DEPARTMENT

OF THE MATHEMATICAL AND PHYSICAL SCIENCES.

ON THE EXTENT AND SIGNIFICANCE OF THE WISCONSIN KETTLE MORAINE.

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At the meeting of the Academy, three years since, I took the liberty of occupying the attention of the members by the presentation of some observations and conclusions in reference to a peculiar series of drift hills and ridges in eastern Wisconsin, known as the Kettle range, and the views then advanced afterwards found a place in my report on the geology of eastern Wisconsin.[2] Similar observations were subsequently made by Professor Roland D. Irving, of the Wisconsin survey, and his conclusions are in perfect agreement with my own.[3]

In neither case, however, was any attempt made to show the full extent of the formation outside of the districts reported upon, or to point out its theoretical significance, the chapters being intended only as contributions to local geology, made under somewhat severe limitations as to space.

It is not now possible to map, or even safely conjecture, the complete extent and limitations of the formation; but it is the purpose of this article to add such trustworthy observations as have since been made, and to gather such evidence as may justify a provisional mapping of the range, where it has not been actually

[1] I have taken advantage of the interval between the date of reading and the printing to introduce new matter. T. C. C.

[2] Geology of Wis., Vol. II, 1877 (revised edition 1878), pp. 205-215.

[3] Geology of Wis., Vol. II, 1877 (revised edition 1878), pp. 608-635.

traced. A portion of the paper will, therefore, relate to well ascertained facts, while other portions will be in various degrees hypothetical. If care is taken to distinguish between these portions, no harm can arise from their association; while the provisional mapping will, it is hoped, prove of service in both stimulating and guiding further investigation. The extent of the range is likely to prove too great for the immediate time and means of a single observer; while the broad and irregular, and sometimes obscure, character of the belt is such that it is likely to be overlooked, as a continuous range, as experience has shown, unless attention be called to it, or the observer be keenly alive to distinctions in drift topography. It is believed, therefore, that the presentation of some things that are only probable, not certain, will not be without value.

It will be advisable to consider first, somewhat critically, the character of the formation. The following description, which is based upon careful observation, relates more specifically to the moraine in Wisconsin, where it is usually well developed, and may require some modification in its application to the range where sub-aqueous deposits overlap or encroach upon it, and in other special situations.

Surface Features.— The superficial aspect of the formation is that of an irregular, intricate series of drift ridges and hills of rapidly, but often very gracefully, undulating contour, consisting of rounded domes, conical peaks, winding and, occasionally, geniculated ridges, short, sharp spurs, mounds, knolls and hummocks, promiscuously arranged, accompanied by corresponding depressions, that are even more striking in character. These depressions, which, to casual observation, constitute the most peculiar and obtrusive feature of the range, and give rise to its descriptive name in Wisconsin, are variously known as "Potash kettles," "Pot holes," "Pots and kettles," "Sinks," etc. Those that have most arrested popular attention are circular in outline and symmetrical in form, not unlike the homely utensils that have given them names. But it is important to observe that the most of these depressions are not so symmetrical as to merit the application of these terms. Occasionally, they approach the

form of a funnel, or of an inverted bell, while the shallow ones are mere saucer-like hollows, and others are rudely oval, oblong, elliptical, or are extended into trough-like, or even winding hollows, while irregular departures from all these forms are most common. In depth, these cavities vary from the merest indentation of the surface to bowls sixty feet or more deep, while in the irregular forms the descent is not unfrequently one hundred feet or more. The slope of the sides varies greatly, but in the deeper ones it very often reaches an angle of 30° or 35° with the horizon, or, in other words, is about as steep as the material will lie. In horizontal dimensions, those that are popularly recognized as "kettles" seldom exceed 500 feet in diameter, but, structurally considered, they cannot be limited to this dimension, and it may be difficult to assign definite limits to them. One of the peculiarities of the range is the large number of small lakes, without inlet or outlet, that dot its course. Some of these are mere ponds of water at the bottom of typical kettles, and, from this, they graduate by imperceptible degrees into lakes of two or three miles in diameter. These are simply kettles on a large scale.

Next to the depressions themselves, the most striking feature of this singular formation is their counterpart in the form of rounded hills and hillocks, that may, not inaptly, be styled inverted kettles. These give to the surface an irregularity sometimes fittingly designated "knobby drift." The trough-like, winding hollows have their correlatives in sharp serpentine ridges. The combined effect of these elevations and depressions is to give to the surface an entirely distinctive character.

These features may be regarded, however, as subordinate elements of the main range, since these hillocks and hollows are variously distributed over its surface. They are usually most abundant upon the more abrupt face of the range, but occur, in greater or less degree, on all sides of it, and in various situations. Not unfrequently, they occur distributed over comparatively level areas, adjacent to the range. Sometimes the kettles prevail in the valleys, the adjacent ridges being free from them; and, again, the reverse is the case, or they are promiscuously distributed over both. These facts are important in considering the question of their origin.

The range itself is of composite character, being made up of a series of rudely parallel ridges, that unite, interlock, separate, appear and disappear in an eccentric and intricate manner. Several of these subordinate ridges are often clearly discernible. It is usually between the component ridges, and occupying depressions, evidently caused by their divergence, that most of the larger lakes associated with the range are found. Ridges, running across the trend of the range, as well as traverse spurs extending out from it, are not uncommon features. The component ridges are themselves exceedingly irregular in height and breadth, being often much broken and interrupted. The united effect of all the foregoing features is to give to the formation a strikingly irregular and complicated aspect.

This peculiar topography, however, finds a miniature representative in the terminal moraines of certain Alpine glaciers. Most of the glaciers of Switzerland, at present, terminate in narrow valleys, on very steep slopes, and leave their debris in the form of lateral ridges, or a torrentially washed valley deposit. A portion of them, however, in their recently advanced state, descended into comparatively open valleys of gentle decline, and left typical, terminal moraines, *formed from the ground moraines of the glaciers*, and only slightly obscured by the medial and lateral morainic products, which have little or no representative in the Quaternary formations. The Rhone glacier has left three such ridges, separated by a few rods interval, that are strikingly similar in topographical eccentricities to the formation under discussion, save in their diminutive size. The two outer ones have been modified by the action of the elements, and covered by grass and shrubs, while the inner one remains still largely bare, and, as they have been cut across by the outflowing glacial streams, they are exceedingly instructive as to glacial action under these circumstances. The inner one graduates in an interesting way into the widespread ground moraine, which occupies the interval between it and the retreating glacier, where not swept by floods, and which presents a different surface contour, illustrative of Till topography. The two Grindelwald glaciers have left similar moraines; those of the upper one, being the more massive, and being driven closer together, present an almost perfect analogy to the Kettle ranges.

The Glacier du Bois, the terminal portion of the Mer de Glace, the Argentière, and, less obviously, the Findelen, and others, so far as their situation favored, have developed similar moraines, and indicate that this is the usual method of deposit under these conditions. Reference is here made *only* to the terminal deposit of the *ground moraine*, eliminating, as it is quite possible to do, for the most part, the material borne on the surface of the glacier.

The Material of the Formation. — This topic, which is one of primary importance in determining the origin of the deposit, readily divides itself into three subordinate ones, all of which need discriminative attention; (1) the *form* of the constituents, (2) their *arrangement* as deposited, and (3) their *source.*

(1) Premising that the Kames, and those deposits which have been associated with them in the literature of the subject, are described as composed mainly of sand and gravel, it is to be remarked, in distinction, that *all* the four forms of material common to drift, viz.: clay, sand, gravel, and boulders, enter largely into the constitution of the Kettle range, in its typical development. Of these, gravel is the most conspicuous element, *exposed to observation.* This qualification is an important one in forming an adequate conception of the true structure of the formation. It is to be noticed that the belt, at many points, exhibits two distinct formations. The uppermost — *but not occupying the heights of the range* — consists almost wholly of sand and gravel, and lies, like an irregular, undulating sheet, over portions of the true original deposit. This superficial formation is confined mainly to the slopes and flanks of the range, and to depressed areas between its constituent ridges; though, when the whole belt is low, it often spreads extensively over it, so as sometimes to be quite deceptive. But, where the range is developed in force, this superficial deposit is so limited and interrupted, as to be quite insignificant, and not at all misleading; and, at some points, where it is more widely developed, excavations reveal unequivocally its relationship to the subjacent accumulations. In such cases, the lower formation shows a more uneven surface than the upper one, indicating that the effect of the latter is to mask the irregular contour of the lower and main formation. Notwithstanding this, the upper

sands and gravels are often undulatory, and even strongly billowy, and the bowls and basins in it commonly have more than usual symmetry. A not uncommon arrangement of this stratum is found in an undulating margin on the flank of a ridge of the main formation, from which it stretches away into a sand flat or a gravel plain.

