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Drumlins in North Dakota

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DRUMLINS
IN
NORTH DAKOTA
by
Lee A. Brouillard



A senior thesis
submitted to the faculty of the
Geology Department at the
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ABSTRACT

The term "drumlin" is of Gaelic origin being derived from druim, a word for a mound or rounded hill, and has been used in glaciological literature since 1866. But with the increased study of subglacial shear features the terminology has become very inconsistent. The glacially formed longitudinal ridges found in northeastern North Dakota can be referred to as either drumlins or drumlinized ground moraine depending on their size, shape, composition, and interpreted origin.

Most of the drumlins observed in North Dakota are cored with glacial outwash deposits but exceptions do exist. Drumlins cored with Pierre shale occur north of Langdon, North Dakota, and till-cored drumlin ridges are present south of Devils Lake, North Dakota. Longitudinal ridges that are generally less than 5 feet in height and made up entirely of till are present in many locations in northeastern North Dakota.

Based on limited field observations, a study of drumlin literature, and an application of several principles of soil mechanics, a model for the formation of drumlins cored with sand and gravel has been developed. Internal pore-water pressure, effective stress (intergranular stress on the sediment), load pressure of the overlying ice, and permeability of the sediment are taken into consideration. Shear strength of the sediment is a function of effective stress.

High pore-water pressure reduces the strength of the material.

If outwash from a previous ice advance contained channelized sand and gravel deposits (great permeability--rapid discharge capacity) surrounded by sediment with a large amount of silt and clay (slight permeability--slow discharge capacity), shear strength would be an important factor in erosion occurring during a second advance. A sand and gravel body with a greater effective stress would survive a shear stress that would erode the surrounding material. The sand-and-gravel-cored drumlin ridges could be the remnants of an advance where shearing forces eroded the surrounding sediment.

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INTRODUCTION

Drumlins have been observed and studied for many years, but still littled is known about them. The terminology that has developed in drumlin studies has become very confusing and has not aided to an understanding of the subject. An explanation of the drumlin-forming process is not a simple task because of the many variables involved. But a close look at the products of the process may give a clue to the most important variables.

TERMONOLOGY

The term "drumlin" is of Gaelic origin, being derived from druim, a word for a mound or rounded hill. It has been used in glaciological literature since 1866. In the Glossary of Geology (1972) "drumlin" is defined as a low, smoothly rounded, elongated and oval hill, mound, or ridge of compact glacial till, built under the margin of the ice and shaped by its flow, or carved out of an older moraine by readvancing ice; its longer axis is parallel to the direction of movement of the ice. It usually has a blunt nose pointing in the direction from which the ice approached and a gentler slope tapering in the other direction.

This definition takes into account composition, form, and origin. But a variety of other forms, compositions and origins differing from this definition have been termed drumlins by some authors. For example, Lemke (1958, p. 278) argued that the long narrow ridges cored with stratified drift near Velva, North Dakota, be termed "drumlins." These drumlins have average length-to-width ratios of about 60 to 1 and are paralleled by shallow grooves. Irregular multiple elongated ridges have been described from Finland by Gluckert (1973) and northwest England by Hollingworth (1931) and termed "drumlins" (Sugden and John, 1976, p. 238).

Some authors prefer to call glacially formed long linear ridges fluted ground moraine or drumlinized ground moraine

instead of drumlins. Prest (1968) made a distinction between fluted ground moraine (where the ridge crests are at the same level as the adjacent ground moraine surface) and drumlinized ground moraine (where the ridges stand above the general level of the ground moraine surface) (Sugden and John, 1976, p. 238).

Concerning composition, not all drumlins are composed of compact glacial till. Gravenor (1953, p. 676) pointed out that drumlins containing stratified materials have been recorded in most drumlin fields both in North America and Europe. It has been suggested by some authors, for example R. F. Flint (1971), that drumlins can consist of a wide variety of material, ranging from almost entirely solid rock to entirely drift (Embleton and King, 1975, p. 409).

The origins described in the given definition are by no means undisputable. There are almost as many theories of drumlin formation as there are drumlins! This definition does imply the two main groups of theories of drumlin formation: one supporting an erosional origin for drumlins and the other supporting a depositional origin.

Drumlins vary considerably in most of their major characteristics, such as elongation, spacing, size, and material, but they have one essential feature in common. This feature is their streamlined form. Terms and phrases used to describe drumlin's streamlined shape include snowshoe-shaped hills, cigar-shaped ridges, basket-of-eggs topography, whalebacks, half-ellipsoid ridges, and topographic forms resembling the inverted bowls of spoons.

