University of Alberta

Drumlinized Terrain of North-Central British Columbia:

Reading Between the Lineations

by

Brian Sawyer

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

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Abstract

High-resolution Global Positioning System surveys delineate the morphology of more than twenty drumlins and related glacial landforms near Prince George, B.C. Closely-spaced transects of sub-meter- resolution elevations are interpolated as digital elevation models. Raster and vector Geographic Information Systems are used for 3D imaging and analysis of surface slope, aspect and microrelief. Regional drumlin and fluting orientations are remarkably consistent over varying elevations and physiographic regions, implying a contemporaneous landform genesis. The variety of drumlin composition and scale, the sinuousity of surface microfeatures, and the regional distribution of a cobble/boulder lag indicate a turbulent erosional agent of limited competence. Oblique till fabrics and truncated drumlin stratigraphy indicate a complex genesis of internal materials involving multiple sediment deposition/erosion cycles. Fraser Glaciation gravels were rapidly deposited in a northeasterly flow, and are overlain by a regional unconformity. Glaciolacustrine rhythmites, previously interpreted as proglacial deposits, were deposited at higher elevations than previously thought, and were subsequently eroded by a northeasterly flow event. The drumlinized rhythmites that remain, distorted at their surface and overlain by eskers and ice-contact deposits, provide evidence for the infilling and catastrophic drainage of a subglacial lake. The results of this study have far-reaching implications for reconstructions of Late Wisconsinan ice sheet evolution based on 'glacial' surface lineations.

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I am indebted to Dr. Howard Tipper for his pioneering work in the area, and was honoured to think that I may have occasionally walked in his footsteps. I am grateful to my wife, Arlene Collins, who convinced me I was capable of succeeding and showed me that good work is its own reward. Finally, I thank my parents for their unconditional support, even when my path diverges far from their expectations.

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CHAPTER 1. INTRODUCTION

1.1 Rationale

This study involves the geomorphology of drumlins and related landforms in an area of north-central British Columbia near Prince George (Fig. 1-1). Glacial features and sediment deposits are abundant on the central plateaus, in river valleys and on mountain slopes (Armstrong and Tipper, 1948). The glacial features have been described and mapped at a reconnaissance scale over the past 100 years, from observations that were mainly recorded incidentally during bedrock studies. Reconstructions of Pleistocene Cordilleran glaciations explain the pattern of surface lineations as products of ice flow from mountain piedmonts, ice domes and late-stage readvances; sedimentary sequences provide evidence for models of multiple glacial/interglacials in northern British Columbia and a single glaciation in southern British Columbia (Clague, 1989). This study examines these landforms and sediments at a level of detail not previouslyt undertaken in the Prince George area, to expand and refine the accumulated observations of previous workers and test the validity of their interpretations.

Progress in the interpretation of glacial geomorphology has been hindered by the difficulty of direct observation and measurement of formative processes; the nature of these processes has been inferred primarily from remnant landforms and sediments. Early observations on the parallel orientation of drumlins, flutings, striations and the transport direction of displaced erratics led to the assumption that glacial ice was the common genetic agent. This assumption underlies most subsequent glacial models, and provides much of the basis for ice-sheet reconstructions. At a continental or regional scale, the generalized lineation patterns are relatively consistent with the concept of a few, discrete ice-flow sources (Prest *et al.*, 1968; Boulton, 1987). At local scales the diversity of the orientations requires more complex explanations, as is the case in central British Columbia.

Smalley and Unwin (1968, p. 377) stated that two primary questions need to be answered regarding the genesis of drumlins: (1) the nature of the force involved, and (2) how the force was applied. They then dismissed investigation of (1) with the argument that "*...the necessary force is generally ascribed to the action of glaciers, so only one problem remains, that of the mode of interaction of the glacier and the terrain which leads to the formation of drumlins...*"

Menzies and Rose (1987, p. VII) noted in the Proceedings of the 1985 Drumlin Symposium that drumlins remain "*...a puzzle to the community of glacial scientists, and above all a sign of our meagre understanding of much that is associated with glaciers...*".

Most theories of drumlin formation have involved the interaction of flowing basal ice and the underlying bed: by deposition of sediment onto a hard substrate or around an obstacle, by stretching and moulding a deformable substrate, by erosion of the substrate, or some combination of these processes. Hart (1997) described three broad classes of drumlins associated with basal shear stress and a deformable bed:

1) Depositional. The deforming substrate flows around an immovable core, such as a boulder or outcrop (Fig. 1-1a). Till is deposited in the low-pressure zone in the lee of the core, and till fabrics would be oriented toward the central axis. Rock-cored drumlins (crag-and-tails) are examples of this class. In other cases, the increased stress and effective pressure results in the build-up of a carapace on the stoss end of an outcrop (Fig. 1-1b), or on a step in the décollement surface. Depositional forms are more common near the ice margin, where shear stress is low and incoming sediment abundant.

