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QUATERNARY GEOLOGY OF THE BURNT HILL (NTS 2D/5)–GREAT GULL LAKE (NTS 2D/6) MAP AREAS IN SOUTHEAST-CENTRAL NEWFOUNDLAND

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ABSTRACT

A 1:50,000 surficial geology map for NTS map sheets 2D/5 and 6, and regional striation maps (1:250,000) that include NTS map sheets 1M/13 and 14 and 2D/5, 6, 11, 12, 14 and 15 have been completed. The glacial geomorphology of the area is highlighted by prominent straight parallel, crescentic to sinuous, and hummocky ridge terrains, each generally occurring in discrete areas. These ridges provide the basis for the surficial geology map, which contains units dominated by one of these ridge types or by outwash or bog.

Ice-flow history as interpreted from striations consists of an early southward flow across the entire area, followed by a later northeastward flow in the area north of Third Berry Hill Pond. Sediment investigations show, 1) straight parallel ridges are oriented parallel to southward striations and are interpreted to have been formed subglacially by that flow; 2) type I and II crescentic to sinuous ridges formed transverse to the southward flow by pushing along the ice margin or within ice-marginal joints; and 3) type III and IV crescentic to sinuous ridges appear to have formed as the result of northeastward ice flow over southward-oriented straight parallel ridges.

Deglaciation is interpreted to have occurred by stagnation of a large ice mass in the southern part of the area. Part of the contact between active southward- and later eastward-flowing ice, and the stagnant ice, is thought to occur along an eastward segment of the Northwest Gander River, north of Third Berry Hill Pond, across most of NTS map sheet 2D/6. Two types of hummocky terrain are interpreted for the area. One consists of relatively small, low (<3 m), sparsely occurring hummocks that are associated with all the map units. They were likely deposited during deglaciation by melt-out of mainly englacial debris. The other, consisting of thicker hummocky deposits (>3 m) that cover large areas, is interpreted to have formed by ice-marginal stacking of englacial and subglacial debris, where the active glacier pushed against the edge of the stagnant ice mass.

INTRODUCTION

The study area is located in central Newfoundland midway between Bishop's Falls and Milltown. Mapping of the surficial geology of the Burnt Hill (NTS 2D/5) and Great Gull Lake (NTS 2D/6) map areas (Figure 1) at a scale of 1:50,000 was completed during the 1988 field season, with limited follow-up excavation in 1989. During 1989, striation mapping (St. Croix and Taylor, *this volume*) was extended to the north. This project is a continuation of mapping begun in 1987 (Proudfoot, 1987, 1988) on Mount Sylvester (NTS 2D/3) and extends surficial mapping northward along the Gander River Ultramafic Belt. Extensive bog cover (greater than 50 percent) is a major hindrance to bedrock mapping and mineral exploration.

This study undertakes a systematic terrain- and materials-mapping survey and includes investigations of the regions geomorphology, ice-flow direction, sedimentology of surficial sediment, pebble lithology and glacial dispersion patterns. It provides a base for drift prospecting and furthering our knowledge of the regions Quaternary history. Prior to this, surficial geology was described by Jenness (1960), who

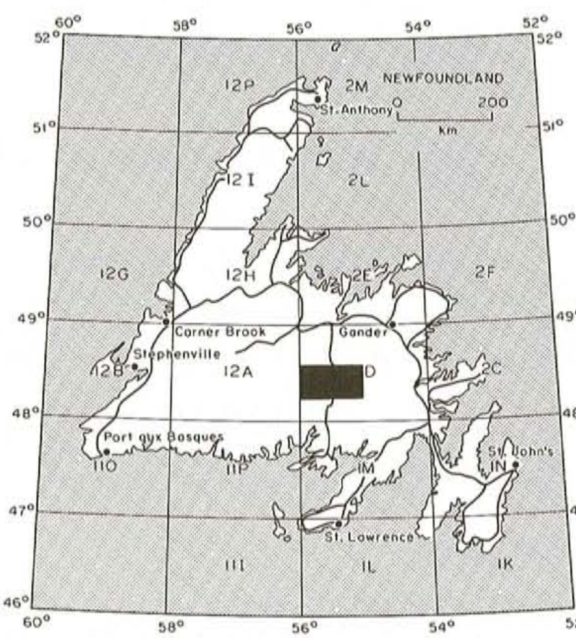

Figure 1. *Location of study area.*

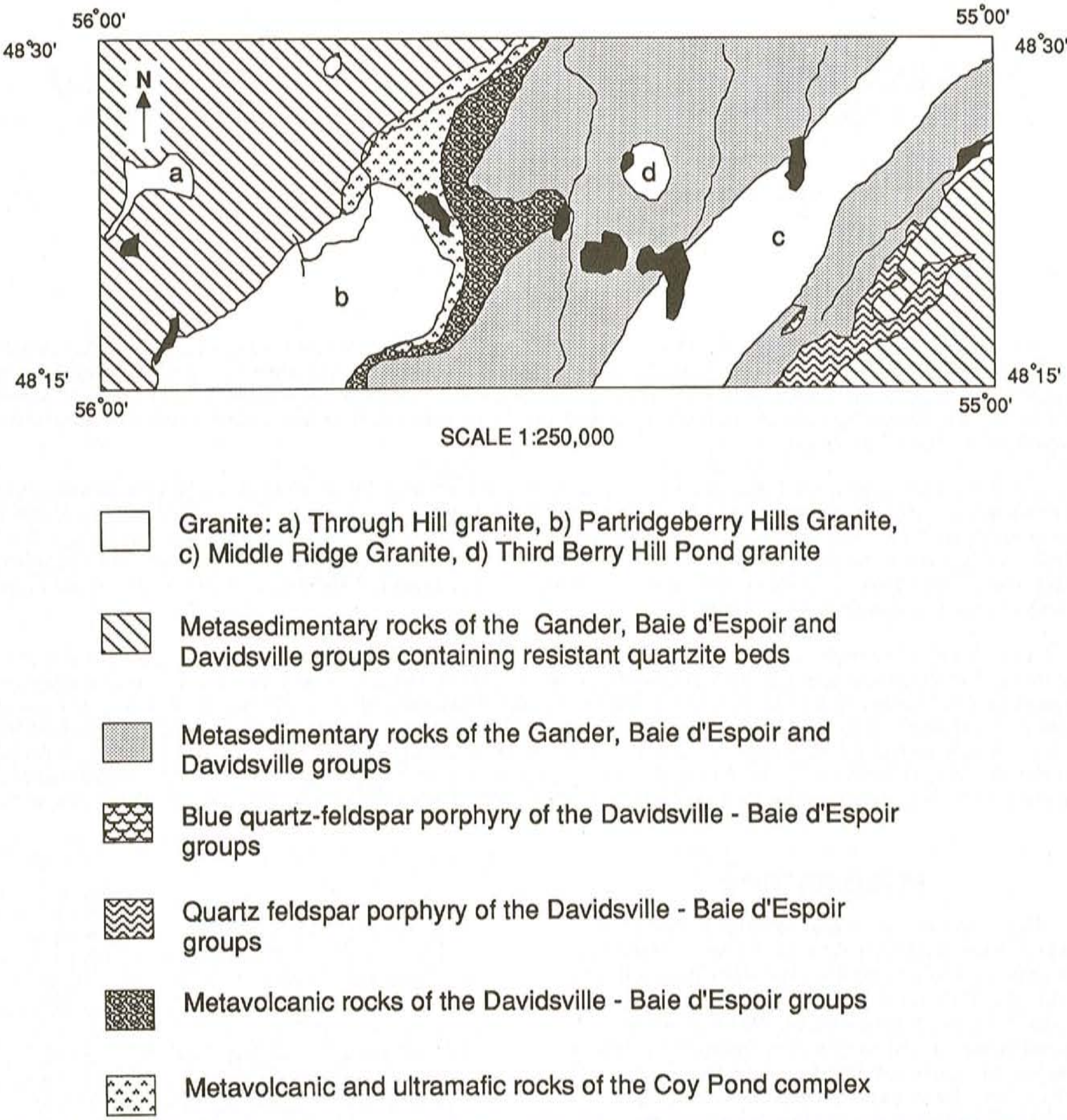

Figure 2. *Generalized geological map of the Burnt Hill—Great Gull Lake area showing major rock types (simplified after Blackwood and Green, 1982, and Colman-Sadd, 1985).*

produced a general map of the distribution of late Pleistocene glacial features and by Vanderveer (unpublished), who mapped surficial geology along the Bay d'Espoir Highway.

