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CHARLES D. WALCOTT, DIRECTOR

THE
DRUMLINS OF SOUTHEASTERN WISCONSIN

(PRELIMINARY PAPER)

BY

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DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., April 11, 1905.

SIR: I transmit herewith the manuscript and illustrations of a report entitled "The Drumlins of Southeastern Wisconsin, (Preliminary Paper)" by Mr. W. C. Alden, and recommend it for publication as a bulletin.

The formation of drumlins has recently awakened renewed interest and discussion, and it seems very desirable that the data carefully gathered and organized in this paper should be placed before scientific investigators who are interested in this difficult subject.

Very respectfully,

C. W. HAYES,
Geologist in Charge of Geology.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

THE DRUMLINS OF SOUTHEASTERN WISCONSIN.

(PRELIMINARY PAPER.)

By William C. Alden.

INTRODUCTION.

For several seasons past the writer has been engaged in a study of the Pleistocene and underlying formations of southeastern Wisconsin, under the direction of Prof. T. C. Chamberlin. Within the area covered by the survey, approximately 4,200 square miles, there are about 1,400 drumlins, of greater or less perfection of development. Most of these drumlins (1,269) belong to the ground moraine of the Green Bay Glacier, the southern 37 miles of whose length is here included; 74 lie in the area traversed by the Lake Michigan Glacier of the late Wisconsin invasion, and 62 form part of an older drift deposit lying outside of the bulky moraines of the late Wisconsin glaciers, which is thought to have been formed at either the Iowan or the Illinoian stage of glaciation. For purposes of study and comparison with similar phenomena of other regions it has been thought advisable at this time to correlate the mass of data already on hand concerning the drumlins of this region and present them in this form. No attempt is here made to reach final conclusions, as the study is yet in its early stages. It should be borne in mind that such deductions as are made are based solely on phenomena thus far observed, and, being tentative, are subject to modification as the study proceeds. By mutual understanding it is expected that the results of a previous study by Mr. I. M. Buell, of which a preliminary statement has been made,[a] together with the wider studies of Doctor Chamberlin, will be combined with these results in a more comprehensive and mature discussion. The writer wishes gratefully to acknowledge his indebtedness to Doctor Chamberlin for suggestions and criticisms in the preparation of the present paper. The discussion is based principally on the drumlins of the Green Bay Glacier.

DISTRIBUTION AND ORIENTATION.

As already indicated, by far the larger number of the drumlins of this area belong to the deposits of the Green Bay Glacier. Though generally present throughout the ground moraine of this glacier, their distribution is by no means uniform, as will be seen by the map

[a] Buell, Ira M., Bowlder trains from outcrops of the Waterloo quartzite area: Trans. Wisconsin Acad. Sci., vol. 10, 1895, pp. 487–509.

(Pl. I). Though distributed over a ground-moraine area of approximately 1,325 square miles, part of which is occupied by terminal moraine deposits formed during the deglaciation of the area, drumlins occur in but 577 sections of land. Some of these sections contain 7, 8, or 9 such hills, and one, section 34, Blooming Grove, near the village of McFarland, about 5 miles southeast of Madison, has 10 distinct drumlins. Where the drumlins are thus crowded, as in a school of dolphin backs, the topography becomes very striking.

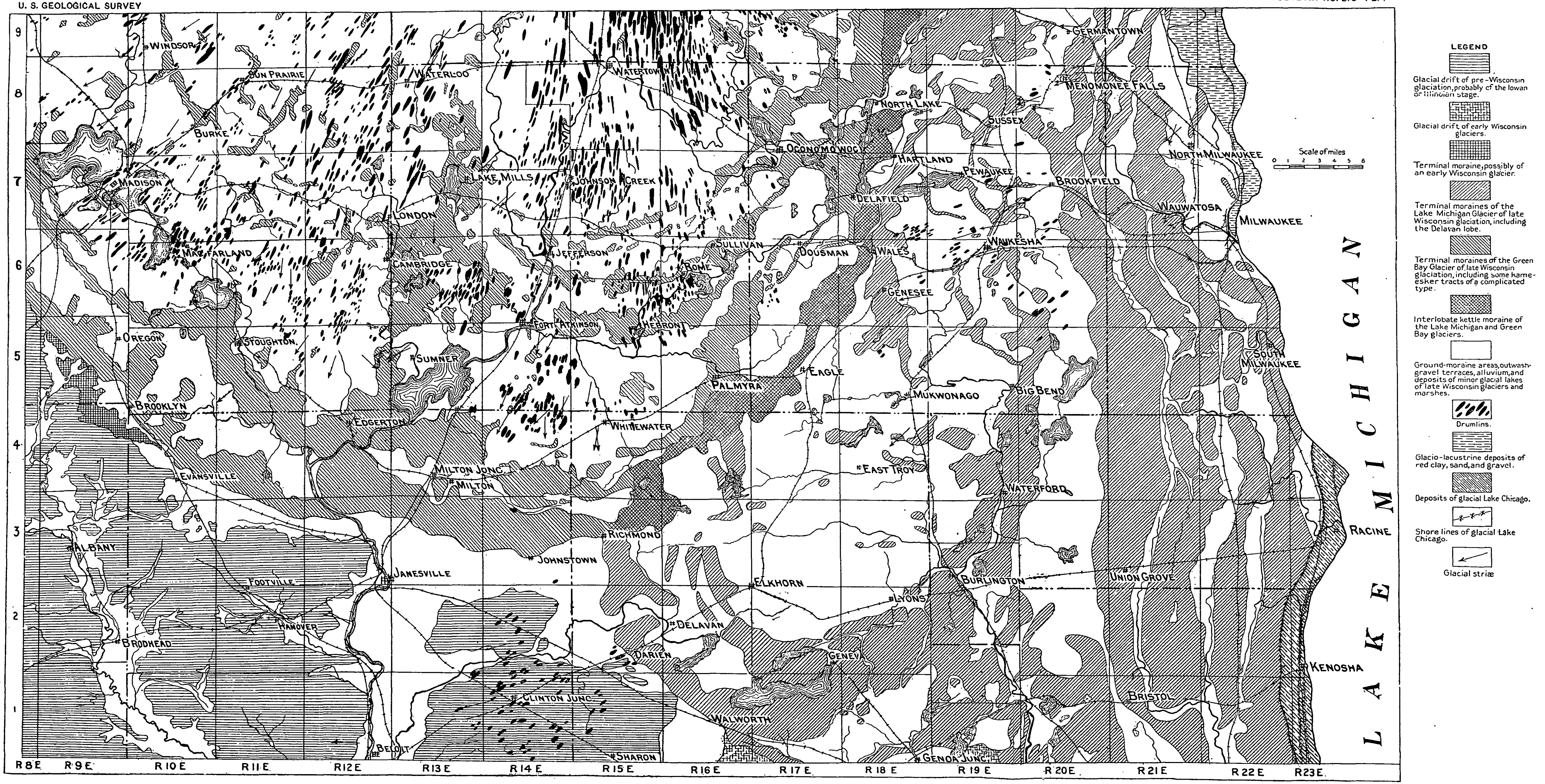
Ranged as the drumlins are, parallel to the lines of glacial flowage, their distribution and orientation in this area shows in a very striking manner the effects of radial deployment of the ice at the southern end of the lobe. The deployment of the lobe as a whole was bilaterally asymmetric. This was due to the monoclinal character of the Green Bay-Lake Winnebago trough, which it traversed, and to the fact that the ice, which surmounted the Niagara escarpment forming the east wall of the valley and began to descend the gentle eastward slope, was stopped by the opposing front of the Lake Michigan Glacier, which was at the same time advancing up that slope. As a consequence the deployment at the south end of the lobe is eccentric, though the curve of the outer moraines is fairly regular through an arc of 180°. The extremes of radial deployment shown by the drumlin axes within this area are S. 86° W. and S. 75° E., a divergence of 161° in a distance of 55 miles across the lobe.

Usually the orientation of the drumlin axes is about the same as that of the glacial striæ observed at adjacent rock exposures. There are, however, frequent divergences of 10° to 20°, and sometimes the divergence is notable. The following table shows some of the cases which have been noted:

Divergent glacial striæ of the Green Bay Glacier.

Town.	Sec.	Striæ.	Trend of the nearest drumlin.
Burke	23	S. 65°–73° W.; S. 72° E.	S. 30°–40° W.
Dunn	23	S. 23° W.; S. 12°–23° E	S. 22° W.
Deerfield	28	S. 3°–29° E	S. 10° W.
Albion	2	S. 35° E	S. 15° W.
Aztalan	20	S. 40°–45° W	S. 22°–30° W.
Aztalan	6	S. 44° W	S. 12° W.
Milford		S. 60° W. [a]	S. 10°–30° W.
Sumner	18	S. 49°–64° W	S. 15° W.
Lima		S. 50° W. [a]	On rock exposed in a road cut through the end of a well-marked drumlin with trend nearly due south.

[a] Buell, Ira M., Bowlder trains from outcrops of the Waterloo quartzite area: Trans Wisconsin Acad. Sci., vol. 10, 1895, p. 494.



MAP SHOWING PLEISTOCENE DEPOSITS OF A PORTION OF SOUTHEASTERN WISCONSIN.

The occurrence of some of these striæ which have the more southwesterly trend has been cited as evidence of the advance of an ice sheet of an earlier stage of glaciation across this area. There is little doubt that the ice sheet which deposited the older drift outside the Wisconsin moraines, and which is shown by the trend of the striæ and the drumlins and by the composition of the drift to have moved in a southwesterly direction, really did cross this tract, which was later covered by the south end of the Green Bay Glacier; and in such an instance as that in the town of Lima, where striæ on a rock surface exposed beneath the very end of a drumlin diverged 50° from the trend of the overlying drumlin, there seems good ground for regarding the striations as the product of an earlier glacial advance. It should be noted, however, that in some instances the divergence is toward the southeast at points where the general direction of the flow of both the earlier and the later ice sheets was southwesterly. (See fig. 2, *J*.) At some exposures, also, there are crossing striæ bearing both to the southeast and to the southwest on the same surface, with no evidence that one set was older than the other. Probably most of the divergences noted could be explained as due to local deflections of the basal currents of the ice by the inequalities of the partially covered rock surface over which the later ice advanced. Some of these rock scorings may be the result of abrasion early in the advance, before the inequalities of the glacial bed were buried in the drift and before the formation of the adjacent drumlin was begun. In this region the directions of the glacial flow are much more truly shown by the drumlins than by the striæ, not only because of the greater abundance of opportunities of observation of the former, but also because of the evident closer conformity of the drumlins than of the striæ to a regular system of radial divergence. Investigators are sometimes disposed to magnify the importance of striæ in these heavily drift-covered regions as indicators of the directions of glacial flow, forgetting that rock exposures are comparatively rare, and that at such as do occur striæ are rarely seen continuous for more than a few yards, usually but a few inches or a few feet, at any one place.

On the other hand, the divergence of the drumlins from the regularity of the radial system of arrangement is rare. One instance occurs in the town of Farmington (secs. 15 and 22, T. 7 N., R. 15 E.), where the axis of one drumlin shows a divergence of 27° westward from the nearly meridional trend of the neighboring drumlins. (Fig. 2, *K*.) Another instance occurs northwest of Lake Kegonsa, in the town of Dunn (T. 6 N., R. 10 E.), 1½ miles northwest of one of the points indicated as showing striæ with an easterly deflection. At this place, which is on a pre-Glacial upland just west of the pre-Glacial valley of the Yahara River, one small drumlin has a trend

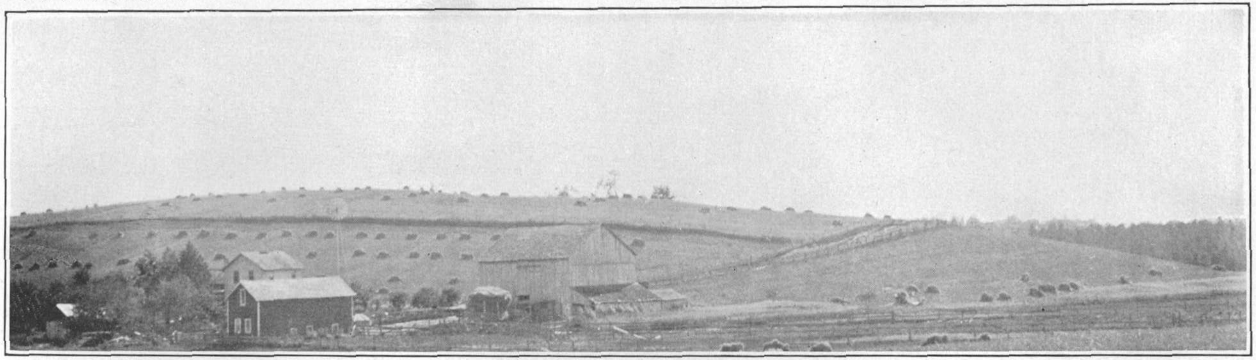
S. 5° E., while its neighbors on the southwest have a trend S. 22° W., which is normal for the locality.

RELATIONS TO TERMINAL MORAINES.

