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THE ORIGIN OF DRUMLINS

CONRAD P. GRAVENOR

ABSTRACT. Theories on the origin of drumlins are grouped as either depositional or erosional, and the merits of these theories are discussed. The fact that many drumlins have a small amount of clay and contain stratified materials makes the depositional theory untenable. It is believed that a modification of the erosional theory will fit the known facts on drumlins.

INTRODUCTION

ALTHOUGH several theories have been advanced to account for drumlin formation, there is still difference of opinion on their origin. Essentially there are two ideas: first, drumlins are formed by the erosion of pre-existing drift; second, they are depositional in origin. Recently the latter theory has gained much favor even though it does not explain fully drumlins of extreme composition (Flint, 1947, p. 121-126). The depositional theory has been applied to only those drumlins which are made up almost entirely of till, and the erosional theory is left to explain those drumlins which clearly have been formed from pre-existing drift or rock.

The purpose of this paper is to review briefly some of the better-known theories and to sum up the facts known about drumlins. It is considered that a modification of the erosional theory best fits the known facts.

DEPOSITIONAL THEORY

In general the depositional theory states that drumlins are formed by the progressive deposition of drift. However, there is a lack of agreement on the factors that determine the start of accumulation. Russell (1895) suggested that since ice under pressure behaves as a plastic solid the introduction of debris into this plastic mass will decrease the rate of flow. At certain points excessive amounts of debris stop ice flowage, and hence nuclei are formed. Ice, containing smaller amounts of debris, which passes over these nuclei will deposit material and form drumlins. An examination of the excellent drumlin sections on the south shore of Lake Ontario led Slater (1929) to believe that in this case a till core initiated the drumlin accumulation.

Chamberlin (1883, p. 306) found that some drumlins have rock cores and from this intimates that a deeply hidden rock boss is usually and perhaps universally the determining cause of the accumulation. Crosby (1934, p. 150-151) concluded that some of the drumlins in the Boston basin area have rock cores. From a study of the drumlins of central British Columbia Armstrong (1949, p. 14) inferred that the nuclei were knobs of frozen till and the drumlins were built up from these knobs. Alden (1918, p. 253-256) found that few of the drumlins of Wisconsin have rock cores and consequently suggested that the radial spreading of ice developed transverse stresses which, although not actually creating longitudinal crevasses, may have induced localized piles or ridges of drift which were later shaped into drumlins.

The concentric layering of material found in a few drumlins has led many geologists to believe that drumlins have been built up by successive additions of clayey till (Alden, 1918; Goldthwait, 1924, p. 91-96; Flint, 1947; and Fairchild, 1929). Fairchild suggested that "the accretion was because of the greater friction between clay and clay than between clay and ice."

The theories of Millis (1911) and Upham (1892) differ from the accretion theory, but fall into the depositional class. Millis suggested that material accumulated in crevasses which were enlarged by melting. Then as the remaining ice melted, drumlins were left. Upham believed that as the ice melted by ablation, englacial drift would appear at the surface in depression areas. When the ice "re-livened," this superglacial material again would become englacial as a stratum of drift. This englacial drift would be shaped into lenticular masses by ice movement and then let down either as a completed drumlin or as an accumulation point.

EROSIONAL THEORY

From an examination of the materials which form drumlins it is evident that many of them were formed from materials which were present prior to the ice advance. This has led to the belief that all drumlins were formed by erosion. Shaler (1889, p. 550-551) thought that the drumlins of New England were formed by two glaciations. The first glaciation provided an irregular till surface and the second scoured this surface

leaving the drumlins. Tarr (1894) found that rock drumlins and till drumlins have the same shape, and consequently he concluded that the same erosive process produced both types.

OBJECTIONS TO THE DEPOSITIONAL THEORY

Although drumlins with cores of bedrock or pre-existing drift are found, more often a central core is absent. While this fact demonstrates that for a drumlin to accumulate no pre-existing core is necessary, it does not disprove the depositional theory. Contrary to Alden's theory, Hollingworth (1931) found that drumlins were formed in regions where there was no radial spreading of the ice.