Bedrock Geology

The Burnt Hill—Great Gull Lake map area is underlain (Figure 2) by a northeast-trending sequence that includes Middle Ordovician or earlier ultramafic rocks, Ordovician to Silurian metasedimentary and metavolcanic rocks of the Gander, Davidsville and Baie d'Espoir groups, and Devonian granitic rocks (Middle Ridge and Third Berry Hill Pond granites; Blackwood and Green, 1982). In the Burnt Hill map area the northeastward bedrock trend is obscured by folding and faulting (Colman-Sadd, 1985). It is underlain by upper Cambrian to lower Ordovician metavolcanic and ultramafic rocks of the Coy Pond complex, and middle Ordovician metasedimentary and metavolcanic rocks of the Baie d'Espoir and Davidsville groups, and Siluro–Devonian granitic rocks (Through Hill and Partridgeberry Hills granites). Gold exploration has concentrated on ultramafic rocks of the Gander Group, particularly where they are in fault contact with the metasedimentary rocks, and on felsic volcanic rocks of the North Steady Pond Formation of the Baie d'Espoir Group (S. Colman-Sadd, personal communication, 1988). The area also contains a significant tungsten deposit within the metasedimentary rocks of the Baie d'Espoir Group (Great Gull Lake property of Falconbridge Limited) and there are occurrences of massive sulphides within the metavolcanic rocks (Meyer *et al.*, 1984).

Field Methods

Mapping was done by field checking of airphoto interpretation. Materials, sediment descriptions and sampling were conducted primarily using backhoe pits because of the sparsity of existing exposures. Access by truck is limited to the Bay d'Espoir Highway, an abandoned logging road south of Berry Hill Pond, and major logging roads along the north side of the Northwest Gander River and southwest of Great Gull Lake. Secondary logging roads and the power line that runs north–south across the Burnt Hill map area were traversed using all-terrain vehicles. Most of the area (75 percent) is accessible only by helicopter and pits in these areas were excavated by hand (1-m deep) or with a portable backhoe (Cricket Tow-Hoe), capable of digging to a depth of 1.8 m. In areas accessible by road, a skidder-mounted backhoe having a 3.5-m depth capability was used.

QUATERNARY GEOLOGY

Glacial Striations on Bedrock

Striations are formed when rock debris at the base of a glacier is dragged across bedrock. The regional distribution and orientation of glacial striations is shown on Figure 3. Most of these measurements were collected during the current study, supplemented from work by Vanderveer (unpublished), southeast of the Bay du Nord River (Proudfoot *et al.*, 1988). The main ice-flow direction across the area, as interpreted from striation data, was southward (160 to 190°). The northeastward ice flow, north of Jubilee Lake, and other deviations from the south, can be explained by the local topographic deflection of ice. North of Third Berry Hill Pond, there are numerous sites where north–south striations have been crosscut by striations that indicate a more recent northeastward to eastward flow (between 040 to 100°). There is no evidence to suggest two distinct glaciations. It is more likely that the northeastward flow occurred during the late glacial stages as ice-accumulation centres migrated.

The southward flow across the area changed from south-southeastward in the northwest to southward and southwestward near the south coast. It is likely that away from the coast, the southward flow was controlled by the slope of the ice surface. Near the coast, flow changed to follow the deep fiords that acted as ice conduits for the ice sheet.

The source for southward-flowing ice is not clear. Regional striation data to the north (St. Croix and Taylor, *this volume*) and west (Vanderveer and Sparkes, 1982) indicate that there is evidence for an extensive southward flow that may have originated as far north as the Long Range Mountains. In the study area, the subsequent northeastward flow originated to the west, possibly in the Meelpeag Lake area.

Surficial Geology

Map units

The characteristics of the ridge types described in this report are contained on Table 1 and the distribution of Quaternary geomorphic features is shown on Figure 4. The map presented in Figure 5 has five units. It is an interpretation based mainly on the data shown on Figure 4 and sedimentologic observations. The positioning of the geomorphic unit boundaries is based mainly on airphoto interpretation and can be drawn with confidence in some places (e.g., around areas of hummocky moraine), whereas in other areas, map-unit boundaries follow topography or are arbitrarily placed midway between adjacent areas that can be assigned to different map units.

Single hummocks and small hummocky areas that generally contain less than 3 m of sediment are scattered across most of study area, sitting on top of ridges that formed parallel and transverse to ice flow. Their areal extent is not large enough to map, but their existence is important to the interpretation of deglaciation in the discussion section at the end of this report.

In the following geomorphic map-unit descriptions, genetic interpretations are made. They are based on two different lines of evidence. First, the sediment has been studied at select locations, to a depth of 1.8 or 3.5 m, depending on the type of backhoe used. However, the interpretation based on the sediments examined does not necessarily provide an explanation for the origin of the geomorphic features in which they occur, because the features are commonly considerably larger than the depth of test pits. The second line of evidence used is based on geomorphic-feature genesis, using for comparison analogous/similar modern features and the processes that formed them (Boulton, 1972). The sediment and geomorphic evidence is then reconciled in the genetic interpretation of a map unit.

If the genesis of a landform is understood, then the likely sources and relative transport distances of sediment can be estimated. Thus, a landform produced by active ice at the base of an ice sheet (e.g., small crag and tails or flutings) may be mainly composed of relatively short-travelled sediment (Boulton, 1976, 1978). Batterson (1989), however, has shown that the stoss side of large crag-and-tail features (>30-m high) contain far-travelled material. He interprets this to be the result of the interception of englacial debris by high crags. For this to happen, the crag must extend far