Setting aside this, which is manifestly a secondary formation, it is still true that gravel forms a large constituent of the formation. Some of the minor knolls and ridges are almost wholly composed of sand and gravel, the elements of which are usually very irregular in size, frequently including many boulders. But, notwithstanding these qualifications, *the great core of the range*, as shown by the deeper excavations, and by the prominent hills and ridges, that have not been masked by superficial modifications, *consists of a confused commingling of clay, sand, gravel, and boulders, of the most pronounced type.* There is every gradation of material, from boulders several feet in diameter, down to the finest rock flour. The erratics present all degrees of angularity, from those that are scarcely abraded at all, to thoroughly rounded boulders. The cobble stones are spherically rounded, rather than flat, as is common with beach gravel, where the attrition is produced largely by sliding, rather than rolling.

Stratification. — As indicated above, the heart of the range is essentially unstratified. There is, however, much stratified material intimately associated with it, a part of which, if my discriminations are correct, was formed simultaneously with the production of the unstratified portion, and the rest is due to subsequent modification. The local overlying beds, previously mentioned, are obviously stratified, the bedding lines being often inclined, rather than horizontal, and frequently discordant, undulatory or irregular.

The Source of the Material. — This, so far as the range in Wisconsin is concerned, admits of the most unequivocal demonstration. The large amount of coarse rock present renders identification easy, and the average abrasion that has been suffered indicates, measurably, the relative distance that has been traveled. The range winds over the rock formations in a peculiar manner, so as

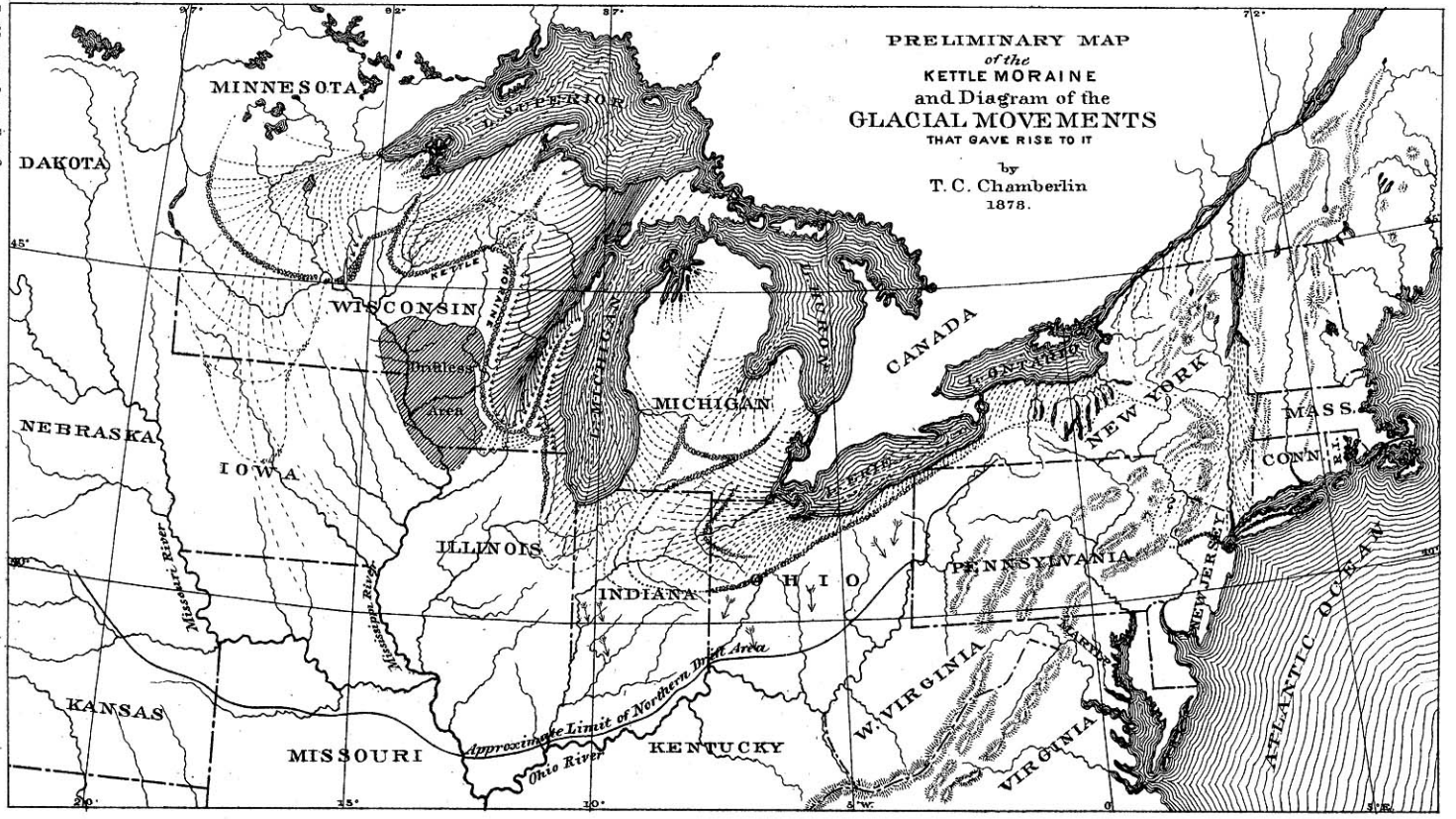
to furnish fine opportunities for decisive investigation. Of the many details collected, there is room here for a single illustrative case only. The Green Bay loop of the range surrounds on all sides, save the north, several scattered knobs of quartzite, porphyry and granite, that protrude through the prevailing limestones and sandstones of the region. These make their several contributions to the material of the range, *but only to a limited section of it, and that invariably in the direction of glacial striation.* Any given segment of the range shows a notable proportion of material derived from the formation adjacent to it, in the direction of striation; and a less proportion, generally speaking, from the succeeding formations that lie beyond it, backward along the line of glacial movement for three hundred miles or more. It is undeniable, that *the agency, which produced the range, gathered its material all along its course for at least three hundred miles to the northward, and its largest accumulations were in the immediate vicinity of the deposit.* For this reason, as the range is traced along its course, its material is found to change, both lithologically and physically, corresponding to the formation from which it was derived.

These facts find ample parallel in the moraines of Switzerland. The marginal portion of the great moraine of the ancient expanded glaciers, on the flanks of the Juras, is composed, very largely, of boulder clay, derived from the limestones that lie in its vicinity, while the quantity of material derived from the more distant formations of the Alps is quite subordinate. Of the more recently formed moraines, those derived from the Bois, Viesch, Rhone, Aar, and other glaciers, which pass over granitic rocks, consist quite largely of sand, gravel, and boulders, clay being subordinate, while those glaciers of the Zermatt region, that pass mainly over schistose rocks, and the Grindelwald glaciers, that, in the lower part of their course, traverse limestone, give rise to a decided amount of clay. The moraines, previously referred to as miniature kettle ridges, are composed of commingled unstratified debris, in the main, but there are instances of assorted and stratified material. The inner moraine of the upper Grindelwald glacier presents much fine assorted gravel and coarse sand, heaped up,

very curiously, into peaks and ridges, in various attitudes on the summit and sides of the moraine.