The presence of stratified materials in drumlins constitutes a more serious objection to the depositional hypothesis. Drumlins containing stratified materials have been recorded in most drumlin fields both in North America and Europe (Ebers, 1937; Deane, 1950; Alden, 1918; Hollingworth, 1931; Tarr, 1894; Upham, 1894; Slater, 1929). Although drumlins containing stratified materials have been described by many geologists, for the most part their origin has been ignored. Deane (1950, p. 12-14) suggested that stratified materials in drumlins indicate a readvance of the ice after each layer of stratified material was deposited. Tarr (1894) pointed out that flowing water could not exist under the great thickness of ice necessary to form drumlins. It seems reasonable that deep within an active glacier any openings which would give access to meltwater would be closed by plastic flow. If eskers and associated deposits are evidence of stagnation, then the time when meltwaters are flowing at the base of the ice is not the time of drumlin formation.

Although it has been suggested by Fairchild that accretion takes place because of the greater friction between clay and clay than between clay and ice, the writer has been unable to find quantitative data which would substantiate this conclusion. Many drumlins have been described which contain little or no clay. The drumlins of northern Saskatchewan, described by Sproule (1939, p. 102-103), are made up largely of sand. Mechanical analyses made by Goldthwait (1948, p. 9-11) of drumlin materials in New Hampshire show that the drumlins of that region contain an average of about 10 per cent clay and in one case the clay content was as low as 5 per cent. In southern

Ontario, Chapman (1951) has found that the drumlins are more numerous in loamy till than in clay till. Mechanical analyses of drumlin materials of southern Ontario give an average of about 12 per cent clay (Chapman, 1951). Indeed most published analyses indicate that drumlins are sand-rich rather than clay-rich. In the states of Indiana and Illinois, where the tills generally contain more clay than those of southern Ontario and New England, no drumlins are found. Therefore it appears that clay is not necessary for drumlin formation.

Concentric banding, found in some drumlins, has been an important factor in the formulation of the depositional theory. However, it seems that this concentric banding is a rarity. Fairchild thought that the banding in the drumlins on the south shore of Lake Ontario was evidence of accretion, but Slater (1929) found that these bands consist largely of stratified materials. In many areas where the internal structure of drumlins has been investigated banding is absent (Hollingworth, 1931; Deane, 1950; Ebers, 1937). Alden (1918) suggested that a definite cleavage found in certain drumlins in Wisconsin could be accounted for either by accretion or by pressure effects.

The alignment of drumlins and their streamlined shape seems sufficient to discount the theory proposed by Millis. Tarr (1894) has objected to Upham's theory on the grounds that no evidence of shearing is found in drumlins. Another objection is the presence of so much englacial material in an ice sheet.

OBJECTIONS TO THE EROSIONAL THEORY

Objections to this theory have been outlined by Thwaites (1941, p. 43-45), but certain of these objections do not appear valid. Thwaites suggested that drumlins of the erosional type should be shaped like roches moutonnées; yet it is well known that drumlins formed from pre-existing materials have the same shape as till drumlins. Other objections advanced by Thwaites include the following:

(1) The stratified materials found in drumlins is unlike that found in kames.
(2) The width of drumlin belts (10-20 miles) exceeds that of most moraines.
(3) The drift in drumlins is apparently the same age as the surrounding drift.

While the second objection holds for most moraines of the Mississippi basin area it is not true of the wide morainic belts found over much of western Canada. The third objection is perhaps the most valid since in many areas where there are till drumlins there is no evidence of readvance of the ice.

MODIFIED EROSION THEORY

It is known that rock drumlins and drumlins carved from pre-existing materials are found in the same drumlin fields as those made of till (Tarr, 1894; Deane, 1950; Hollingworth, 1931; Shaler, 1889; Armstrong, 1949). Consequently it is reasonable to suppose that all these drumlins were formed at the same time and by the same process. During the past 80 years many facts have been learned about drumlins and any one theory should satisfy the following conditions:

(1) Drumlins may consist of (a) clay till, (b) sandy or loamy till, (c) rock, (d) pre-existing drift.
(2) They frequently have lenses and layers of stratified materials which sometimes are faulted and folded.
(3) Rock drumlins are found side by side with other varieties and have the same shape.
(4) Many glaciated regions do not support drumlins.
(5) They exist in fields wider than most moraines and rarely occur singly.
(6) They have a streamlined shape with the stoss end usually pointing upstream.
(7) Lamination may or may not be present.
(8) Some drumlins have cores but most do not.
(9) They are found behind terminal moraines which mark approximately the outer limit of the ice advance.
(10) Their long axes parallel the direction of ice movement.

