THE STRATIFIED NATURE OF DEPOSITS IN STREAMLINED GLACIAL LANDFORMS ON SOUTHERN VICTORIA ISLAND, DISTRICT OF FRANKLIN

Project 830018

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Sharpe, D.R., The stratified nature of deposits in streamlined glacial landforms on southern Victoria Island, District of Franklin; in Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 365-371, 1985.

Abstract

The structure of streamlined landforms near Cambridge Bay, Northwest Territories, suggests that these major glacial deposits may be produced by deposition from subglacial meltwater. Fluted landscapes are spatially gradational to drumlin features, which in turn are transitional to large eskers, all comprising stratified deposits including interbedded sand and diamicton. These sediments are intact, interbedded, and conformable with the landform, and they probably represent accumulation in a subaqueous environment. Both drumlinoid and fluted forms could result from meltwater eroding subglacial cavities that were subsequently filled with sediment from the meltwater and from the glacier.

The implications of the proposed meltwater origin of streamlined landforms are that landform-sediment descriptions are crucial to mapping glacial sediments and that interpretation of the glacial geology and sediments of many areas needs to take into account the significance of subglacial meltwater deposition.

Résumé

La structure des formes de relief fuselées que l'on trouve près de Cambridge Bay, dans les Territoires du Nord-Ouest, semble indiquer que ces importants dépôts glaciaires sont, peut-être dus aux apports des eaux de fonte sous-glaciaires. Un modelé en cannelures passe horizontalement à des drumlins, puis à de larges eskers; toutes ces formes sont constituées de dépôts stratifiés qui renferment du sable et du diamicton interstratifiés. Ces sédiments sont intacts, interstratifiés et conformes, et ils résultent probablement d'une accumulation de matériaux dans un milieu subaqueux caractérisé par de faibles tensions. Pour expliquer les formes drumlinoïdes et cannelées des dépôts, on pourrait émettre l'hypothèse que les eaux de fonte ont érodé des cavités sous-glaciaires qui ont par la suite été remplies de sédiments déposés par les eaux de fonte et par les glaciers.

Si les eaux de fonte sont effectivement à l'origine des formes de relief fuselées, les descriptions des modelés et des sédiments assument alors une importance capitale pour l'étape de cartographie des dépôts glaciaires et les interprétations de la géologie et des sédiments glaciaires de nombreuses régions doivent tenir compte du rôle important des eaux de fonte glaciaires dans le dépôt des sédiments.

Introduction

Fieldwork carried out to map the glacial geology on southern Victoria Island, Northwest Territories, during the summers of 1983 and 1984 has concentrated on understanding the origin of distinct glacial landforms (Sharpe, 1984). Relationship between form and the enclosed sediments has been investigated for till plains, hummocky moraine, end moraine, drumlins, and fluted surfaces. As measured sections in drumlins and fluted terrain were obtained around Cambridge Bay, Victoria Island, these two landforms will be emphasized in the present report.

Much of Victoria Island is covered by streamlined glacial landforms (Fig. 47.1).

This report describes the measured sections from fluted terrain and drumlinoid features mapped in southern Victoria Island. Data from measured sediment sequences are used to show that current views on the origin of streamlined glacial forms do not explain the landforms studied in this report. An origin of deposition that considers stratified and interbedded sequences in drumlins (Shaw, 1983) and fluting to have been deposited by subglacial meltwater is tested using field mapping from the Cambridge Bay area, Victoria Island.

The geomorphic setting

The sections studied are located 50 km north of Cambridge Bay (Fig. 47.1). One set (field sites 76, 78, and 79) lies in a field of longitudinal ridges described as drumlinoid features (Fig.47.2). Most of the drumlinoid ridges are straight crested, 10 to 25 m high, and 500 to 2000 m long. Slightly sinuous ridges (esker or drumlinoid) intersect a large main esker system at right angles. Thaw erosion of the landscape has modified up to a third of the terrain, and this is now largely covered by lakes. In addition, it appears that chains of low-lying areas, which cut across the fluted landscape and terminate at the large esker, are former tunnel valleys. Much of the remaining landscape consists of a poorly formed ridged surface that has been thaw eroded. The transitional relationship between the drumlinoid landscape, eskers, and a field of drumlins can be seen in Figure 47.3.