Relations to Drift Movements. — This is manifestly of most vital consideration. The course of drift movement may be determined, (1) by the grooving of the rock surface, (2) by the direction in which the material has been transported, (3) by the abrasion which rock prominences have suffered, (4) by the trend of elongated domes of polished rock, and, (5) less decisively, by the arrangement of the deposited material and the resulting topography. Recourse has been had to all these means of determination, in that portion of the range that has been carefully investigated, and their individual testimony is entirely harmonious, and their combined force is overwhelming. Exceptional opportunity for positive determination is afforded by the protruding knobs of Archæan rocks before alluded to, from which trains of erratics stretch away in definite lines, continuous with the striation on the parent knobs, and parallel to that of the region, as well as concordant with the general system. The united import of all observations, in eastern Wisconsin, testifies to the following remarkable movements, which may be taken as typical, and which are here given, because they have been determined with much care. Between Lake Michigan and the adjacent Kettle range, the direction was obliquely up the slope, as now situated, southwestward, towards the range. On the opposite side, between the Green Bay valley and the range, the course was, after surmounting the cliff bordering the valley, obliquely down the slope, southeastward, toward the range. In the Green Bay trough, the ice stream moved up the valley to its watershed, and then descended divergingly the Rock river valley. Between the Green Bay valley and the Kettle belt on the west, the course was up the slope, westward, or southwestward, according to position. These movements, which are imperfectly shown on the diagram, exhibit a remarkable divergence from the main channel toward the margin of the striated area, marked by the Kettle range.

Much of the data relating to the movements, outside of Wisconsin, has been derived from a study of publications relating to the geology of the several states, to whose authors I am indebted,


PRELIMINARY MAP
of the
KETTLE MORAINE
and Diagram of the
GLACIAL MOVEMENTS
THAT GAVE RISE TO IT
by
T. C. Chamberlin
1878.
MINNESOTA
DAKOTA
WISCONSIN
Driftless Area
L. SUPERIOR
L. MICHIGAN
L. HURON
L. ERIE
L. ONTARIO
CANADA
MICHIGAN
NEW YORK
MASS.
CONN.
R.I.
NEBRASKA
IOWA
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA
NEW JERSEY
W. VIRGINIA
VIRGINIA
KENTUCKY
MISSOURI
KANSAS
Missouri River
Mississippi River
Approximate Limit of Northern Drift Area
Ohio River
ATLANTIC OCEAN
97°
92°
87°
82°
45°
40°
35°
30°

but who should not be held responsible for the special collocation presented in the accompanying diagram, which, in some of its details, may prudently be held as somewhat tentative, until more rigorously verified. But the grand features of these movements, which may be confidently accepted, are very striking, and are very singularly related to the great basins of the lake region. The three main channels were the troughs of the great lakes, Superior, Michigan, and the couplet, Erie and Ontario, while between these lay three subordinate ones in the basins of the great bays, Saginaw, Green and Keweenaw.

The divergence of the striations from the main channels toward the range, in the case of the Green Bay valley, and, so far as the evidence goes, in other troughs, was an unexpected result, developed by combining individual observations; but, when the method of wasting and disappearance of a glacier is studiously considered, appears not only intelligible, but a necessary result, and one which finds partial illustration among existing glaciers.

Topographical Relations and Distribution. — The topographical relations of the formation are an essential consideration, but may be best apprehended in connection with its geographical extension, which now claims our attention. If we start with the northern extremity of the long known Potash Kettle Range, in Wisconsin, we find ourselves about midway between the southern extremity of Green Bay and Lake Michigan, and on an eastward sloping, rocky incline. The base of the range is here less than 200 feet above Lake Michigan, and is flanked on either side by the lacustrine red clays of the region; and seems, in some measure, to be obscured by them. From this point, it stretches away in a general south-southwestward direction, for about 135 miles, ascending gradually, and obliquely, the rocky slope, until it rests directly on its crest.

When within about twenty miles of the Illinois line, *it divides*, one portion passing southward into that state, and the other, which we will follow, curves to the westward, and crosses the Rock river valley. A profile of the rock surface across this valley, beneath the range, would show a downward curve of more than 300 feet. The range should not, perhaps, be regarded as sagging

more than half that amount, however, in crossing the valley, as the canon-like channel of the pre-glacial river, seems to have been filled without much affecting the surface contour of the drift. But the fact of undulation to conform to an irregular surface, produced by erosion, and not by flexure of the strata, is a point to be noted, as it is a serious obstacle in the way of any explanation that is only applicable on the supposition that the formation was in a horizontal position when formed, as the view that it was produced by beach action, or the stranding of icebergs.

After crossing Rock river, the range curves gradually to the northward, passing over the watershed between the Rock and Wisconsin rivers, "descends abruptly 200 feet into the low ground of the valley of the Wisconsin,"[1] crosses the great bend of the river, sweeping directly over the quartzite ranges, according to Prof. Irving, with a vertical undulation of over 700 feet, after which it gradually ascends the watershed between the Mississippi and St. Lawrence drainage systems, until its base reaches an estimated elevation of 700 to 800 feet above Lake Michigan. From thence it has been traced across the headwaters of the Wisconsin river, by Mr. A. Clark, under my direction.[2]

Within the Chippewa valley, it has been observed by Prof. F. H. King, of the Wisconsin Survey, and I have observed it in the vicinity of the Wisconsin Central railroad. This region is covered by an immense forest, mainly unsettled and untraversed, even by foot paths, so that geological exploration is difficult and expensive, and, as no industrial importance attaches to it, and the rock below is deeply concealed by it, I have not deemed it sufficiently important to trace the belt continuously to justify the large expenditure of time and means requisite, especially as I entertain no serious doubts as to its continuity and general position. The observations made, indicate that it descends obliquely the east-

[1] Prof. Irving, Geol. of Wis., Vol. II, 1877, page 616.

[2] To the eastward of the range, as thus traced, Col. Whittlesey describes (Smithsonian Contributions, 1866) a similar formation in Oconto county. I have observed the same at several points. Mr. E. E. Breed informs me that it occurs on the watershed between the Wolf and Oconto rivers, but it has not yet been traced through the wilderness, to any connection with the main range, and it is uncertain whether it is so connected or constitutes a later formation, as such later moraines have been observed at other points.

ern slope of the Chippewa valley, and crosses the river below the great bend (T 32, R. 6 and 7), near which the Flambeau, Jump, and several smaller streams gather themselves together, in a manner very similar to that of the branches of the Rock and Upper Wisconsin rivers, just above the point where they are crossed by the range. From this point the belt appears to curve rapidly to the northward, forming the western watershed of the Chippewa. It is joined in eastern Burnett county by a portion of the range coming up from the southwest, the two uniting to form a common range, analogous to that of eastern Wisconsin. The conjoint range thus formed, extends along the watershed of the Chippewa and Nemakagon rivers, to the vicinity of Long and Nemakagon lakes, on the watershed of Lake Superior. This part is given mainly on the authority of Mr. D. A. Caneday, who visited a portion of the formation with me, and whose discrimination can, I think, be trusted. Mr. E. T. Sweet, of the Wisconsin Survey, describes[1] a kettle range as lying along the axis of the Bayfield peninsula, but it has not been ascertained that this is connected with the belt under consideration.

Returning to the junction of the two ranges in eastern Burnett county, I have traced the belt thence southwestward through Polk and St. Croix counties to St. Croix lake, on the boundary of the state. The lower portion of this has also been studied by Prof. L. C. Wooster, of the Wisconsin Survey. The southeastern range of the belt may be conveniently seen on the North Wisconsin railroad, near Deer Park, and on the Chicago, St. Paul & Minneapolis line, to the west of the station Turner, but only in moderate force.

If a good surface map of Minnesota be consulted, it will be seen that there lies along the watershed, between the Upper Mississippi and the conjoint valleys of the Minnesota and Red rivers, a remarkable curving belt of small lakes. Along this line, lies a chain of drift hills, known in its northwestern extension as the Leaf hills. In the Sixth Annual Report of the Geological Survey of Minnesota, received just as this article is going to the printer,

[1] Manuscript report on Douglas and Bayfield counties, to form a part of Vol. III, Geol. of Wis.

Prof. N. H. Winchell, speaking of the great moraines of the northwest, says: "There are two such that cross Minnesota, the older being the Coteau and the younger, the Leaf hills. Corresponding to the latter, the Kettle Range in Wisconsin seems a parallel phenomenon."[1] I have seen this belt, west of Minneapolis, and concur in Prof. Winchell's opinion. I have also observed, hastily, what I regard as portions of it — dissevered by the river channels — on the peninsula formed by the bend of the Mississippi and the Minnesota, south of St. Paul, and on the similar peninsula between the Mississippi and Lake St. Croix; and this seems to be the line of connection between the Wisconsin and Minnesota ranges. It appears to me, therefore, well nigh certain, that the Leaf hills of Minnesota are not only analogous to the Wisconsin Kettle range, but are portions of the same linear formation.