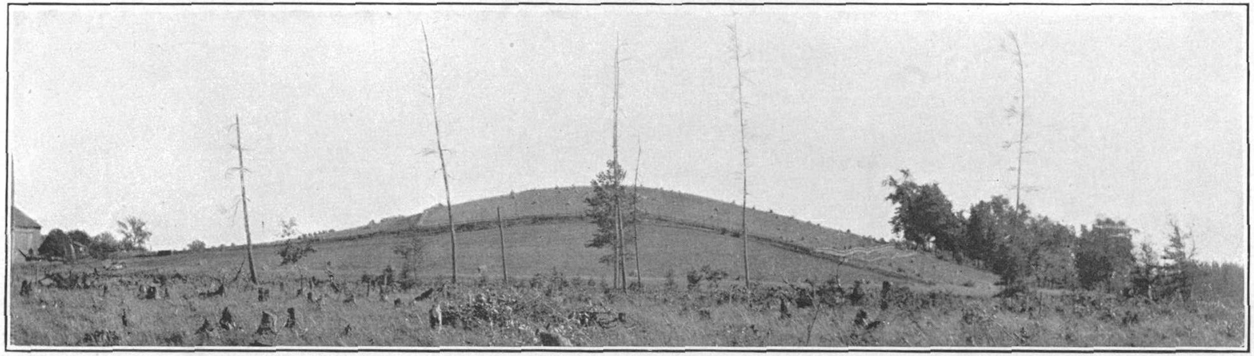
If we examine the relations of the drumlins to the outer terminal moraine, the Johnstown moraine, which marks the limit of the ice advance along the south and southwest margins of the Green Bay Glacier (Pl. I), it appears that the process of the drumlin construction was carried on to within distances of 6½ to 13½ miles—an average of 9 miles—of the limit of the advance as marked by the outer margin of the Johnstown moraine, and to an average of 7 miles from the inner margin of the moraine. On the east and the southeast, where the free deployment of the ice was prevented by the opposing front of the Lake Michigan Glacier, drumlins occur at distances varying from 1¼ to 7½ miles from the inner margin of the interlobate moraine, the average distance being about 5 miles. In this part of the lobe, in addition to the opposition to free advance offered by the Lake Michigan Glacier, the occurrence of a deep pre-Glacial trough excavated in the "Cincinnati shale"[a] and underlying formations, where the protecting cap of the "Niagara limestone" had been removed, and the enormous accumulations of morainal and outwash deposits through a belt 4 to 10 miles in width doubtless interfered with the normal development of drumlins and their continuance as unobscured features of the landscape.

The relations of the drumlins to the terminal moraine deposits formed during the several stages of halt of the ice front in the progress of final deglaciation of the area are shown in Pl. I, and more in detail in figs. 1 and 2. While no exposures have been found showing the actual superposition of morainal deposits on drumlins, the areal and topographic relations are such as to make it evident that the morainal deposits were superposed on a previously formed drumlin topography. Several instances occur where drumlin heads and considerable parts of the lengths have typical forms, but where the tails lose their identity, merging into morainal deposits with sag-and-swell or knob-and-kettle topography. About 2½ miles west of the village of Rome (sec. 14, T. 6 N., R. 14 E.), where the morainal belt is very slight, having a width of 40 rods to one-half mile, the tails of one or two drumlins are lost in the deposit, and the tails of two other small ones, otherwise almost completely buried, emerge at the south side of the belt, while a long, slender ridge 20 feet in height, barely 20 rods

[a] The names Niagara limestone, Lower Magnesian limestone, St. Peter sandstone, Huronian quartzite, Galena limestone, Trenton limestone, Cincinnati shale, Hamilton beds, and Potsdam are used in this paper in a strictly quotational sense, from the publications of the Wisconsin Geological Survey.



A. DRUMLIN 2 MILES WEST OF SULLIVAN, WIS., VIEWED FROM THE NORTHEAST.



B. TRANSVERSE PROFILE OF THE DRUMLIN SHOWN ABOVE, VIEWED FROM THE NORTH.

in width, sharp, distinct, and straight, emerges from the belt and tapers to a point 1 mile to the south (fig. 1, *C*). Either the head

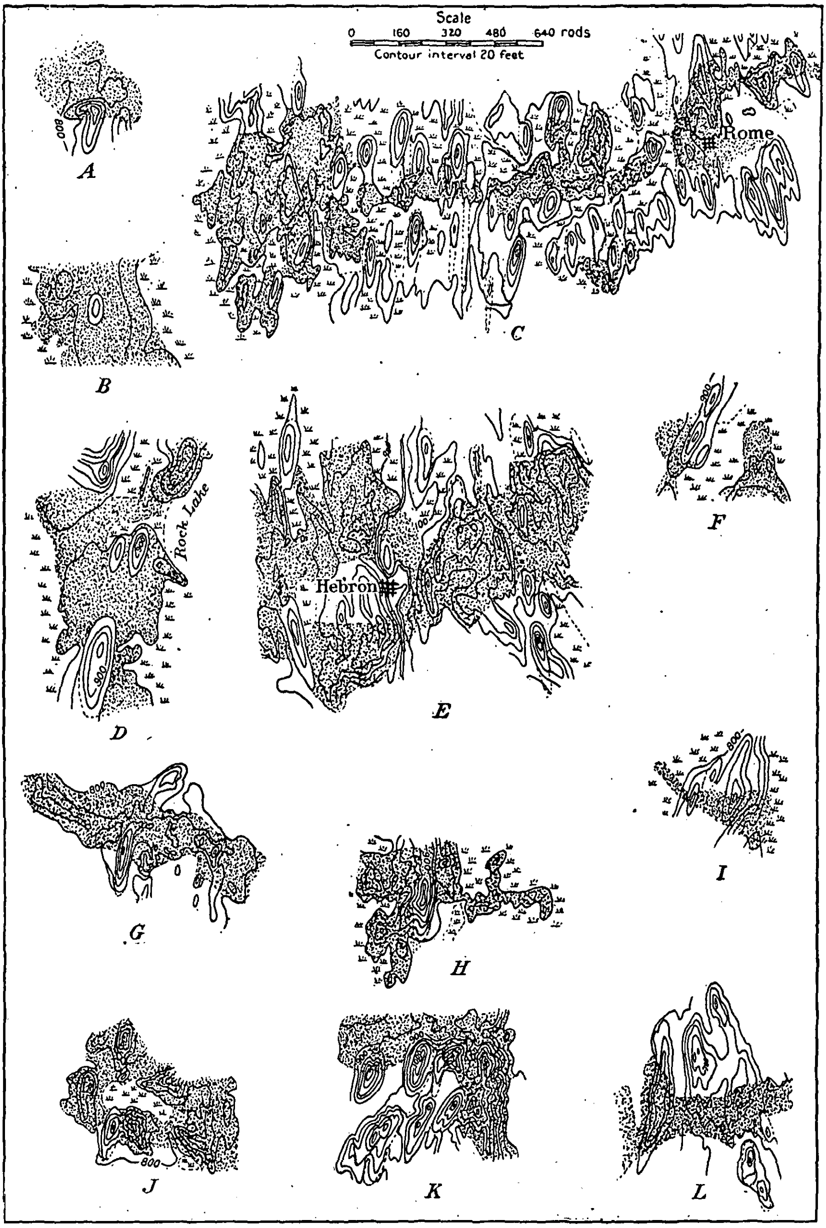


FIG. 1.—Relations of drumlins of the Green Bay Glacier to terminal moraine deposits formed during the final retreat of the ice front. Shaded areas represent morainal deposits. (Topography from maps of United States Geological Survey and notes of the writer.)

of this slender drumlin is the small hill directly opposite, at the north side of the morainal belt, or the head is buried. The moraine here is marked by a very gentle sag-and-swell topography. In the

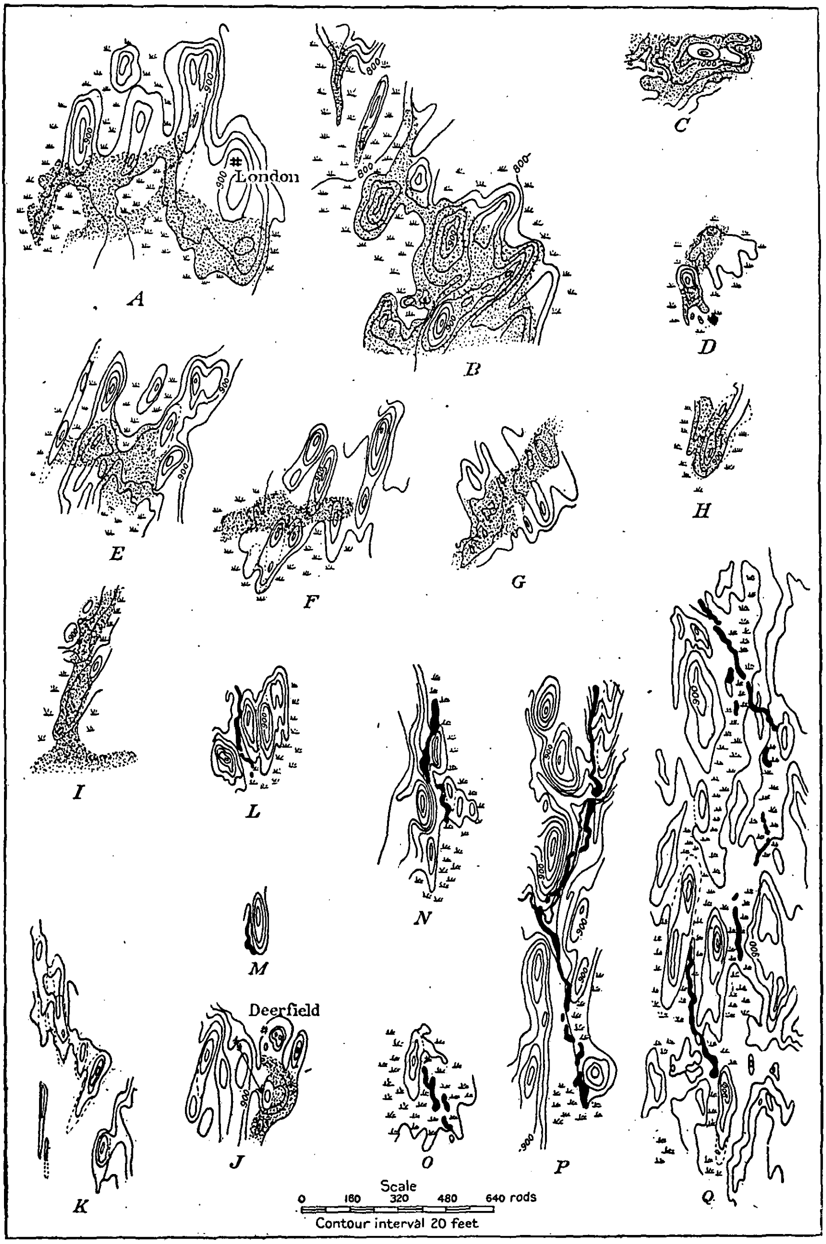


FIG. 2.—Relations of drumlins of the Green Bay Glacier to terminal moraine deposits formed during the final retreat of the ice front, relations of drumlins to eskers, and divergent drumlins and striæ. Shaded areas represent morainal deposits; heavy black lines, eskers; arrow shows trend of glacial striæ. Basal outlines of drumlins and divisions of crests are shown by broken lines where not adequately shown by contours. (Topography from maps of United States Geological Survey and from notes of the writer.)

northeast part of the city of Jefferson (fig. 1, *A*) a drumlin crest heads in a very abrupt hill, which curves around to the west, is somewhat irregular, and appears to be due to the piling of morainal deposits against the head of the drumlin. In the town of Oakland (T. 6 N., R. 13 E.) a well-formed drumlin, one of a group, merges at its head in the side slope of a great, irregular hill of morainal drift (fig. 1, *K*). At several places drumlins are entirely surrounded by morainal deposits, but retain their distinctive forms, and at some other places, as just east of the village of Hebron, a gentle sag-and-swell topography shows something of a drumloidal ridging, as though drumlins were covered by the morainal deposits, the resulting topography being of a rather mixed type.

In some cases hills having fairly good drumlin forms and the same trend as the adjacent drumlins are more or less irregular in detail, with undulating or slightly serrate crest lines and lobed and gullied slopes, and with the crests or slopes pitted with a few kettle holes. Examples of this occur west of the village of Waterloo (secs. 1 and 12, T. 8 N., R. 12 E.). They appear as having been modified from normal drumlins, probably in connection with the formation of the slight morainal belts with which they are associated.

RELATIONS TO ESKERS.