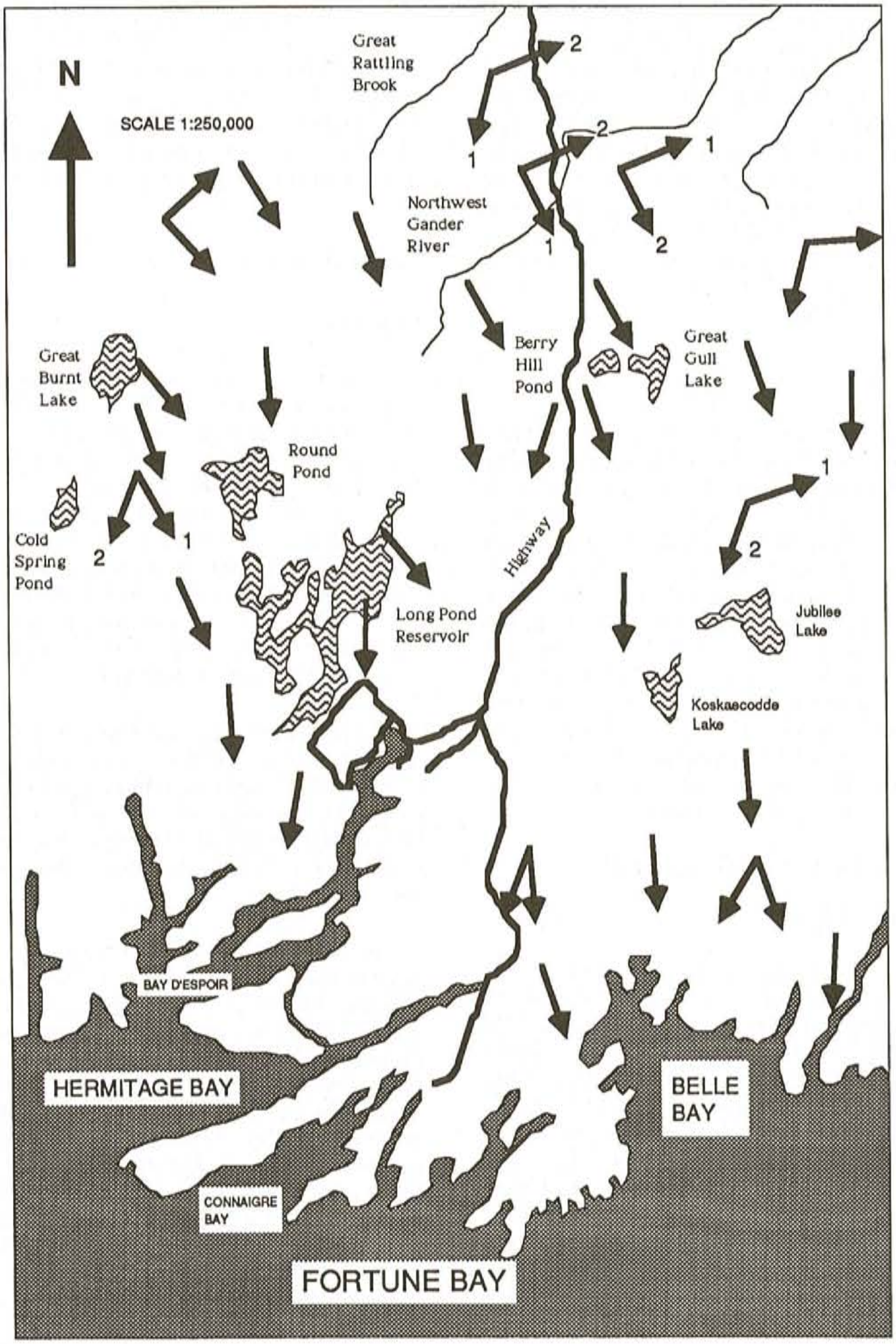

Figure 3. *Regional map showing glacial striations measured on bedrock surfaces (after Proudfoot* et al., *1988).*

enough up into the ice to pass through the basal debris zone and into englacial material. The height of the landforms described in this study are thought to be too low to intercept englacial debris, although there is no quantitative data to support this hypothesis.

Many landforms produced by melting-out are mainly composed of sediment transported englacially or supraglacially (Gravenor and Kupsch, 1958). This sediment rises relatively slowly up into the glacier as it is carried along, so that when it melts out of the ice and is deposited near the

Table 1. Distribution of geomorphic features in the study area

Plan view	Ridge Name	Dimension (height, length, width in m)	Spacing (m)	Texture	Map unit (Figure 5)	Plate
	straight parallel	(2-10, 200-1500, 50-200)	0-300	silty-sand diamicton	2	1
	Type I crescentic to sinuous	(5-15, 100-800, 50-100)	<20	pebbly silty-sand	3a	2
	Type II crescentic to sinuous	(5-15,50-500, 40-120)	80-250	silty-sand diamicton	3b	3
	Type III crescentic to sinuous	(2-10, 200-1500, 30-100)	50-300	silty-sand diamicton	3c	4
	Type IV crescentic to sinuous	(2-10, 200-2800, 30-100)	0-30	pebbly silty sand	3d	5

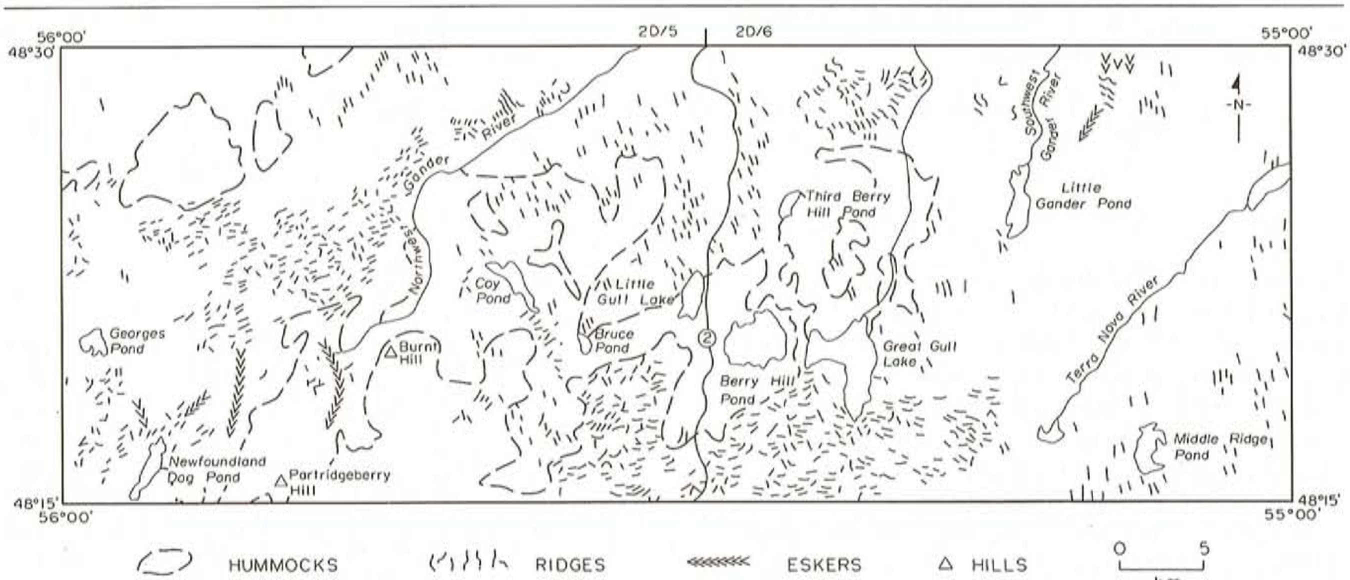

Figure 4. *Simplified map showing the distribution of geomorphic features. No attempt is made to distinguish ridge types. This map is intended to show ridge length, orientation, distribution and density of occurrence.*

glacier margin, it is likely relatively far travelled (Boulton, 1978). This mechanism may apply to hummocks found in the study area although other processes are also discussed.

Pebble Fabric

An analysis of the orientation of elongate pebbles in diamicton (pebble fabric) can provide clues to its genesis (Boulton, 1971; Lawson, 1979a,b; Dowdeswell and Sharp, 1986). At each site, the orientation of 25 or more pebbles was measured (trend and plunge), and the results plotted on Schmidt equal area projections. Studies of modern glaciers indicate that a relatively strong unimodal pebble fabric is formed by basal melt-out and lodgement depositional