The multitude of small lakes, found in Wisconsin, lie almost exclusively either along the Kettle belt itself, or in the area within, or north of it. The surface outside has a much more perfect system of drainage, and is almost entirely free from lakelets. The Kettle range constitutes the margin of the lake district. But in Minnesota, south of the Leaf hills, there is an extensive lake region stretching southward in a broad tongue, nearly to the center of Iowa, though the lakes are not very numerous in the latter state. The question naturally arises, whether this lake district is likewise bordered by similar drift accumulations, and this question, though not essential to the present discussion, has much interest in connection with it. In respect to this, I can only give some detached observations and quotations. As already stated, accumulations of this character occur south of St. Paul. Still further to the southward, in the town of Aurora, Steel county, there is a moderate exhibition of gravelly boulder-bearing hillocks and ridges, accompanied by shallow basins and irregular marshes, much after the manner of the formation in question. From the descriptions of Prof. Harrington,[2] these features appear

[1] Sixth Annual Rept. Geol. & Nat. Hist. Sur. Minn., p. 106. The R. R. profiles crossing this belt furnish valuable data. See Ann. Rept. for 1872, pp. 53 and 57, and Sixth Ann. Rept., pp. 47 and 156.

[2] Geol. and Nat. Hist. Sur. Minn., Ann. Rept. 1875, pp. 103 *et seq.*

to characterize the county somewhat widely, especially in the southern part. Near Albert Lea, in the adjoining county, on the south, and only a few miles from the Iowa line, there is a more prominent development of similar features, the ridges having a southwestward trend. Dr. C. A. White, in the Geology of Iowa, describes a terrace in the northern part of the state, which, in its eastern extension, "becomes broken up into a well marked strip of 'knobby country.' Here it consists of elevated knobs and short ridges, wholly composed of drift, and usually containing more than an average proportion of gravel and boulders. Interspersed among these knobs and ridges, are many of the peat marshes of the region."[1] One knob he estimates as rising 300 feet above the stream at its base. This area lies in the line of the preceding localities, and near the Minnesota border. Between this "knobby country" and the Algoma branch of the C., M. & St. P. R. R., and stretching southwestward from the latter, there is a broad belt of low mounds and ridges, some of which show the structure and composition common to the Kettle moraine, while others present externally only a pebble clay, similar to that which characterizes the level country to the west of it. The whole presents the appearance of a low range modified by lacustrine deposits.

Near the center of the state, Dr. White describes a second range under the name of "Mineral Ridge,"[2] as consisting, "to a considerable extent, of a collection of slightly raised ridges and knolls, sometimes interspersed with small, shallow ponds, the whole having an elevation, probably, nowhere exceeding 50 feet above the general surface, but, being in an open prairie region, it attracts attention at a considerable distance." Both these ridges, Dr. White classes as probable moraines.

This Mineral ridge lies south of the lake district, and may be regarded as forming its margin in that direction. On the western border, Dr. White describes "knobby drift," in Dickinson county, which, however, is "without perceptible order or system of arrangement."[3] To the northwest from this, we soon encounter the

[1] Geol. of Iowa, 1870, p. 99. [2] Loc. cit. [3] Geol. of Iowa, Vol. II, p. 221.

morainic accumulations of the "Coteac de Prairie,"[1] and the "Cobble Knolls" and "Antelope Hills."

These observations do not indicate a continuous, well defined range, but seem rather to point to a half-buried moraine, that only here and there, along its course, protrudes conspicuously, and this is the impression gained from an inspection of the formation. It is to be noted, as supporting this view, that, at least so far as the eastern side is concerned, this supposed moraine is flanked on the *exterior* by level plains, of smooth surface, often underlaid by sand and gravel, that seemingly owe their origin to broad rivers or lakes that fringed the border of the glacier, in its advanced state, when it probably discharged its waters over the moraine at numerous points, rather than at one, or a few, selected points, as would more likely be the case during its retreat, when accumulations of water could gather along its foot, within the moraine, and large areas be discharged at some single favorable point. But on the inner side of the moraine, the surface, although nearly level, in its general aspect, undulates in minor swells and sags, and the drainage is imperfect. The substratum, instead of being gravel, sand, or laminated clay, is generally a pebble or boulder clay. *Outside* of the moraine, the existing surface contour was formed in the presence, and, to some extent, under the modifying influence, of a fairly established drainage system. But on the *interior*, the drainage system has not, even yet, become fully established, much less impressed itself upon the surface configuration, except in the vicinity of the main rivers.

The terrace-like ridge mentioned by Dr. White, and some of the lines of hills described by Prof. Winchell in Minnesota, as running in a similar direction, may be perhaps regarded as minor morainic lines, stretching across the glacial pathway and marking oscillations in its retreat, analogous to some quite clearly made out in Wisconsin.[2]

This southern morainic loop is, of course, presumed to be older than the Kettle range, and is here discussed because of the inter-

[1] See note of Prof. Mather, Nat. Hist. Sur. 1st Dist. N. Y., p. 193. See also 2d Annual Report Geol. and Nat. His. Sur. Minnesota, by N. H. Winchell, pp. 193 to 195; also *loc cit.*, *ante*.

[2] Geol. of Wis., Vol. II, 1876, p. 215 *et seq*.

esting way in which it is associated with the latter formation, and the suggestions it may contribute to the final solution of the main problem, to which the special one under discussion is only a tributary, viz.: the definite history of the Quatenary formations.

Returning to the branching of the range in southeastern Wisconsin, we find the left arm, or that nearest Lake Michigan, striking southward into Illinois. If we lay before us Prof. Worthen's geological map of that state, and attentively observe its topographical features and its drainage systems, it will be observed that nearly all the lakelets, the greater part of the marshes, and most of the region of abnormal drainage may be included in a curving line, rudely concentric with the shore of Lake Michigan, starting near the center of McHenry county, on the Wisconsin line, and ending in Vermillion county, on the Indiana border. It may also be observed, on a similar inspection of Indiana, that nearly all the lake district lies north of the Wabash.

In Wisconsin, as already stated, we have found this area bordered by the Kettle range, which is itself notably lake-bearing. The range continues to sustain this relationship in Illinois, so far as I know it to be directly continuous. It exhibits a progressive broadening, and flattening, as it enters upon the level country that encompasses the head of Lake Michigan. The pebble clay deposit — not coarse boulder clay — that characterizes the flat country, and which, to the north, has been separated from the range by a belt of coarse boulder clay, here approaches, and appears, to some extent, to overlap the range, and to be one cause of its less conspicuous character. From what I have seen of the region south of Lake Michigan, and from all I can find in geological reports relating to the region, I gather that the range, so far as it escaped the destructive action of the floods issuing from the Lake Michigan basin, both while occupied by ice, and subsequently, is, to a large extent, buried beneath later deposits, or so modified as to be inconspicuous. Whatever the correct interpretation, it remains a fact beyond question, that the belt becomes very obscure, compared with its development to the northward. Dr. E. Andrews says: "As we trace it southward, the material becomes finer, and the hills lower, until they shade off impercepti-

bly into the drift clay, of the Illinois prairies."[1] The members of the geological corps of Illinois did not recognize it distinctively, in the sense in which it is now considered, but Dr. Bannister, in his report on Lake county, says: "In the western part of the county, near the Fox river, we find the ridges, in some places, to be largely composed of rolled limestone boulders. The same character has been observed further south along the same stream and remarked upon in the chapter on Cook county."[2] In respect to McHenry county he says: "In the vicinity of the Fox river, the same kind of gravel ridges are met with as those which have been described as occurring in the western part of Lake county."[3] This lies in the belt identified by me, from personal observation, as belonging to the Kettle range.