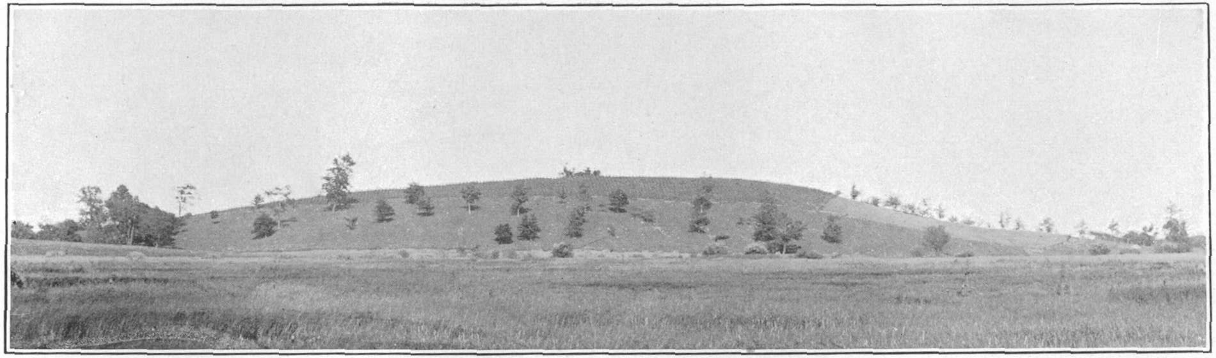
Several small eskers occur within the area, and their relations to the drumlins and the drumloidal ridges are illustrated in fig. 2, *L–Q*. From the disposition of these sinuous gravel ridges, generally in the low tracts between the drumlins and more or less parallel to their trend, it would appear that the drumloidal ridging was already accomplished before the initiation of the gravel-depositing streams and that the streams flowed sufficiently near the base of the ice for the moderate relief to control the directions of their flow. In no case within this area has an esker been seen crossing a drumlin. In some places eskers lie close to the side slopes of drumlins, swinging against the slopes and then away, so as to inclose kettle-like depressions. The only case in the drumlin tract where an esker-forming stream appears to have crossed a drift ridge is in section 6, Concord (fig. 2, *Q*), and here the relief of the ridge is but 20 or 25 feet. In some instances the eskers terminate at or near morainal deposits, suggesting that the streams were discharging from their ice channels or tunnels when the ice front was retreating from the drumlin tract.

DISTRIBUTION OF DRUMLINS RELATIVE TO THE PRE-GLACIAL TOPOGRAPHY AND TO THE GENERAL CONFIGURATION OF THE DRIFT SURFACE.

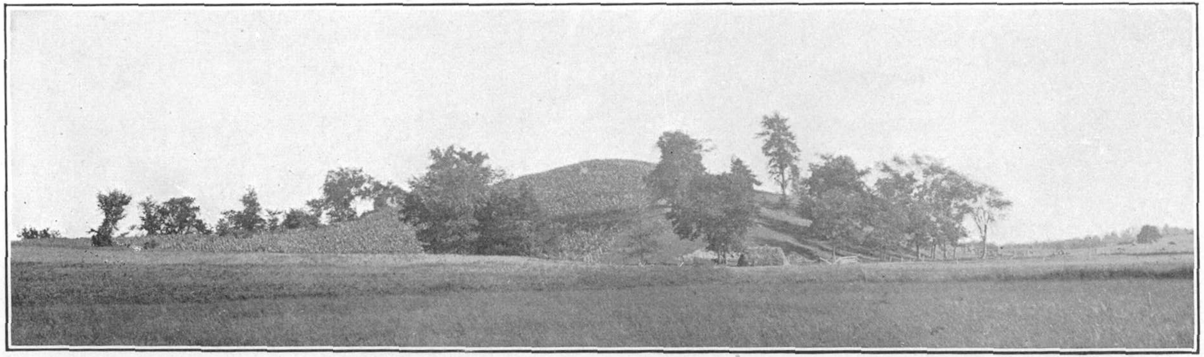
The effect of the pre-Glacial topography upon the distribution of the drumlins throughout the ground moraine is not altogether clear. The area is so heavily drift-covered that it is not always possible to determine the configuration of the underlying rock surface. However, by means of the correlation of the records of thousands of wells the main pre-Glacial valleys and uplands have been located. In the towns of Christiana (T. 6 N., R. 12 E.), Oakland (T. 6 N., R. 13 E.), Koshkonong (T. 5 N., R. 14 E.), Lima (T. 4 N., R. 14 E.), Hebron (T. 6 N., R. 15 E.), and Sullivan (T. 6 N., R. 16 E.), for example, there is considerable bunching of the drumlins over pre-Glacial highlands, the appearance of bunching being enhanced by their absence or scarcity over the adjacent pre-Glacial valleys. (Pl. I.) Drumlins are notably infrequent along the line of the pre-Glacial Rock River Valley from Lake Koshkonong northeastward in the towns of Koshkonong, Hebron, and Jefferson, and also through a broad belt, largely occupied by morainal deposits, which extends northward from Lake Koshkonong to the north limits of the area. The belt is largely, though not entirely, underlain by pre-Glacial troughs. On the other hand, in some places, as in the vicinity of McFarland (T. 6 N., R. 10 E.), drumlin groups extend over pre-Glacial uplands and buried valleys without distinction, and, again, in other places, as north of Lake Mendota, drumlins are absent or infrequent over tracts which were uplands of the pre-Glacial topography. It has not been apparent that the large features of the pre-Glacial topography—the drift-filled valleys and the drift-mantled uplands—had any very definite effect on the distribution of the drumlins of the last ice invasion, except, perhaps, that where the pre-Glacial valleys either were not filled by the drift of the earlier glaciers or were reopened by inter-Glacial erosion drumlins, if developed, were apt to be buried in subsequent fillings of morainal or outwash drift, lacustrine, or marsh deposits. Two miles east of Lake Kegonsa (T. 6 N., R. 11 E.) 5 or 6 small drumlins lie side by side on the crest of a narrow transverse ridge of rock, like packs on the back of a mule.

So far as has been noted, the influence of the several rock formations—the limestones, sandstones, shale, and quartzite of the area—on the formation and distribution of the drumlins is manifested indirectly through the pre-Glacial topography, whose features depend in large measure on the character of the rock from which they are carved.

There are no great reliefs in the drumlin tract; the drumlins themselves very largely constitute whatever variation there is to the gently undulating plain. There are, however, moderate elevations, with slopes in various directions. The relations of the drumlins to these larger features of the topography, though sometimes interesting, do not appear vital to the question of drumlin formation. Drumlins occur indiscriminately on the tops, banked against the stoss slopes or tailing down the declivities in the lee. Where lying on the stoss



A. DRUMLIN ABOUT 2 MILES NORTH OF SULLIVAN, WIS., VIEWED FROM THE WEST.



B. TRANSVERSE PROFILE OF DRUMLIN SHOWN ABOVE, VIEWED FROM THE NORTH.

slopes, the tails sometimes merge indefinitely with the undulations of the uplands. A notable example of this occurs southeast of Waukesha, in the towns of New Berlin (T. 6 N., R. 20 E.) and Muskego (T. 5 N., R. 20 E.), in the ground moraine of the Lake Michigan Glacier, where the troughs between several large ridges of drift, which have a drumloidal trend, shallow at distances of one-half to 1 mile from the heads of the ridges, causing the ridges to merge into one continuous upland, whose gentle undulations show the same southwesterly trend, but where well-marked drumlins are absent. It is as though the edge of the upland itself was fluted by the ice as it moved up over the elevated tract. At this particular place, however, there are some small morainal deposits, which tend to obscure the relations to a certain extent.

Not infrequently drumlins occur on or banked against lateral slopes, making the uphill slopes short and the downhill slopes abnormally long, thus distorting the basal outlines of what may otherwise be symmetrical forms.

DISTRIBUTION OF DRUMLINS RELATIVE TO ONE ANOTHER.

The most common arrangement of the drumlins, where grouped, is with their longer axes overlapping side by side; or, if not actually overlapping, the axes are rarely in perfect alignment, being either side by side or tandem. Usually as one drumlin begins to tail out the head slope of another rises at one side or the other. These neighboring drumlins are generally separated by distances greater than the shorter axes, but sometimes several may be closely dovetailed together, though entirely distinct. As the drumlin-forming ice at one point was closing about the tail of one individual, it was spreading and riding up over the head of a close-by neighbor. Where so closely crowded that the side slopes coalesce, these overlapping groups grade into the elongated ridges with overlapping crests, described under "Forms of drumlins," p. 22. A notable instance of overlap is seen 1 mile northwest of the village of McFarland (sec. 34, T. 7 N., R. 10 E.), where the slender tail of a small drumlin lies like a terrace for 40 rods along the lower slope of a neighbor, tapering to a sharp point, while the abrupt head slope at its side rises 30 feet or more to the finely shaped crest of the succeeding drumlin. Occasionally this overlapping arrangement is shown by more or less distinctly formed crests on a ridge lying obliquely to the direction of the glacial movement, as though they had been carved from the ridge of drift and the positions of successive overlaps were due to the oblique position of the initial drift ridge. Where drumlins are so closely set side by side that their lateral slopes coalesce, they pass by gradations from twins and triplets to double- and triple-crested forms, elsewhere discussed. An occasional arrangement is of a tiny drumlin close beside a large one, like the young beside the mother. (Fig. 6, *A–E*.) Rarely two or more drumlins are arranged tandem with their axes in almost perfect alignment.

FORMS OF DRUMLINS.

From the limited discussions of class room and text-book, students are apt to get the notion that drumlins are always sharply defined, easily recognizable forms, whose contours vary within but narrow limits. As a matter of fact, however, there is considerable variety of form and dimensions, with all gradations from the beautifully symmetrical, typical forms to drift hills of indefinite shape or orientation. So closely are they related and so thoroughly intermingled that it is very largely a matter of the judgment of the individual worker in the field as to which ones shall be mapped as drumlins and what shall be regarded as mere undulations of the ground moraine. So far is this true that the maps of no two independent workers in the drumlin areas would be just alike; indeed, the maps of the same worker are apt to show the effects of changes of opinion resulting from successive visits to the drumlin area. Such a map as that reproduced in Pl. I, where, in the main, only the more perfect and clearly marked drumlins are shown, tells but a part of the story. Intermingled throughout the area in which have been selected hills worthy of definite representation as drumlins are hills and ridges of drift showing the drumloidal trend more or less clearly, and often but a few degrees less symmetrical in form and outline than many of their neighbors that are admitted to the class. To appreciate the drumlin-making forces one must have a carefully sketched topographic map of considerable detail and small contour intervals, drawn by a topographer who is at the same time a student of physiography. Such a map would show something of the thoroughness with which the spreading ice lobe recorded the details of its movement on the forms of its ground-moraine deposits.

We may regard as a typical drumlin a hill of glacial drift which approximates the form of a segment of an elongated ovoid, of which the widest part of the basal outline and the highest point of the crest are not more distant from the stoss end than one-third the length of the major axis, and whose major axis is oriented parallel to the direction of the movement of the glacier which formed it. Though by far the larger part of the drumlins of the Green Bay Glacier within the area under consideration are variations of this type, individual drumlins conforming closely to the type are not infrequently seen in different sizes and heights scattered throughout the drumlin tract. (Pls. II–VI.) This is true especially if we consider the contours somewhat above the foot of the slopes, as the unevenness of the surrounding surface or the spreading out of the lower slopes not infrequently gives to a form, otherwise nearly perfect, a basal outline which is sometimes distorted as traced on the map. There are many drumlins which have beautifully regular crest lines and contours, and the symmetrical appearance is still more striking where the intervening low areas are occupied by nearly continuous marshes, giving the drumlins the appearance of rising abruptly from a uniform base. Doubtless this uniformity of base is more apparent than real, inasmuch as the marshes contain deposits of peat and muck which vary considerably in depth. Since the marsh levels were developed subsequent to the formation of the drumlins, by the blocking of the lines of drainage by the transverse belts of the terminal moraine deposits formed during the stage of glacial wastage, there appears to be no reason for regarding the basal plain on which these drumlins were formed as any more uniform in character than in the higher parts of the area, where the marshes do not occur.

In figs. 3 and 4 are illustrated 91 variations in size, form, and height of the simple, single-crested drumlin. The contours are copied from the topographic sheets of the United States Geological Survey, with some modifications from the field notes of the writer. The contour interval is 20 feet, and, where necessary, dotted lines are added to show the basal outlines of the hills. The forms would be much better shown were the contour interval 5 or 10 feet instead of 20. The variations are from small elliptical mounds of drift having the forms and axial orientations of true drumlins, but only 5 or 10 feet in height and a few rods in length, to hills 140 feet in height and ridges 2 miles in length. The ratio of width to length varies from 1:2 to about 1:19. There appear to be no fixed ratios between any of the dimensions, and it would be difficult to determine the average of these various forms. The most common heights are 30 to 60 feet. Three of the highest forms occur in Windsor (sec. 34, T. 9 N., R. 10 E.), 1½ miles east of McFarland (sec. 36, T. 7 N., R. 10 E.,) (Pl. IV, *B*, and Pl. V, *A*), and 3 miles east of Stoughton (sec. 2, T. 5 N., R. 11 E.). These have lengths of two-fifths to one-half mile, widths two-fifths to one-half the lengths, and heights of 100 to 140 feet.

