are found in depressions protected against disturbance by waves. Thus in the Erie-Maumee basin deposits are thick in the area covered by Defiance Bay of Lake Whittlesey west of the Defiance moraine, and are very light on the submerged portion of the moraine and the plain to the east. The deposits become thicker, however, west of Napoleon and near Toledo and are drawn upon extensively for use in clay industries and for the manufacture of Portland cement. In the Rouge River basin west of Detroit, in a small area that stands a little lower than the Detroit interlobate moraine, lake clays are thick and furnish material for extensive brick works. In the Saginaw basin extensive deposits of nearly pebbleless clay exist but are not drawn upon for commercial use so much as the shales of that region. They are largely covered by sand deposits, so that their extent is greater than might be inferred from surface exposures.

[1]Ann. Rept. Michigan Geol. Survey for 1906, 1907, 302 pp.

[2]Thirty-first Ann. Rept. Indiana Dept. Geol. and Nat. Res., 1908, 225 pp.

[3]Indiana peat, its origin and value: Jour. Am. Peat Soc, vol. 2, 1909, pp. 30-33, 64-67.

[4]Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908, pp. 12-13.

On the borders of the Michigan basin lake clays are scarce, the eastern shore being prevailingly sandy. At the south end of the basin, however, from the vicinity of Michigan City to Hob art, Ind., some deposits of sufficient depth to be of commercial value are found. In the Grand Traverse region in Michigan, in Antrim and Grand Traverse counties, extensive deposits of clay or silt underlying the surface till have been utilized to some extent for brick manufacture, for which they are much more suitable than the overlying till sheet. They promise to be a valuable resource and are accessible with very little stripping on the bluff-like borders of the lowlands and lakes of the region.

West of Rensselaer, Ind., in the Iroquois basin, which was covered by a small glacial lake, lie silt deposits of considerable depth. These deposits are utilized by a brick plant at Brook, Ind.

Many valleys formerly occupied by pools held in place by ice dams are filled to great depth by silt deposits. Several such valleys are found in southwestern Indiana in Gibson, Pike, Vanderburg, and Posey counties.

In northwestern Indiana and southwestern Michigan, in many lines of drainage which were obstructed by the Lake Michigan glacial lobe, silt deposits underlie the surface sands. Deposits of this sort have been utilized in the clay industries at South Bend for more than 50 years. As far back as 1859[1] extensive explorations were made to test the thickness of the clay.

As the value of the clay for use in the industries depends on its freedom from objectional ingredients and properties no statements concerning the importance of particular deposits can be made. However, clay having but little stony material is found extensively, and no doubt much of it will prove to have high commercial value.

The clay deposits and clay industries of northwestern Indiana have been made the subject of a special paper by Blatchley,[2] and the shales and clays of Michigan have been briefly discussed by Ries.[3] On the whole, however, this resource, so far as these two States are concerned, seems to have received scanty treatment in geologic literature.

SAND AND GRAVEL.

The many uses to which sand and gravel are put in the building trades and in road construction are making them a resource of far greater importance than was dreamed of a few years ago. Even the drifting dune sand on the shores of Lake Michigan is being used in the manufacture of sand brick and is shipped by the train load to Chicago for use in masonry. The gravel hills, which a few years ago were considered useless by the farmer, are now in demand for road material at a price per acre far above that of other farm land.

The roads and road materials of Indiana are the subject of a report of more than 1,000 pages,[4] much of which deals with the occurrence of gravel and the use already made of it. It is shown that throughout the area covered by the Wisconsin drift in Indiana suitable material for road building is so widely distributed as to obviate all long hauls. Hundreds of miles of gravel road have already been constructed. In southern Indiana some of the lines of glacial drainage furnish extensive gravel deposits suitable for road building, but a more widespread source for that part of the State is found in the rock formations, especially the limestone.

In Michigan, sand and gravel are easily accessible in nearly all parts of the State. In some of the more sandy parts the sand is so light as to render the roads difficult to travel, and it has been found expedient to stiffen the roadbed with a coating of clay. Gravel is less widely distributed than sand, and broad areas in the Saginaw basin and on the lake plains in the southeastern part of the State are inadequately supplied. Railroad facilities are, however, so good in these districts that road material is easily brought in. The additional cost of

running a gravel train a few extra miles is a smaller item than the loading and unloading of the cars.

[1]Indiana Geol. Survey, 1860, p. 200.

[2]Blatchley, W. S., Twenty-second Ann. Rept. Indiana Dept. Geology and Nat. Res., 1897, pp. 105-153.

[3]Ries, Heinrich, Michigan Geol. Survey, vol. 8, pt. 1, 1900, pp. 1-66, especially pp. 48-62.

[4]Thirtieth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1906, pp. 17-1057.

As yet no special report on the gravel and sand deposits of Michigan has been attempted, but many details as to their distribution may be obtained from the Pleistocene map of the southern peninsula issued in the reports by the Michigan Geological Survey for 1907 and 1912.

UNDERGROUND WATERS.

Underground waters from the glacial formations are generally abundant and are drawn upon not only for farm use but also for public supplies in a large number of villages and small cities in Indiana and Michigan. Several reports on these supplies have been issued by the United States Geological Survey and incidental mention has been made in the several county reports of the Indiana and Michigan geological surveys.