Concerning the district farther south, he says: "Boulders of granite, quartzite, greenstone, and various other rocks are abundant in various localities on the surface of the ground, and are frequently met with in excavations for wells, etc., and large deposits of rolled boulders, chiefly of limestone from the underlying Niagara beds, similar to those already described in the report on Cook county, occur in the drift deposits of the adjoining portions of Kane and Du Page counties."[4] Concerning the topography, the same writer says: "Along some of the principal streams, and especially the Fox river in Kane county, the country is more roughly broken, and can, in some parts, even be called hilly, although the more abrupt elevations seldom exceed eighty or one hundred feet above their immediate base."[5] This broken country, if we may judge from what is true of the rough country along the same river to the north of this, it not due so much to the drainage erosion of the river as to the original deposition of the drift. The same features are said to continue into Kendall county, next south, which brings us to the vicinity of the ancient outlet of Lake Michigan, where, of course, the moraine is locally swept away. Still farther south, in Livingston county, Mr. H. C. Freeman mentions a ridge running southeast-

[1] On Western Boulder Drift, Am. Jour. Sci., Sept., 1869, p. 176.
[2] Geol. Sur. of Ill., Vol. IV, p. 130.
[3] Loc. cit., p. 131.
[4] Geol. Surv. of Ill., Part IV, p. 113.
[5] Geol. Surv. of Ill., Part IV, p. 112.

erly from a point in La Salle county, to near Chatsworth, a distance of about forty miles. "This is gravelly and sandy, giving it a distinctive character as compared with the adjacent prairie."[1] This is quite too meager to base an identification upon, but I have thought it worthy of quotation here. At Odell, which lies near this ridge, the drift is said to be 350 feet deep.[2]

On the railroad line from Chicago to Kankakee, there is no recognizable indication of the formation under consideration. Southwestward from Kankakee, on the line to La Fayette, Ind., there are a few mounds and ridges that bear a somewhat morainic aspect, but they are isolated in a generally level tract of lacustrine, rather than glacial, topography. They are, perhaps, remnants of a formation that has been largely eroded or buried. Near Fowler, in Benton county, Indiana, there is a belt of low mounds and ridges, accompanied by shallow depressions, that quite closely resemble the Kettle range in its more modified phases. Boulders appear upon the surface, and, in the more immediate vicinity of the village, are large and numerous. This is probably a portion of the "stream of boulders two miles wide," which Mr. F. H. Bradley mentions as extending through the eastern part of Iroquois county, Illinois, and the central part of Benton county, Indiana,[3] and which he attributes to floating ice. He does not, however, mention the associated topography or underlying drift formation. South of this low range, the country again becomes level, or gently undulating, as far as the Wabash."

The Indiana geologists have not yet critically examined the heavy drift region in the northern part of the state, through which the moraine might be supposed to pass, but in such preliminary inspection as has been made, they have not recognized any prominent moraine-like accumulation. The superficial expression of the region is quite monotonous, and presents to view deposits of sand, gravel, lacustrine or pebble clays, but more rarely the coarse boulder clay or mixed material, that I regard as the unmodified ground moraine. The modifying agencies which produced this phase of the deposits, would be antagonistic to

[1] Geol. Surv. of Ill., Vol. IV, p. 227. [2] Geol. Surv. of Ill., Vol. VI, p. 237.
[3] Geol. Surv of Ill., Vol. VI, p. 236.

ridge-like morainic accumulations, and their presence, in sharp outline, is not to be expected. In the vicinity of Ligonier, in Noble county, there is a feeble, but somewhat characteristic development of some of the features of the formation. So also, in the vicinity of Rome and La Grange to the northeast. Between La Port and Otis there is a kindred, though somewhat peculiar formation, but I am in doubt as to its true character.

On entering Michigan, we find the formation more unequivocally developed. Just north of Sturgis, which is near the southern line of the state, the formation appears in marked development. It does not attain a great altitude, but presents the peculiar strongly undulating and hummocky contour, and the coarse, mingled material, characteristic of the deposit. It may be seen to advantage on the line of the Grand Rapids & Indiana R. R. To the northeast in the vicinity of Albion, it may be seen from Springport on the north, to Condit on the south. It is here broad and flat, and superficially composed of gravel, for the greater part, but some of the deeper excavations reveal the characteristic coarser material. On the Michigan Central R. R., the formation may be observed between Jackson and Dexter, the most prominent portion being between the stations Francisco and Chelsea. It is not very prominent on the immediate line of the road, which was doubtless selected to avoid it, but in the vicinity it rises into prominent hills and ridges. Some of these, on the north, are conspicuous objects at considerable distances. Still farther to the northeast, my friend, Dr. D. F. Boughton, whose identifications I have elsewhere verified, informs me that the range is well developed in Oakland county, and is finely exhibited near the line of the Flint & Pere Marquette R. R., between Plymouth and Holly. Still farther to the northeast, it may be seen at great convenience and advantage, along the Detroit & Milwaukee R. R. from Birmingham, below Pontiac, to Holly. On the flanks, its features are subdued, the hills and ridges being rather low, with more or less level surface between them, and the superficial sands and gravels are prevalent; but from Waterford to beyond Clarkston, the range has a fine, though irregular development. The hills rise with characteristic contours, to an esti-

mated altitude of 200 feet or more above the surface of the beautiful lakelets embosomed at their base. The deep cuts near the latter station, amply exhibit the coarse, commingled material, characteristic of the core of the range.

Putting the foregoing observations together, they seem to establish beyond reasonable doubt the existence of a broad, massive belt stretching northeastward on the highland between the Saginaw and Erie basins.

If we return again to the southwestern part of the state, we are informed by Dr. Boughton that we shall find a similar accumulation at, and in the vicinity of, Kalamazoo. To the north-northeast, in Barry county, the Thorn Apple river cuts across this range between Sheridan and Middleville. This belt here, though broad, presents a more prominent and ridge-like aspect, with better defined limits than elsewhere observed in Michigan. To the north of this, opposite Saginaw bay, there occurs, near Farwell, broken, rough country and abundant coarse drift, that probably belongs to the belt in question, but my opportunity for observation was unsatisfactory. Beyond this point, I have no definite information, but I deem it highly probable that the moraine will be found extending some distance farther, on the highlands of the Peninsula.

The lake survey charts show that Grand Traverse bay has the remarkable depth of over 600 feet. This great depth, together with its linear character, and the form and arrangement of the associated inlets and lakes, has suggested that it may have been the channel of a separate minor glacier, analogous to that of Green Bay on the opposite side of the great lake, but I have no direct evidence that such was the fact.

In the reports of the geological survey of Ohio, a formation of nearly, or quite, identical characteristics is carefully described by the several writers whose districts embraced it. In the second volume,[1] Dr. Newberry gives, under the name of "Kames," an excellent summary of its leading features. These harmonize very nearly with those of the Kettle belt. The main points of differ-

[1] Pages 41–47. See also "Surface Geology of Northwestern Ohio," Proc. Am. Assoc. Ad. Sci., 1872, by Prof. N. H. Winchell, under heads of St. Johns and Wabash Ridges.

ence are the less conspicuous character and massiveness of the Ohio range, and the greater prevalence of assorted and stratified material; in other words, its features are the same that the Kettle range presents in its more subdued aspects, especially where it is formed in a comparatively smooth country, and is flanked by pebble clays, with level surface, instead of coarse boulder clay, with ridged, or mammillary, contour. I cannot turn aside, here, to define, with sufficient circumspection, the distinction between these clays, further than to indicate my belief that the former are sub-aqueous, and the latter sub-ærial, or, if you please, sub-glacial, deposits.[1]

Where I have seen the Ohio formation, it presents almost precisely the characteristics that are exhibited by the Kettle range in northern Illinois, where it is similarly related to plane topography and pebble clays, and it is also very similar to the same formation opposite Green Bay, where it is bordered on both sides by red lacustrine clays of later date. Dr. Newberry quite clearly recognizes the parallelism, but perhaps not the identity, of the formations.[2] Col. C. Whittlesey, in his article on the "Fresh Water Glacial Drift of the Northwestern States,"[3] classes the formations together as identical in character, though he does not seem to have considered them members of a continuous formation, and could not well do so with the prevalent view, which he somewhat emphasizes, that it is peculiarly a *summit* formation. It very often does occupy the summit of a rock terrane, and it sometimes *forms* a watershed by its own massiveness, but it likewise occupies slopes and crosses valleys, as shown in detail in the Wisconsin report. Prof. Andrews of the Ohio survey, in a personal communication, adds his conviction that the Ohio and Wisconsin deposits are parallel formations. It would seem, then, that the only question relates to the *continuity* of the belts. Unfortunately there intervenes the Wabash valley, the ancient drainage channel

[1] I have mapped these formations separately in Eastern Wisconsin. See Atlas accompanying Vol. II, Geol. of Wis., 1877, Plate III, Map of Quaternary formations. See, also, p. 225 of the volume.