The lengths of the drumlins are extremely variable within the limits indicated. An average would probably be somewhat less than a mile, perhaps one-half to three-fourths of a mile. As will be seen by the map (Pl. I), there is a notable lengthening of the drumlins toward the axis of motion in the lobe, as though in some way related to the greater vigor of flow there than elsewhere. These long forms are especially abundant in the region of Watertown and Johnson

Creek, and where they lie closely side by side, with differences of 40

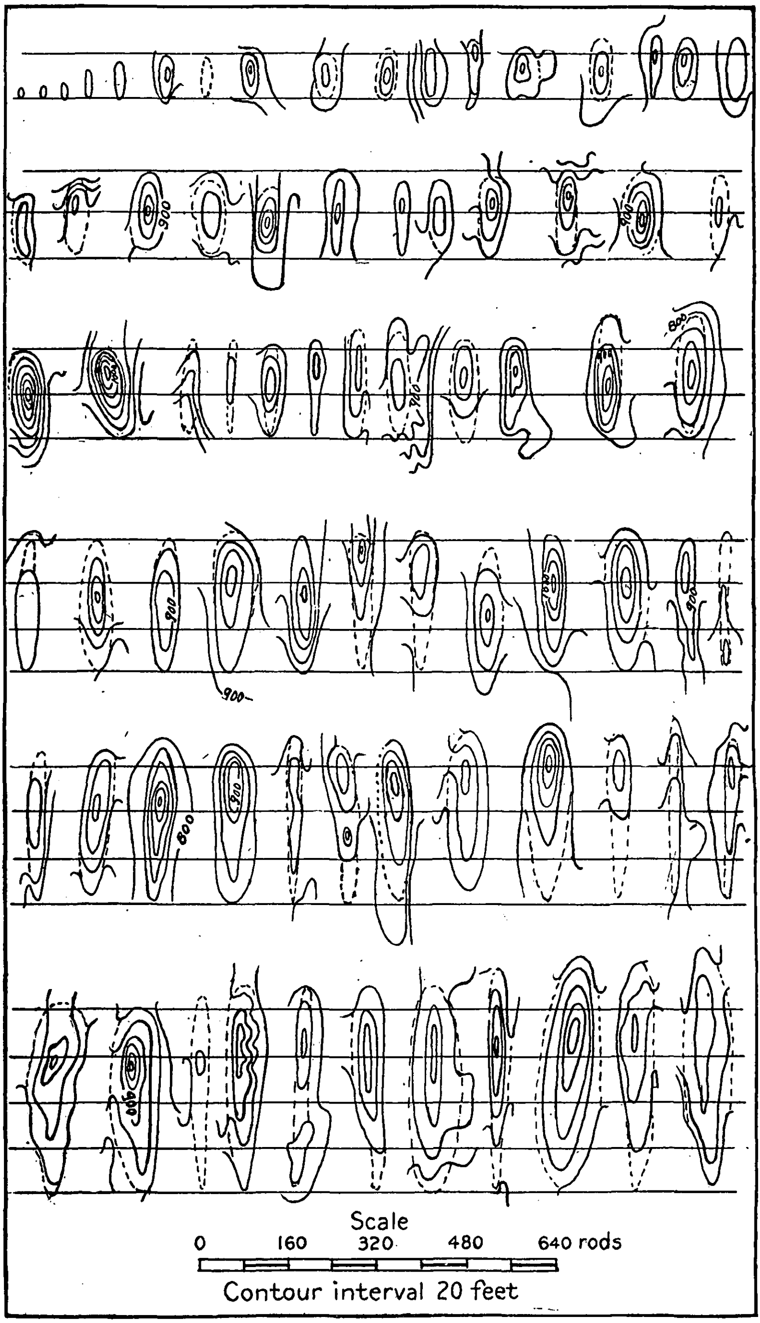
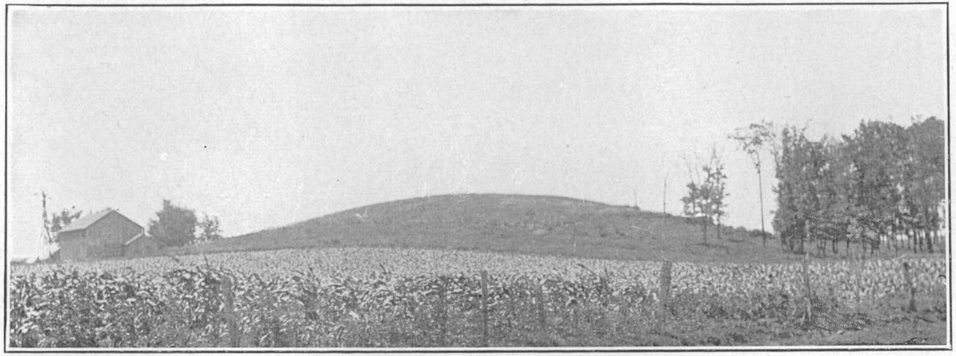


FIG. 3.—Variations in forms and sizes of drumlins of the Green Bay Glacier. Outlines of drumlin bases are shown by broken lines where not shown by contours. (From topographic maps of United States Geological Survey and notes of the writer.)

to 80 feet between the crests and the bottoms of the intervening



A. TRANSVERSE PROFILE OF A DRUMLIN 5 MILES SOUTHEAST OF STOUGHTON, WIS., VIEWED FROM THE NORTH.

B. DRUMLIN 2 MILES NORTHEAST OF McFARLAND, WIS., VIEWED FROM THE WEST troughs, the resulting topography is very striking. These elongated

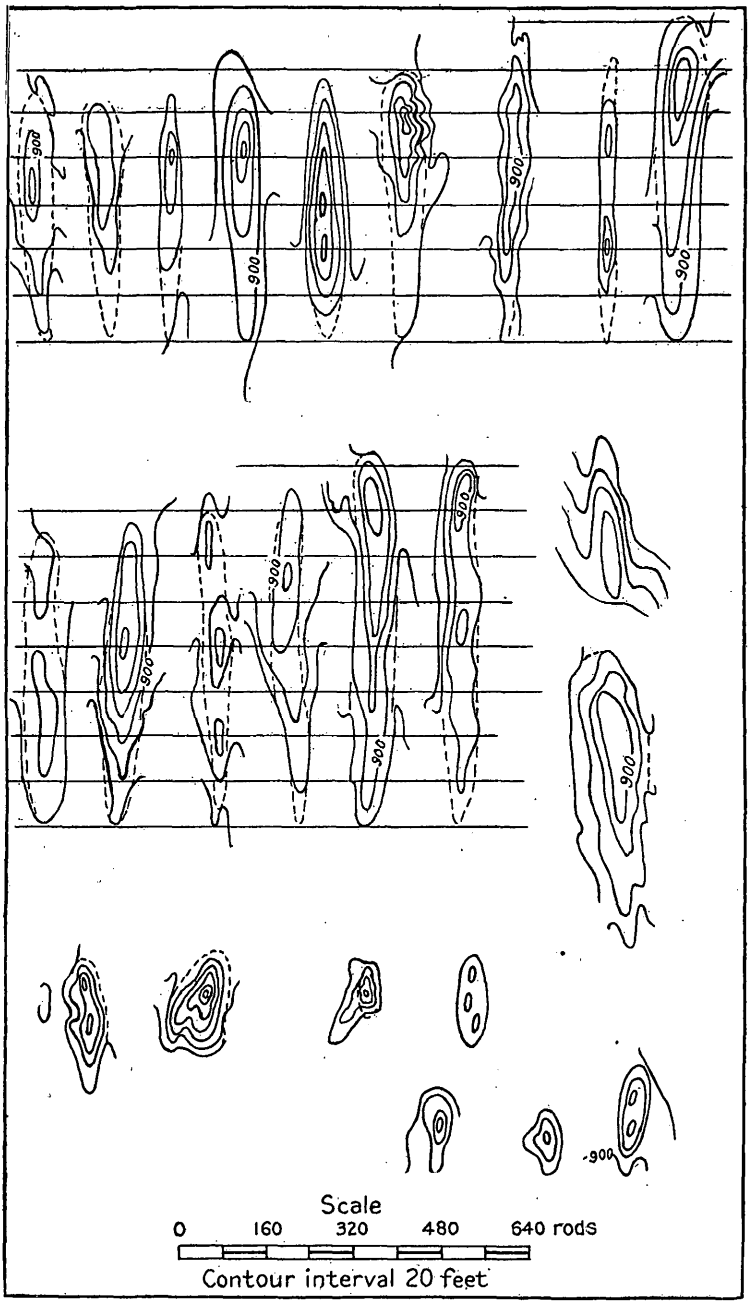


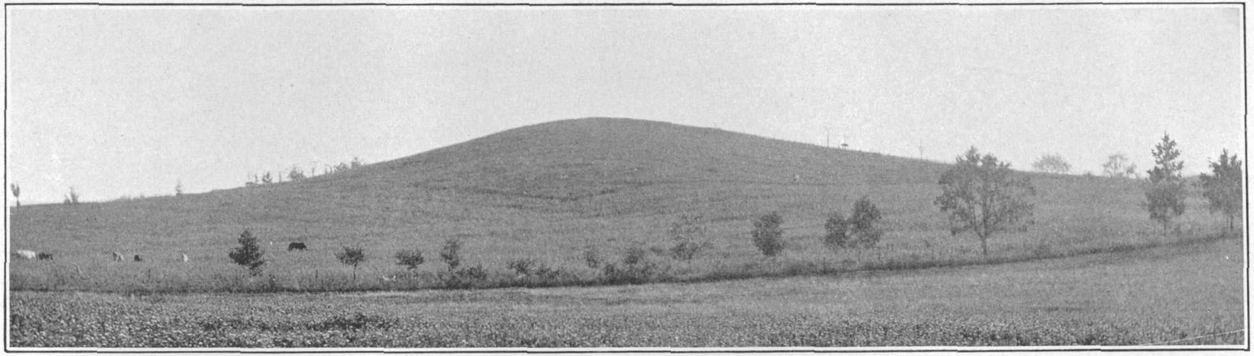
FIG. 4.—Variations in forms and sizes of drumlins of the Green Bay Glacier. Outlines of drumlin bases are shown by broken lines where not shown by contours. (From topographic maps of United States Geological Survey and notes of the writer.)

drumlins have heads of the ordinary form, the stoss slopes rising steeply to the highest points of the crest lines, which are frequently not more than 80 to 100 rods from the north ends. The tails, however, are drawn out to great lengths, frequently more than a mile, sometimes nearly 2 miles. The major axes are usually straight, and the side slopes are remarkably regular. Frequently they appear much more regular to the eye than is indicated by the contours on the maps. Some of the smaller of the long forms are remarkably symmetrical and slender, like half torpedoes or cigars, the tails tapering to points. Occasionally the crest line sags and a second high point occurs midway of the length. Rarely the normal form is reversed, the stoss end being narrower and its slopes more gradual than the lee.

The variations of the normal form are numerous. Sometimes the side slopes are lobed. Sometimes on surmounting what appears to be the head of a normal drumlin the crest is seen to divide, the drumlin having two more or less distinct tails. (Fig 5, *A*–*H*.) Examples of this double-tailed form occur 1 mile southeast of the village of Johnson Creek and 1 mile east of the village of Rome.

Sometimes the crest is divided throughout its length, or, in other words, the hill has a double crest. The sag between these crests may be but 5 or 10 feet in depth, or it may divide the hill in two (fig. 5), resulting in twin forms. An excellent example of the double-crested form occurs 80 rods northwest of the village of McFarland (fig. 5, *S*). Viewed from the east this hill, which is 60 feet in height, presents one of the most beautiful longitudinal drumlin profiles of the whole area (Pl. V, *B*), but viewed from the south the ridge is seen to be about as broad as long and to be marked by two crests with a sag 20 or 30 feet in depth (Pl. VI, *A*). Just south of this is a still broader ridge with three distinct crests. (Pl. VI, *B*, and fig. 5, *U*.) One and one-half miles southwest of the village of Rome three crests mark more nearly separate triplets. (Fig. 5, *V*.) In all these cases the view from the side shows the longitudinal profile of a simple drumlin, but a view from the end suggests that a ridge of drift lying transverse to the direction of glacial motion was overridden and but partially molded to the form of distinct drumlins.