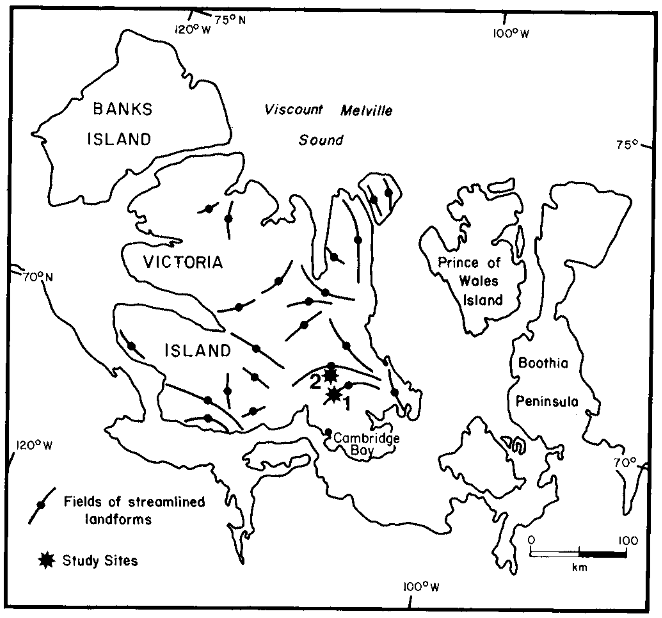

Figure 47.1. Location of study sites (1, 2) and fields of streamlined landforms on Victoria Island.

The geomorphic setting for the second set of sites (115, 118) is an overall level upland on which longitudinal ridges occur (Fig. 47.4). One third of this terrain has also been eroded by thaw slumping. The pattern of ridges and the longitudinal ridges themselves, are more clearly defined than at study site 1 and almost all are straight crested. The fluted ridges are 5-8 m high whereas the underlying glacial sediments are 40-50 m thick in places, with the inter-ridge area comprising a level upland plain. Many other excellent exposures, besides the measured ones, (110, 111, 115A, 118, 118B, and 119; Fig. 47.4) occur on the margins of the thaw eroded terrain. The relationship between the fluted terrain, esker system, and drumlin field is shown in Figure 47.5.

The exposures in drumlinoid forms (76, 78, 79) have diamicton facies associated with them whereas the exposures in fluted forms (115, 118) are dominated by sand strata and contain little or no diamicton. Most of the diamictons are considered to be glacial drift deposited as debris flows.

Drumlinoid landscape

Section 76

This sequence of sediments consists of three major units exposed in the end of a drumlinoid ridge (Fig. 47.6). The lower diamicton (A) comprises sandy silt pebbly beds 10-25 cm thick, interbedded with the overlying sand. The contacts between diamicton and sand units are conformable. The lower part of unit B consists of rippled, medium sand (B1) overlain by irregularly crossbedded pebbly sand (B2). Massive sand units (B3), including several normally graded sand strata 15-20 cm thick, occur next, overlain by ripple-bedded sand near the top of the unit (B4). Minor faulting (possibly related to thaw erosion) has resulted in small displacements. The sand is capped by a 1.5 m-thick massive cobbly sandy silt diamicton (C) that has a nonerosional interbedded contact with the underlying sand unit. The section represents the upper 9 m of a drumlinoid ridge that stands about 20 m at its crest, sloping to 15 m near the flank; thus the section represents a significant part of the total landform thickness.

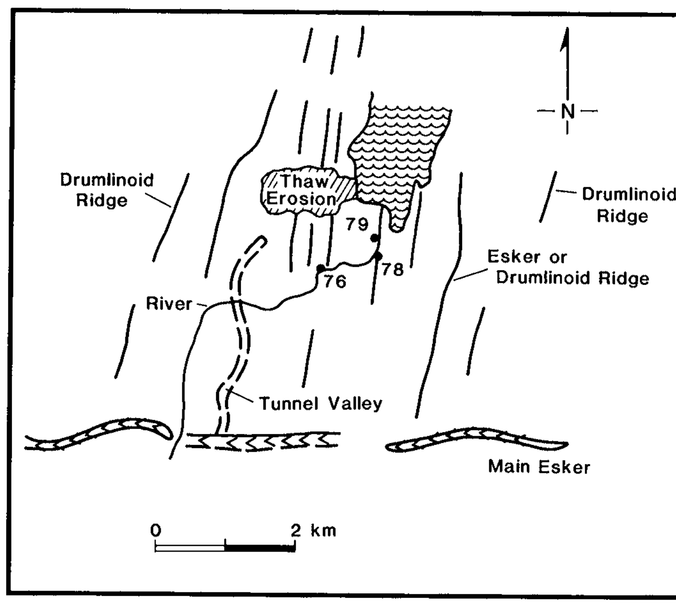

Figure 47.2. Location of sites (76, 78, 79) in drumlinoid landscape. See Figure 47.1 (study site 1) for location on Victoria Island and Figure 47.3 for aerial view of adjacent landforms including main esker and drumlin field in the distance.