[2] Geol. Surv. of Ohio, Vol. II, pp. 4, 5, and 43. Dr. Newberry's views as to the origin of the Ohio "Kame" belt are at variance with those here presented.

[3] Smithsonian Contributions, 1866.

of the Erie basin. Absolute continuity undoubtedly does not exist. If my views are correct, this was the great — not exclusive — channel of discharge of the glacial floods, at the very time the moraine was being formed, where it could be formed, and, for that reason, the debris was swept away or leveled. In addition to this, the region has been subjected to the vicissitudes of erosion, of a reversal of drainage systems, and of lacustrine and fluviatile accumulation. It is to be presumed, therefore, that a portion of the range, where once formed, has been lost, leveled, or buried. Some remnant indications of the range, on the upper slopes, might, however, rationally be presumed to exist. But, awaiting a critical examination of the region, we must confess a want of direct evidence. The belt stretches entirely across Ohio and enters Indiana, but has not been traced farther.

In the line of indirect testimony, however, some facts may be noticed. Prof. N. H. Winchell describes in the Ohio reports[1] six ridges running parallel to Lake Erie, and Mr. G. K. Gilbert has described that portion of these which lie in the more immediate Maumee valley.[2] Two of the inner ones are conceded to be lake beaches. The two outer ones are members of the "Kame," or Kettle belt, according to Dr. Newberry.[3] The one next within, the St. Mary's ridge, Prof. Newberry distinguishes, apparently, with justness, from both the other classes. Mr. Gilbert gives a clear and discriminating description of this, and expresses the conviction that it is "the superficial representation of a terminal glacial moraine, that rests directly on the rock bed and is covered by a heavy sheet of Erie clay, a subsequent aqueous and iceberg deposit."[4] The views of Professors Newberry and Winchell, while they each differ somewhat, agree with this in the only point essential to the present discussion, viz.: *that this ridge represents the margin of the glacier at the time it was formed.* This shows the glacier to havebeen a tongue or lobe of ice, differentiated from the supposed continental glacier, and having its axis coincident with the Maumee valley, and, withal, capable of forming a morainic accumulation on both sides. The St. Mary's ridge crosses the

[1] See also Proc. Am. Assoc. Ad. Sci., 1872.
[2] Geol. Surv. Ohio, Vol. I, pp. 537 *et seq.*
[3] Geol. Sur. Ohio, Vol. II, pp. 56 and 57.
[4] Loc. cit.

Maumee - Wabash valley — the glacial trough — and, recurving upon itself, bears away to the northeast, approximately parallel to the Kettle belt already described in southeastern Michigan. This wing of the St. Mary's ridge bears the same relation to the Kettle belt bordering the Erie basin on the Michigan side, that the opposite wing does to the "Kame" belt on the south side. The force of this relationship is not easily escaped.

If my views are correct, that this Michigan belt was formed along the right hand margin of the Erie glacier (conjointly with the Saginaw glacier), just as the "Kame" belt was formed on the left hand margin, then its composition should give evidence of the fact. In the case of the Green Bay glacier, I have shown that the lines of striation and transportation diverge from the main axis toward the margin,[1] and, so far as the paths of other glaciers lie within Wisconsin, the observations made upon them, imply the same method of movement, and this habit finds partial exemplification among the glaciers of the Alps — partial, because their contracted valleys and steep slopes afford little opportunity to deploy in this fashion. If this manner of movement holds true with the Erie glacier, material from its trough will be found to have been transported westward and northwestward toward the moraine. Thirteen years ago, in an article in the American Journal of Science, entitled, "Some Indications of a Northward Transportation of Drift Material in the Lower Peninsular of Michigan,"[2] Professor Alexander Winchell called attention, with much detail and precision, to a large mass of evidence, which finds, for the first time, so far as I am aware, satisfactory explanation in the view now presented, and, in return, has the force of confirmatory evidence. It appears that immense, and often but slightly eroded masses of Corniferous limestone, have been borne in the direction indicated, and scattered over the areas of the Hamilton group, the Marshall sandstone, and the Subcarboniferous limestone; that similar blocks of Hamilton rock have been deposited over the two last named formations and even beyond; that the Marshall sandstone has likewise been borne on to the Carboniferous limestone, and that this transportation has

[1] Geol. of Wis., Vol. II, pp. 199 *et seq.*

[2] Am. Jour. of Sci., Vol. XL, Nov., 1865.

been from lower to higher levels, as the strata now lie, and are presumed to have lain, since the basin is one of excavation and not of flexure. These phenomena, in all their details, are precisely what we should expect from the action of a glacier advancing through the Erie valley, and moving in a manner analogous to that of the Green Bay glacier. That a glacier moved through this valley has been abundantly shown by the Ohio geologists. The only labor of this article is to show that it was an individualized stream, forming the Ohio "Kame" belt on one side, and the Michigan on the other, simultaneously, and that they are collateral members of a common moraine.

Eastward from Ohio, there has been, so far as I am aware, no definite attempt to trace out the extent of the belt. In western New York, Prof. Hall mentions, as one of the three general aspects of the superficial deposits, a surface "broken into irregular hills or ridges, with deep bowl-shaped depressions, or long valleys, which often communicate in more extensive ones, or are enclosed on all sides by drift,"[1] but he does not definitely locate the formation, or indicate whether it assumes the form of a belt, or otherwise. In central New York, Prof. Vanuxem says: "There is another class of deposits, well defined as to position, but irregular as to composition, which are worthy of note. They occur in the north and south valleys, which are on the south of the Mohawk river, or the great level." "The whole of these deposits have a common character. They are in short hills, quite high for their base and are usually in considerable numbers." "They consist of gravel, of stones also of greater size, sand and earth."[2] These, he says, greatly resemble the "deluvial elevations" noticed in the survey of Massachusetts,[3] the description of which is perfectly applicable to the formation under consideration. Furthermore, Prof. F. H. King, of the Wisconsin survey, has examined the same deposits in the vicinity of Ithaca, and recognizes their identity in kind. Neither of these observers, however, discern a definite belt, although Prof. Vanuxem destroys the force of his apparent limitation of the formation to the valleys, by stat-

[1] Nat. Hist. Surv. 4th Dist., Geol., Pt. IV, pp. 320, 321.
[2] Nat. Hist. Surv. N. Y., 3d Dist., p. 218. [3] Geol. of Mass., E. Hitchcock, 1833, p. 144.

ing that there are numerous points where it has formed over the hill sides, and by associating in mention with it accumulations on the "heights, apparently in no regular order."[1] As these are deep, canon-like valleys, they would probably modify in some degree, the comparatively thin margin of the glacier, giving it a somewhat digitate outline, and the greatest accumulations would take place near the extremities of the tongues, in the valleys, so far as drainage permitted; while the connecting chains would form retreating lines, and be less conspicuous, and might, therefore, escape observation not definitely turned to the subject. This, at least, is suggested by some observations of my own in similar situations. Such valley accumulations, however, do occur at the extremities of linear glacial lakes that are unconnected with a definite belt, as in the case of Green Lake, Wisconsin.[2]

On the line of the Erie R. R., along the small tributary of the Delaware river that is followed up, westward, from Deposit, I have observed winding Osar-like ridges, parallel to the valley, and Kame-like hills upon the slope, up to the watershed of the Delaware and Susquehanna; likewise in the valley of the latter, at and near the village of Susquehanna, but I have no knowledge of their intimate structure, extent, or relations.

In the southeastern district of New York, Prof. Mather recognizes the distinctive aspect of this class of accumulations.[3] He cites several instances of its occurrence on the east side of the Hudson, leaving the impression that they are local features. But on Long Island, it forms "an elevated ridge, called by some, 'Green Mountains,' and by others, the 'Backbone' of the island."[4]

This he describes in detail and maps, showing that it branches at the east, one chain extending along the southern peninsula to Montauk Point, and the other, along the northern to its extremity, and, theoretically, to the islands beyond.