What may be regarded as a modification of the double-crested forms occurs when one of the crests lags behind the other. (Fig. 6.) The crests may overlap more than half their lengths, or they may be drawn out more and more into elongated ridges with two or more distinct crests slightly out of alignment. Sometimes the lateral shift midway in the length of the ridge is very slight, one crest tailing out as a new one is gradually developed at its side. The sag separating the crests may be very slight, barely enough to distinguish them, or it may be 20 to 30 feet in depth. There are a number of these forms with overlapping crests, and most, though not all of them, occur in



A. TRANSVERSE PROFILE OF DRUMLIN SHOWN IN PLATE IV, *B*, VIEWED FROM THE NORTHEAST.

B. LONGITUDINAL PROFILE OF A DOUBLE-CRESTED DRUMLIN AT McFARLAND, WIS., VIEWED FROM THE EAST.

the region of Watertown and Johnson Creek, with the elongated

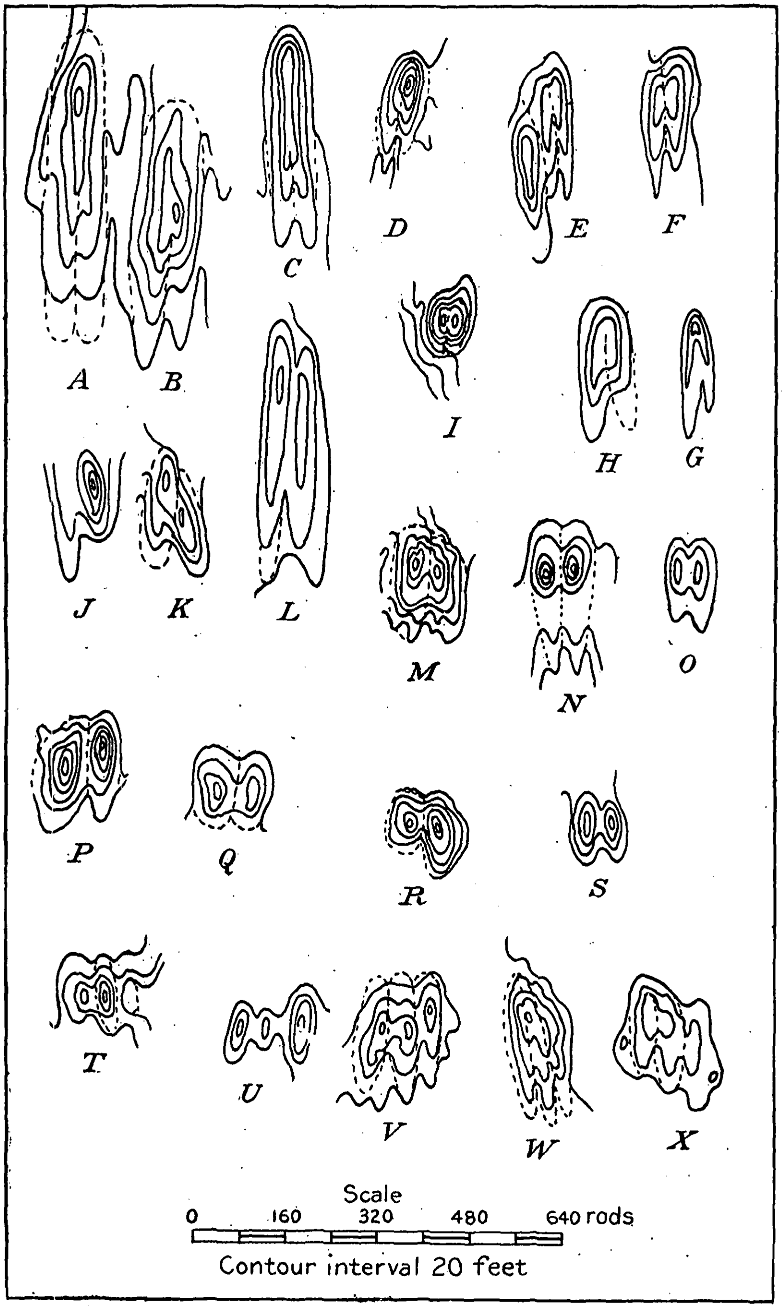


FIG. 5.—Double-tailed, double- and triple-crested drumlins, and drumlin twins and triplets. Outlines of drumlin bases and division of crests are shown by broken lines where not shown by contours. (From topographic maps of United States Geological Survey and notes of writer.)

drumlin forms. By means of these overlapping crests even greater lengths are obtained than in the simple forms. Sometimes three or

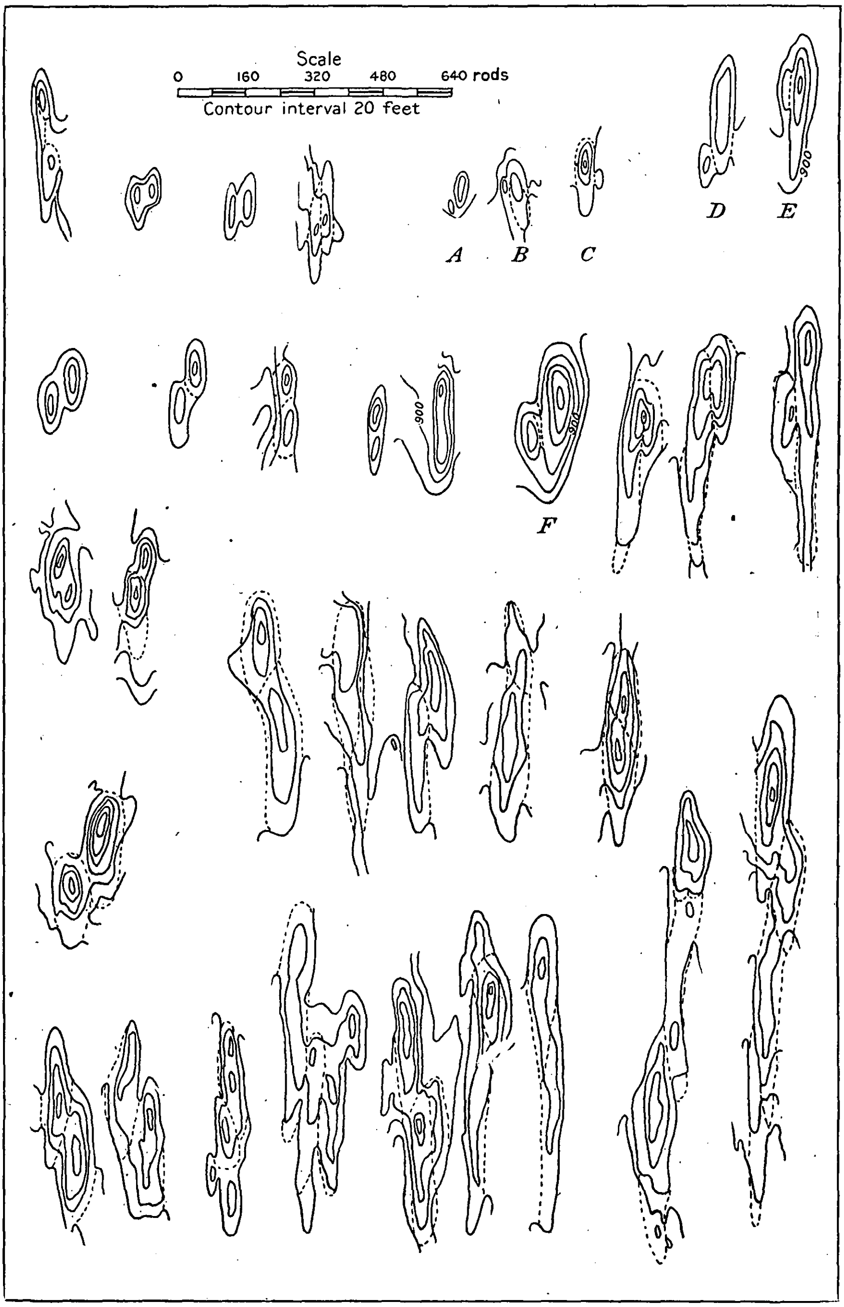
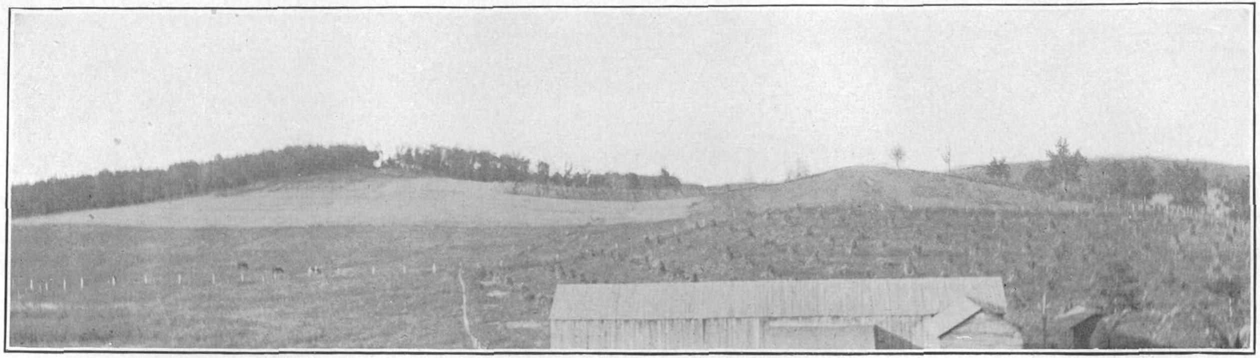


FIG. 6.—Association of large and small drumlins and development of overlapping crests on elongated drumloidal ridges. Basal outlines and division of crests shown by broken lines where not adequately shown by contours. (Topography from maps of United States Geological Survey and notes by the writer.)

four crests are combined in this way and the ridges are drawn out to



A. TRANSVERSE PROFILE OF DOUBLE-CRESTED DRUMLIN SHOWN IN PLATE V, *B*, VIEWED FROM THE SOUTH.

B. TRANSVERSE PROFILE OF A TRIPLE-CRESTED DRUMLIN AT McFARLAND, WIS., VIEWED FROM THE SOUTH.

lengths of 2 to 4 miles. Not infrequently there are in these variations of form strong suggestions that some at least of the drumlins may have resulted from the erosion of previously formed drift accumulations.

STRUCTURE OF DRUMLINS.

A question that arises concerning the structure and mode of formation of drumlins is, Are the drumlins built up on rock cores? In order to obtain data bearing upon this important question, considerable pains have been taken to collect and to correlate the records of hundreds of wells on the crests, on the slopes, and in the immediate vicinity of the drumlins. The information was obtained very largely from the owners, sometimes from neighbors, and sometimes from drillers. While the data can not, of course, be regarded as uniformly reliable, yet on the one point of depth to rock there is generally reasonable certainty, and only those records regarded as good have been used. The drumlins on which the wells are situated include all sizes and forms; 41 were 10 to 25 feet high, 69 had heights ranging from 25 to 50 feet, and in 43 the crests stood 50 to 100 feet above the bases. Of the wells on 158 drumlins 37 were on the crests near the heads, 46 near the middles, 61 on the tails, and 24 were on the side slopes.

The results obtained from the correlation of the well records are summarized in the following tables, which include also data concerning a few drumlins of the Lake Michigan Glacier and a few of the pre-Wisconsin drift.

TABLE 1.—*Showing thickness of drift below the bases of drumlins in the cases where the wells do not reach rock.*

Number of wells which penetrated to the level of the drumlin bases	3
Number of wells which penetrated to depths of 5 to 25 feet below the drumlin bases	9
Number of wells which penetrated to depths of 25 to 50 feet below the drumlin bases	20
Number of wells which penetrated to depths of 50 to 100 feet below the drumlin bases	12
Number of wells which penetrated to depths of 100 to 240 feet below the drumlin bases	4

The following table shows the relation in the cases in which wells drilled on drumlins encountered rock:

TABLE 2.—*Showing depths to rock from the bases of the drumlins.*

Number of wells which encountered rock at elevations 5 to 25 feet above the bases of the drumlins	4
Number of wells which encountered rock approximately on a level with the drumlin bases	13
Number of wells which encountered rock at depths of 5 to 25 feet below the bases of the drumlins	39

Number of wells which encountered rock at depths of 25 to 50 feet below the bases of the drumlins	47
Number of wells which encountered rock at depths of 50 to 100 feet below the bases of the drumlins	16
Number of wells which encountered rock at depths of 100 to 290 feet below the bases of the drumlins	4

By far the larger part of the drumlins, however, have no wells on their crests or slopes, and concerning many wells which do exist no information was obtained. A large amount of data has been collected concerning wells in the immediate vicinity of drumlins which, while not determining the presence or absence of rock cores, contributes considerable to the probabilities in the case by indicating the general thickness of the drift about the drumlin bases. For this determination we have the records of more than 300 wells almost all within 80 rods of some one or more of about 350 drumlins. Many of them are at or near the foot of the slopes. It is difficult to give any satisfactory summary of this mass of data because of the greatly varying conditions, but such summaries as have been made are presented in the following tables:

TABLE 3.—*Showing the depths to rock in the vicinity of drumlins.*

Number of drumlins in whose vicinities wells show 5 to 25 feet of drift over rock	67
Number of drumlins in whose vicinities wells show 25 to 50 feet of drift over rock	63
Number of drumlins in whose vicinities wells show 50 to 100 feet of drift over rock	46
Number of drumlins in whose vicinities wells show 100 to 300 feet of drift over rock	10

TABLE 4.—*Showing the thickness of drift in the vicinity of drumlins.*

Number of drumlins in whose vicinities wells penetrated 20 to 50 feet of drift without reaching rock	25
Number of drumlins in whose vicinities wells penetrated 50 to 100 feet of drift without reaching rock	29
Number of drumlins in whose vicinities wells penetrated 100 to 300 feet of drift without reaching rock	24

In numerous cases wells show considerable variability in the elevation of the underlying rock surface in the immediate vicinity of drumlins. This is indicated by the following data:

TABLE 5.—*Showing variations of the rock surface in the vicinity of drumlins.*

Number of drumlins in whose vicinities wells show the depth to rock to vary between 0 and 50 feet	27
Number of drumlins in whose vicinities wells show the depth to rock to vary between 0 and 100 feet	17
Number of drumlins in whose vicinities wells show the depth to rock to vary between 0 and 280 feet	10

In addition to these there are numerous cases in which rock is exposed within distances of 80 rods from the bases of drumlins, though there is nothing indicating the presence of rock cores. These outcrops occur in all directions from the drumlins and, in numerous cases, close to the drumlin bases. The following are the instances noted:

TABLE 6.—*Showing drumlins near rock outcrops.*

Number of drumlins of the Green Bay Glacier within 80 rods of which occur outcrops of rock	60
Number of drumlins of the Lake Michigan Glacier within 80 rods of which occur outcrops of rock	5
Number of drumlins of the pre-Wisconsin drift within 80 rods of which occur outcrops of rock	5

While in 17 cases there was evidence that rock lay as high as the drumlin bases or rose beneath the hills to heights of 5 to 25 feet, and in 70 other cases the rock rose to the surface in the immediate vicinity of drumlins, with no evidence as to how it lay beneath the hills, yet there would seem to be little question, from the mass of evidence presented, that in by far the larger number of instances concerning which any evidence at all was secured the formation of the drumlins must have been entirely independent of the elevation or configuration of the rock surface beneath.