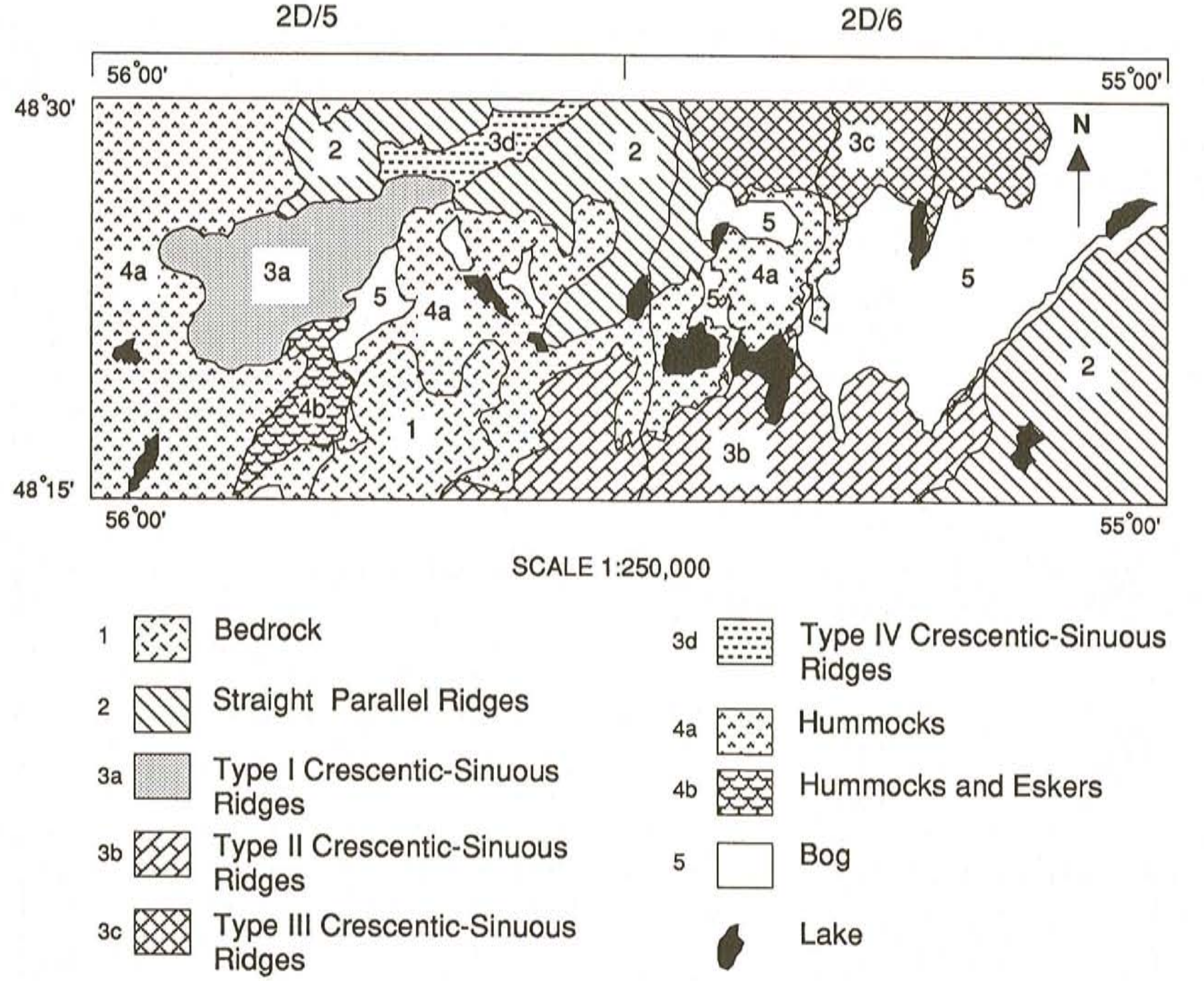

Figure 5. *Simplified surficial geology map.*

processes, whereas relatively weak fabrics are the result of melt-out from englacial and supraglacial positions (Dowdeswell and Sharp, 1986). The value S_1 for each fabric is a measure of the fabric strength (Mark, 1973). A value of 1 indicates the strongest possible orientation and values below 0.46 are weak (Dowdeswell and Sharp, 1986). Pebble fabrics are presented on Figure 6 as Schmidt equal area stereograms using the Kamb (1959) method. They were plotted using a commercially available program called Stereo™ (McEachran, 1989) on an Apple Macintosh microcomputer.

Unit 1: Bedrock

Areas of bare rock occur on the Partridgeberry Hills, Burnt Hill and east of Great Gull Lake. All bare-rock areas are associated with granitic bedrock, probably because these rocks lack sufficient nutrients to support vegetation. There are also numerous outcrops throughout the area that are too small to map at 1:50,000 scale (refer to maps by Colman-Sadd, 1985 and Blackwood and Green, 1982).

Unit 2: Straight Parallel Ridges

Straight parallel ridges (crag and tails and flutings) are 2- to 10-m high, 200- to 1500-m long and 50- to 200-m wide, having length to width ratios of greater than 5 to 1 (Plate 1).

This map unit is characterized by straight parallel ridges that extend as much as 10 m above the surrounding bog and bog covered lineaments; all the ridges are parallel and oriented at 170° ± 10° (Plate 1). Ridges are commonly partially or completely tree covered. Most of the map unit contains greater than 2 m of unconsolidated sediment cover.

Sediment Description. The near-surface sediment (<1.5-m thick) on ridge tops is commonly a moderately compact, silty to sandy diamicton containing small (<2-cm thick by 5-cm long) irregular sand and granule gravel lenses. In most places examined, the material below this depth within the ridges is a compact to highly compact, massive silty sandy diamicton having moderately to well-developed horizontal fissility. Some pebble fabrics measured below 3.3 m on 4

Plate 1. *Straight parallel ridges north of Little Gull Lake (from Newfoundland Department of Environment and Lands, NFLD. A 19830-37).*

ridge tops (e.g., Site 88895, Figure 6a) have strong preferred orientations (S_1=0.59 to 0.77 in 5 out of 7 fabrics). Preferred orientations range up to 40° from parallel to the ridge crest. In low areas between ridges, the sediment characteristics are similar to the ridge-top material. The near-surface, less compact diamicton between ridges, however, is thicker (about 2 m). Well-developed horizontal fissility was observed in several test pits between ridges at depths ranging between 1.9 and 2.2 m. At one site, a fabric having a bimodal distribution was measured (S_1=0.71, Site 88864, not shown on figure) at a depth of 2.2 m, overlying a sand bed that is at least 10-cm thick (unable to dig deeper).

Interpretation. The straight parallel ridges are crag and tails and flutings, and may have formed by subglacial deposition and moulding (Boulton, 1976), particularly down-ice of resistant quartzite ridges. This interpretation is based mainly on ridge geometry, their orientation parallel to striations on bedrock outcrops, the strong preferred orientation of pebble fabrics and the horizontal fissility and high degree of compaction of diamicton within the ridges. Strong fabrics that are parallel to ridge crests were likely produced by ice flowing over the top of the up-ice obstruction that caused the ridge to form (Boulton, 1975, 1976). Strong fabrics that are oriented obliquely to ridge crests could have formed as ice flowed around the up-ice end of the ridge or as it flowed into the lee side area (Boulton, 1976).

It is also possible that the straight parallel ridges were formed by squeezing of subglacial sediment into cavities that were eroded into the base of the ice by meltwater (Shaw *et al.*, 1989). The strong fabrics measured in the near-surface sediment of some of the ridges would thus be the result of subglacial moulding of sediment. The weak fabric measured at 3.3-m depth at Site 88896 (Figure 6a) may be the result of subglacial sediment flow, induced by squeezing of sediment into a cavity in the base of the ice (Boulton, 1976) or by melt-out. The near-surface, less compact diamicton containing sand lenses found on ridge tops was likely deposited from an englacial or supraglacial position by melt-out. This would account for the weaker fabrics and lower compaction (Boulton, 1971) found in some places. Where preferred orientations are high in near-surface diamicton, it is possible that the surface mantle of less compact sediment has been removed by slumping and water erosion, thus exposing more compact sediment.

In areas between the ridges, strong pebble fabric and horizontal fissility at depths greater than about 3 m are also interpreted to have formed, subglacially, by processes at the base of the ice. Diamicton found between ridges, and having low compaction and bimodal fabrics, is likely the result of sediment-gravity flows into low areas. This transfer of sediment to low areas may account for the apparent thicker accumulation of less consolidated sediment in these areas.

Subglacial landforms are likely to contain relatively short-travelled sediment (Boulton, 1976, 1978). Hence, sampling for drift-prospecting purposes should be from compact lens-free diamicton, below the less compact surface sediment on ridge tops, and in the low areas between them. Shallower samples should be avoided because of the potential that the surface cover may be composed of farther travelled material derived from above the base of the glacier.

Unit 3: Crescentic to Sinuous Ridges

Four types of crescentic to sinuous ridges have been identified in the study area (Table 1). They are differentiated by geometry and sediment composition.

Type I—subunit 3a. Type I crescentic to sinuous ridges are 5- to 15-m high, 100- to 800-m long, 50- to 100-m wide having a length to width ratio greater than 5:1, and generally occur less than 20 m apart (Plate 2).

This map unit is located west of the Northwest Gander River in the central part of NTS 2D/5. The crescentic to sinuous ridges lack tree cover and occur in contact with each other or singly, separated from others by as much as 300 m of low-lying ground that is commonly bog covered and contains abundant irregular ridges and hummocks.