Clayton and Moran (1974, p. 100) believe drumlins belong to a family of glacially sheared forms including "rock drumlins," "roches moutonnees," "crag and tail," "flutings," "fluted ground moraine," "glacial grooves," and "striations." They chose to refer to these forms as longitudinal shear marks.

In the following discussion I will refer to the forms found in North Dakota as either "drumlins" or "drumlinized ground moraine." The forms referred to as "drumlins" conform to accepted characteristics of drumlins as pointed out by Lemke (1958, p. 277) although they do not fit the ideal definition. The following considerations support this definition: (1) They are orientated in the direction of ice movement as indicated by the fact that they lie transverse to washboard moraines. (2) Their stoss ends are higher than their tapering lee ends. (3) They are extremely parallel and linear over distances of several miles. (4) They have a streamlined form.

The forms with the following characteristics will be referred to as drumlinized ground moraine: (1) The ridges stand above the general level of the ground moraine surface. (2) They are composed entirely of unstratified drift. (3) They are paralleled by linear grooves in the surrounding ground moraine. (4) They are generally less than 5 feet high.

STUDY AREA

Drumlins and drumlinized ground moraine are found only in the northeastern quarter of North Dakota. Their major occurrence is in the following counties: Cavalier, Walsh, Rolette, Pierce, McHenry, Benson, Eddy, Ramsey, Nelson, Stutsman, Larimore, Towner, and Emmons. After a study of air photos and topographic maps of these counties locations of the best possible exposures were visited (Fig. 1).

Drumlins in Cavalier, Pierce, McHenry, Benson, and Eddy counties were studied because of their abundance and the good exposures in road cuts revealing their internal composition.