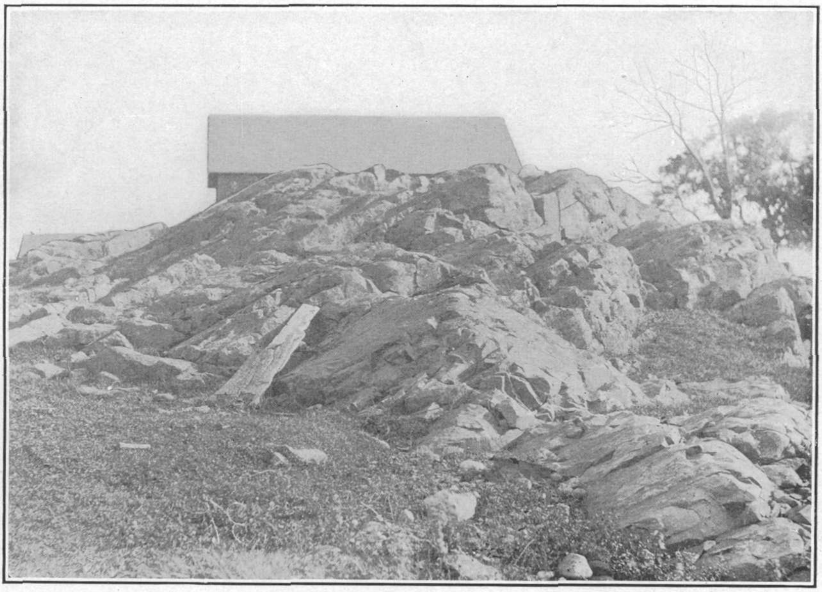
There are a very few hills having the general drumlin forms where the drift appears but to mantle rock hills. One instance of this class of veneered hills occurs on the town line 3 miles south of Madison and about 80 rods west of the Chicago and Northwestern Railway. Here limestone is exposed in the stoss slope. A few other thinly veneered hills of drumloidal form occur in the region north and northeast of Lake Mendota. A well on the stoss slope of a drumloidal hill 1 mile northeast of the village of McFarland shows but 5 feet of drift mantling the rock surface. About 4 miles southwest of the village of Cambridge (sec. 27, T. 6 N., R. 12 E.) there is an abrupt drumlin, slightly lobed on one side, within 40 rods of two low knolls of limestone. It would not be strange if a similar knoll underlies the drift of the drumlin. As there is no well on the hill, however, the presence or absence of a rock core could not be determined.

On the other side of this question it may be noted that there are some ledges or knolls of rock which, it would seem, would have formed excellent nuclei on which to have built up drumlins, if this was the mode of their formation, but which are now barely covered with drift. One of these is a ledge of quartzite in Portland (sec. 35, T. 9 N., R. 13 E.), about 5 miles northeast of the village of Waterloo. As will be seen in Pl. VII, *B*, the strata dip eastward at angles of 22° to 28°, presenting the edge of the strata to the ice. This ledge, which rises 15 feet above the adjacent marsh, was a source of derivation of drift rather than a nucleus for its accumulation. Being closely cut by cross fractures, it afforded an excellent opportunity for plucking, and a large amount of bowlder material appears to have been derived therefrom. Tailing out several rods in the lee of this ledge, until lost in the marsh, is a ridge or train of bowlders apparently almost entirely derived from the ledge itself (Pl. VII, *A*), but as a cause of lodgment and accumulation of the drift brought to it in the base of the ice, for which it would appear excellently adapted, this ledge was an almost total failure. While it is, of course, impossible to determine the various reasons for this condition, the occurrence of so admirable a nucleus without any drumlin, while so many drumlins occur in this region without rock nuclei, has a very suggestive bearing on the question of drumlin formation. It may be said that there is here in the bowlder tail itself an excellent example of drumlin formation in an early stage; and this is a suggestion not to be neglected. Yet while this nucleus was accumulating its tail, other drumlins in the vicinity, with no rock nuclei, matured in form with reliefs of 60 to 100 feet or more.

Certain other features in the vicinity of the Portland quartzite ledges which might have served as nuclei for drumlins are low mounds of bowlders. One of these is about 500 feet long, 160 feet wide, and 16 feet in height above the marsh which borders it on the west. So far as can be seen from the surface, this appears to be composed entirely of quartzite bowlders from the adjacent ledges and from the island ledge one-half to three-fourths of a mile northeastward. The major axis has the drumlin trend, and the north end resembles the head of a small drumlin. It might, perhaps, be regarded as a drumlin in the early stage of development. Whether it has a rock core could not be determined, but 10 rods east naked quartzite ledges rise 15 feet higher than this bowlder mound. It should, perhaps, be noted that this and neighboring mounds of similar character and the adjacent quartzite ledges occur at the side of a considerable drift-filled pre-Glacial valley, a position not especially adapted to the formation of drumlins. Some of these quartzite ledges are only partially covered with drift, and roches moutonnées are finely developed.

In the collection of well data the depths to rock have been quite satisfactorily determined, but efforts to learn with any degree of accuracy the character of the drift penetrated in farm wells met with much less success, so that for a knowledge of the structure of the drumlins one is limited almost entirely to the exposures afforded by wagon-road and railroad cuts and other excavations. Nowhere has a complete section through the middle of a drumlin been found. Though the roads are generally straight over hill and valley, it is rare that cuts are more than 15 to 20 feet in depth. Frequently, also, in

A. LEDGE OF QUARTZITE 4 MILES NORTHEAST OF WATERLOO, WIS., VIEWED FROM THE WEST.



B. LEDGE OF QUARTZITE SHOWN ABOVE, VIEWED FROM THE NORTH.

such cuts as do occur the structure is more or less obscured by vegetation, surface wash, and sliding in such a manner that it can not easily be cleaned off. It is therefore not possible to present wholly satisfactory data concerning the structure of the drumlins. Such observations as have been made, however, are presented. Seventy cuts varying in depth from 5 to 60 feet have been examined. In 47 of these cuts the material exposed was structureless till of the character common to the area. The matrix of this till varies in character from dense, solid clay to very sandy clay, the more sandy clay occurring in those parts where the sandstones made large contributions to the drift. One feature of the matrix of the till seen in many of these cuts, and also of the till in parts of those cuts where stratified beds occur, is a more or less definite cleavage of the clay. Under the side slopes of the drumlins these lines of cleavage lie parallel to the sloping surfaces. This cleavage manifests itself in faint lines—not lines of bedding—along which the clay breaks down, in digging, into more or less definite laminæ. Where a stone occurs the lines below curve downward and up behind the stone, concentric with its surface. Those meeting the stone medially end, and those near the top have a slight tendency to curve upward over the stone, though less definitely than the downward curve of those below. Where another stone occurs close above the first the cleavage is apt to be well developed between the two. This cleavage is best shown where the material is rather fine, stoneless clay, less so where the clay is coarse, and it is scarcely noticeable where the clay is very sandy. It has the appearance of being due to pressure, possibly that of the overriding ice. In some places the cleavage planes are accentuated by the deposition of a whitish coating of lime by percolating waters. The view shown in Pl. VIII, *B*, was taken in Shields (sec. 21, T. 9 N., R. 14 E.) near the side slope of a drumlin 100 feet in height, in a 35-foot transverse cut, about 80 rods from the north end. In the deepest part of the cut the cleavage was seen, but less distinctly. This cleavage has been observed in a dozen or more drumlins, but it is very readily overlooked unless one has it especially in mind when the examination is made. It is very readily obscured by surface wash, and doubtless it is much more generally present than the observations would indicate. It is not confined to drumlin sections, but has been observed in cuts elsewhere in the ground moraine.

STRATIFIED BEDS IN DRUMLIN SECTIONS.

In 19 of the cuts examined more or less of stratification appeared. Frequently this amounted to no more than a bed of sand or sandy clay running partly through the section. Frequently patches of stratified sands and gravels occur in the till, sometimes showing cross-bedding. These usually grade laterally and vertically into the till, which in all the cuts constitutes the bulk of the material exposed.

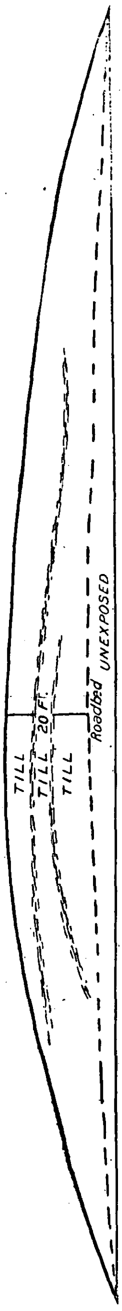


Fig. 7.—Transverse section of drumlin 2½ miles northwest of Johnson Creek, Wis.

The relations of the stratified beds in a few cases may be mentioned. One instance is the structure exhibited by a 25-foot cut through a drumlin one-half mile south of the village of Windsor (sec. 29, T. 9 N., R. 10 E.). This drumlin has a length of one-fourth of a mile, a width of 100 yards, and a height of 40 feet. The road runs diagonally across the hill at a distance from the head equal to one-third of the length. The lower 15 feet of the exposure afforded by the cut is of stratified material, largely of fine sand, with included thin layers of gravel; this grades upward into rather coarse gravel. Overlying the stratified drift is about 10 feet of till with a matrix of sandy clay in which the cleavage is well developed.

About 5½ miles north of Edgerton (T. 5 N., R. 12 E.) there is a gravel pit in the crest of a small drumlin, which is developed on the east slope of a broad ridge. At the top is a layer of till which, from a thickness of 4 feet near the crest, diminishes to 0 on the side slope. Beneath this is 2 to 5 feet of fine to 3-inch gravel. The gravel beds do not have the curve of the drumlin slope, but are cut across by the side slope. Beneath the gravel is 1 to 3 feet of cross-bedded sand.

In a few cases the stratified beds lie in curves more or less concentric with the surface of the drumlins. The best illustration of this was seen in a cut through a small drumlin about 2½ miles northwest of the village of Johnson Creek (SE. ¼ sec. 3, T. 7 N., R. 14 E.). The drumlin has a length of about three-eighths of a mile, a width of 20 rods, and a height of 30 to 35 feet. The road crosses the hill about 120 rods from the north end, through a cut 20 feet in depth. The structure is represented diagrammatically in fig. 7. The greater part of the material exposed is buff stony till with sandy clay matrix. About 7 feet below the crest is a definite bed, somewhat less than 1 foot in thickness, and lying in a curve approximately concentric with the curve of the drumlin crest. At the east side this bed runs out nearly to the surface of the side slope; at the west

A. CONTORTED BEDS OF STRATIFIED CLAY AND SAND.

Exposed in a road cut through a drumlin 1½ miles east of Hebron, Wis.

B. ROAD CUT THROUGH A NARROW DRUMLIN 5 MILES NORTHEAST OF WATERLOO, WIS.

Showing cleavage developed in the clay matrix of till exposed.

side it is obscured by sliding. This bed consists of sand, gravel, and clay. In places the sand and gravel are distinctly stratified, at others not clearly so. The clay and sandy clay show definite lamination. Five to 8 feet below this is a second bed of sand, gravel, and laminated clay, with till above and below. Under the west slope this bed becomes too indefinite to be traced. These beds are clearly seen on both sides of the cut. Such structure as this strongly suggests the building up of the drumlin by successive stages de novo as a drumlin. This is, however, the only instance of the kind which has been noted thus far.

In a few cases the stratified beds of sand and clay exposed in sections of drumlins are crumpled as though having been subject to lateral pressure. One case of such folding of stratified beds, exposed in a transverse cut through the crest of a drumlin, is shown in Pl. VIII, *A*. This drumlin, $1\frac{1}{2}$ miles southeast of the village of Hebron (SE. $\frac{1}{4}$ sec. 1, T. 5 N., R. 15 E.), has a length of one-half mile, a width of about 60 rods, and a height of 60 feet. The crumpled beds shown occur just below the crest, midway in the length of the hill.