Sediment Description. The pebbly silty sand is too well-drained to support forest cover. Detailed investigation using a small backhoe (four 1.5- to 1.8-m-deep pits per ridge) was carried out on 3 ridges within subunit 3a. These pits exposed poorly sorted pebbly silty sand containing small lenses (less than 1-cm thick) of moderate to well-sorted, fine and medium sand. It has a horizontal fissility about 1 m below the surface in a few sites and is more compact near the base of investigation pits. Pebbles are commonly striated and some

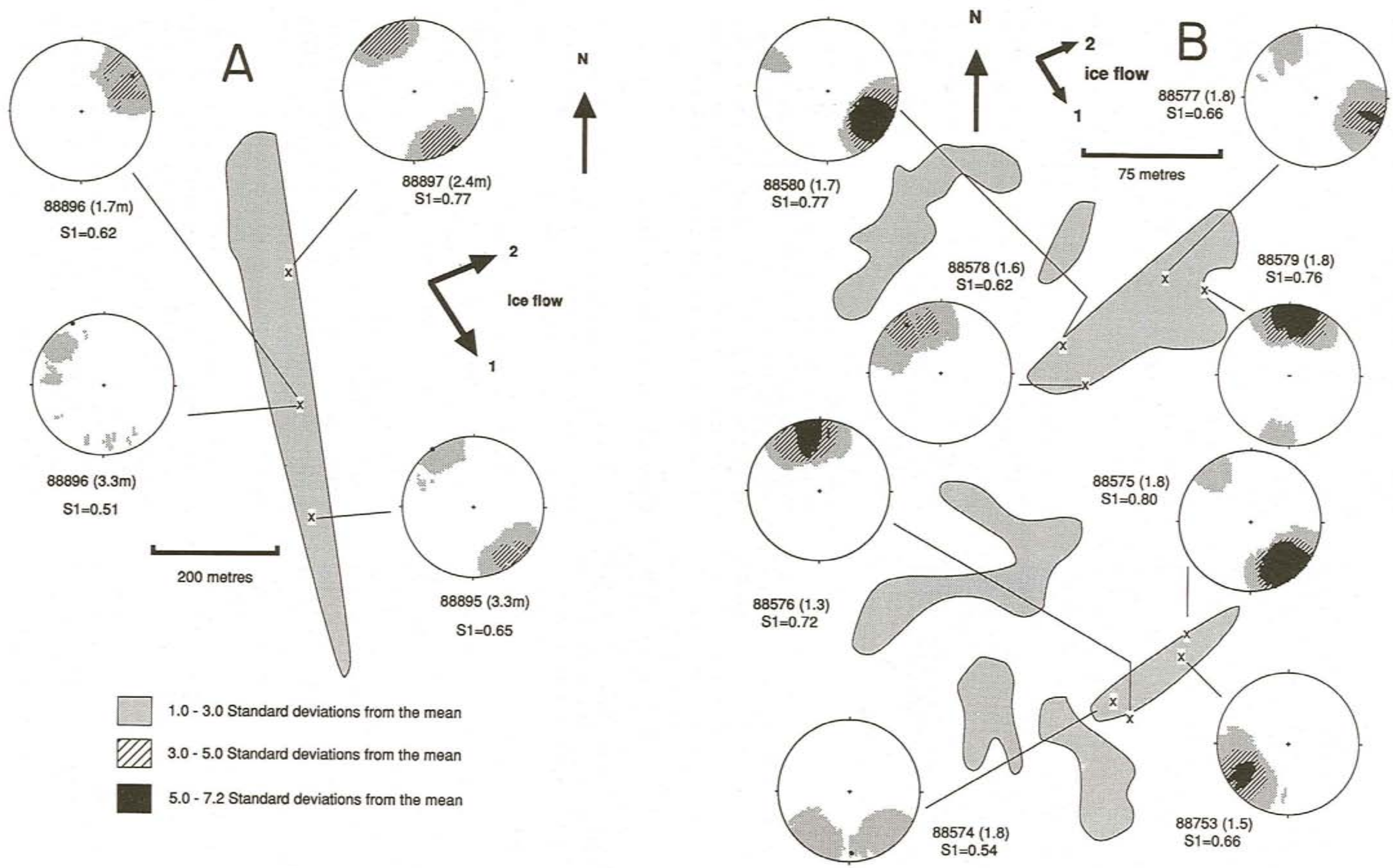

Figure 6. *Pebble-fabric data from 3 ridge terrains; a: straight parallel ridges west of Great Gull Lake; b: Type I crescentic to sinuous ridges within subunit 3a. These ridges were selected for study because they are easily accessible. Unfortunately their morphology is more complicated than typical crescentic to sinuous ridges shown on Table 1; c: Type II crescentic to sinuous ridges; d and e: Type III crescentic to sinuous ridges.*

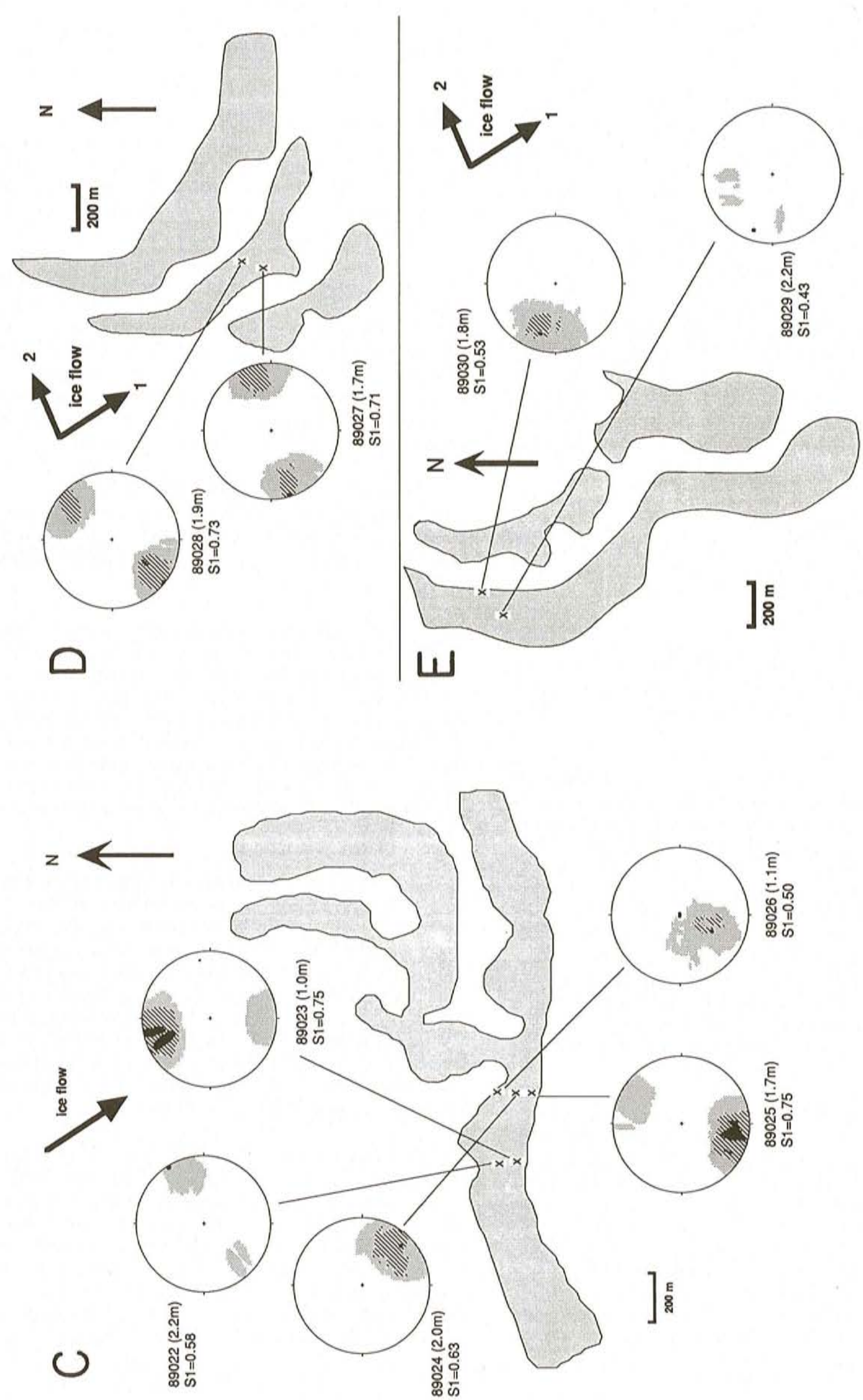

Figure 6. *(Continued).*

Plate 2. *Type I crescentic to sinuous ridges southwest of Berry Hill Pond Ridge tops are light coloured because they are not tree covered (from Newfoundland Department of Environment and Lands, NFLD. A 19837-68).*

are surrounded by a single grain-thick coating of coarse sand. On the upper surface of some pebbles, there are thin (<2 mm) laminations or lenses of silt and clay. In one pit, a sandy gravel bed greater than 1-m thick was exposed 50 cm below the surface.