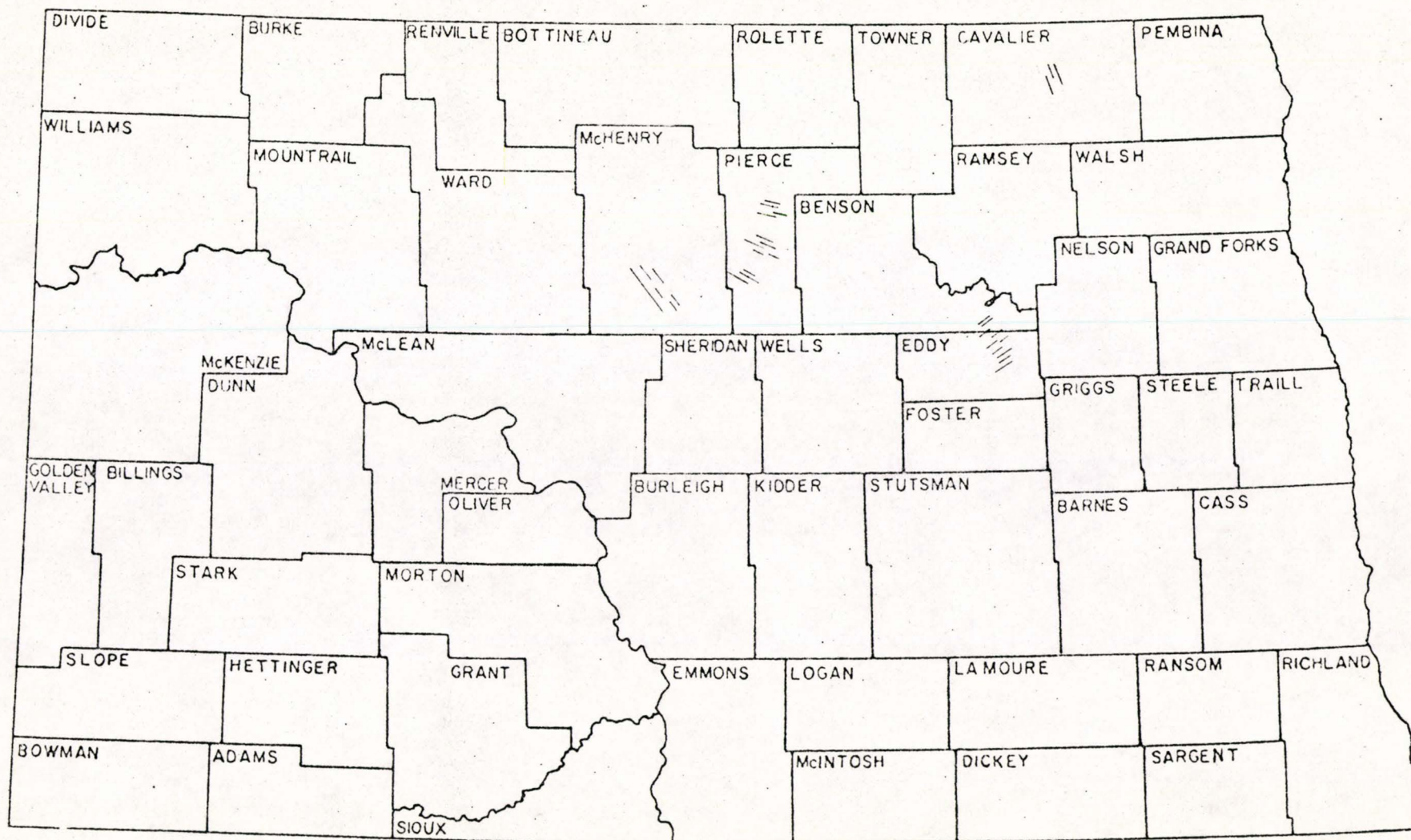


Fig. 1 Location of Drumlins studied in North Dakota.



DRUMLINIZED AREA

COMPOSITION

Most of the drumlins observed in the study area were cored with stratified drift. Internally they consisted mainly of sand and gravel. Drumlins north of Langdon, North Dakota, were augered by Arndt (1975) and found to be cored with bedrock (Pierre shale). Till-cored drumlins were observed south of Devils Lake, North Dakota. All the drumlins observed were covered with a layer of till (see Table 1).

Drumlinized ground moraine was encountered in the study area but exposures were very limited. Lemke (1958) reported the ridges less than 5 feet in height in the Velva area to be composed chiefly of till. This seemed to be the case in the study area, but augering should be done for a better indication of internal characteristics. The origin of the material in the drumlinized ground moraine is unknown.

TABLE 1

Internal Composition and Surface Material of
Drumlins in the Study Area

<u>Drumlin Location</u>	<u>Internal Composition</u>	<u>Origin of Material</u>	<u>Surface Material on Drumlin</u>
Voltaire Quadrangle SE $\frac{1}{4}$ sec. 11 T.153N. R.79W.	no exposure	-	upper 2 feet of till- pebbles with long axes in direction of ridge
Voltaire Quadrangle SW $\frac{1}{4}$ sec. 14 T.153N. R.79W.	no exposure	-	till with medium sized boulders
Voltaire Quadrangle NE $\frac{1}{4}$ sec. 14 T.153N. R.79W.	none bedded, fairly well sorted fine-medium sand	fluvial outwash	till with small boulders
Bergen Quadrangle NW $\frac{1}{4}$, SW $\frac{1}{4}$ sec. 32 T.154N. R.79W.	trough and tabular sets of fine-medium sand --finely laminated clay- silt beds --plane bedded gravels	fluvial outwash	till with medium sized boulders
Bergen Quadrangle SE $\frac{1}{4}$ sec. 36 T.153N. R.78W.	none bedded, well sorted fine-medium sand	fluvial outwash	till with small boulders

<u>Drumlin Location</u>	<u>Internal Compostion</u>	<u>Origin of Material</u>	<u>Surface Material on Drumlin</u>
Bergen Quadrangle SW $\frac{1}{4}$ sec. 23 T.153N. R.78W.	plane bedded fine sand mized with clay --plane bedded silt-fine sand	fluvial outwash	till
Balfour Quadrangle SW $\frac{1}{4}$ sec. 29 T.151N. R.77W.	plane bedded, poorly sorted gravel --plane bedded, well sorted fine-medium sand	fluvial outwash	till
Langdon East Quad. NE $\frac{1}{4}$ sec. 2 T.161N. R.60W.	no exposure --Pierre shale (Arndt, 1975)	marine	till with a high concentration of pebbles and cobbles, large amount of shale chips present
Langdon East Quad. SW $\frac{1}{4}$ sec. 26 T.162N. R.60W.	no exposure	-	" " "
Rugby Quadrangle NE $\frac{1}{4}$ sec. 29 T.156N. R.72W.	none bedded, fairly well sorted fine-medium sand --none bedded, fine-medium sand mixed with clay	fluvial outwash	till with a high concentration of pebbles and cobbles present
Balta Quadrangle NE $\frac{1}{4}$ sec. 29 T.155N. R.73W.	none bedded, fairly well sorted clay-silt-fine sand	fluvial outwash	" " "
Warwick Quadrangle SW $\frac{1}{4}$ sec. 24 T.150N. R.63W.	till- with angular medium sized boulders	thrust moraine or kame material	till with rounded medium sized boulders

