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DRUMLINS AND RELATED STREAMLINE FEATURES IN THE WARWICK-TOKIO AREA, NORTH DAKOTA*

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ABSTRACT. Northeast-trending drumlins and related streamline features of late Pleistocene age are found in the Warwick-Tokio area of the Devils Lake region of North Dakota. These features range from small drumlins to large ridges or "scorings" in end moraines. Some isolated end moraine patches contain exposures of Pierre shale bedrock of Cretaceous age. These bedrock "highs" seem to have controlled the location of the morainal patches but do not seem significant in the origin of the streamline features. The origin of the streamline features is uncertain but they are probably erosional rather than depositional. Why they are localized in this part of the Devils Lake region and absent elsewhere is not clear. No significant differences of terrain or materials were found among the various parts of the region. Possibly some as yet unknown factor in the now vanished ice is responsible for their formation in this small area.

INTRODUCTION AND PREVIOUS WORK

Drumlins and related large-scale streamline glacial features paralleling

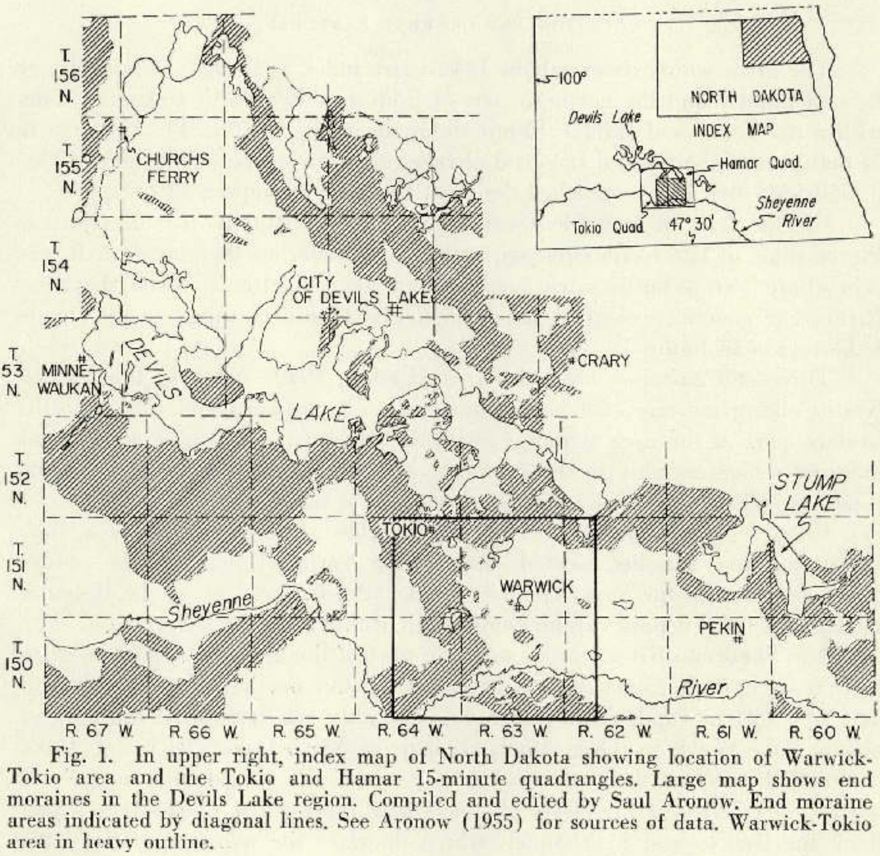

Fig. 1. In upper right, index map of North Dakota showing location of Warwick-Tokio area and the Tokio and Hamar 15-minute quadrangles. Large map shows end moraines in the Devils Lake region. Compiled and edited by Saul Aronow. End moraine areas indicated by diagonal lines. See Aronow (1955) for sources of data. Warwick-Tokio area in heavy outline.

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former ice movement have been only recently noticed in North Dakota (Lemke, 1954 and 1958; Colton and Lemke, 1955; Aronow, 1955). Most of these features are readily apparent only on aerial photographs, which probably accounts for their comparatively late recognition. This paper concerns those in the Devils Lake region of North Dakota near the villages of Tokio and Warwick, mentioned by Colton and Lemke (1955) in their note.

The Devils Lake region in which these drumlins and related features are found was first described and mapped geologically by Upham (1896). His plate XVIII of the Devils Lake region shows moraines only. The Devils Lake region as a whole was later also described by Simpson (1912). The 15-minute Tokio quadrangle in which the western part of the Warwick-Tokio area (see fig. 1) falls was mapped by Easker (1949). Easker's map was later revised and the drumlins added to it by the writer (1955) who also mapped the adjoining 15-minute Hamar quadrangle. Colton and Lemke (1955) noted the occurrence of these features within the area in a general note on their occurrence in North Dakota.