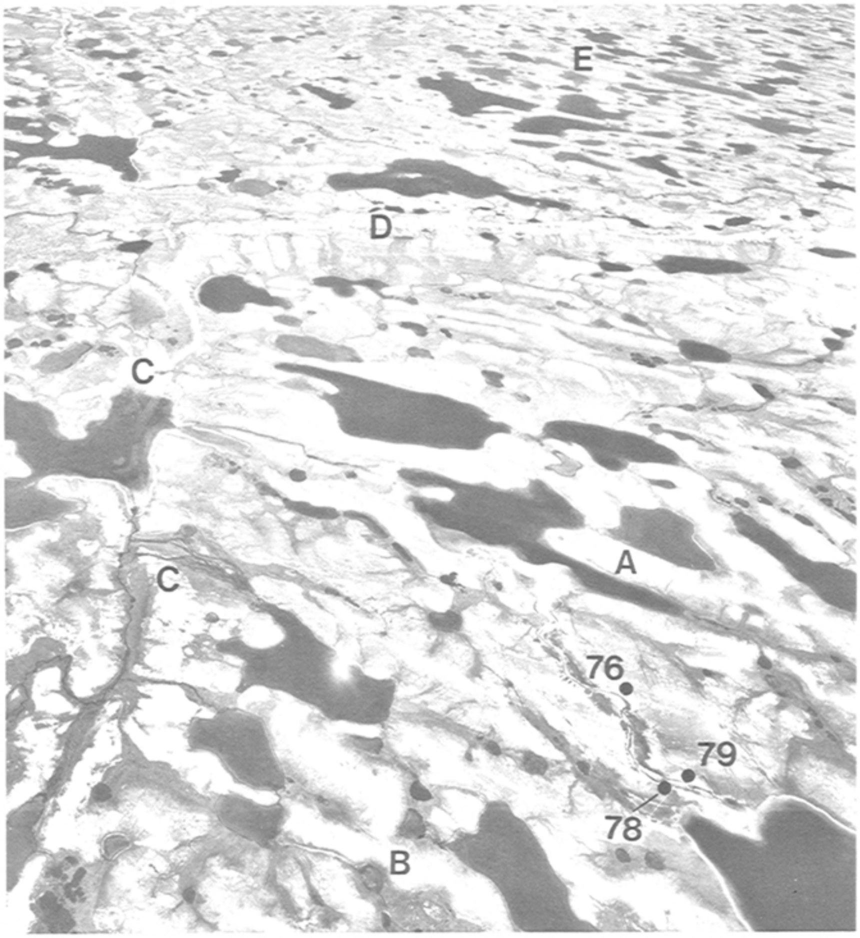

Figure 47.3

Aerial view (oblique) of drumlinoid landscape (A), drumlinoid or esker (B), trunk esker (C) and main esker (D) and relationship to field of drumlins (E), near study site 1, Figure 47.1. (NAPL T466L-120)

There are adjacent exposures in this landscape although they are not part of the same drumlinoid ridge in which section 76 was recorded, but they are in similar and contiguous features.

<u>Section 78</u>

This section is exposed on a drumlinized ridge or on the flanks of the drumlinized terrain, adjacent to section 76. Section 78 reveals predominantly massive sand (A, C_3), interrupted by a series of minor debris flow units (Fig. 47.7). The bedding in the section is inclined at 5-10° to the south indicating some postdepositional settlement of all the strata. The lowest unit (A) consists of sand with minor pebbly sediment and the unit is faulted. The faults, however, are bounded by the next unit of interbedded sand and debris flow diamictons (B). This is followed by a fining-upwards pebbly sand (C_1 and C_3). The upper part of the unit consists of a series of (pebbly) sand beds, massive to faintly bedded and stratified, and interbedded with these are fine textured diamictons. A cryoturbated colluvial sand unit (D) forms the top metre of sediment exposed in this 7 m section.

<u>Section 79</u>

This section was measured in a river bank cut into drumlinoid landscape eroded by a lake-drainage event. The section consists of eight units: stratified diamicton and sand, massive to banded sand, gravelly sand, rippled sand, gravelly sand, massive diamicton, soil, and slope debris (Fig.47.8).