SIZE AND SHAPE

Most of the drumlins in North Dakota are 1 to 3 miles long, 150 to 200 feet wide at their base, 5 to 15 feet high, steep sided, and sharp-crested. The average length-to-width ratio is about 60 to 1. They are only slightly asymmetrical in longitudinal profile (highest at their upglacier ends) and are symmetrical in transverse profile.

The largest and most conspicuous drumlin extends southeast for a distance of $13\frac{1}{2}$ miles from the Souris River at the town of Verendrye, North Dakota (Lemke, 1958).

LODGEMENT

Subglacial observations indicate that lodgement occurs when the frictional drag between clasts in traction and the bed over which they move is such that the force imposed on them by the moving ice is insufficient to maintain them in motion. When lodgement occurs against soft deformable materials such as sand or till matrix, it is ploughed up in front of the moving clast and progressively consolidated until it provides a large enough resistance to inhibit further movement (Boulton, 1974, p. 20). This plowing process may cause a general upglacial dip and parallelism to stones being lodged. Measurements of stone orientation in drumlins are of value as is the actual form of the drumlin and gives an independent indication of the direction of ice flow.

At the stoss end of one of the drumlin ridges observed in McHenry county (Voltaire quadrangle, T.153N., R.79W., sec. 11) a large concentration of stones within the upper 2 feet of the till had a noticeable lineation of their long axes in the direction of the ridge. H. E. Wright (1957), in a study of orientations of stones in the Wadena drumlin field of Minnesota, made similar observations (Embleton and King, 1975, p. 411). Nearly all the sites Wright examined showed stones in the upper few feet of till to have a major orientation trend parallel to the elongation of the drumlin. This suggests that the till was formed by accretion of basal material from the lowest

layers of the ice and that the stones were carried by basal sliding until lodgement occurred.

ORIGIN OF THE SAND AND GRAVEL
IN THE CORES OF DRUMLINS
IN NORTH DAKOTA

Most of the drumlins observed in northeastern North Dakota are cored with stratified drift and covered with till. A depositional environment that would account for the drumlins' sand and gravel cores will be considered (Fig. 2).

As the terminus of the ice sheet retreated back from its first advance, sediment was being deposited in an outwash plain in front of the ice. Material with a large amount of silt and clay was being deposited initially, and sand and gravel was deposited later. The coarse sediment was deposited in channels cut into the previously deposited fine-grained material in some areas. As the ice continued to melt back, alluvial fan deposits with channeled sand and gravel were left. Upon a second advance of the ice these alluvial-fan deposits were overridden, and drumlins cored with sand and gravel occurred where the channeled sediment existed. This type of depositional environment would account for the fact that the drumlins cored with sand and gravel in North Dakota are generally found in groups and only in certain areas.

