ART. III.—*The Glacial Features of Green Bay of Lake Michigan, with some observations on a probable former outlet of Lake Superior;* by N. H. WINCHELL, of the Geological Corps of Michigan.

THE topographical features of the region of Green Bay, are strikingly dependent on the geological structure as acted on by glacial forces. The west coast is low, and in but few places can the underlying rock be seen above the drift deposits. The immediate shore varies but little from the regular trend of the outcropping Trenton limestone. But two considerable bends occur on the west coast; and they are caused by alluvial deposits at the mouths of the Peshtigo and Menominee rivers. Across these rivers the bearing of the Trenton limestone is disclosed in the rapids which occur a few miles above their mouths. At the mouth of Little Bay de Noc the course of the coast line takes a direction nearly N. and S., an interesting fact, the special significance of which will be noticed further on.

The east coast is in the same way dependent on the line of bearing of the Niagara limestone; but, very unlike the west coast, it is frequently indented by bays which by their great depth of water form beautiful ship harbors. Of these Sturgeon Bay is the most remarkable, and may be taken as a type of all the deep indentures occurring on the east shore of Green Bay. The vast escarpment of Niagara limestone rises sometimes

immediately from the water, but more frequently it passes a short distance from the shore, forming an almost continuous rock-barrier 150 to 200 feet in height from the head of Great Bay de Noc to near the south end of Green Bay. It also underlies the whole table-land of the peninsula which encloses Green Bay, and affords by its natural dip a gentle descent E.S.E. toward Lake Michigan. Hence the entire drainage of the peninsula is into that lake, the "divide" being along the shore of Green Bay. The east and west shores afford another noticeable contrast in the comparative depth of the off-shore water. By inspecting the charts of the U. S. Lake Survey the recorded soundings along the west side show very shoal water, while on the east side the "ten-fathom line" runs near the land, frequently uniting with the shore-line, the entrances to the little bays being uniformly very deep. The passage through Port des Morts is 21 fathoms, north of Louse island 24 fathoms. The mouth of Eagle harbor is 11 fathoms, of Ellison's bay 12 fathoms, and of Hedgehog harbor 17 fathoms. The average depth of Green Bay is 16 to 18 fathoms.

The uniformity in the direction of these bays is another remarkable fact. They indent the peninsula in a southerly or southeasterly direction. On the contrary the bays on the opposite side of the peninsula, and opening into Lake Michigan, have a very uniform direction northerly or northwesterly, complementing those opening into Green Bay in such a way, that the peninsula is in several cases almost intersected by their near inosculation.

The barrier of the Niagara limestone is broken through at each of these bays, and its broken off ends form perpendicular and bald bluffs which face each other across their entrances, and rise to the height of 75 to 175 feet. Government and Hibbard's bluffs enclose Sturgeon bay. The former has a height of 115 feet, the latter about 80 feet. Eagle Bluff is on the south side of Eagle harbor and has a height of 149 feet 10 inches. Its counterpart on the north side is about 60 feet. Garden Bay in Great bay de Noc is another example of the same phenomenon. The Niagara barrier is more broken down between Port des Morts and Pt. de Morts and Pt. de Tour than at any other place. Projecting southward, the peninsula which encloses Great bay de Noc and terminates with Pt. de Tour, is a counterpart of that which encloses Green Bay; and the whole interval between Door Bluff on the south and Sag Bluff in Great bay de Noc on the north, is but an enlarged illustration of the phenomena already described. In this case the Niagara limestone is so completely broken down as to admit the waters of Lake Michigan, the Potawatamie islands, which lie in that interval, being its only parts remaining above the level of the lake.

Glacial striæ and polished surfaces at the head of Green Bay have a direction N. 34° E. coinciding with the axis of Green Bay. In the bay north of Sag and Burnt Bluffs, in Great Bay de Noc, they run about N.W. and S.E.

Among the glacial features may be mentioned the general aspect of the east shore of Green Bay and of Great Bay de Noc. Those deeply cut bays before mentioned must be regarded as of the nature of fiords, and doubtless owe their origin to spurs from the main glacier which excavated the Green Bay valley. The Sturgeon Bay spur was probably aided in taking its more easterly trend by a local glacier which contemporaneously descended the valley of the Uenominee. By their uniformity of direction a tendency is indicated in the main glacier to move in a more southerly direction than the general direction of Green Bay requires. In fact the islands between Port des Morts and Pt. de Tour exhibit the effect of intense glacier action in a direction N. and S. Long trails of detritus from these islands shoal the water for several miles southward; but toward the north the water becomes suddenly very deep.

A natural result of this spurring off from the main glacier is exhibited in the westward tendency of the coast line immediately south of the bays thus formed. The diversion of that portion of the moving glacier which passed through the valley of Sturgeon Bay would allow the extension of the opposing barrier of the Niagara limestone farther toward the west, thus bringing into view lower formations (Clinton and Cincinnati); and the spur which excavated Eagle harbor, acted in the same way to permit the existence of the point just west from the harbor on which the Clinton limestone is again exposed.