Professors Cook and Smock have recently examined this, and have shown its connection with a similar moraine, that stretches across the northern part of New Jersey, from Perth Amboy to

[1] Loc. cit., p. 219. [2] Geol. of Wis., 1877, Vol. II, p. 138.
[3] Nat. Hist. Surv. N. Y., 1st Dist., Pt. IV, p. 212. [4] Loc. cit., p. 161.

the Delaware river, below Belvidere.[1] The descriptions of this range tally quite perfectly with that of the Kettle moraine. This range, however, lies on the margin of the area of northern drift, while the western one is medial in position, and at some points is quite distant from the margin. It will be observed, nevertheless, that this distance is greatest, in general, at the west, and that in Ohio it becomes very greatly reduced, so that the fact of coincidence on the Atlantic coast, presents no reason for supposing the ranges to be distinct. But, whether distinct or not, is a matter to be settled by observation, and it is to be hoped that it will not long remain undecided for want of it. The extension of the New Jersey moraine westward has not, so far as I can learn, yet been traced, but the survey of Pennsylvania, in progress, will, doubtless, soon leave nothing to be desired, so far as that State is involved.

To the eastward, Mr. Warren Upham has recently been engaged in studying its probable continuation in southeastern Massachusetts. In a personal communication he writes: "A very clear line of terminal moraine extends along the chain of the Elizabeth islands southeast of Buzzard's Bay; thence it bends to the northeast and north as far as to North Sandwich, when *it turns at a right angle* to the east, and extends through Barnstable and other towns to Orleans, running along the east and west portion of Cape Cod, and terminating at its east shore." "This terminal moraine, like the 'Kettle moraine', is not at the outmost limit reached by the ice-sheet; for hills, in series nearly parallel to the moraine already described, and similarly composed of glacial drift with many boulders, occur on Martha's Vineyard and Nantucket islands, corresponding, perhaps, to the terminal moraine which forms the 'backbone' of Long Island. * * The moraine of the Elizabeth islands and Cape Cod has a length of about 65 miles." It may be suggested that the range along the Elizabeth islands may correspond to the northern branch of the Long Island moraine described by Prof. Mather, and that, as Mr. Upham suggests, that of Martha's Vineyard and Nantucket corresponds to the southern.

[1] Ann. Rept. of State Geologist, N. J., 1877, pp. 9 *et seq.*

Dr. E. Hitchcock refers to these accumulations in his report on the geology of Massachusetts,[1] and classes with them "diluvial elevations and depressions," occurring at other points in that and adjoining States. It would appear, from the geological reports of the Eastern States that analogous, though not certainly identical formations, occur locally, more frequently than in the interior, and this, from the mountainous nature of the country, is not strange; but no continuous massive range seems to have been discerned, except the southern one already described.

In the interior, so far as yet ascertained, the drift limit is not marked by any such persistent ridge-like accumulation, but gradually dies away or is buried by later deposits, so that the precise limit of glacial advance is not easily determined. The only approach to an exception to this, known to me, is the case of the Kettle moraine in Central Wisconsin, where it lies near the border of the driftless area. Elsewhere around that area, the drift thins out very gradually, so as to render the mapping of its margin a work of close inspection; and, as the region presents no evidence of subsequent submersion, or any other special modifying agency, except the usual meteorological forces, this would seem to represent approximately the original form of deposit.

It is evident from the foregoing sketch that much observation remains to be made before the complete geography of this formation is determined. The conjectural lines on the map are only theoretical suggestions, preliminary to observation.

Summary.— It may be helpful at this point to summarize, and bring into close juxtaposition, in thought, the leading characteristics of this remarkable formation.

1. Its linear extent is very great, whatever its final limits may be found to be.

2. It has a width of from one to thirty miles.

3. Its average vertical thickness can only be very roughly estimated, but may, very prudently, be placed at 200 or 300 feet.

4. Its surface configuration is peculiarly irregular, and denotes an extraordinary origin.

[1] Geol. of Mass. 1833, pp. 144 *et seq.*

5. It is a complex range, the component ridges being often arranged in rude parallelism.

6. A distinction is usually to be observed between the superficial and lateral portions of the deposit on the one hand, and the central, underlying one on the other, the former being chiefly sand and gravel, the latter complex commingled debris.

7. The superficial sands and gravels are usually stratified in various attitudes, but the core of the range is mainly unstratified.

8. The irregularities of the range are most conspicuous where the superficial sands and gravels are least abundant.

9. The material was derived, in part, conspicuously so, from the vicinity of the range, and, in part, from the formations lying backward along the line of drift movement for at least 300 miles.

10. A portion of the material is spherically rounded, a part is scratched and polished, and some is little affected, though sometimes soft or friable, the latter being usually from adjacent formations.

11. The range is tortuous in its course, but sustains a remarkable and significant relationship to the great lake basins.

12. It undulates over the face of the country, varying at least 800 feet in its vertical oscillations.

13. It does not sustain any uniform relation to present, or what are presumed to have been, preglacial drainage systems in their details. In some portions, it occupies water-partings; in others, lies on slopes; and in still others, stretches across valleys.

14. It crosses, in its course, all the indurated formations, from the Laurentian to the Coal measures, but exhibits no specific relation to their strike or dip.

15. It sustains a definite and most important relationship to the lines of general drift movement.

16. The range is frequently flanked on its southern, or outer edge, by level areas of sand and gravel, of greater or less extent. These also occur between the component ridges of the belt, and on the inner flank, but less frequently.

17. The surface contour of the adjacent region within, or north of, the belt, usually, though not invariably, has a less perfect drainage system, and exhibits less noticeably the effects of superficial modification, than the outer side.

Origin.— Waiving, for the present, some further generalizations, it is thought that the foregoing phenomena present a *specific combination* which points unequivocally to a morainic origin. To the writer, familiar with the multitudinous details, that cannot here find a place, and having studied recent moraines with special reference to this formation, they have a force little less then demonstrative. The range is confidently regarded as a moraine formed at the margin of a group of glaciers — which may be regarded as a single lobate one — and marking a definite stage of their history. A more vivid and graphic view of the outline and movements of these glaciers, than can be given in words, may be obtained from the accompanying map, from which it will appear that through each of the great lake troughs there poured an ice stream, attended by minor currents through the lesser channels.

Its Medial Position.— It has already been remarked that, in the interior, this moraine does not mark the extreme limit of glacial advance. Numerous striations, and other evidences of glaciation, occur on the south side of it. A line has been drawn on the map intended to indicate the approximate limit of northern drift, based on several authorities.[1] How nearly this shows the limit of actual glacial progress, in distinction from other means of transportation, is not, I think, as yet definitely ascertained, but the general fact of progress, to a considerable distance beyond the Kettle moraine, is sufficiently established. The moraine was, therefore, formed *after the retreat of the glacier had commenced, and marks a certain stage of its subsequent history.*

Glacial Movements before the Formation of the Moraine.— It becomes an interesting question to ascertain whether the glacial movements were the same before the formation of the moraine, as afterwards. Fortunately, in southern Wisconsin, we have very definite and specific evidence bearing on this question. In the towns of Portland and Waterloo, which lie within the area of the Green Bay glacier, and from twenty-five to thirty miles distant from the moraine, there are several domes of quartzite that rise through the horizontal sandstones and limestones, which occupy the surrounding region. These domes are glacially abraded and grooved in a direction S. 30° W., and trains of quartzite boulders

[1] Tesley, Newberry, Cox, and assistants, Worthen, Swallow, and Mudge.

stretch away in that direction to the moraine, and, mingling with it, pass onward to an equal distance beyond. At the same time there is abundant evidence from the material of the drift, from the surface contour and from striation, recently observed by Mr. I. M. Buell, that the westerly movement of the Lake Michigan glacier, near the Illinois line, extended to the west side of Rock River, and that the line of junction of the two glaciers was on the west side of that stream. It appears then, that in this region, the movements were in the same general direction before and after the formation of the moraine, but that there were changes in the details, and that the relative size and position of the glaciers were somewhat different, the Green Bay glacier being relatively smaller in the earlier epoch. Testimony of similar general import, but less specific, may be gleamed from the reports of the other states involved.