LOCATION AND GENERAL FEATURES

The area, which covers about 144 square miles, is in the western part of Benson County and the northern part of Eddy County, North Dakota. It falls within the Tokio and Hamar 15-minute quadrangles (see fig. 1). The area is in that part of the Central Lowland physiographic province (Fenneman, 1938, p. 559-588) that has been called the Drift Prairie by Simpson (1929, p. 5).

Glacial drift of late Pleistocene age mantles virtually the entire area. Pierre shale of late Cretaceous age everywhere underlies the glacial drift, except where it crops out in a few road cuts and along the trench of the Sheyenne River. The general geology is shown in figure 2; and moraines in the Devils Lake region in figure 1.

Three end moraines cross the area (Easker, 1949; Aronow, 1955). The North Viking moraine, the northernmost, trends eastward and in the northwestern part of the area it merges with the Heimdal moraine. The Heimdal moraine strikes roughly to the southeast and merges with the northeastward trending Hillsdale moraine in the southern part of the area.

Pitted outwash deposits cover considerable portions of the area. The largest of these deposits, located south of the North Viking moraine, covers about one-third of the area. Another, smaller, deposit lies west of the Heimdal moraine. A third deposit can be found south of the Sheyenne River.

The Sheyenne River, in the southern part of the area, flows from west to east. It occupies a trench which, in places, is over one-half a mile wide and over 100 feet in depth. This trench was probably cut during the draining of glacial Lake Souris in the northwestern part of North Dakota (Upham, 1896, p. 267-272). Before the excavation of the trench the glacial Sheyenne River flowed in a series of high-level channels now represented by terraces which flank the trench, and by channels which interlace the moraine south of the trench.

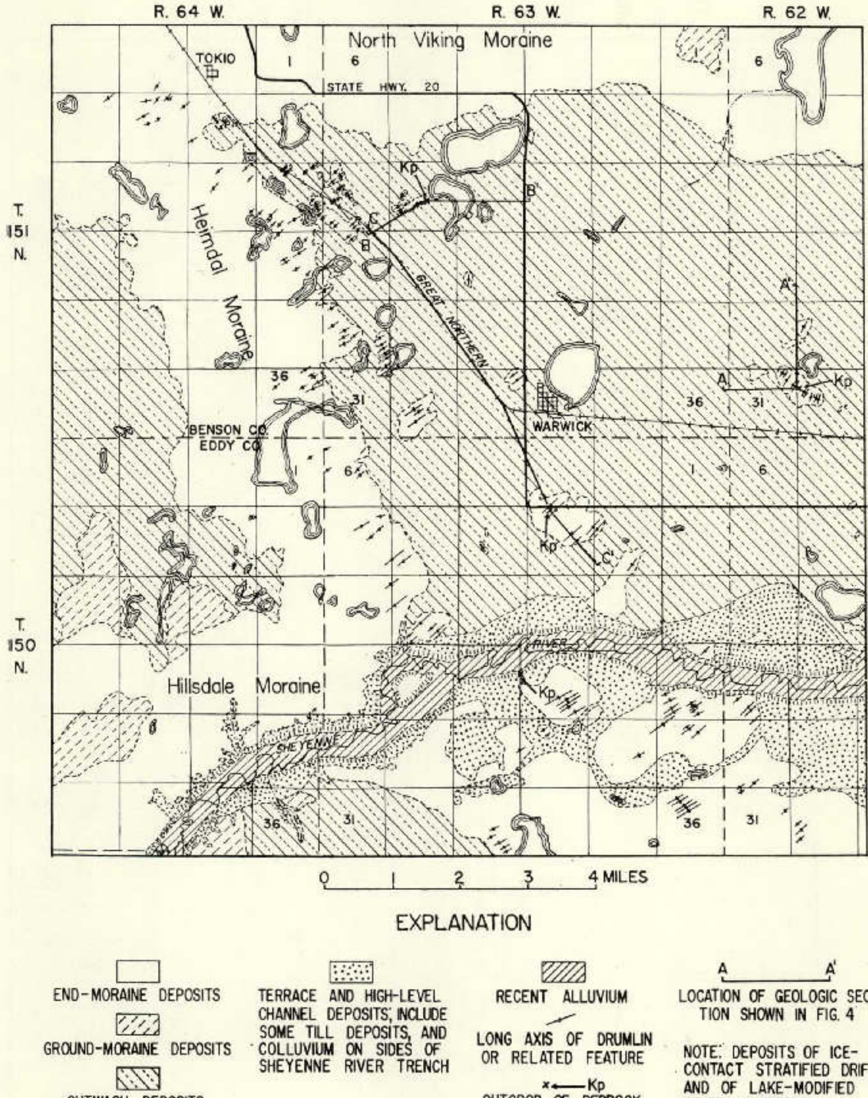

Fig. 2. Map showing geology of Warwick-Tokio area, Benson and Eddy Counties, North Dakota, and location of geologic sections.