The lowest unit (A) is a stratified diamicton with a graded sand bed separating the two massive segments; the contact is conformable and possibly gradational with the

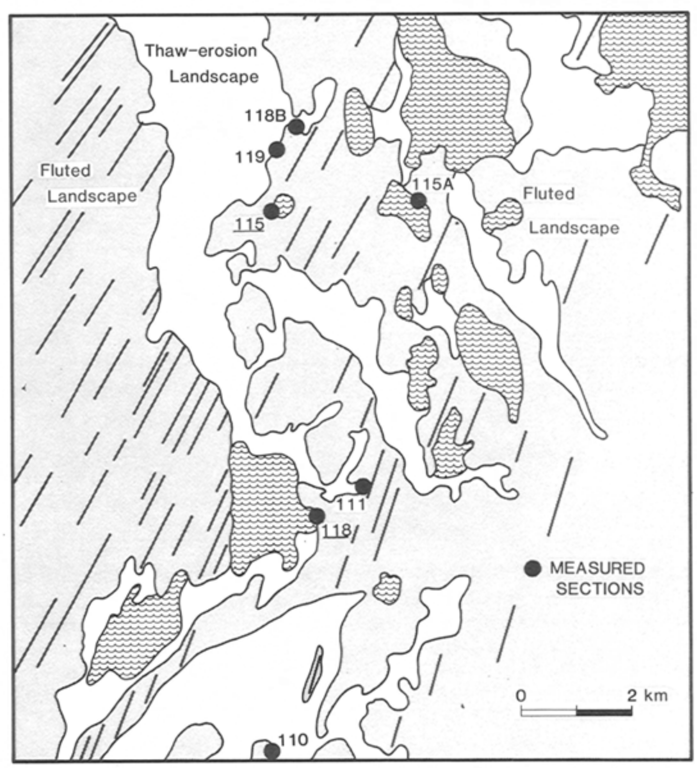

Figure 47.4. *Location of reported sites (115, 118) and other measured sections in fluted landscape. See Figure 47.1 (study site 2) for location on Victoria Island and Figure 47.5 for aerial view of adjacent landforms.*

Figure 47.5. *Aerial view (oblique) of fluted landscape (A), thaw-eroded landscape (B), esker complex (C), and drumlin field (D) near study site 2, Figure 47.1. (NAPL T466L-126)*

overlying diamicton. There is a sharp contact to the overlying massive to weakly banded sand (B). This sand coarsens upwards to gravelly sand (C) and is overlain by a rippled sand (D_1). A sharp, erosional contact marks the pebbly, massive and unsorted sand (D_2). This is overlain by a sandy silt diamicton (E) with an irregular contact and by a soil horizon consisting of organic-rich sand and silty sand. The top of the sequence is a slope deposit (F) consisting of a greenish marine silt with clasts included in the unit.

Summary and comments

In summary, the strata in sections 76, 78 and 79 represent a conformable, intact unfolded set of beds that probably represent essentially continuous deposition with minor current erosion. All the contacts are conformable as there are no angular unconformities nor apparent hiatuses in the sequence. All the strata are intact, with the exception of some minor faulting in section 78; similarly no evidence exists for deformation except in the top unit (D). There are many graded sand and massive sand units suggestive of rapid subaqueous deposition. The paucity of ripple structures indicates mass flow deposition of the sand. Therefore, an episodic but continuous subaqueous deposition of (pebbly) sand and unsorted debris is suggested.

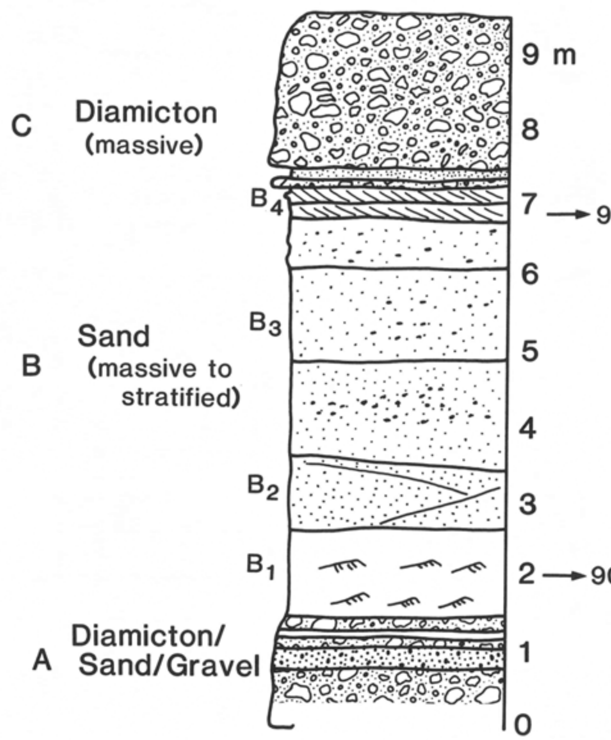

Figure 47.6. *Measured end section (76) in a drumlinoid ridge.*

Fluted landscape

Section 115

Section 115 is in a fluting occurring at the edge of a thaw lake on a level upland surface that has abundant longitudinal ridges or flutings (Fig. 47.4). The 7 m-high section exposes the sediments of this landscape (Fig. 47.9). One third of the area has been thaw eroded, exposing sandy sediments that have been wind eroded.