The most interesting case of stratification noted in a drumlin occurs 1 mile east of the village of Johnson Creek, where the road crosses a drumlin about midway of its length and about 20 rods south of the highest point. The hill is about three-fourths of a mile long, 60 rods wide, and 40 to 50 feet high. The cut at this place affords a clean section 20 feet high. By far the larger part of the material exposed is light-buff till, with a solid clay matrix. In the west half of the section on the north side of the cut there is considerable stratified sand and gravel disposed in undulating layers, as shown in Pl. IX, *B*, and fig. 8. At one point there is what appears to be an overthrust fold about 12 feet in height. The beds run up the west side of the fold and bend over the top, but can not be traced continuously downward in the east limb of the fold. At the point where they should turn downward there are short crumpled layers, and below these the beds of the east limb drop down vertically, and, curving gradually out to a horizontal position, may be traced thence eastward several yards in gentle undulations. In Pl. IX, *A*, are shown in detail some of the little,

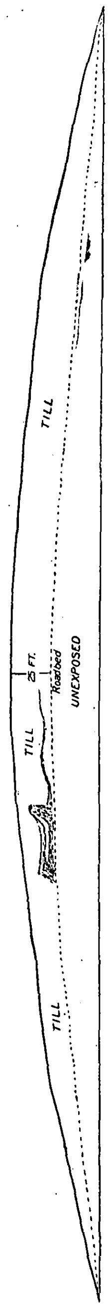


FIG. 8.—Transverse section of drumlin 1 mile east of Johnson Creek, Wis.

sharp overthrust folds at a point just west of the spade in Pl. IX, *B*. Intercalated between stratified layers in this section is a bed of till 3 or 4 feet in thickness. The continuation of these stratified beds is seen in the opposite side of the cut about 16 feet south, but the fold does not appear there.

While it is possible that the distortion of these beds may have been due to settling, resulting from buried masses of ice or from the general compacting of the drift, the appearance of the folded and crumpled layers is as though they had been subjected to lateral pressure. The surface of the drumlin over the distorted beds shows no sag such as would have resulted if such a settling took place subsequent to the molding of the contour of the hill and after the disappearance of the drumlin-forming ice.

One-half mile northwest of the village of Cold Spring there is a drumlin 40 feet in height, 40 rods in width, and tailing out in a very long lee slope, being about one-half mile in length. About midway of the length a private road crosses the ridge by a cut 15 feet in depth. The lower 7 feet of the section thus afforded is of very stony, grayish till, with rather coarse-grained, sandy-clay matrix. Overlying the curved surface of the till is a layer about 1 foot thick of nearly stoneless reddish-brown clay of rather fine grain showing in places slight indications of lamination. Overlying this clay layer is 7 feet of sand, becoming gravelly toward the top. This layer of sand and gravel thins somewhat down the side slopes, but it overlies the lower deposits like a mantle so far as the excavation permits examination.

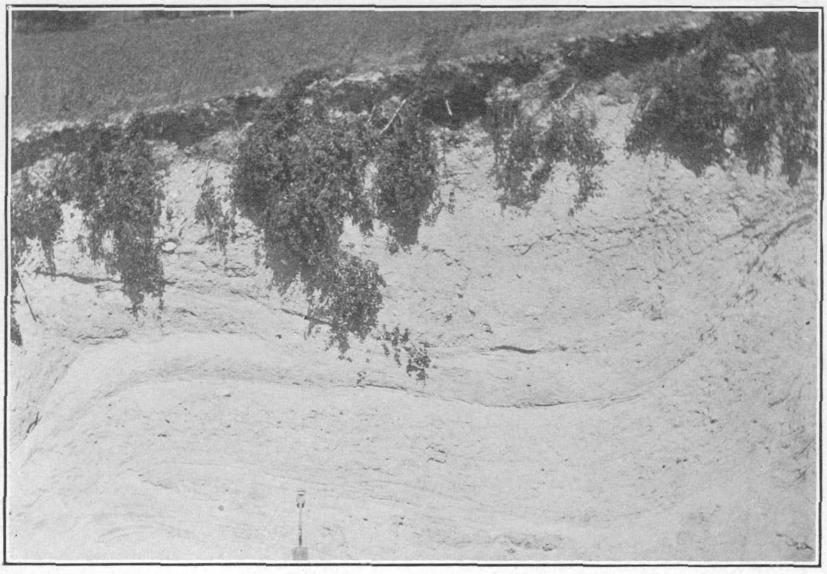
BROWN LOAM AND LOESS COATINGS.

Frequently the exposures show a coating of brownish clay or loamy clay, somewhat less stony than the till below. Sometimes this appears as a deposit more or less distinct from the till, but in most cases it looks like the weathered upper part of the till. It usually thickens down the side slopes, being thin or absent at the crest. This thickening down the side slopes has the appearance of being due to the wash of the finer material of the weathered layer from the crest and upper slopes and its concentration below.

About 1¼ miles east of Hubbleton station the line of the Chicago and Northwestern Railway from Waterloo to Watertown (sec. 5, T. 8 N., R. 14 E.) makes a 60-foot cut through the north end of a large drumlin. Two-thirds to three-fourths of the section is grassed over, but such material as is exposed in the upper part of the cut is solid, structureless till, hard to dig with a hammer. The only indication of bedding is a slightly sandy band at one point. A deposit of fine, stoneless, loesslike, clayey sand mantles the hill at this point. This

A. ROAD CUT 1 MILE EAST OF JOHNSON CREEK, WIS.

Showing in detail the distortion of stratified beds of clay and sand exposed.



B. ROAD CUT THROUGH A DRUMLIN 1 MILE EAST OF JOHNSON CREEK, WIS.

Showing exposure of stratified sand and clay interbedded with till.

mantle thins from 5 feet at the base of the west slope to 1 foot at the crest, thence thickening down the east slope to 10 feet at the base. This deposit is highly calcareous, except the upper 2½ feet, where the lime is leached out. Some of this lime has been concentrated as whitish coatings in the fine cracks. The seepage of water has also concentrated the iron at the top of the denser underlying till, making a brownish zone there. There is also a brownish zone 1 to 1½ feet thick at the top of the deposit, due to weathering.

At the foot of the west slope this deposit is continuous with similar sand, clayey sand, and sandy clay composing a series of low, rounded knolls. A road cut in this shows a banded structure, some layers being more clayey than others. The bands are wavy up and down and have not the distinct lamination of water-laid material. It looks like a loess or dune deposit blown up from the shore of a lake which once occupied the extensive marshy flat along the Crawfish River. There is also the appearance of banking of the material on the east slope of the drumlin, such as would result from its being blown over the crest and lodging on the lee slope.

LITHOLOGICAL COMPOSITION OF THE DRIFT.

As a means of determining roughly the lithological composition of the drift composing the drumlins and other features of the glacial deposit, a large number of analyses of the drift of the region have been made. In making these analyses one hundred to several hundred pebbles have been taken indiscriminately from the drift at numerous exposures, and these have been sorted with reference to the rock formations from which they were derived and the percentages have been noted. Owing to the infrequent occurrence of fossils, the determinations were necessarily based on lithological characters. The character of the several rock formations within the area is generally so distinctive as to be recognizable to one familiar with them. There are, however, gradations from one type to another, so that discriminations can not always be made; thus at the best the determinations can be considered but as approximations of the truth. Undoubtedly the judgment of different persons would differ considerably as to the identifications of the rock specimens at any given exposure. There would be little variance, however, in their judgment as to what is of local derivation and what is foreign to the area. In consequence of the conditions under which the determinations were made care must be taken not to press too far inferences based on mere local differences.

The following is a summary of the results of the examinations of thousands of rock specimens collected at 250 exposures of the drift distributed over those parts of the drift sheets of the Lake Michigan and Green Bay glaciers embraced within the area under discussion. Of these analyses 28 were made in cuts in drumlins of the Green Bay Glacier, 2 in drumlins of the Lake Michigan Glacier, 20 in other parts of the ground moraine of the Green Bay Glacier, and 4 in other parts of the ground moraine of the Lake Michigan Glacier; 8 were estimates of gravels composing eskers of the two glaciers; 79 were made in the several terminal moraines of the Green Bay Glacier, 94 in the several terminal moraines of the Lake Michigan Glacier, and 15 in the interlobate Kettle moraine, the combined deposit of the two glaciers.

In considering the drift of any given part of this area we may regard as foreign constituents all those rock fragments for which no parent formations are known within the limits of eastern Wisconsin in the path of the glacial movement which reached or crossed the tract in question. Thus in the area traversed by the Lake Michigan Glacier we may regard as foreign all the crystalline rocks, quartzites, and sandstones, and all the limestones and shales which can be identified as from formations below the "Trenton group" or above the Devonian. As a matter of fact, the determinations of the writer have warranted the classification of the crystalline rocks, the sandstones, and the quartzites only as foreign material in the drift of the Lake Michigan Glacier.

In the drift of that part of the area traversed by the Green Bay Glacier all the Paleozoic material—limestones, sandstones, and shales from the "Potsdam" to the "Niagara," inclusive—may be of local deriviation. The knobs of "Huronian quartzite" in northwestern Jefferson County and southeastern Dodge County, in what is known as the "Waterloo area," contributed much quartzite material from which it is difficult, without very careful examination, to discriminate quartzite material which may be from more distant points, so that in the drift of the Green Bay Glacier only the crystalline material is regarded as certainly of foreign derivation. Certain crystalline knobs occur in eastern Wisconsin, but not in the track of the ice reaching the south end of the lobe.

If we consider the 250 analyses made of the drift of these two glaciers with reference to the percentages of local and foreign material, it is seen that the foreign material ranges from 2 to 32 per cent, the average percentage of foreign material shown by all the analyses being 12.63. That the variations are within narrow limits is shown by the following:

Résumé of analyses of drift materials.

	Number of analyses.	Percentages of foreign material.
Group 1	172	2.00–15.00
Group 2	64	15.00–20.00
Group 3	12	20.00–25.00
Group 4	1	28.00
Group 5	1	32.00
Total	250	[a] 12.63

[a] Average.

The relative percentage of foreign material in the drumlins of the Green Bay Glacier as compared with that in the other features of the drift of this glacier is shown in the following table:

Comparative amounts of foreign material in the drift of the Green Bay Glacier.

	Number of analyses.	Average percentages of foreign material.
Drumlins	28	9.10
Eskers (including one of the Lake Michigan Glacier)	8	8.50
Other parts of the ground moraine	20	11.14
Terminal moraines	79	10.98

A similar comparison of the composition of the drift of the Lake Michigan Glacier is presented in the following table:

Comparative amounts of foreign material in drift of the Lake Michigan Glacier.

	Number of analyses.	Average percentages of foreign material.
Drumlins	2	12.00
Other parts of the ground moraine	4	15.60
Terminal moraines	94	15.09
Interlobate Kettle moraine (combined drift of the Green Bay and Lake Michigan glaciers)	15	15.95

Judging from the above analyses, it would appear that the drumlins and eskers have a lower percentage of foreign material and a correspondingly higher percentage of local material in their composition than have the other parts of the ground moraine or the terminal moraines. The difference is not notable, however, and it is not clear that it may not be more apparent than real. It seems to be clearly shown, however, that the drift of the Lake Michigan Glacier contains a little higher percentage of foreign material than that of the Green Bay Glacier. This appears in all the comparisons made.

Subglacial drift, that transported at or near the base of the ice, is much less likely to be transported long distances before its deposition than englacial drift, which is carried well up in the body of the ice. This proposition is well supported by the phenomena observed in this area where, as shown by the above analyses, 85 to 90 per cent of the coarser material in the body of the drift is of local derivation, while of the bowlders scattered over the surface often in great abundance fully 85 to 90 per cent are of foreign crystalline rock from the Canadian regions north of the Great Lakes. This bowlder deposit apparently represents the englacial drift let down upon the subglacial deposit on the final melting of the ice. As shown by the analyses, the drift composing the drumlins, mostly exposed in superficial excavations, contains high percentages of local material, as high as, if not higher than other parts of the ground and terminal moraines. This being the case, we are led to the conclusion that the drift composing the drumlins is subglacial drift and that its accumulation in these hills took place at the base or in the lower part of the glaciers.

DISTRIBUTION OF LOCAL MATERIAL IN THE DRIFT.

The predominant local character of the drift composing the drumlins, as also of that composing the other parts of the ground moraine and the terminal moraines, is emphasized by the correspondence of the predominant constituent of the drift at any given place with the underlying rock formation.

The several Paleozoic formations underlying the eastern part of the State have general easterly dips and strikes approximately parallel to the axis of the Green Bay Glacier. Were the drift stripped off this part of the State, the beveled edges of the eroded formations would be found outcropping in a succession of belts extended in a direction generally parallel to the axis of movement of this glacier. In crossing the area from west to east, therefore, one crosses successsively the outcropping belts of the Cambrian sandstones, the "Lower Magnesian limestone," "St. Peter sandstone," "Trenton limestone," "Galena limestone," "Cincinnati shale," "Niagara limestone," and, near the shore of Lake Michigan, "Hamilton beds"[a] of the Devonian.

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[a] See footnote on page 12.