DESCRIPTION OF LINEAR FEATURES

The drumlins and related linear features are confined to (a) the Heimdal moraine, (b) its continuation south of the Sheyenne River trench, and (c) isolated end moraine patches, some bedrock cored, completely surrounded by outwash on the proximal side of the Heimdal moraine. In some places in the outwash plain small isolated elongate hills of till rise above the level of the

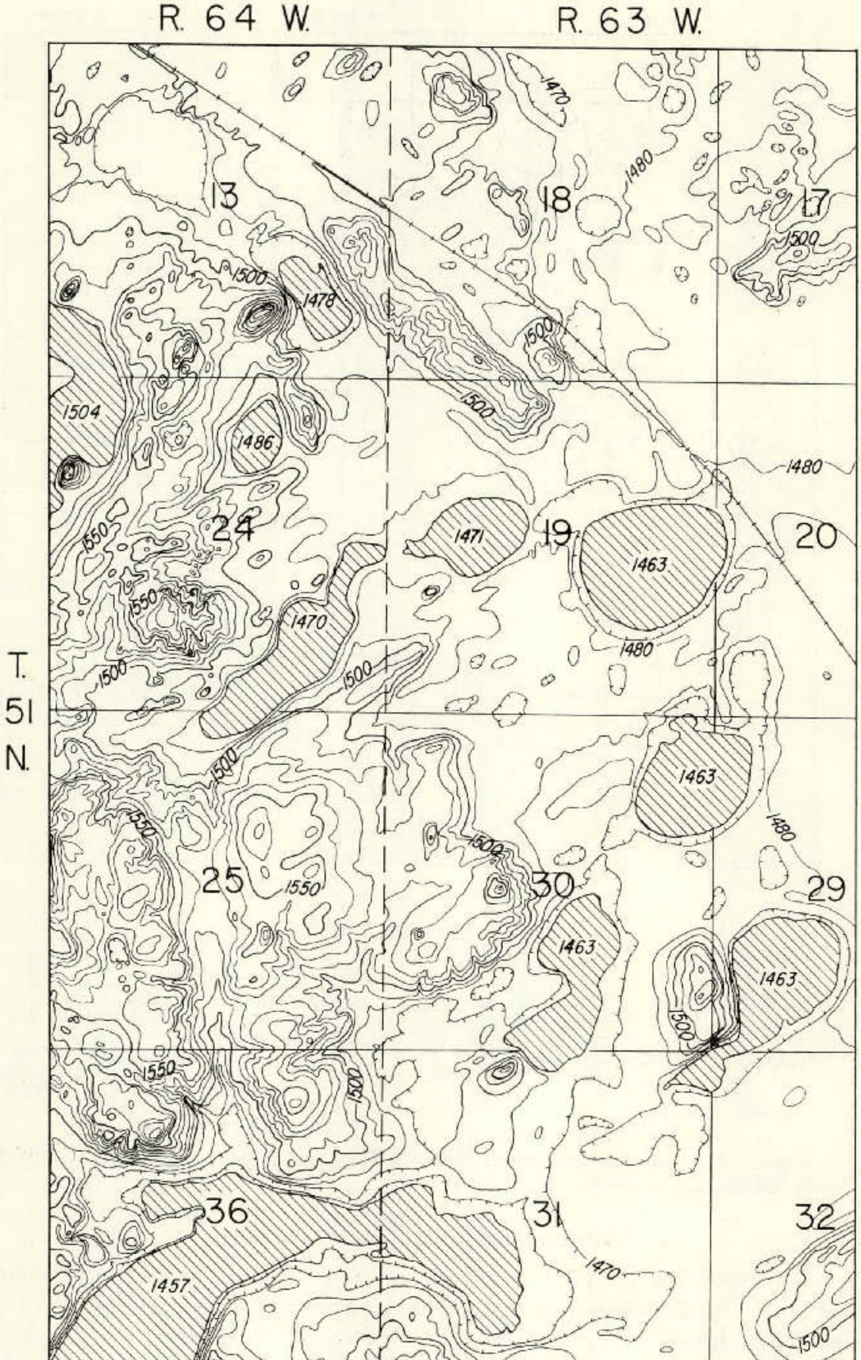

Fig. 3. Topographic map, 10-foot contour interval, of part of Warwick-Tokio area, North Dakota. Traced from the Tokio and Horseshoe Lake 7½-minute quadrangles which cover the eastern half of the 15-minute Tokio quadrangle. Contours simplified in the vicinity of roads; road and swamp symbols omitted.

outwash deposits. These small hills, some of which are drumlin-shaped, were mapped as end moraine because of the occurrence of transitional forms between them and end moraine topography, and because of their till content.

The linear features in the area have a variety of shapes. A small minority have the classic drumlin shape. The bulk of these features, however, fall into a rather nondescript second group which, through transitional forms, make a continuous range of shapes between drumlins and end moraine topography.