The lowest and thickest unit (A) is a sand sequence that comprises inclined, weakly to strongly bedded to massive sand and pebbly sand. In places the unit comprises 30-40 cm-thick beds of normally graded coarse to medium sand (A_1). The contacts appear to be gradational or at least they are not indicative of major erosion where they are not gradational. These sand beds are inclined about 15° to the north, and minor normal faulting affects the lowest unit (A_0).

A stone line (B) represents a lag from water or wind that winnowed a coarse layer which has subsequently been buried by slope and wind deposits. The top unit (C) has stones at the surface and organic material throughout the massive silty sand; the unit is interpreted as a combined slope movement and windblown deposit that forms a thin capping on the lower sand.

A similar sequence was observed in similar terrain about 5 km south of site 115.

Section 118

Much of the sequence comprises a sand unit (7+ m) that displays massive horizontally bedded, well sorted to pebbly sand and common normal grading (Fig. 47.10). Fine pebbly gravel is also common and it occurs as massive to well sorted or banded beds. Several striated clasts occur on the fluted upper surface. There are no major breaks in this sequence of

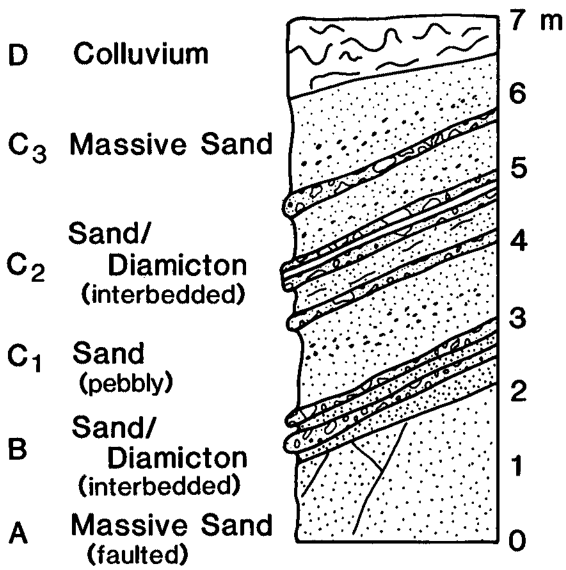

Figure 47.7. Measured side section (78) in a drumlinoid ridge.

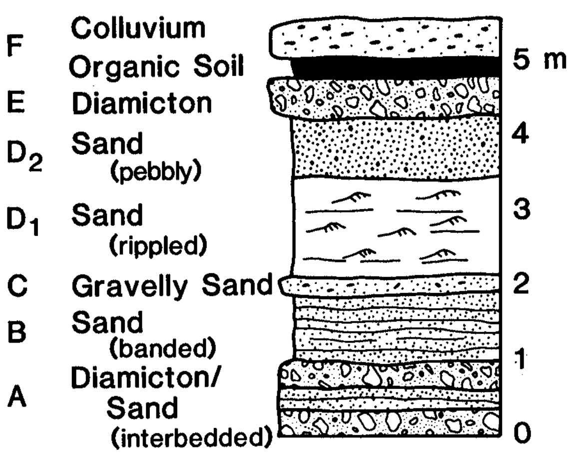

Figure 47.8. Measured side section (79) in a drumlinoid ridge.

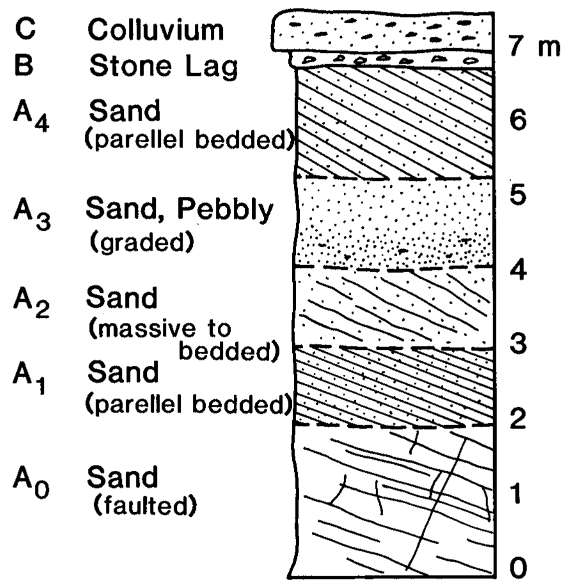

Figure 47.9. Measured section (115) in fluted landscape.