Pebble fabrics from the diamicton within two ridges in subunit 3a are strong on the north side (2 of 2 fabrics, sites 88575 and 88580 on Figure 6b) trending southeastward and two of 2 fabrics on the south side of ridges have a strong north–south-preferred orientation (sites 88576 and 88579, Figure 6b). Deviations in direction appear to be related to location on the ridge. For example, the preferred orientation of pebbles on the eastern, down-ice side of one ridge (Site 88579, Figure 6b) is about 20 to 40° west of the ice-flow direction interpreted from striations, possibly due to a change in ice flow as it went around the ridge. Fabrics measured in pits on top of 3 ridges (2 fabrics per ridge) are weaker (S_1= 0.54 to 0.66) and one is bimodal (one ridge not shown on Figure 6b).

Interpretation. The most likely genesis for the near-surface sediment (to 1.8-m depth) from which fabrics were taken, is from the basal debris-rich zone of a glacier (Boulton, 1971; Lawson, 1979a; Dowdeswell and Sharp, 1986). The strong preferred orientations of pebbles (S_1 >0.7) were inherited from flowing ice, whereas weaker fabrics formed by mass movement and collapse during melt-out. The presence of a washed zone around pebbles and cobbles and the presence of silt and clay laminations can be explained by the process of melt-out (Haldorsen and Shaw, 1982), debris flows, and flowing and ponded water within the ice or on the ridge surface. The horizontal fissility seen near the base of one pit and the moderate degree of compaction found near the base of several pits suggest that below about 1.5 m, the sediment is lodgement till.

The pebbly sandy composition of the ridges differs from the silty sandy diamicton composition of most other map units in the area. This compositional difference is not associated with changes in bedrock composition. It is, however, similar to the composition of subunit 4b (Figure 5), which is interpreted to be glaciofluvial.

This sedimentologic interpretation does not explain the geometry or genesis of Type I crescentic to sinuous ridges. Similar ridges have been observed in modern glacial environments (Minell, 1977; Kruger, 1985; Eybergen, 1986), where they form by pushing or subglacial compression. The ridges of subunit 3a could have formed by similar mechanisms at the ice margin and beneath it, as a glacier over-rode sand and gravel that occurred beneath or in front of it.

Subunit 3a is, therefore, not a suitable medium for drift prospecting in surveys where mineral detritus is sought because it is a derivative of glaciofluvial sediment, which is much more difficult to trace to its source than till (Shilts, 1976).

Type II–subunit 3b. Type II crescentic to sinuous ridges are 5- to 15-m high, 50- to 500-m long and 40- to 120-m wide (Plate 3) having length to width ratios ranging from 2:1 to 5:1. Generally, they occur 80 to 250 m apart, are oriented mainly east–west and have northern slopes that are generally in the range of 4 to 7°, whereas southern slopes are steeper (12 to 17°). All ridges examined are composed mainly of silty sandy diamicton. Similar ridges have been referred to as ribbed moraine by Prest (1967) or Rogen moraine (Lundqvist, 1969, 1981, 1989).

Type II crescentic to sinuous ridges (subunit 3b, Figure 5; Table 1) are located in the southeastern corner of NTS 2D/5 and south of Berry Hill Pond and Great Gull Lake on NTS 2D/6. East of the Bay d'Espoir Highway, within this subunit, Type II crescentic to sinuous ridges, occur between and on top of subdued linear ridges that are likely large crag-and-tail and fluting features (Plate 3). These ridges are prominent where highlighted by water between them. Hummocks also occur within this subunit, but appear to be superimposed on the crescentic to sinuous ridges. Most of the ridges and hummocks in subunit 3b are tree covered.

Sediment Description. The sediment cover over most of subunit 3b is more than 3-m thick, and boulders average about 1 m in diameter scattered across the surface. Sediment consists mainly of silty sandy diamicton. Two, Type II crescentic to sinuous ridges were examined to a depth of 3.5 m. They are composed of massive sandy diamicton that contains silt and sand laminations 0.3- to 1-cm thick, some of which are normally graded. In places, laminations are parallel to the modern slope. Fabrics measured from

Plate 3. *Type II crescentic to sinuous ridges superimposed on subdued southward trending flutings south of Great Gull Lake (from Newfoundland Department of Environment and Lands, NFLD. A 19837-68).*

diamicton containing this laminated sediment are generally weak (4 out of 5 fabrics, Figure 6c). One strong fabric has a preferred orientation that is oriented northeastward, transverse to ice flow interpreted from striations in the area (Site 89022).

Interpretation. The diamicton examined within the Type II crescentic to sinuous ridges was likely deposited by melt-out. The two fabrics with S_1 values of 0.6 and 0.7 were probably inherited from flowing ice, whereas the weaker fabrics formed by mass movement and collapse during melt-out (Boulton, 1971; Lawson, 1979a; Dowdeswell and Sharp, 1986). Laminations within the diamicton were deposited by flowing water, which is also typical of the melt-out process (Haldorsen and Shaw, 1982).

This sedimentologic interpretation can be applied with certainty only to the upper 3.5 m of sediment of subunit 3b. It does not necessarily explain the geometry of the ridges because they are considerably higher. In modern glacial environments, geometrically similar but much larger ridges (50- to 100-m high) have been observed forming (Kalin, 1971), and smaller features (3 to 5 m high) have been observed forming by ice marginal pushing (Kruger, 1985; Eybergen, 1986). Pleistocene examples of similar features (ribbed moraine and Rogen moraine) have been interpreted to be of subglacial depositional origin or to have been pushed up within ice-marginal joints or at an ice margin (Cowan, 1968; Lundqvist, 1969, 1989; Bouchard, 1989). All of these studies have similar sedimentologic and fabric data to those described in this study. Consequently, it is suggested that Type II crescentic to sinuous ridges formed by ice pushing within ice-marginal joints or at an ice margin.

Type II crescentic to sinuous ridges commonly occur between, and on top of, straight parallel ridges within subunit 3b. This does not change the genetic interpretation but suggests that crescentic to sinuous ridges formed where ice was flowing over straight parallel ridges.

For drift prospecting purposes, the silty sandy diamicton within subunit 3b is probably of subglacial origin or is composed of reworked (pushed?) subglacial sediment. It likely contains mostly local material and is a suitable sampling medium.

Type III—subunit 3c. Type III crescentic to sinuous ridges are 2- to 10-m high, 200- to 1500-m long and 30- to 100-m wide and generally 50 to 300 m apart. They are wider and considerably longer than Type I and II crescentic to sinuous ridges (Plate 4). Commonly, they are concave northeastward and in many places appear to be joined to several adjacent ridges to form larger composite ridges that are oriented north—south, extending for up to 2500 m and commonly relatively straight. Material in the ridges is mainly silty sandy diamicton. Western slopes are much shallower (4°) than eastern slopes (18°). They occur north of Third Berry Hill Pond on NTS 2D/6 (Figure 5, subunit 3c), are tree covered and separated by boggy areas. In many places, composite ridges are parallel to, and have about the same dimensions as ridges in the straight parallel ridge map unit to the south. Some have scalloped western margins and much more irregular eastern or cuspate margins (Plate 4). Other ridges in this part of subunit 3c form large arcs (e.g., Figure 6d and e).

Plate 4. *Type III crescentic to sinuous ridges having cuspate margins and some arcuate shapes northeast of Third Berry Hill Pond (from Newfoundland Department of Environment and Lands, NFLD. A 19835-9).*

Sediment Description. The sediment in the ridges is mainly massive silty sandy diamicton. Compaction increases downward from moderate to high in the upper 2 m. In one ridge (Figure 6d, 89027, 89028), there are sand and gravel beds and lenses and a steeply dipping (60°) sand dyke. The pebble fabrics measured on both flanks of this ridge are strong, having a northeastward preferred orientation and a difference between them of 40°. Another ridge (Figure 6e, 89029, 89030) contains diamicton, having synformally deformed sand lenses beneath some cobbles, and a sandy gravel bed more than 30-cm thick. The two fabrics measured in this ridge are weak. Some of the ridges excavated in this part of the unit contain a surface layer of gravelly sand less than 1-m thick that overlies silty sandy diamicton. Most ridges have boulders and cobbles at the surface.