Of the approximately 160 shown in figure 2, less than 20 are drmulin-shaped. Most of these are shown in figure 3. They are almost all less than a fifth of a mile long and less than 50 feet in height. Compared with other drumlins, for example, in Wisconsin (cf. Thwaites, 1946, figs. 54 and 55) and New York (cf. Atwood, 1940, figs. 92 and 93) they are rather small. In general, here the smaller the feature the more drumlin-like in form it is.

The individual ridges lacking the drumlin form in end-moraine areas or in isolated hills in the outwash are generally larger than the drumlins. These may be up to about a half a mile in length. Their relief in places may reach 60 feet either in height above the surrounding outwash plain or height above intervening swales. On aerial photographs[1] the ground surface in the places where these are located appears as if it were scored by a gigantic rake which produced elongate ridges and narrow intervening swales. Many of the isolated end moraine patches, when seen in profile, at right angles to the trend of the linear features, have steep stoss slopes and gentle lee slopes although the end moraine mass itself may be elongated parallel to the main trend of the Heimdal moraine. Examples may be found in secs. 31 and 32, T. 151 N., R. 62 W., in SE. ¼ sec. 30 and SW. ¼ sec. 29, T. 151 N., R. 63 W. and in W. ½ sec. 18, T. 151 N., R. 63 W. (see figs. 2 and 3).

Most of the features have strikes that are within the northeast quadrant of the compass. Most strike between N. 40° E. and N. 60° E. Extreme values for strike directions range from N. 14° E. to N. 80° E. Several, however, have strikes that do not fall within the northeast quadrant. These strike to the north and to the northwest and are located in sec. 31, T. 151 N., R. 64 W. and sec. 21, T. 151 N., R. 63 W. (see figs. 2 and 3). Although these few trend more or less parallel to the Heimdal moraine, and perhaps should be considered as just small morainal ridges, they do have the inverted spoon shape. The most puzzling of these is in the SW. ¼ sec. 9, T. 150 N., R. 63 W.; it has the steep slope facing southeast and the gentle slope facing northwest.

The till in this, as in the rest of the Devils Lake region, is a clayey till. Mechanical analyses of till samples collected from other parts of the region, when plotted as cumulative curves on semi-log paper, approximate straight lines. Particle sizes range from clay to boulders. The linear features, except where Pierre shale crops out, are composed of the same type of till.

RELATION OF MORAINAL AREAS WITH LINEAR FEATURES TO BEDROCK

Pierre shale bedrock crops out in road cuts in three of the scored end moraine patches, and in a road cut at the edge of the Sheyenne River trench. The three exposures in end moraine patches are located respectively due west,

[1] An excellent stereopair of part of the area is given in Smith (1943, p. 304). East and West have been reversed on these photographs.

and due south of the village of Warwick, and in sec. 17, T. 151 N., R. 63 W. The exposure at the edge of the trench is on the south side, almost due south of the village of Warwick (see fig. 2).

Several geologic sections (fig. 4) have been prepared using U. S. Geological Survey test hole data, and the outcrops to show the relation of the bedrock to the surface glacial features. Although these sections have considerable vertical exaggeration, they clearly demonstrate the relationship of these particular

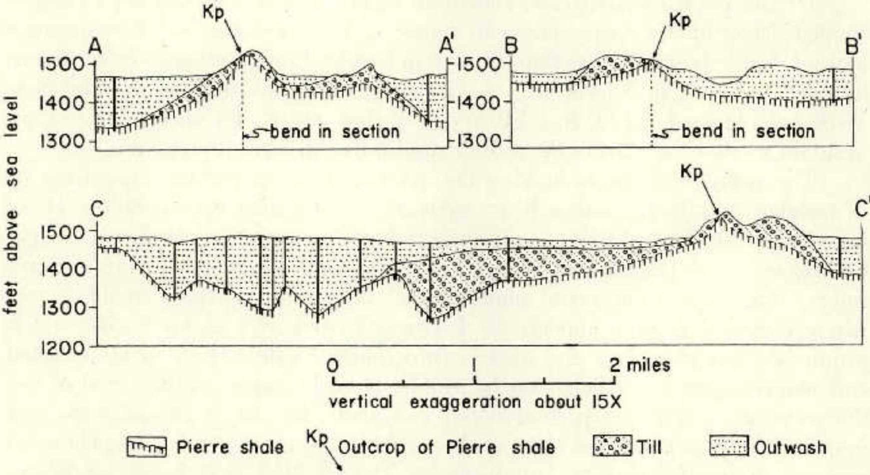

Fig. 4. Geologic sections in the Warwick-Tokio area, North Dakota, based on USGS test hole data. Locations of sections shown in figure 2. Note bends in sections.

end moraine patches to the bedrock. The bedrock, it may be noticed, crops out in at least two of the larger end moraine patches. One is tempted to generalize that most of the other isolated end moraine patches, both north and south of the Sheyenne River are likewise cored with bedrock "highs." This seems to explain the otherwise curious and anomalous patchy and discontinuous distribution of end moraine on the proximal side of the North Viking moraine.[2]

Sections B-B′ and C-C′ have been drawn with the bedrock as a "pinnacle"; the bulk of the morainal patch then consisting largely of drift. The validity of this interpretation is debatable but it seems the safest one. The writer has found that for subsurface data interpretation in the Devils Lake region the best approach is to assume the presence of till unless otherwise indicated.