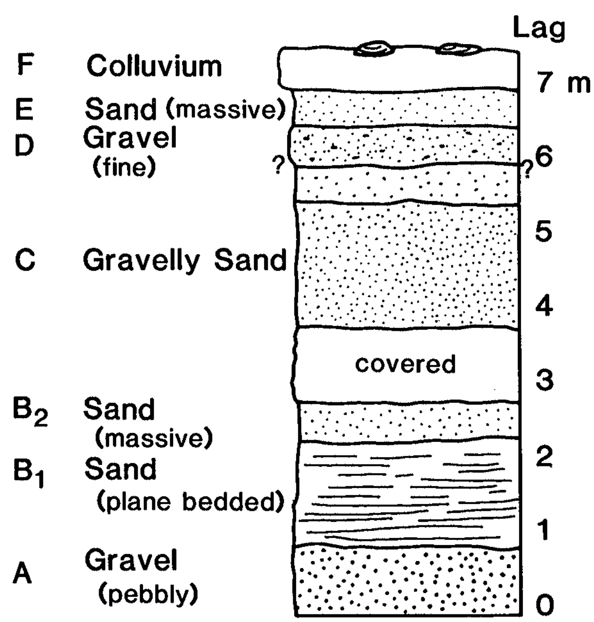

Figure 47.10. Measured section (118) in fluted landscape.

sand and gravel and this seems to indicate continuous sedimentation. Few structures occur in the sequence but no deformation is evident in the structures that are present.

Summary and comments

Additional sections were measured within the fluted terrain (sites 110, 111, 115A, 118B, 119, Fig. 47.4). Except for section 110 these sequences, together with 115 and 118, consist almost entirely of sand with pebbles. The sand is massive with conformable and gradational contacts and common graded bedding. There are no or few traction current structures. Thus the most likely depositional environment is one with high rates of sedimentation from suspension. This can explain the occurrence of both graded and massive sand. A mass of sediment flowing by gravity into a subaqueous environment could also form the massive sand. In places (site 110) the sandy facies is interbedded with diamictons that are probably debris flow units. The fact that the above sections have clearly marked colluvial deposits on top rules out the possibility that the lower deposits were emplaced by slope failure.

The interpretation of the sediments exposed in the drumlinoid landscape and the fluted landscape is that they represent mainly aqueous deposition with little erosion or wholesale deformation. Debris units are taken to represent slumping in this subaqueous environment, from the accumulating sediments or directly from the glacier. These descriptions will be compared with the common views on the origin of drumlinized and fluted terrain.

Discussion of streamlined landforms

Current views on the origin of drumlins

Drumlins are commonly described as being composed of basal till, generally lodgment in origin (Smalley and Unwin, 1968; Menzies, 1979; Boulton, 1982). Various mechanisms of deposition have been proposed for a lodgment till including mechanisms of formation initiated by a pre-existing obstacle (Gillberg, 1976), deformation of subglacial material (Smalley and Unwin, 1968; Menzies, 1979), or englacial agglomeration (Gravenor and Meneley, 1958; Evenson, 1971; Shaw and Freschauf, 1973; Aario, 1977). Many of these mechanisms require deposition of debris under high glacially applied stresses. This is said to result in accumulation of massive, dense, thick subglacial till. One key test of these modes of emplacement would be evidence of high shear stress, deformation, flame or load structures, and drag folds (Whittecar and Mickelson, 1979). In the apparent absence of these features other modes of deposition should be explored.

Stratified sediment has been noted as a component of drumlins and is normally explained as a pre-existing sediment that has been overridden (Gravenor, 1953; Lemke, 1958; Goldthwait, 1974). While folding and faulting of some stratified cores (Slater, 1929; Whittecar and Mickelson, 1979) may attest to overriding, many stratified cores are not deformed (DeJong et al., 1982, Fig. 7) and therefore may not have formed in a high stress subglacial environment.

Dardis and McCabe (1983) have studied three sand-cored drumlins in Ireland and they concluded that sediment gravity flows filled subglacial cavities. The sands are undisturbed and they are overlain by various diamictons that appear to have been deposited at the same time as the adjacent sands.

This discussion indicates that drumlins are not necessarily or demonstratively produced by strong glacier flow. In fact, it may be that drumlin sedimentation occurred in stagnating ice where there was no sediment in the upper portions of the ice and where no ice marginal moraines were formed. Thus, a sequence of conformable, nondeformed stratified sediments may have aggraded beneath the glacier in water-eroded and sediment-filled cavities.