Interpretation. An origin of Type III crescentic to sinuous ridges is suggested based on the geomorphic evidence, their orientation with respect to ice flow, sediment character and pebble fabric data. Zones of straight parallel ridges can be traced northward over a distance of less than about 5 km into composites of crescentic to sinuous ridges that are parallel to them and have about the same dimensions. It is clear from the above discussion that straight parallel ridges formed subglacially. The diamicton and pebbly sand observed within 2 m of the surface of the Type III crescentic to sinuous ridges is also interpreted to have formed subglacially. This is based on the two strong pebble fabrics, which are most likely the result of orientation by basal ice flow, the increase in compaction with depth to a highly compact diamicton, and the moderate fissility of this more compact diamicton (Dowdeswell and Sharp, 1986; Kruger, 1979).

Given the apparent continuum between straight parallel ridges and Type III crescentic to sinuous ridges, the fabric data is inconsistent. This is because the long axis of most of the Type III crescentic to sinuous ridges is north–south oriented, whereas the fabrics indicate a northeastward flow. It is suggested that the irregular to cuspate margins of some of these ridges (Plate 4) could have been formed by northeastward-flowing ice that over-rode north–south straight parallel ridges. The irregular to cuspate ridge margins are likely the result of subglacial erosion and pushing (Lundqvist, 1989). The northeast–southwest orientations of the two fabrics measured on the sides of the ridge shown on Figure 6d support a northeastward flow. In places, the ridges are arcuate (Figure 6d), possibly as a result of pushing. The irregular margins are likely the result of melt-out and mass movement down the slopes of the ridge as interpreted from the weak fabrics (Figure 6e) (Dowdeswell and Sharp, 1986). The slope asymmetry of some of the ridges, 4 to 8° on the west side and as high as 18° on the east could be due to the collapse of water-saturated ice-proximal sediment as the glacier melted. Thus, the distal side, which was not supported by ice, may have retained a steeper slope. The difference of about 40° between the 2 fabrics shown on Figure 6d may be the result of basal-ice deflection around the core of the ridge.

As noted above, the Type III crescentic to sinuous ridges appear to grade into straight parallel ridges to the south. Using the above interpretation, there must have been a northeastward ice flow that did not affect the straight parallel ridges to the south. The absence of northeast striations where southward-oriented straight parallel ridges occur supports this hypothesis (Figure 3). Therefore, the origin of the Type III crescentic to sinuous ridges is probably due to subglacial moulding and pushing of pre-existing streamlined forms by northeastward-flowing ice. More obvious evidence of glacial over-riding, such as northeastward flutings on top of the irregular parallel ridges (Lundqvist, 1989), has not been observed.

Sediment transport northeastward may have been relatively minor because most ridges have not been obliterated. The major direction of sediment transport, therefore, was probably southward along the path of the earlier glacier flow. The sediment dispersal train from this earlier flow was probably not significantly altered by the later northeastward flow. Boulders and cobbles on the surface within this unit are likely relatively far travelled because they were probably transported englacially. Sampling for drift prospecting should be deep enough to penetrate the surface mantle of low compaction englacial sediment.

Type IV Crescentic to Sinuous Ridges—subunit 3d. Type IV crescentic to sinuous ridges are similar in shape, height and width to relatively straight Type III ridge composites. They are, however, longer—up to 2800 m, and more closely spaced, generally less than 30 m apart.

Type IV crescentic to sinuous ridges (Plate 5) occur on NTS 2D/5, north of the Northwest Gander River (Figure 5, subunit 3d). They have a similar geometry to Type III ridges, differing mainly in their distance apart—there is no space between them, and in their vegetative cover—ridge tops are covered with caribou moss and few trees, whereas low areas between them are forested. The southern boundary of subunit 3d is formed by the Northwest Gander River valley. Straight parallel ridges having the same orientation and similar dimensions occur on the south side of the river.

Sediment Description and Interpretation. The sediment within these ridges is indistinguishable from the pebbly silty sand found in subunit 3a, and has formed subglacially. The similarity in geometry with Type III ridges is used as a basis to suggest that Type IV ridges formed by a similar pushing mechanism. Their pebbly sand composition is probably related to the material over-ridden by the glacier and not to a genetic difference in the ridges. The absence of space between ridges is probably related to the distance between straight parallel ridges from which Type IV ridges are thought to have been derived. This close spacing of straight parallel ridges can be seen directly south of subunit 3d.

Unit 4: Hummocky Terrain

There are two types of hummocky terrain within this map unit.

Subunit 4a. Subunit 4a (Figure 5) is characterized by irregularly spaced, tree-covered hummocks that range from

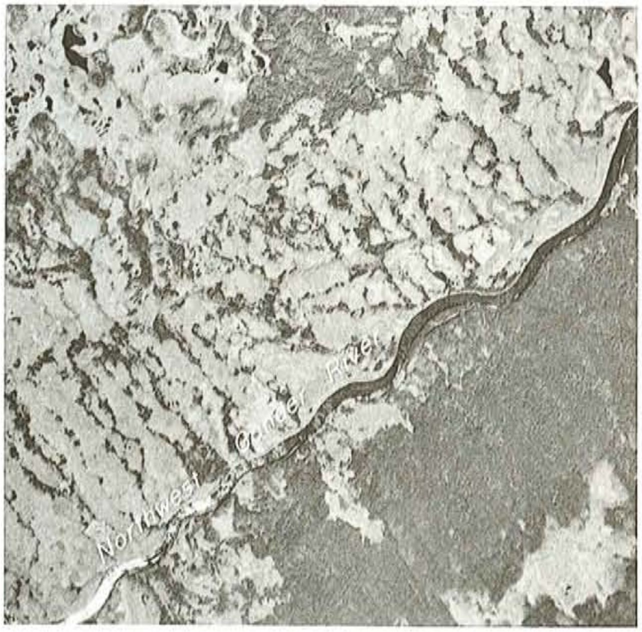

Plate 5. *Type IV crescentic to sinuous ridges on the north side of the Northwest Gander River. Straight parallel ridges with the same orientation occur beneath the dark tree cover on the south side of the river (from Newfoundland Department of Environment and Lands, NFLD. A 19835-12).*

5 to 10 m in height and 50 to 100 m in diameter. They occur so closely together that they are not mapped individually but as areas. Their surface is commonly strewn with boulders. This map unit is easy to delineate on aerial photographs.

Sediment Description. The sediment comprising these hummocks is mainly sandy diamicton that contains numerous sand and gravel lenses. Several hummocks also contain silty pebbly sand and moderately sorted sand. Sand and gravel deposits 0.5- to 1.5-m thick, overlying diamicton, are common between hummocks. At two locations between hummocks, bedrock was intersected within 1.5 m of the surface. The sediment is therefore estimated to be 5- to 10-m thick in hummocks, based on the assumption that they are entirely constructional landforms, so that sediment thickness is about equal to their height. Sand and gravel lenses occur throughout the diamicton and also, pebbly sand, particularly beneath pebbles, cobbles and boulders. Some hummocks contain as much as 30 percent clasts by volume. In general, compaction increases with depth, and horizontal fissility was observed near the base of, and between, several hummocks. Pebble-fabric data was collected from 8 hummocks (16 fabrics). Generally, sites on the sides and top of hummocks have weaker fabrics (S_1: 0.44 to 0.56, 5 fabrics; 0.66 and 0.73, 2 fabrics; average 0.57 for the 7 sites) than between hummocks (S_1:0.57 to 0.84, average 0.66 for 9 sites).

Interpretation. The genesis of hummocks is generally better understood than the other geomorphic features described in this paper. Consequently, they are not discussed here in as much detail as other features.

The diamicton containing lenses within hummocks was likely deposited by melt-out. This interpretation is based on sediment structure and the relatively weak pebble fabrics measured (Boulton, 1970, 1971; Kruger, 1979; Haldorsen and Shaw, 1982; Dowdeswell and Sharp, 1986). Variation in size and frequency of lenses relates to the rate of ice melting, and therefore to the amount of meltwater draining through the ice. The high concentration of clasts may be a function of debris concentration in the ice. The presence of sandy and gravelly material at the surface between hummocks is likely the result of meltwater running between them and of debris flows from adjacent hummocks (Eyles, 1979). The strong fabrics found within compact material between and within hummocks suggest that the sediment is of subglacial origin (Dowdeswell and Sharp, 1986). This sediment may be basal melt-out till or in the case of very strong fabrics, lodgement till.