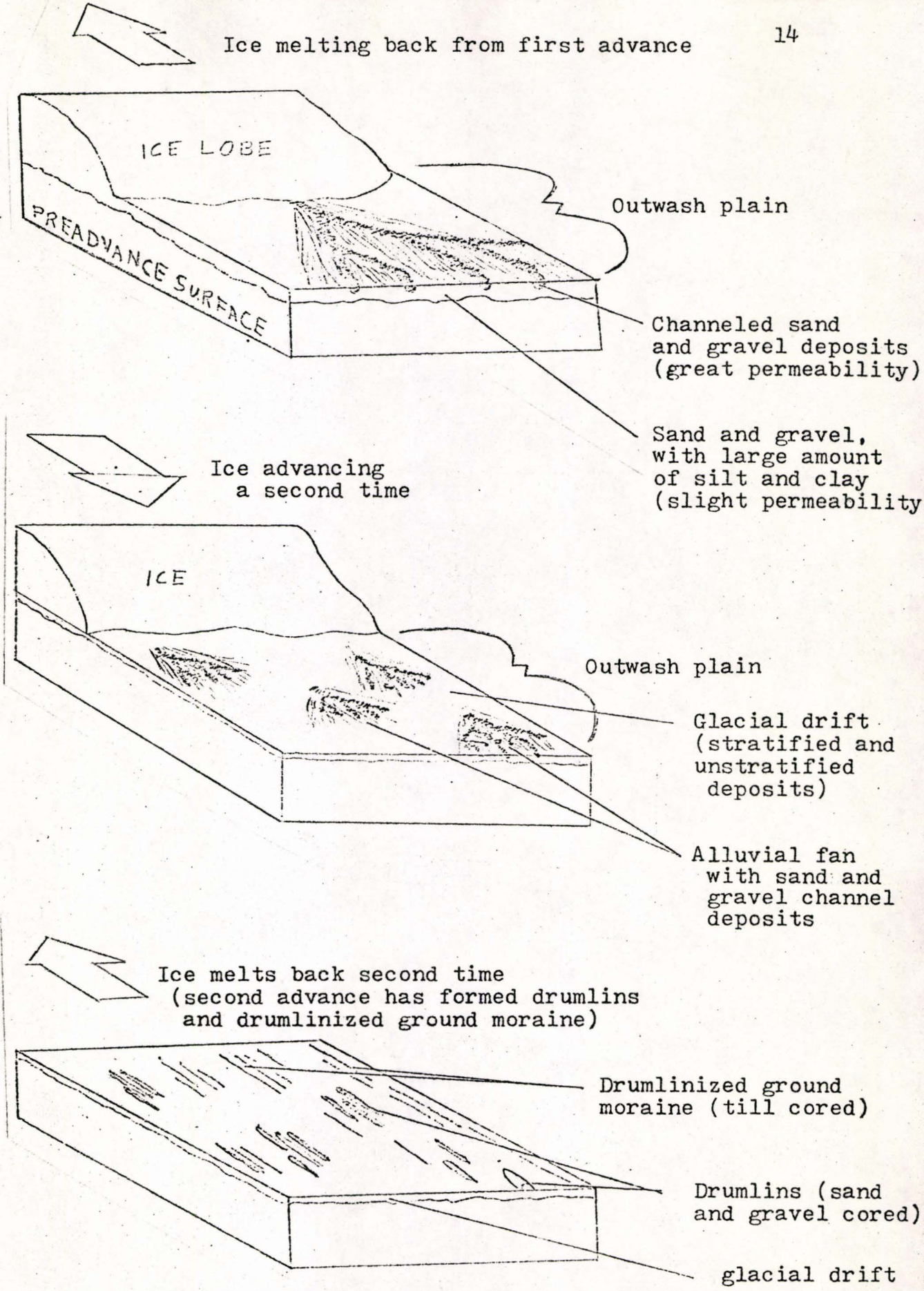


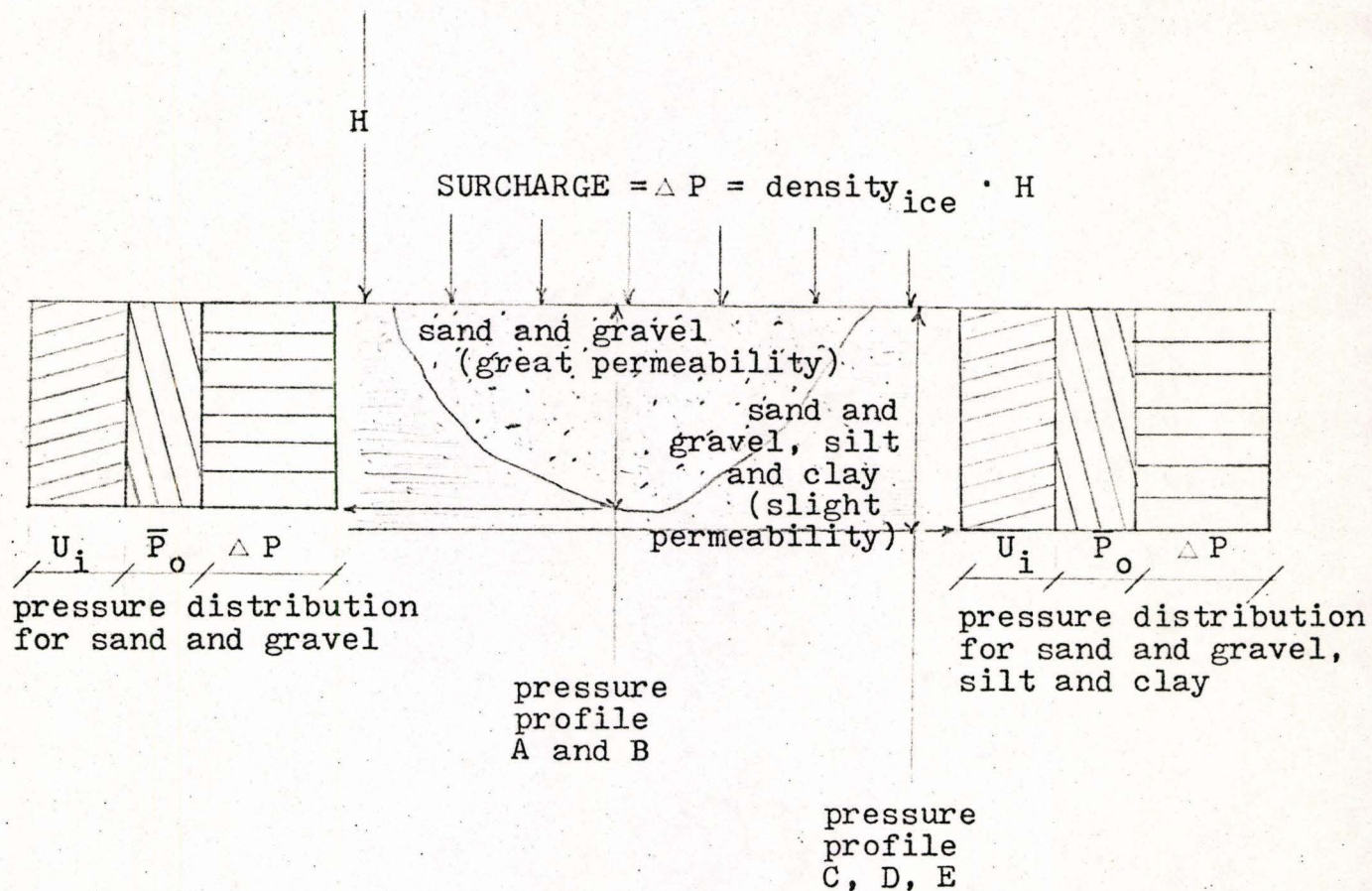
Fig. 2 Sequence of events in forming of drumlins.

PROCESSES RESPONSIBLE FOR
THE FORMATION OF DRUMLINS
WITH SAND AND GRAVEL CORES

The processes responsible for the formation of drumlins with sand and gravel cores can be explained by the use of several principles of soil mechanics. A diagrammatic representation is useful in understanding the mechanisms at work (see Fig. 3, 4).

The total pressure distribution under the ice sheet can be represented by three factions: (1) U_i , the initial pore-water pressure without the surcharge. (2) \bar{P}_0 , the initial effective stress (effective stress is the stress that exists between the grains). (3) ΔP , the surcharge or load pressure of the overlying ice. In the model the surcharge is assumed to be applied instantaneously at an initial time $t = 0$. The total pressure at any time can be divided up into the pore-water pressure plus the effective stress. At $t = 0$ all the surcharge or load pressure of the overlying ice is transferred to the initial pore-water pressure. ΔP causes excess pore-water pressure to develop. At some time $t = t_1$, the sand and gravel body having a great permeability relieves the excess pore-water pressure quickly and ΔP becomes part of the effective stress. The effective stress between the grains at this time has increased an amount equivalent to ΔP .

The sediment surrounding the sand and gravel channel



U_i : Initial pore-water pressure (without surcharge)

\bar{P}_o : Initial effective stress (intergranular stress)

ΔP : Surcharge or load pressure of overlying ice
(assumed applied instantaneously)

Fig. 3 Pressure distribution.