The meltwater origin of drumlins

An alternative hypothesis of drumlin formation by meltwater has been proposed by Shaw (1983) based on the analogy between the shape of drumlins and strikingly similar forms created by water erosion called flutes (Allen, 1969, 1971). Erosion marks are considered to form on the underside of glaciers by subglacial meltwaters that ultimately filled in the eroded cavity. An expected sediment sequence would consist of undisturbed stratified beds conformable with the landform. Deposition by water current and/or mass flows would result in interbeddded massive or stratified units and diamictons. These types of features were found in measured sections from a drumlin at Camden East, Ontario (Shaw, 1983). Muller (1974) considered that stratified sediment accumulated as an integral part of drumlin formation deposited within a cavity. Dardis and McCabe (1983) described complex drumlin sediments from Ireland that they consider to have formed in water-filled cavities associated with a major subglacial meltwater escape route. However, Muller concluded that it was difficult to explain the origin of the cavity, whereas Dardis and McCabe (1983) concluded that the sand cores and melt-out till facies were deposited before the drumlins were streamlined. Shaw (1983) has provided a mechanism for subglacial cavity formation and filling. This report discusses sediment sequences that were not deformed by a "streamlining" glacier, but more probably accumulated in place beneath an ice sheet.

The origin of fluted terrain

Hoppe and Schytt (1953) and Boulton (1976) believed that small-scale fluted terrain develops when till intrudes into tunnels that open up in the lee of an obstruction. Boulton considered that all true fluted terrain consists of lodgment till, particularly small-scale fluted forms related to boulder obstructions. Shaw and Freschauf (1973), however, considered that larger fluting formed by the redistribution of subglacial sediment by secondary flow cells. Jones (1982) combined a thrusting and streamlining concept (Moran et al., 1980) and secondary flow cells to explain glacial flutings in Alberta. Paul and Evans (1974) described flutes in stratified sands and considered them to possess bedded inclined structures that indicate upward movement of sediment within the flute.

None of the above features are found in the fluted terrain north of Cambridge Bay, Victoria Island. Here fluted terrain comprises undeformed sandy sediments (massive to graded) that apparently represent continuous sedimentation in a subaqueous environment.

It is speculated that inverted meltwater erosion marks (Shaw, 1983) may explain the Victoria Island fluted terrain by analogy to the water-eroded forms of Allen (1969, 1971). Allen showed experimentally that at lower discharges (than needed to form meandering, flute, or transverse marks), turbulent flow produces longitudinal erosion marks on clay beds. Thus it is possible that subglacial meltwater erosion of the glacier base produced a linear form that is filled with sands to obtain the fluted forms on Victoria Island.

Summary

The observed internal structure of drumlinoid and fluted landforms on Victoria Island does not correspond to the predictions of commonly presented theories on the origin of these forms. These theories hold that both drumlin and fluted forms develop when stress at the base of the glacier exerts enough pressure to deform pre-existing or basal sediment (till or stratified drift) into these streamlined forms. The observed strata on Victoria Island comprise intact, conformable, and interbedded massive sand, stratified sand, and diamictons that form sediment accumulations in subaqueous environments without deformation by high shear stresses. Shaw (1983) has proposed that meltwater-eroded subglacial cavities are probable sites for this deposition.

The implication of the stratified nature of streamlined landforms on Victoria Island is that current mapping techniques may provide misleading results if they do not include sediment descriptions of the landforms. The implication of the potential meltwater origin of streamlined landforms is that the apparent cross-cutting relationship of fields of streamlined landforms on Victoria Island (Fig. 47.1), which are located in depressional areas, may be more readily explained as subglacial drainage events (transverse forms of Allen, 1969) related to stagnating ice. Furthermore, our understanding of the glacial history of Victoria Island, and other similar glaciated areas, may need to be amended to take account of the significance of subglacial meltwater deposition.

Acknowledgments

Field logistics were well managed and supplied by Polar Continental Shelf Project and the DEW Line station at Cambridge Bay. Appreciation is extended to Adlair Aviation for air services and Terry Snelgrove and Wanda Sheldrick for helpful field assistance. I thank D.A. Hodgson, D.A. St-Onge and J. Shaw for their helpful comments on this paper.

References

Aario, R.
1977: Classification and terminology of morainic landforms in Finland; Boreas, v. 6, p. 87-100.

Allen, J.R.L.
1969: Erosional current marks of weakly cohesive mud beds; Journal of Sedimentology, v. 39, no. 2, p. 607-623.