GLACIAL HISTORY OF THE AREA

The drift in the area is of late Pleistocene age and all the moraines were formed during the retreat of the ice.

The first major halt or readvance of the ice within the area is indicated by the Hillsdale moraine and its modified continuation east of the Sheyenne River. The ice front during this period trended more or less east-west. Probably the stratigraphically lower portion of the outwash in the extreme southern part of the area was laid down at this time.

[2] Upham (1896, plate XVIII) "tied" these isolated end moraine patches together to form a continuous moraine.

The Heimdal moraine marks the next stable location of the ice front, which now trended to the northwest. The gap between the Heimdal and Hillsdale moraines in the western part of the area shows that the ice front must have retreated considerably to the north before pivoting, so to speak, and readvancing from the northeast. Tetrick (1949) and Aronow (1955) suggest that this "pivoting" as well as the merging of the Heimdal and North Viking moraines (see figs. 1 and 2) was caused by the presence of a Pierre shale bedrock "high" in the northwest part of the area which acted as a kind of "bastion" holding up the southward advance of the ice. Farther to the south and east apparently there were no bedrock "highs" of sufficient magnitude to prevent the ice from advancing southward and partly overriding the eastern portion of the Hillsdale moraine. The end moraine patch in secs. 31 and 32, T. 151 N., R. 62 W., with "scorings" more or less perpendicular to the trend of the Heimdal moraine, is almost five miles from the moraine. The ice front must have migrated northward at least to this point before re-advancing to the Heimdal moraine position. The linear features probably were made during this readvance. If not this distant end-moraine patch may have been "scored" in one or more minor readvances during the general retreat from the Heimdal moraine position. The outwash deposits in the western part of the area and the uppermost portion of those in the southern part of the area were laid down during the period when the ice front was at the site of the Heimdal moraine.

The North Viking moraine, in the northern part of the area indicates the last major stand of the ice in the area. The large body of outwash in the central and eastern parts of the area testifies to a lengthy stay of the ice in this position as well as to copious amounts of meltwater. The outwash, in places, is over 200 feet thick. As shown in the geologic sections (fig. 4) some till must have been eroded away by meltwater from the surface now underlying the outwash. Many of the isolated end moraine patches may have been further separated from the main mass of the Heimdal moraine or reduced in size by the activities of these meltwaters. The outwash was then deposited over the partly till-covered, partly bedrock surface, forming a gently southward-sloping plain. Ice blocks, left during the retreat of the ice, were partly or wholly buried by the outwash. They melted, thus pitting the surface of the outwash. The end moraine patches and isolated drumlin-like features were now partly buried, some presumably completely, by this "flood" of outwash.

DISCUSSION

Streamline molded forms, to use Flint's terminology (1957, p. 66), (including, perhaps, small drumlins) are fairly numerous in North Dakota (R. B. Colton, oral communication, 1957). They are generally inconspicuous and difficult to identify from ground view. There are no great drumlin fields in North Dakota comparable say to those of New York or Wisconsin. Charlesworth (1957, p. 391), writing in 1953, says that:

> The conditions necessary for drumlin building were apparently seldom realized: drumlins occupy only a small proportion of the till country. They are rare over vast regions of glaciated Europe, and in North America are infrequent in Pennsylvania and New Jersey and lacking in Ohio, Indiana, Minnesota, the Dakotas and south Michigan.

Whether or not this is true for streamline molded forms in general may be questionable and awaits the systematic perusal of thousands of the Department of Agriculture's county photo index sheets. Most summary discussions in the literature, with the exception of Flint's (1957, p. 66-72), are concerned with drumlins and tend to ignore the less distinct, less prominent features.

On a local scale, the intriguing problem is why these streamline forms, including drumlins, are present in this particular area, absent from the rest of the Devils Lake region and poorly developed, as drumlins, in the rest of North Dakota. The writer has not come up with any unusual thoughts on the problem but will suggest that revival of the basic idea underlying a generally unacceptable view may be in order. Before delving into the local problem, the writer will review and comment upon some current thoughts on the origin of these features.[3]

On drumlins proper, the traditional diversity of opinion can be placed under two major headings: (a) the depositional, constructional or accretional view, currently accepted by Thwaites (1946), Thornbury (1956) and Charlesworth (1957), among others, and (b) the destructional or erosional view, held at present, in a modified kind of way, by Gravenor (1953) and Flint (1957, p. 66), among others.