This hummocky terrain was likely deposited during stagnation during glacial retreat because there is no evidence of the streamlining that created nearby crag and tails and flutings. The sediment having very strong fabrics may have been deposited as part of streamlined ridges that are now buried by hummocks. Deposition was probably by melting-out mainly from an englacial position with some sediment that has strong fabrics from the basal debris-rich zone of the glacier (Gravenor and Kupsch, 1958; Eyles, 1979). This englacially transported sediment is relatively far-travelled compared to subglacially transported sediment.

An alternative genetic interpretation of hummocks involves subglacial squeezing of sediment into cavities in the ice (Stalker, 1960). In this mechanism, strong fabrics have likely survived squeezing and weaker fabrics are probably the result of it.

Drift sampling for mineral exploration should avoid sampling hummocks on property-scale surveys because much of the sediment is probably relatively far-travelled. Instead, sampling should be concentrated in depressions between hummocks, where basal till or bedrock may be intersected at relatively shallow depths.

Subunit 4b. The second type (subunit 4b, Figure 5) is a hummock and esker complex. It is characterized by treeless hummocks that are generally smaller in diameter and height (3- to 7-m high). It also contains a major esker that is 3- to 10-m high, 10- to 30-m wide and 5-km long. This subunit is located west of the Northwest Gander River to the northeast of Newfoundland Dog Pond.

Sediment Description. The hummocks within this subunit contain mainly pebbly sand. Sediment thickness in hummocks is estimated to be of the same order as hummock heights. The internal composition of the eskers appears to be sand and gravel but excavation was impossible because of a surface mantle of boulders. An esker, 30-m wide and 5- to 8-m high that is covered by large angular to subangular boulders runs from north to south across the eastern part of this unit. A discontinuous network of closely spaced ridges is connected to the northern part of this esker. The surface appearance and width of the esker and the discontinuous network of ridges are similar. The sediment in this unit is mainly pebbly sand that has well-developed bedding in some places.

Interpretation. Eskers are glaciofluvial channel deposits that require an ice wall to confine them, so that they must form subglacially, englacially or along an ice margin. The hummocks within this map subunit are of similar composition to the eskers and are spatially associated with them so that in many places it is impossible to distinguish between short esker ridges or ridge segments and hummocks. They may all have been connected as part of a subglacial or englacial drainage network. Consequently, the hummocks are also interpreted to be of glaciofluvial origin. The hummocky morphology could be the result of melting-out of buried ice (Gravenor and Kupsch, 1958). The sediment was, therefore, probably deposited on, within or at the margin of the ice by glaciofluvial processes, and formed hummocks as it melted out. It is also possible that the hummocks formed by subglacial squeezing of pre-existing sand and gravel deposits into cavities (Stalker, 1960).

Sediment within this subunit is a poor medium for sampling in drift-exploration programs because it has been transported by fluvial or glaciofluvial processes, which are much more difficult than glacial deposits to trace to their source (Shilts, 1976).

Unit 5: Organic Deposits

The organic deposits consist of fen (raised organic peat deposits containing minor surface water) and boggy areas with small ponds surrounded by peat accumulations. Peat thickness, measured by driving a steel rod to its base, ranges up to more than 4 m, but averages less than 2 m.

DISCUSSION AND SPECULATION

The variety, distribution, composition and genesis of geomorphic features provide a foundation for speculation on possible genetic associations. First of all, bedrock does not appear to have controlled the distribution of geomorphic features. The compositional difference in ridges between pebbly sand in subunits 3a and 4b and diamicton elsewhere, is likely not associated with changes in bedrock composition, but with the type of unconsolidated material that the glacier over-rode. It is possible that the pebbly sandy ridges (subunit 3a) formed from glaciofluvial sand and gravel that was deposited beneath, or in front of, a glacier.

Two types of ridges that formed transverse to ice flow have been identified (Type I and II crescentic to sinuous). Their genesis is best explained by one, or a combination of, subglacial deposition and subglacial or ice-marginal pushing. In some places, these ridges occur on top of, and between, straight parallel ridges. They are always transverse to straight parallel ridges in the same area. It is suggested that this occurred sequentially, with straight parallel ridges forming first, and later when subglacial conditions had changed, transverse ridges formed, in part from the sediment that was streamlined.

Single hummocks and areas of hummocks that are too small to map occur throughout the map area on top of, and between all, transverse and straight parallel ridges. They likely formed after the ice had stagnated because they show no evidence of ice flow. The surface of most of the area has a discontinuous veneer of cobbles, boulders and finer sediment. It is likely that this material was deposited from a position above the basal debris-rich zone of the glacier after stagnation. This material has probably been transported relatively farther than the underlying sediment.

Two types of ridges that are the result of glacial over-riding transverse to straight parallel ridges have been identified. They both occur along the north side of the Northwest Gander River where the occurrence of a late northeastward glacial flow is interpreted.

There is no direct evidence of an ice margin related to southward flow, probably because glacial retreat was not gradual, but instead occurred as regional stagnation. There is, however, no evidence that flowing ice, over-rode the hummocks of subunit 4b. They have been protected by stagnant ice. This suggests that the boundary between subunits 3a (Type I crescentic to sinuous ridges) and 4b (hummocks and eskers) was also the contact between active southward-flowing ice and stagnant ice during deglaciation.

There is also no obvious southern margin (e.g., lateral moraine) for the second (northeastward) flow that affected only the northern part of the area. This might be explained if later flow was in contact with a large stagnant part of the ice sheet to the south. Across most of NTS 2D/6, the Northwest Gander River valley marks the southern limit of northeastward flow. It is possible that in this area it formed as an ice-marginal river between the flowing glacier and stagnant ice to the south. South of where the Northwest Gander River turns eastward (where it crosses the Bay d'Espoir Highway), it is speculated that the river carrying glacial meltwater flowed subglacially. This interpretation is based on the close association of the valley with glaciofluvial sediment contained within subunits 3a and 4b (Figure 5). The 3-km-long esker (Figure 4) within subunit 4b parallels the modern river valley and is within 1 km of it for about 2 km, possibly because it was deposited within a parallel channel beneath the ice as part of the same subglacial drainage system.

The relatively large areas of thicker hummocky moraine (subunit 4a, Figure 5) may also be indirect evidence of an ice margin or margins. They are interpreted to have formed along an active ice margin where the ice rode up on the northern edge of the stagnant ice mass, greatly increasing local debris content by stacking sediment-laden ice. This is the most likely mechanism for concentrating the large volumes of sediment contained in the hummocky moraine. Hummocky moraine of this type has been associated with both directions of ice flow.

CONCLUSIONS

1) Sediment in the area south of Coy Pond was transported by only one direction of ice flow, i.e., southward.

2) In the northernmost part of NTS 2D/6, despite later northeastward flow, the dominant direction of sediment transport was also probably southward.
3) Most of the study area contains small hummocks and most of the surface has a discontinuous veneer of cobbles, boulders and finer sediment. This sediment has been transported relatively farther than the underlying sediment. Consequently, all samples should be taken from below the near-surface, less compact sediment.
4) Sub-bog sampling is inevitable in the area because of extensive bog cover. Sampling should be from more than 1 to 2 m below bogs to avoid sampling material of farther travelled origin.
5) Straight parallel ridges formed, subglacially, parallel to ice flow by lodgement and moulding and are good sites for drift prospecting samples.
6) Type I and II crescentic to sinuous ridges formed transverse to ice flow by subglacial and ice-marginal pushing. Type I ridges probably formed from glaciofluvial sediment and are therefore poor sites for drift prospecting. Type II ridges contain basal till, which is a good sampling medium.
7) Type III and IV ridges are probably the result of glacial over-riding of north–south oriented straight parallel ridges formed by southward-flowing ice.
8) Large areas of hummocky moraine may have been deposited along the south margin of southward- and eastward-flowing ice.

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