While there is, of course, considerable mixing of the drift derived from the several formations, yet careful examinations and analyses such as are here presented show very clearly the change in composition of the drift as the successive outcropping belts are crossed. In the region of Madison the drift is apt to be sandy and to show much of the irregular-textured "Lower Magnesian limestone" and chert derived therefrom. Going eastward the "Trenton limestone" predominates, the drift generally being less sandy except where considerable pre-Glacial valleys have exposed the underlying sandstones. The percentage of quartzite also notably increases where the bowlder trains, stretching out in the lee of the ledges exposed in the towns of Waterloo, Portland, and Shields, are crossed. At some places in these trains 15 to 27 per cent of the pebbles are of this local quartzite. As soon as the most easterly of the lines of glacial movement which crossed these ledges are passed the quartzite element becomes very small, what is present very likely being derived from more distant sources. In ranges 14 to 17 "Galena limestone" is apt to be the predominant constituent, though it can not always be distinguished from the "Trenton" material in the drift, and the "Niagara limestone" begins to appear as a notable component. At some exposures the "Cincinnati shale" is present in large amounts, but so soft is this shale that its contribution is usually more to the finer material composing the matrix of the till than as recognized pebbles or fragments.

In the drift of the Lake Michigan Glacier the "Niagara limestone" is everywhere the predominant constituent, but on going eastward toward the lake some other Silurian and Devonian material appears.

LOCAL QUARTZITE DRIFT IN THE DRUMLINS.

One element of the local material in the drift is especially noteworthy in this connection because of the possibility of tracing it definitely to its source within the area under discussion. This is the quartzite material derived from ledges exposed in the towns of Waterloo, Portland, and Shields, to which reference has just been made. This quartzite material is found in trains tailing out in the lee of the ledges, in considerable mounds of bowlders in the vicinity of the ledges, in thousands of cords of bowlders scattered indiscriminately over the surface of the ground moraine, the drumlins, and the terminal moraines, and incorporated in the drift composing all these drift features developed in the lee of the ledges. The incorporation of the quartzite material is noted in the first good drumlins occurring in the lee of the ledges, and decreases thence in amount as the distance from the source increases. A few estimates were made in cuts in drumlins to determine the relative amounts of this local quartzite material, the estimates being based on the measurement of the areal extent of quartzite material exposed in the faces of the cuts or on the actual amounts of quartzite found in the excavation and sifting of a few cubic feet of the drift, or by a combination of the two methods. The following are the results obtained:

Table showing percentages of local quartzite in the drift.

Location.	Distance from ledges.	Percentage of quartzite.
	Miles.	
Waterloo Township (sec. 5)	1½– 3½	4.26
Waterloo Township (sec. 16)	2½– 4½	6.51
Deerfield Township (sec. 25)	11½–13½	3.385
Christiana Township (sec. 10)	15 –17	.024
Christiana Township (sec. 15)	16½–18½	.00729

It should be noted in this connection that there is a marked difference between the estimates of the percentages of quartzite composing the drumlins as determined in this way and the percentages determined from enumeration of the pebbles. While the estimates in section 5, Waterloo, and section 25, Deerfield, indicated 4.26 per cent and 3.385 per cent, respectively, as the quartzite content of the drift, estimates based on the enumeration of the pebbles and bowlderets at the same exposures showed 27⅓ per cent and 21 per cent, respectively. This difference may be fortuitous or it may result from the hard, indurated quartzite fragments not having suffered sufficient comminution within such comparatively short distances of the place of derivation to be fully represented in the finer material of the drift, so that an examination of the larger pebbles and bowlders shows a higher percentage of the local quartzite than an estimate which involves the cubical contents of both the coarse and fine material.

ORIGIN OF THE DRUMLINS.

We now come to the consideration of the question, Are the drumlins of the Green Bay and Lake Michigan glaciers wholly the products of the last advance of these glaciers?

If we consider the forms and orientations only, there can be little question that the shaping, at least, of the drumlins was done by the last glaciers to traverse the area. In very few cases is there any divergence of the drumlins from the regularity of the radiating system which corresponds to the lines of flow in the deployment of the lobe. As already indicated, some of the forms, especially the coalesced forms with the overlapping crests, quite strongly suggest that they are the result of erosion of previously formed drift deposits, of fluting and remolding of drift ridges which lay in the path of the glacier more or less obliquely to the direction of flow. The writer has not, however, been able to determine satisfactorily that the drift composing the ridges was deposited by an earlier glacier. Similar suggestions arise also from the occurrence of the double- and triple-crested forms which have been described.

There can be no doubt that one or more earlier glaciers traversed the tract later occupied by the Green Bay Glacier. This is shown by the general distribution of the older drift outside of the later moraines, by the composition of this older drift, and by the orientation of striæ and drumlin axes. So, also, as has already been noted, there have been observed within the later moraines striæ conforming more closely to the trend of those of the older drift than to the directions of flow of the Green Bay Glacier. Further, the distribution of the quartzite bowlders in widely dispersed fans leading out from the local ledges in more southwesterly directions than those taken by the last ice flow which crossed the ledges indicates one or more earlier dispersions.

Beginning at a point about 2½ miles northwest of the village of Evansville there is a small terminal moraine which appears to have emerged from beneath the Johnstown terminal moraine of the Green Bay Glacier, extends thence about 10 miles northwestward, and again disappears beneath the Johnstown moraine. (Pl. I.) The relations of this moraine show it to be older than the Johnstown moraine, yet the degree of weathering and erosion which the drift has suffered is not notably greater than that of the later moraine. It is possible that this emerging moraine is a terminal of the Green Bay lobe of an earlier Wisconsin sheet, formed at the time when the glaciers had the wide deployment in Illinois, described by Mr. Frank Leverett in his monograph on the Illinois Glacial Lobe,[a] yet this has not been demonstrated.

The relations being such, it has not been possible thus far in the study to determine whether the local accumulations which have now the drumlin forms were due wholly to the last advance or in part to one or more earlier advances. Nowhere in that part of the Green Bay drift sheet examined has the writer seen drift exposed which he could with any certainty regard as older drift, nor has it been possible to discriminate the older drift from the later in the records of wells collected. In the area of the Lake Michigan Glacier some drift has been observed which very probably belongs to one or more of the older sheets, and at several places buried vegetal deposits, probably to be referred to some one or more of the inter-Glacial horizons, have

[a] Mon. U. S. Geol. Survey, vol. 38, 1899.

been reported, but none of these occur in the neighborhood of drumlins, and hence do not aid in the determinations desired.

The drift exposed in the drumlin sections corresponds in character, composition, and degree of freshness with that in other parts referred to the latest drift sheet. The average depth of leaching of the lime from the highly calcareous till is about 2½ feet; frequently on the crests of the drumlins, where some of the weathered parts are washed away, this depth is less than 1 foot. The bulk of the drift appears to be bluish till, but to the depths exposed it is usually of a very light-buff color, sometimes becoming bluish towards the bottom of the deepest cuts. Generally a thin zone at the tops of the exposures, varying in thickness from 0 to 3 feet, is brownish in color, sometimes dark brown or reddish brown, the result of further oxidation and staining. Not infrequently included crystalline pebbles and bowlders are disintegrating so that they crumble to pieces under the blows of the hammer. A few cases have been seen where crystalline bowlders 2 to 3 feet in diameter, in the upper parts of the exposures, were so thoroughly disintegrated that they crumbled to coarse sand and could be cut with a spade, yet every detail of the surface was sharply and clearly shown in the enveloping drift mold. These might have been picked up from the surface of an older drift with disintegration already in its inception. Where these disintegrating bowlders occur, as elsewhere, the bulk of the stony material is fresh and clean in appearance and rings sound under the hammer.

The cuts in the drumlins are not usually deep enough or so situated as to demonstrate the presence or absence of cores of older drift in the drumlins, nor has this been determined from the wells. Indeed, it is not certain that the drift of an earlier Wisconsin glacier or of the older deposit outside of the moraines could be discriminated from the later drift if it were exposed, especially if the zone of moderate weathering had been removed, since the drift of the several sheets exposed in southeastern Wisconsin is very similar in character and composition.

Bearing on the question whether the drumlins were formed beneath the marginal parts of the ice sheet during a late stage of its action, or formed further back and earlier, certain suggestions may be made. It has already been shown that the formation of the drumlins preceded the formation of the eskers and inner terminal moraines, and it may be noted, further, that the radial arrangement of the drumlin axes is in close conformity with the curve of the outer terminal moraine which was formed at the limit of the advance, but somewhat less so with what appears to have been the curve of the margin of the lobe during the stages of the retreat. As the Green Bay lobe was notably asymmetric, spreading out on the west nearly twice as far as on the east, so, when the melting of the ice occurred, the west and southwest margin of the lobe appears to have retreated more rapidly than that on the southeast and east; in fact many miles of ice melted away on the west and southwest while the east front was yet pressed snugly against the interlobate moraine. The asymmetry of the south end of the lobe, which is manifest in the radiation of the drumlins as well as in the curve of the moraines, appears to have been reduced by this one-sided melting. As a consequence the trend of the drumlin axes is not so nearly normal to the innermost of the recessional moraines as it is to the moraine which marks the limit of advance. While this appears to have been the case, it is not yet demonstrable because of the somewhat diffuse character of the inner moraines. Further mapping of these inner moraines may show this more clearly. So far as the evidence now in hand can be trusted, the drumlins appear to be the product of the advance of the last ice sheet; in their final form, at least, they are clearly so. Unfortunately, however, the evidence as to the exact method of their formation is very meager and indecisive.

SUMMARY.

A few drumlins occur on the older drift sheet east of Rock River and a few on the drift sheet of the Lake Michigan Glacier. They reach their finest development in the ground moraine of the Green Bay Glacier, there being 1,269 distributed through 577 sections of the 1,325 square miles of ground moraine of this glacier in the area examined.

The drumlins are, with rare exceptions, arranged in a regularly radiating system corresponding to the radiating lines of flow in the deploying glacier. They are generally but unevenly distributed through the ground-moraine tract, the average limit of their formation being 9 miles within the extreme limit of the glacial advance on the south and west, where the deployment of the ice was unrestricted.

The inner terminal moraines formed during the retreat of the ice front were deposited indiscriminately over drumlins and other parts of the ground moraine.

Where the drumlins and eskers are closely related, it appears that the drumlins must have been formed previous to the eskers, and that the esker-forming streams must have flowed so close to the base of the ice that the direction of their flow was influenced by the relief of the drumlins and the intervening low areas.

In some places drumlins are bunched together on the pre-Glacial uplands; elsewhere they are few or absent on such uplands, so that the relation of drumlin formation to the larger features of the pre-Glacial topography is not altogether clear.

The drumlins are inclined to be bunched rather than distributed uniformly over the ground moraine area, and in some parts they are closely crowded together, with heads and tails closely overlapping side by side.

There is considerable variation in the form and size of the drumlins. Single-crested forms predominate, but double- and triple-crested forms, forms with double tails, and also twins and triplets occur. The drumlins generally increase in length toward the axis of the movement of the lobe. In this part they are drawn out into elongated ridges reaching a maximum length of about 4 miles, and are often characterized by several overlapping crests.

In the larger number of cases concerning which determination could be made the drumlins appear to be without rock nuclei, and no relation between drumlin formation and the configuration of the indurated rock surface was detected.

The majority of observed exposures show only structureless till as the component material. The matrix of this till frequently shows a distinct cleavage parallel to the curving surfaces of the hills, assignable, perhaps, to the pressure of the overriding ice. Stratified beds frequently occur, but only in rare cases was any definite relation to the forms of the drumlins observed. In some cases these stratified beds are folded and crumpled, apparently the result of lateral pressure. If due to settling, this settling must have occurred before the hill was molded to the final drumlin form.

More than 90 per cent of the coarser part of the drift composing the drumlins of the Green Bay Glacier appears to be of local derivation, being of similar lithological character to the rock formations underlying the area. About 9 per cent must have been brought from the Canadian crystalline rocks several hundred miles to the north. In the drift of the Lake Michigan Glacier the foreign constituent is a little larger. The several constituents of the local drift are distributed through the drumlins and other parts of the drift sheet in a manner conforming to the distribution of the underlying rock formations.

Quartzite material from the ledges outcropping within the area is incorporated in the drumlins, as well as distributed over their surfaces in large amounts within short distances of the parent ledges, decreasing thence with the increase of distance from the sources.

The high percentages of local material in the drumlins indicate that the drift was carried at or near the base of the glacier and that its concentration in hills took place at this low horizon. The general conformity of the distribution of the quartzite material incorporated in the drumlins with the bowlder trains due to the last glacial advance is an argument in favor of the concentration of the drift in distinct hills by the same glacier. There can be no question that the final forms of the drumlins are the result of the last advance of the ice. The writer has been unable to determine whether or not any of these drumlins are composed of older drift or whether nuclei of older drift occur. The drift exposed is generally fresh, having been subjected to but moderate weathering. Nothing has been noted indicating that the drift of the drumlins is any older than that of other parts of the ground moraine.

The formation of certain eskers and morainic deposits subsequent to the formation of the drumlins appears to indicate that the latter were the product of the earlier, rather than of the later, stages of the ice action, whether such action were constructive or erosive.

Doctor Chamberlin has recently suggested that the possible agency of longitudinal crevasses in giving rise to drumlins be tried as an additional working hypothesis. Preliminary attempts to test this hypothesis by the distribution of the drumlins have been made, but owing to the difficulties of determining just where the tensional stresses, to which longitudinal crevasses are referable, would be located and just how they would affect basal accumulations, it is uncertain whether these first trials have any decisive value; and until the subject is more maturely considered it is premature to report upon the hypothesis further than to say that the early trials are not especially encouraging.

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