The first view is that drumlins were built up under moving ice from drift derived from that ice. Apparently older drift to qualify here must have been reworked to the extent of having its fabric or stratification destroyed. A new form composed of drift with a new fabric was then molded, possibly by the gradual accretion of drift. Thwaites (1946, p. 44-45) has a good point by point discussion and defense of this view.

A variant of this view is a recent suggestion by Hoppe and Schytt (1953) concerning fluted moraine surfaces associated with certain Icelandic and Scandanavian glaciers. The fluting, small ridges, all less than a meter high and less than 200 meters long "may have been formed by the great weight of ice pressing water-soaked moraine . . . up into hollows formed in the lee of boulders." That this process operated on the scale necessary for the formation of large fluted surfaces and drumlins associated with continental glaciers is not known at present. If large scale operation of this process did occur, the form that was molded (or "extruded" like some industrial plastics, as suggested by Flint (1957, p. 71)) may be composed of "new" drift deposited directly from the ice immediately above as well as "old" drift that was reshaped.

The second, the erosional view, holds that drumlins are the carved out or reshaped remnants of drift deposited prior to the advance of the ice. The fabric and stratification in this case would date back to the original deposition of the drift. An analogy to point up the difference between the two views is the difference between the work of a sculptor modeling in clay and one chiseling a form out of rock.

Gravenor (1953) attempts to reconcile the evidence in favor of the depositional view with the erosional view by a "modified erosion theory." His suggestion, in brief, is that the drift, stratified and unstratified, out of which the drumlins were carved was deposited during the advancing and waxing

[3] For a complete and unculled review of the literature on drumlins the reader may consult Charlesworth (1957, p. 389-403).

stage of the ice, largely as "moraines of advance" and associated drift, and later overridden. This ingenious line of argument thus presumably accounts for the diversity of drumlinal material as well as the similarity in age of drumlins and surrounding and underlying drift.[4]

Flint (1957, p. 66), impressed with the varied morphology, size and composition of streamline molded forms ("from 100% bedrock to 100% glacial deposits") says "Obviously those consisting of bedrock are entirely the work of erosion. Those made largely of drift may also be chiefly erosional . . . " He notes the continuum of forms including striations, large groovings, and flutings and drumlins.

What is of most interest here is that Gravenor and Flint point up the fact that hills with the classic drumlin shape are found composed of till, stratified drift, bedrock or combinations of all three. This is significant in relation to the assertion by Thornbury (1956, p. 391) and Thwaites (1946, p. 44) that, among other reasons, drumlins are constructional because they lack the roche moutonnée or stoss-and-lee form characteristic of indisputably eroded bedrock. This difference in form may be a function of the strength of the material or the type of resisitance it offers to erosion: for example, the possibly fine scale removal of massive weak material versus the large scale removal of jointed bedrock by plucking. In a sense, this argument from form is begging the question.

In the late 1930's O. D. von Engeln popularized and extended the views of a German glacial geologist, Flückinger. These views, as expounded by von Engeln (e.g., 1938) are that the attack of glacial ice on bedrock topography is so gross that structural differences in the terrain, as well as the previous topography, exerts virtually no control over the final end product of glacial erosion, namely, the roche moutonnée form. This form, he asserts, is due to something inherent in the motion of the ice: that ice moves in a wave form because of the friction of the moving ice with the underlying bedrock. The powerful undulations of the ice erode the surface into roches moutonnées. The lat Max Demorest (1938), this writer believes, successfully refuted the notions of both the grossness of attack and the wave motion of the ice.

Obviously the shape and lithology of land forms, constructional and destructional, left after the ice disappears from a given region are the result of the interaction of the ice and its load of debris, and the given initial terrain and rocks. Though the cause-and-effect relationships often cannot be clearly differentiated in this interaction we can say that the physical and dynamic condition of the ice is modified by the terrain and rocks, and the terrain and rocks by the ice. For the purpose of discussion an attempt will be made to arrive at a "first approximation" of the factors in the ice that would modify the terrain and rocks, and the converse. Let us consider the following simplified cases: Given two areas identical in topography and geology, each covered by ice advancing from the same direction, any differences in the land forms and materials left by the ice would probably be the result of differences in the glaciers of

[4] About the only one of Thwaites' (1946, p. 44-45) arguments not answered is that of the "reshaped" drumlin.

(1) thickness
(2) velocity
(3) rate of melting
(4) load of debris, sub-, en-, or superglacial.

If the situation were reversed, namely, that two glaciers identical in physical and dynamic condition enter two areas of contrasting topography and materials from the same direction, the ensuing dissimilarity of the areas after the ice left would be due to differences in

(1) topographic "grain" (the orientation of major valleys)
(2) regional slope
(3) texture or roughness of the topography
(4) the resistance of the bedrock or superficial unconsolidated materials to erosion, and the manner in which they can be eroded.