Pressure profile for sand and gravel channel

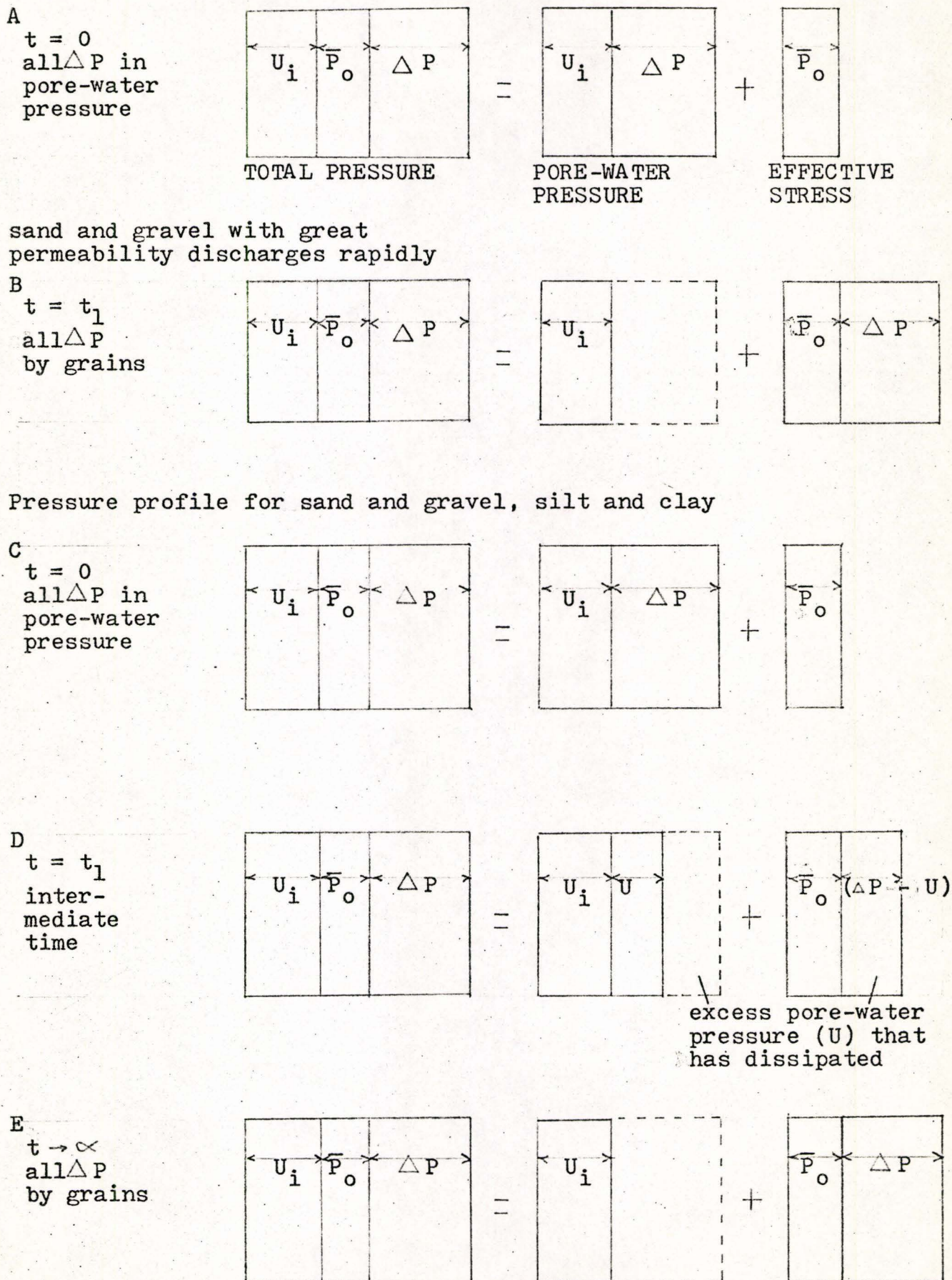


Fig. 4 Variation in pressure distribution with time.

deposits has a large amount of silt and clay, giving it a slight permeability and slow discharge capacity. At $t = 0$, the pressure distribution is the same as for the sand and gravel. But at $t = t_1$, the sediment is not able to relieve its excess pore-water pressure quickly, and excess pore-water pressure is still present. The amount of ΔP that has dissipated as excess pore-water pressure is taken up in the effective stress. Eventually as $t \rightarrow \infty$ all the excess pore-water pressure is reduced and ΔP is added to the intergranular stress.

Shear strength of the sediment is a function of the effective stress. The higher the effective stress the greater the shear strength of the material. At $t = t_1$, the sand and gravel channel deposits have a greater shear strength than the surrounding sediment. A shear force exerted by the ice at this time could be resisted by the sand and gravel body, but it would erode the surrounding sediment. The channeled sand and gravel deposits would remain as a ridge or drumlin as the surrounding sediment was being eroded (Fig. 5).