1971: Transverse erosional marks of mud and rock: their physical basis and geological significance; Sedimentary Geology, v. 5, Special Issue No. 3-4, p. 167-385.

Boulton, G.S.
1976: The origin of glacially fluted surfaces – observations and theory; Journal of Glaciology, v. 17, no. 76, p. 287-309.

1982: Subglacial processes and the development of glacial bedforms; in Research in glacial, glaciofluvial and glaciolacustrine systems, ed. R. Davidson-Arnott, W. Nickling, and D.B. Fahey; Proceedings of the 6th Guelph Symposium on Geomorphology, 1980, Geo Books, Norwich, p. 1-33.

Dardis, G.F. and McCabe, A.R.
1983: Facies of subglacial channel sedimentation in late-Pleistocene drumlins, northern Ireland; Boreas, v. 12, p. 263-278.

De Jong, M.G.G., Rappol, M., and Rupke, J.
1982: Sedimentology and geomorphology of drumlins in western Algara, south Germany; Boreas, v. 11, p. 37-45.

Evenson, E.B.
1971: The relationship of macro- and micro-fabrics in till and the genesis of glacial landforms in Jefferson County, Wisconsin; in Till: A Symposium, ed. R.P. Goldthwait; Ohio State University Press, p. 345-364.

Gillberg, G.
1976: Drumlins in southern Sweden; Bulletin of the Geological Institutions of the University of Uppsala, New Series, v. 6, p. 125-189.

Goldthwait, R.P.
1974: Rates of formation of glacial features in Glacier Bay, Alaska; in Glacial Geomorphology, ed. D.R. Coates; State University of New York, Binghampton, New York, p. 163-185.

Gravenor, C.P.
1953: The origin of drumlins; American Journal of Science, v. 251, no. 9, p. 614-684.

Gravenor, C.P. and Meneley, W.A.
1958: Glacial fluting in central and northern Alberta; American Journal of Science, v. 256, no. 10, p. 715-728.

Hoppe, G. and Schytt, V.
1953: Some observations on fluted moraines surfaces; Geografiska Annaler, v. 35, no. 2, p. 105-115.

Jones, N.
1982: The formation of glacial flutings in east central Alberta; in Research in Glacial, Glaciofluvial and Glaciolacustrine Systems, ed. R. Davidson-Arnott, W. Nickling, and B.D. Fahey; Proceedings of the 6th Guelph Symposium on Geomorphology, 1980, Geo Books, Norwich, p. 49-70.

Lemke, R.W.
1958: Narrow linear drumlins near Velva, North Dakota; American Journal of Science, v. 256, no. 4, p. 270-283.

Menzies, J.
1979: A review of the literature on the formation and location of drumlins; Earth Science Reviews, v. 14, no. 4, p. 315-359.

Moran, S.R., Clayton, L., Hooke, R.L., Fenton, M.M., and Andriashek, L.D.
1980: Glacier-bed landforms of the Prairie Region of North America, Journal of Glaciology, v. 25, no. 93, p. 457-476.

Muller, E.H.
1974: Origin of drumlins; in Glacial Geomorphology, ed. D.R. Coates; State University of New York, Binghampton, New York, p. 187-209.

Paul, M.A. and Evans, H.
1974: Observations on the internal structure and origin of some flutes in glaciofluvial sediments, Blomstrandbreen northwest Spitsbergen; Journal of Glaciology, v. 13, no. 69, p. 393-400.

Sharpe, D.R.
1984: Late Wisconsinan glaciation and deglaciation of Wollaston Peninsula, Victoria Island, Northwest Territories; in Current Research, Part A, Geological Survey of Canada, Paper 84-1A, p. 259-269.

Shaw, J.
1983: Drumlin formation related to inverted melt-water erosional marks; Journal of Glaciology, v. 29, no. 103, p. 461-479.

Shaw, J. and Freschauf, R.C.
1973: A kinematic discussion of the formation of glacial flutings; Canadian Geographer, v. 17, p. 19-35.

Slater, G.
1929: Structure of drumlins on southern shore of Lake Ontario; New York State Bulletin of the New York State Museum, no. 281, p. 3-19.

Smalley, I.J. and Unwin, D.J.
1968: The formation and shape of drumlins and their distribution and orientation in drumlin fields; Journal of Glaciology, v. 7, no. 51, p. 377-390.

Whittecar, G.R. and Mickelson, D.M.
1979: Composition, internal structures and an hypothesis of formation for drumlins, Waukesha County, Wisconsin, U.S.A.; Journal of Glaciology, v. 22, no. 87, p. 357-371.