Each of the factors within each group would, to a certain extent, depend on the others. Probably each of the terrain and lithology factors modify each of the glacial factors and vice versa. As far as drumlins and related streamline features are concerned, the physical and dynamic condition of the ice is probably as important as the initial terrain and materials.

Now, with this approach in mind, we will examine the problem of the origin of the drumlins and related features in the Warwick-Tokio area. This area will be compared with other parts of the Devils Lake region lacking in these linear features to find out if anything now seen or inferable about the original topography and materials can be considered significant. Though there is insufficient information available to present a clear-cut and incontrovertible example of the first ideal case (same topography, and materials, different physical and dynamic conditions in the glacier), the writer believes that enough is known to approximate to a surprising degree the conditions necessary for this case. Comparison between the Warwick-Tokio area and other parts of the Devils Lake region will be made under the following heads:

(a) regional slope
(b) topographic grain
(c) character of the drift
(d) configuration of the bedrock
(e) character of the bedrock
(f) topography prior to the last drift.

(a) The bedrock topography on a 250-foot contour-interval map of the central United States by Horberg and Anderson (1956, fig. 1) shows that in a rough sort of way the Devils Lake region lies on the northeast side of a southeast-trending depression. This depression extends below the 1500-foot contour and presumably lies above the 1250-foot depression. Bedrock altitudes, however, less than 1250 feet above sea level were found by test drilling in many places in the Devils Lake region, particularly adjacent to the lakes and in the dry beds of the lakes. This area, under and subjacent to the lakes, may be the lowest place or axis of the depression shown on Horberg and Anderson's map. Thus there may be a reversal of the regional slope within the Devils Lake region which would place the Warwick-Tokio area on the southwestern flank of the depression. Streamline features are absent in other places on this hypothetical flank, which may indicate that the regional slope may not be a critical factor in controlling their formation.

(b) The present surface topographic grain of the Devils Lake region is expressed by the southeast-east orientation of the long axis of the lake complex and the southeast-east to southeast orientation of the moraines that flank the lakes (see fig. 1). Test drilling has shown that in a general way the grain of the bedrock topography more or less parallels that of the surface: the moraines are more-or-less underlain by thin drift or bedrock "highs," and the lowest places in the bedrock flank the lake basins or underlie the dry lake beds. In particular, the southwest-trending moraine north of the city of Devils Lake, with an orientation similar to that of the Heimdal moraine in the Warwick-Tokio area and probably reflecting a similar bedrock topographic grain, has no streamline features associated with it.

(c) The drift in the Warwick-Tokio area, as far as can be seen in numerous road cuts and from numerous drill-hole samples, does not perceptibly differ here from other places in the Devils Lake region which lack streamline molded forms. Factors such as an increased stony or clayey character of the drift, which might cause differences in degree of resistance to erosion, once deposited, or degree of plasticity ("moldability"), thus do not seem significant.

(d) At first glance the configuration of the bedrock in the Warwick-Tokio area seems important. Some of the isolated morainal areas in the outwash are known to be cored with bedrock. Probably most of them are. However, as far as can be determined from road cuts and other exposures in the field, neither the individual flutings nor drumlins seem to have individual cores of bedrock which might have served as starting points for accretion. A gross relationship exists but that is all. The obvious thought here is that the "highs" in the bedrock may have influenced the velocity or local thickness of the ice, possibly critical factors in the origin of these features. But bedrock "highs" are common in other morainal areas in the Devils Lake region as found by test drilling. For example, in a high place in the moraine north of the city of Devils Lake, bedrock was found by test drilling with a cover of drift only about 13 feet thick.

(e) The Pierre shale bedrock, as found in cores and drill cuttings, is fairly uniform from place to place in the Devils Lake region, and like the drift, exhibits no easily discernible differences in the Warwick-Tokio area. Variations in the erodibility of the bedrock are more likely attributable to topographic position rather than changes in the lithology.

(f) The topography just prior to the deposition of the last drift is almost impossible to reconstruct. Ice of several glacial stages prior to the Wisconsin, and several substages of the Wisconsin probably covered the area at different times (see drift border maps in Flint, 1955, fig. 27; 1957, fig. 20-1). Buried weathered zones in the drift, outlining the previous surface, were not found either in surface exposures or in drill hole samples. Presumably any older drift immediately below the latest was at least superficially removed. In the geologic sections (fig. 4) it may be seen that any older drift in many places must have been stripped off down to the bedrock by the erosive action of the ice or flushed out by meltwater. In view of the comparatively small width of the ridges and drumlins it is unlikely that as yet unobserved centers of accretion of smaller size would have been preserved. An imponderable factor here, though, is the influence of the older topography on the velocity and local thickness of the ice, regardless of the possible preservation of portions of the older drift surface as centers of accretion.