Generally it is agreed that drumlins are formed under actively flowing ice and their form is one which offers the least resistance to ice movement. This assumption seems valid since it accounts for the position of the drumlins with respect to moraines, their alignment and streamlined shape.

The usual interpretation of the erosional theory is that during a retreat of the ice moraines are formed which are shaped by a later advance. It is the writer's belief that this retreat is not necessary. Upon the retreat of an ice sheet moraines are formed which mark stationary positions of the ice. Is it not possible that during the advance of an ice sheet the rate of

movement would vary? If this were the case there should be evidence of "moraines of advance." However, such surface irregularities would be shaped by the over-riding ice and would not be recognizable as moraines.

Where the ice advance is more rapid and the material distributed homogeneously throughout the ice a relatively flat till plain is formed. Chapman (1951) found that the flat till surfaces of southern Ontario are scored with shallow grooves or "flutings." These flutings may result from the same process as that which formed the drumlins.

The complete process of drumlin formation can be outlined as follows:

(1) Masses of till and stratified materials would be deposited at the front of an advancing glacier if there was a temporary halt during the ice advance.

(2) Ice riding over this drift would erode and shape it and thereby produce drumlins.

Debris derived from this erosion and shaping eventually could move to the front of the ice and be redeposited either as "moraine of advance" or as terminal moraine. It is known that the second part of this theory is feasible since drumlins of erosional origin are found. Consequently all that is needed is an irregular surface of till with or without stratified materials. It is believed that such a surface can be formed during an ice advance.

Obviously, one other prerequisite to drumlin formation is a supply of drift. Consequently drumlins form best in the softer materials, such as shales and limestones, which are removed readily by glacial erosion.

Objections to the previously outlined erosional and depositional theories can be explained by this modification of the erosional theory.

(1) The absence of drumlins from certain regions of clay till can be explained by a relatively rapid ice advance.

(2) The lamination found in a few drumlins could be the result of ice pressure. Any clay minerals which are present would have preferred orientation as a consequence of the applied pressure, and this would give rise to a rough fissility in the till.

(3) Meltwater action at the front of the advancing ice would give rise to stratified materials.

(4) Although Thwaites pointed out that drumlin belts are much wider than most moraines, it should be realized that the nature of retreat is quite different from that of advance. During a retreat, wide intermorainal areas, covered by eskers, superglacial till, and related deposits, are left by the downwasting process. An advance would not produce these ablation areas since wasting would take place mainly at the front of the ice, and wider morainic belts would result.

(5) Thwaites also stated that the stratified material found in drumlins is unlike that found in kames. It may be pointed out that the bedded material in drumlins is quite similar to the stratified material found in ground moraine. It is thought that the origin of the stratified material found in ground moraine is similar to that postulated for drumlins.

(6) Where drumlins have been found with cores it is possible that during a slow advance any pre-existing irregularities would have a layer of till deposited on top of the obstruction and thus present the type of surface necessary for drumlin formation.

SUMMARY

Since some drumlins are made of pre-existing materials, it is known that erosion can produce a drumlin. It is believed that halts or a slow advance during the forward movement of a glacier can give rise to a wide irregular surface of drift which would be shaped into drumlins by the advancing ice.

This modification of the erosion theory is less intricate in its mechanics than those previously described. It avoids the necessity for two theories and offers adequate explanations for the known facts on drumlins.

The erosional theory is not acceptable in its present form because of the following objections:

(1) In many areas where there are till drumlins there is no evidence of readvance of the ice.

(2) Morainic belts usually are not as wide as drumlin fields.

(3) The stratified materials found in drumlins is unlike that found in kames.

The currently accepted depositional theory is untenable because of the following objections:

(1) Stratified materials found in drumlins could not have been deposited under a thick ice sheet.

(2) The accretion theory hinges on the idea that drumlins are clay-rich; however, descriptions and mechanical analyses show that many drumlins contain little or no clay.
(3) Many areas of clay-rich till do not support drumlins.
(4) The absence of nuclei and concentric banding from most drumlins.

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University of Alberta
Edmonton, Alberta, Canada