Excess pore-water pressure reduces the frictional force at the ice/bed interface (Boulton, 1974, p. 14). As excess pore-water pressure is reduced, frictional forces and conditions for lodgement are increased. As pore-water is dissipated by an hydraulic gradient towards the snout of the ice or by some other mechanism, frictional forces are increased. Lodgement of till on top of the sand and gravel ridges could have occurred simultaneously with the erosion of the surrounding sediment.

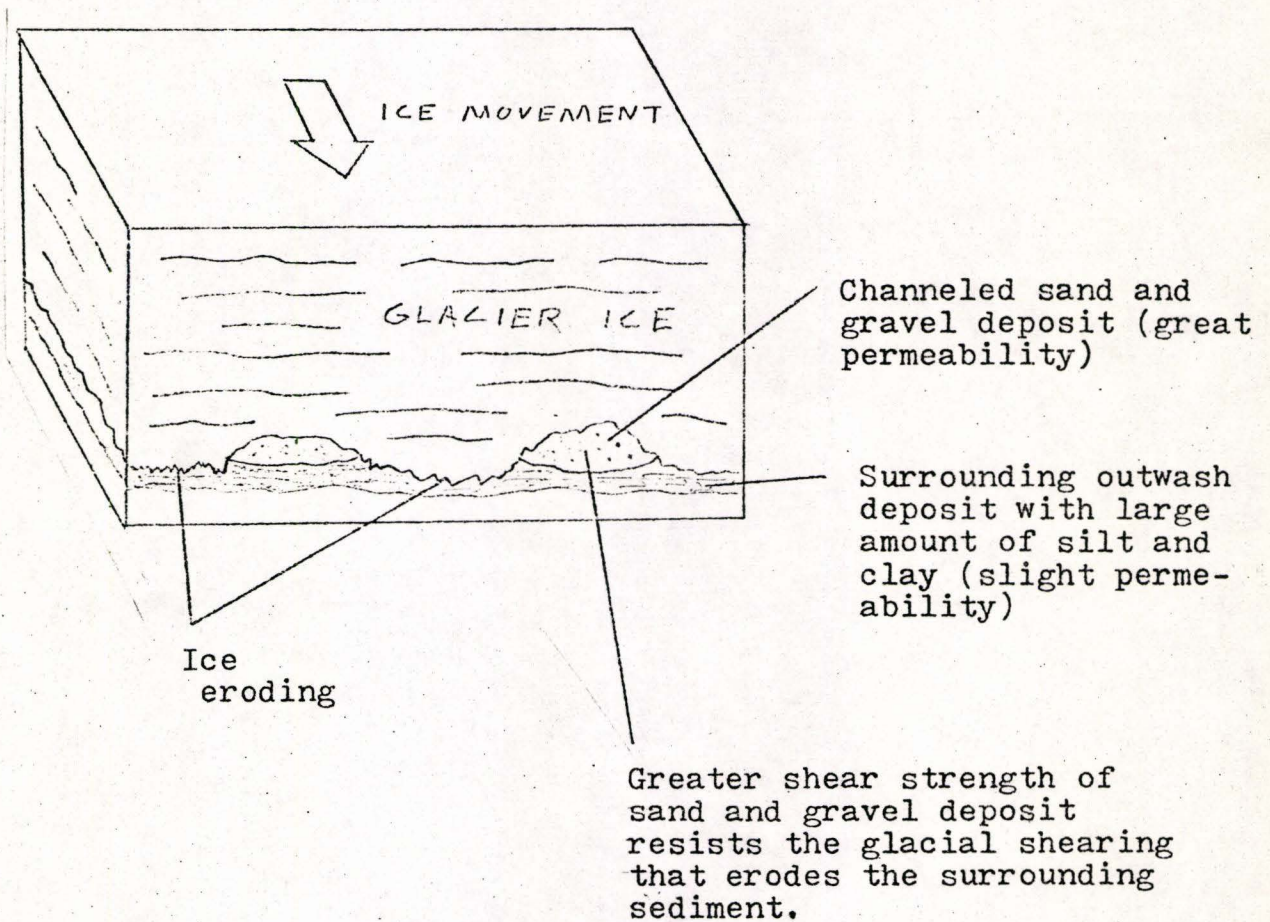


Fig. 5 Formation of drumlin by erosion of surrounding sediment.

DISCUSSION

Internal characteristics of drumlins are an important clue to the processes responsible for their formation. More augering and sampling of drumlins in North Dakota would aid to a better understanding of the processes responsible for their formation. The study of drumlinized ground moraine in North Dakota is an area where much work still needs to be done.

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