Another evidence of the more southward tendency of the main glacier consists in the fact that it actually broke through the Niagara barrier in numerous instances in a southerly direction, but did not once encroach upon the Trenton, on the opposite side of Green Bay, although it hardly rises above the water level.

We may therefore regard the fact established that the local glacier which excavated the valley of Green Bay, as far south as to include lakes Winnebago and Horicon in Wisconsin, was deflected from its N. and S. course by the escarpment of the Niagara limestone; and we must infer that its greatest force was felt where it first encountered it. We see the escarpment most demolished between Port des Morts and Pt. de Tour, and conclude that that interval must lie in the course of the original glacier. A course nothward thence carries us up the valley of Little Bay de Noc and the Whitefish river to the shore of Lake Superior. If we examine the south shore of Lake Superior,

we find that in a line directly north from the head of Little Bay de Noc occurs the only break in the otherwise continuous rock barrier. Dr. D. Houghton, in his report to the Michigan Legislature in 1840, says that "an elevated range of hills," or in another place, "an elevated and very regular chain of hills stretches from Point Iroquois to the Pictured Rocks," from which place they "pass away from the shore southwesterly," and Dr. Houghton adds that "the western prolongation of this rock has not been determined." From the mouth of the Chocolate river, six or eight miles east of Marquette, to a point one-and-a-half miles east of the mouth of Train river, the shore is low and occupied with drift deposits, the usual rocky barrier of sandstone is interrupted and entirely wanting. Both to the east and to the west from this interval the shore of the lake is formed by the rocky rampart either of the Lake Superior sandstone on the east, or of the Huronian and other Eozoic rocks on the west. Although this barrier passes a few miles away from the shore east of the Pictured Rocks it is nevertheless a continuous barrier of "sandstone hills" which cause the Falls of the Taquomenon, 90 feet in height, and appear in precipitous cliffs at or near Iroquois Point.

Again, from the mouth of Chocolate river to the falls of the upper Menominee occurs, in general, the strike of the Huronian, and from the latter place to the head of Keweenaw bay, a right line would pass some of the highest primary knobs and through the head waters of some of the principal rivers of the Upper Peninsula of Michigan. This rough and elevated character continues westward to the Montreal river, near the western extremity of Lake Superior. It is therefore rendered probable that the last lingering glacier, which was able to prolong itself beyond the south shore of Lake Superior, passed through the gap which occurs north from the head of Little Bay de Noc. It has been repeatedly stated by geologists who have observed the glacial striæ about Lake Superior, that their general direction is N.E. and S.W. It is therefore a fact of special significance, that the grooves at and near the mouth of Chocolate river show a north and south direction. At a point two miles west of the mouth of Carp river, and a few miles east of Marquette, there are two systems of glacial grooves, one running north 55° east, and the other north 5° east. Mr. Desor says of these: "The latter are distinctly seen crossing the others, and are therefore more recent. Some of them are besides distinctly curved, as if the body which produced them had been deflected in ascending the slope, a peculiarity not yet observed elsewhere." On an island east of Dead river (near Marquette) there are also two systems of furrows, one running N. and S. and one N. 20° E., the latter being the more distinct

and sometimes taking the form of troughs four feet wide and two feet deep.* These indicate that the continental glacier moved in a direction N.E. and S.W., forming the deepest furrows, but that the local glacier passed N. and S. It was also, doubtless, "deflected" from its course, and the opposition of the Huronian formation, which gives the coast great elevation and abruptly turns it north from this place, may be supposed to have caused that change in direction.

In relation to the country between the head of Little Bay de Noc and the shore of Lake Superior we may infer that a valley exists, or did exist when the glacial epoch was waning, connecting Lake Superior with Lake Michigan through Little Bay de Noc, and that the present outlet of Lake Superior is of comparatively recent date. Not only do the descriptions of this tract by Messrs. Foster and Whitney confirm that inference, but examinations made the present summer, by Mr. A. S. Wadsworth of the Michigan Geological Survey, almost directly demonstrate the former outlet of Lake Superior to have been through the Whitefish valley. There is a continuous valley with high drift banks uninterrupted, from the mouth of the Whitefish river to Lake Superior. Upon reaching the watershed which lies but little above Lake Superior and within twelve miles of the mouth of the Train river, the head waters of the two rivers interlock on an extensive flat and rocky bed from which the drift has been removed and piled up in continuous bluffs on either side. From the summit of these bluffs extend extensive "pine plains," toward the east and west. On this rocky bottom are traces of running water, spread over an area of many acres, consisting of the peculiar "pot holes," from which "many cords of rock" have been removed. There are also deep gorges and crevices worn smooth by the motion of water and drifting sand.

Thus it appears that not only was the outlet of Lake Superior through Little Bay de Noc up to the close of the Tertiary, but that it continued to exist there after the stratification of the drift. The curious excavation and piling up of the drift on either side of the Whitefish valley could only have been done since the deposit of the same, and the water-worn surface of the Trenton limestone, on the top of the water-shed, must have been produced since the dawn of the Terrace Epoch. The old Tertiary channel is still obscured by the drift, either to the east or west of the channel discovered by Mr. Wadsworth.

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* Foster and Whitney's Report on L. Superior, Part I, p. 205.