Contamination of underground water is very rare in these States. Only isolated cases have come to notice, most of them being in rural districts where pollution might easily have been avoided by a better selection of the well site or of the place for dumping slops and refuse.

The following list embraces the special reports issued on the underground waters of these States. They pertain in part to waters from rock formations but are chiefly devoted to those from the Pleistocene formations.

BLATCHLEY, W. S., The mineral waters of Indiana: Twenty-sixth Ann. Rept. Indiana Dept. Geology and Nat. Res., 1903, pp. 11-158.

LANE, A. C., Geology of Lower Michigan with reference to deep borings: Michigan Geol. Survey, vol. 5, pt. 2, 1895, pp. 40-87.

——— Water resources of the Lower Peninsula of Michigan: Water-Supply Paper U. S. Geol. Survey No. 30, 1899, 97 pp.

——— Lower Michigan mineral waters: Water-Supply Paper U. S. Geol. Survey No. 31, 1899, 97 pp.

——— Deep wells and prospects for oil and gas: Ann. Rept. Michigan Geol. Survey for 1901, pp. 65-75, 211-237.

——— Underground waters of lower Michigan: Water-Supply Paper U. S. Geol. Survey No. 114, 1905, pp. 242-247.

——— Many of the records published in Water-Supply Papers Nos. 182 and 183 were contributed by Lane from records in the office of the State geologist. Two special papers contributed by him deal with the water supplies of Lansing and vicinity (Water-Supply Paper No. 182, pp. 170-175) and with Huron County (Water-Supply Paper No. 183, pp. 257-268).

LEVERETT, FRANK, Water resources of Indiana and Ohio: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 4, 1897, pp. 425-559 (especially pp. 474-482, 487-493, 495-501, 511-522, 527-531, 537-544).

——— Wells of northern Indiana: Water-Supply Paper U. S. Geol. Survey No. 21, 1899, 82 pp.

——— Wells of southern Indiana: Water-Supply Paper U. S. Geol. Survey No. 26, 1899, 64 pp.

——— Geological conditions of municipal and institutional water supplies in Michigan: Eighth Ann. Rept. Michigan Acad. Sci., 1906, pp. 99-110.

——— and others. Flowing wells and municipal water supplies of the southern peninsula of Michigan: Water-Supply Papers U. S. Geol. Survey Nos. 182 and 183, 1907. Contributions by Isaiah Bowman, W. F. Cooper, C. A. Davis, W. M. Gregory, M. L. Fuller, A. C. Lane, C. D. McLouth, J. F. Nellist, W. H. Sherzer, and J. A. Udden.

RUSSELL, I. C., and LEVERETT, FRANK, Underground waters: Ann Arbor folio (No. 155), Geol. Atlas U. S., U. S. Geol. Survey, 1908, pp. 14-15.

VAUGHAN, V. C., Michigan water supplies: Eighth Ann. Rept. Michigan Acad. Sci., 1906, pp. 111-118.

SOILS.

Close correspondence between glacial formations and the several kinds of soil developed on them is natural, and the glacial maps (Pls. VI and VII, in pocket) will serve to some degree as soil maps. The surface-geology map issued by the Michigan Geological Survey in the annual report for 1907 has on its legend not only glacial terms but also terms used by the Bureau of Soils of the United States Department of Agriculture for the sands, gravels, and clays of the southern peninsula of Michigan. It is questionable, however, if there was warrant for this definite application of the terms used by the Bureau of Soils, except in the particular districts covered by the soil mapping of that bureau. The classifications made by the Bureau of Soils are much more complex than the glacial classifications, in some places differentiating several grades of soil on a single kind of glacial formation on account of slight differences in color or in texture, or in coarseness of grain.

The mapping by the Bureau of Soils has been done in scattered areas of small extent. The following is the complete list of the maps published to October 31, 1914:

Soil maps of Indiana and Michigan.

Indiana.		Michigan.	
Allen County.	Marshall County.	Allegan County.	Pontiac area.
Boone County.	Montgomery County.	Alma area.	Saginaw area.
Boonville area.	Newton County.	Cass County.	Wexford County.
Greene County.	Posey County.	Genesee County.	
Hamilton County.	Scott County.	Munising area.	
Madison County.	Tippecanoe County.	Owosso area.	
Marion County.	Tipton County.	Oxford area.	

The mapping has been so distributed in Indiana and Michigan as to embrace nearly every class of glacial, fluvial, and lacustral formation. Thus in Michigan the Oxford and Pontiac areas represent the complex features of an interlobate district with associated gravelly and sandy outwash. The Saginaw area is wholly in a glacial lake bottom where characteristic lake clays and

lake sands are found. The Alma and Pontiac areas are partly on lake bottom, partly on moraines and their associated till plains, and partly on fluvioglacial drainage lines. The Allegan area illustrates the combination of sandy plains and gravelly or loose-textured moraines found on the east side of the Lake Michigan basin. In Indiana, Allen County embraces a lake plain as well as moraines and till plains. Madison, Marion, Newton, and Tippecanoe counties are largely a till plain, though Newton County embraces also an extensive sand plain bordering the Kankakee. Greene, Posey, and Scott counties embrace loess-covered glacial formations and also unglaciated loess-covered districts (see Pl. VI), and the Boonville area lies entirely in an unglaciated loess-covered district.