As far as can be determined from the available surface and subsurface information, there seem to be no clearly discernible, critical differences among the glacial and bedrock features in the Devils Lake region that would account for the presence of the drumlins and related streamline features in the Warwick-Tokio area.

The writer would like to suggest that recourse must be had to "something" in the now vanished ice. In working out the origin of drumlins and related streamline features we perhaps should shift the emphasis from the investigation of given rock we can now see to hypothetical conditions in the ice to account for their occurrence. To point up the necessity for reorientation of our thinking, let us consider the fact, discussed previously, that the drumlin *form* seems to some extent to be "available" in a variety of materials, and combinations of materials. Thus molding or extrusion of till may be locally important in their origin. On the other hand, erosion or carving of till, stratified drift, and bedrock may be the dominant processes in some places. Combinations of these processes probably are necessary for drumlins composed of several materials. The suggestion here is that when the conditions within the ice are present for making drumlins and related features they are formed, seemingly, regardless of the materials available. Flint (1957, p. 68-69) says " . . . there is a complete gradation, independent of outward form and within a single field, from rock to drift. This suggests that any one group was molded contemporaneously under a single set of conditions." The continuum of streamline forms would probably indicate variations away from the conditions necessary for the formation of drumlins. Now the writer does not mean to imply that drumlins will be formed regardless of the conditions of the given terrain and rocks, but that when a nice balance between the ice, and the terrain and materials is struck and certain unknown conditions are met, the drumlins will be formed. If the conditions vary other streamline molded forms will be made. The writer would hesitate to extend this idea to the finest members of the continuum, namely striations and small flutings.

Up to now the only hypothesis which has stressed "something" in the ice has been the one of Flückinger's as popularized by von Engeln. This is an unsatisfactory hypothesis. What appears to be needed is a hypothesis of this *type*.

ACKNOWLEDGMENTS

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References

Aronow, Saul, 1955, Problems in late Pleistocene and recent history of the Devils Lake region, North Dakota: Ph. D. thesis, Univ. of Wisconsin.

Atwood, W. W., 1940, The physiographic provinces of North America: Boston, Ginn and Co.

Charlesworth, J. K., 1957, The Quaternary era: London, Edward Arnold Ltd., v. 1.

Colton, R. B., and Lemke, R. W., 1955, Drumlins in North Dakota: Geol. Soc. America Bull., v. 66, p. 1673 [abstract].

Demorest, Max, 1938, Glacial movement and erosion—a criticism: Am. Jour. Sci., v. 237, p. 594-605.

Easker, D. G., 1949, The geology of the Tokio quadrangle: N. Dak. Survey Bull. 24.

Fenneman, N. M., 1938, Physiography of the eastern United States: New York, McGraw-Hill Book Co., Inc.

Flint, R. F., 1955, Pleistocene geology of eastern South Dakota: U. S. Geol. Survey Prof. Paper 262.

———, 1957, Glacial and Pleistocene geology: New York, John Wiley and Sons, Inc.

Gravenor, C. P., 1953, The origin of drumlins: Am. Jour. Sci., v. 251, p. 674-681.

Hoppe, Gunnar, and Schytt, Valer, 1953, Some observations of fluted moraine surfaces: Geografiska Annaler, v. 35, p. 105-115.

Horberg, Leland, and Anderson, R. C., 1956, Bedrock topography and Pleistocene glacial lobes in central United States: Jour. Geology, v. 64, p. 101-116.

Lemke, R. W., 1954, Revised interpretation for the origin of linear glacial ridges in north-central North Dakota: Geol. Soc. America Bull., v. 65, p. 1380 [abstract].

———, 1958, Narrow linear drumlins near Velva, North Dakota: Am. Jour. Sci., v. 256, p. 270-283.

Simpson, H. E., 1912, Physiography of the Devils-Stump Lake region, North Dakota: N. Dak. Geol. Survey, 6th Bienn. Rept., p. 101-157.

———, 1929, Geology and ground-water resources of North Dakota: U. S. Geol. Survey Water-Supply Paper 598.

Smith, H. T. U., 1943, Aerial photographs and their applications: New York, Appleton-Century-Crofts, Inc.

Tetrick, P. R., 1949, Glacial geology of the Oberon quadrangle: N. Dak. Geol. Survey Bull. 23.

Thornbury, W. D., 1954, Principles of geomorphology: New York, John Wiley and Sons, Inc.

Thwaites, F. T., 1946, Outlines of glacial geology: Ann Arbor, Mich., Edwards Bros.

Upham, Warren, 1896, The glacial lake Agassiz: U. S. Geol. Survey Mon. 25.

von Engeln O. D., 1938, Glacial geomorphology and glacial erosion: Am. Jour. Sci., v. 35, p. 426-440.