Method of Formation.— If, then, the glacial movements were the same, in general, before and after the formation of the moraine, and yet the minor movements and relative size of the glaciers somewhat different, how was the moraine formed? A halt in the retreat of the glaciers, by which their confluent margin should remain stationary for a period, would doubtless cause an unusual accumulation of debris, but this would fail to account for the varying width or irregularities of the moraine. The structure of the range seems to indicate an alternating retreat and advance of the ice mass. During the former, debris was thrust out at the foot of the melting mass, which, when the glacier advanced, was plowed up into immense ridges. If this process be repeated several times paralled ranges will be accounted for, and the irregularities incident to such advance and retreat will explain the complexity of the range. Where the later advances were equal to the earlier ones, the accumulation of drift material would be forced into a single massive ridge. Where any advance failed to equal a former one, an interval between the accumulations of the two would result, giving rise to a depression whose form would depend upon the relations of the two accumulations, but would in general be more or less trough-like in character. Where tongues of ice were thrust into the accumulated material an irregular or

broken outline would be the result. If masses of the ice became incorporated in the drift, as has been suggested, their melting would give rise to depressions, constituting one form of the kettles that characterize the range. The suggestion just made, with reference to the irregular advance of the ice mass, accounts for other forms, and, at the same time, for the irregular hills, mounds, and hillocks. Certain of the kettles may be due to underdrainage, through the action of strong underground streams that occasionally flow, as full brooklets, from its base. The drainage of the glacier, while it was advancing and pushing the debris before it, was probably quite general and promiscuous *over* the moraine, and this would give rise to the stratified sands or gravels, and other evidences of the action of water, among which may perhaps, be reckoned some of the minor mounds, ridges and depressions. The changing attitudes, which the debris would be likely to assume, as it was forced along, would, perhaps, give peculiar force to torrential effects.

The gaps in the range, attended by plains, or long streams of gravel and sand, appear to represent the more considerable points of discharge of the glacial floods. When the surface about the margin of the glacier permitted the accumulation of water, the moraine would doubtless be much modified by it and present a subdued aspect.

The Alpine moraines, above referred to, are regarded as miniature exemplifications of the process by which the Kettle moraine was formed.

But, in addition to the structure of the range, the change in the relative position of the Green Bay and Lake Michigan glaciers, already alluded to, affords evidence of an exceedingly interesting character, which has a significance much beyond what can be here indicated. It appears that the junction between the Green Bay and Lake Michigan glaciers at the last observable stage, preceding the formation of the Kettle moraine, was about twenty-five miles farther west, than at the time of the latter's formation, or, in other words, there is an abrupt easterly shift of the line of junction. It appears, also, that the width of the ante-morainic Green Bay glacier, measured just south of the Kettle moraine, was only half

that of the post-morainic glacier, north of it, measured at a distance just far enough to escape the terminal curvature. An inspection of the outline of the Green Bay glacier shows that this eastward shift of the junction of the two glaciers was not due simply to encroachment on the Lake Michigan stream, nor to a common movement of both in that direction, for the opposite margin of the Green Bay glacier lay close upon the borders of the driftless region, demonstrating that there was no eastward swaying on that side. Indeed, the indenture of the outline of the driftless area strongly suggests actual encroachment on that side also, and this view is not without independent support.

In harmony with these phenomena are the fiords of the Green Bay peninsula, which indicate that the Green Bay ice stream overflowed into the basin of Lake Michigan. These facts, taken altogether, seem to warrant the belief that both glaciers retreated sufficiently far to the northward, and within their respective basins, to allow time and opportunity for the change in the relative size and position of the two ice streams, and that, under slightly changed conditions that favored the Green Bay glacier, they advanced to the position of the Kettle moraine, and, after a series of oscillations, retreated permanently. This view seems also to be demanded by certain details in the distribution of the drift material that are otherwise enigmatical, but whose discussion would too much extend this article.

Significance.—As forty-five years have passed since Dr. Hitchcock called attention to some of the phenomena under consideration, or, at least, to some distinctly related to it, and yet, the matter has received so little consideration, that our present knowledge is limited to such a degree, that I lay myself liable to the charge of undue temerity in attempting to correlate the observations, I may be pardoned in attempting to indicate, briefly, something of the significance and importance the foregoing conclusions, if sustained, have in relation to the Quaternary history of the region involved. The moraine constitutes *a definite historical datum line*, in the midst of the glacial epoch, and becomes a basis of reference and correlation for adjacent formations. It is an historical rampart, outlining the great dynamic agency of the period, at an important

stage of its activity, and separating the formations on either hand by a chronological barrier. It is manifest that the true Boulder Clay, or ground moraine, south of the belt, must have been formed earlier than that north of it, and that the two portions are not at all synchronous. In sedimentary formations synchronism is found in horizontal strata, but in glacial deposits it is to be sought in linear belts, concentric with the margin of the glacier. This fact finds illustration, and emphasis, in the demarcation introduced by this singular corrugation of the wide-spread glacial sheet. It is difficult to limit the value of such a determinate line, in the midst of the complex drift formations, if fully established, and should similar belts be found to mark other stages of glaciation, there would be opened a definite line of investigation that promises much assistance in unraveling the gnarled skein of Quaternary history.

While it does not follow, necessarily, that all formations overlaying the true glacial clay, south of the Kettle moraine, are older than those occupying similar relations to the newer Till, north of it, it is clear, that similarity of stratigraphical sequence is not, by any means, sufficient ground for assuming chronological equivalence. It is evident, that all endeavors at correlation between the superficial deposits, on the opposite sides of the moraine, should be attempted with much circumspection.

These suggestions have especial application to the discussion of the vegetal deposits, so frequently found in the later Quaternary formations. By many writers, the various deposits of this kind, in the Mississippi basin, have been, very naturally, in the present state of our knowledge, grouped together without reference to the necessary discriminations above indicated, and, as a result, beds of diverse age are referred to a common stratum. A general discussion of these deposits is not sufficiently germane to our subject to be fittingly introduced here, but it is appropriate to point out the fact that some of the vegetal strata sustain such a relation to the Kettle moraine, that they must be widely separated from others, in the date of their accumulation and burial. Some of these organic strata lie at the immediate foot of the moraine, beneath fluviatile and lacustrine deposits that, I am confident, began

to be accumulated during the accumulation of the moraine, and through the agency of glacial floods; while it is even more certain, that other vegetal deposits accumulated much subsequently, as those found in the red clays of Wisconsin, which are lacustrine deposits of the great lakes formed after the recession of the glacier. It would be too much to assume that all plant remains, found south of the moraine, antedate its formation, but it is safe to affirm that, with only phenomenal exceptions, e. g., such as escaped glacial abrasion, all north of it are more recent.

The bearing of these definite determinations of the glacial outlines and movements upon the question of the origin of the remarkable driftless area of Wisconsin, Minnesota, Iowa and Illinois (see map) was early perceived, and it was clearly foreseen that this line of investigation promised a *demonstrative* solution of the problem. The driftless area manifestly owes its origin to the divergence of the glaciers through the Lake Superior channel, on the one hand, and that of Green Bay and Lake Michigan, on the other, and to the obstacle presented by the highlands of northern Wisconsin and Michigan. This obstacle the glacier surmounted, and passed some distance down the southern slope, but apparently not in sufficient thickness to overcome the melting and wasting to which it was subjected, and so it terminated midway the slope. But the deep, massive ice currents of the great channels pushed far on to the south, converging toward each other; and, if they did not actually unite, at least commingled their debris south of the driftless area.[1] An instance closely similar to this, considered from a dynamical point of view, may be seen, at the present termination of the Viesch glacier, and illustrations of the general principles involved in the explanation may be seen in connection with several other Alpine glaciers.

If the evidence adduced to show that the Kettle moraine was due to an advance of the glaciers be trustworthy, then, to the extent of that advance, whether much or little, the moraine marks a secondary period of glaciation, with an interval of deglaciation

[1] Compare N. H. Winchell in An. Rep., Geol. of Minn., 1876, and R. D. Irving, Geol. of Wis., Vol. II, 1877, whose views are closely analogous to the above and each to the other but are not strictly identical. See, also, J. D. Dana, Am. Jour. Sci., April, 1878.

between it and the epoch of extreme advance. Its great extent indicates that whatever agency caused the advance was very wide spread, if not continental in its influence. The moraine, therefore, may be worthy of study in its bearings upon the interesting question of glacial and interglacial periods.

It will also furnish definite data bearing upon the somewhat mooted question of the origin of the Great Lakes, as well as other questions involving both perglacial and postglacial topography.