2) Deformational. An inhomogeneous substrate results in inhomogeneous strain response. Vertical heterogeneity of substrate viscosity results in folding over the stiffened internal layer (Fig. 1-1c); lateral heterogeneity of substrate porosity or plasticity results in drumlinization around the more competent cores; pre-existing bedforms are stretched and deformed in the direction of flow (Fig. 1-1d).

3) Erosional. A deformed but competent core is truncated by the surface, or by a carapace of lodgement till. Such drumlins are more likely to have been formed up-

glacier from the margin, where flows are faster, stress is higher and sediment less available.

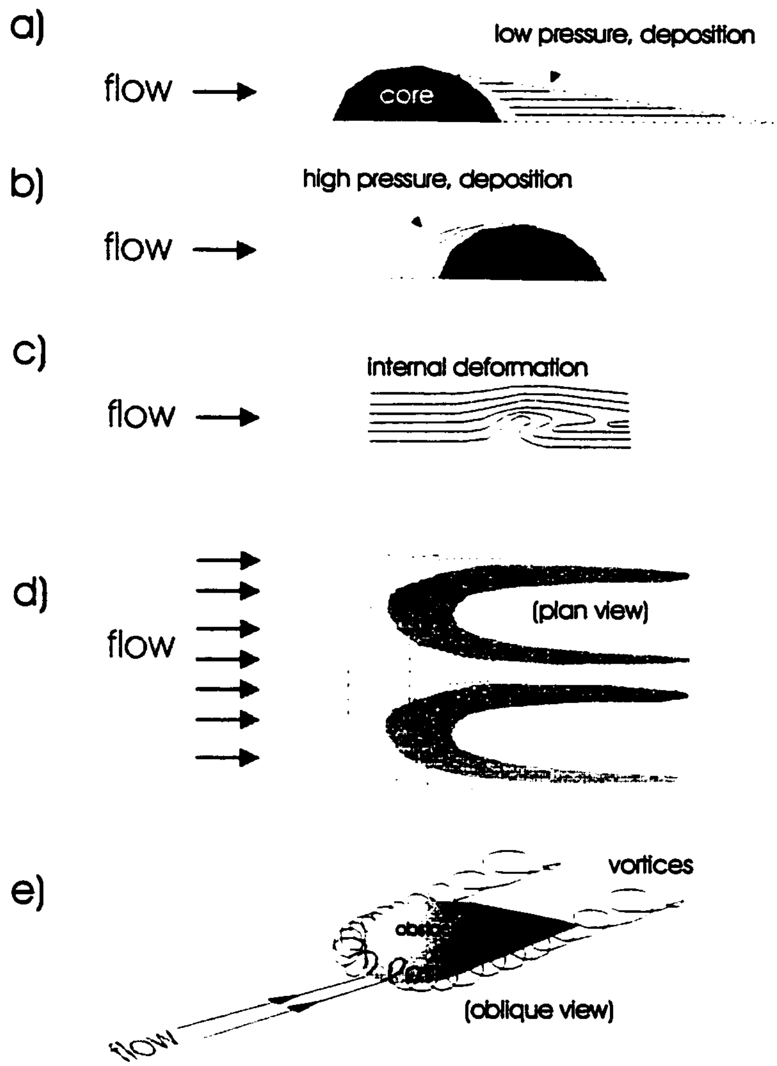


Figure 1-1. Drumlin formation by deposition (a, b), deformation (c, d) and erosion (e).

A growing body of work has focused on the role of subglacial meltwater in the drumlinization process. Shaw and Kvill (1984) found drumlins comprised of glaciofluvial deposits draped over sandstone in northern Saskatchewan. Their interpretation was that subglacial meltwater eroded cavities in the basal ice, which were later infilled with stratified sediment. They noted a strong association between the drumlins and smaller erosional bedforms in the bedrock. Kor *et al.* (1990) related a suite of erosional bedrock marks in Georgian Bay, Ontario, to coherent flow structures in meltwater sheet flow. Shaw (1994) described hairpin scours demarcing linear landforms at scales from centimetres to tens of kilometres, and explained the form and distribution of the scours as the product of erosional 'horseshoe vortices' in a turbulent fluid, as flow meets and wraps around a surface obstacle (Fig. 1-1e). He also pointed out that the density and viscosity of ice are too high for turbulent flow. Further work has resulted in the development of a model that elegantly explains drumlins, flutings and other glacial features in Ontario, Alberta and elsewhere as erosional products of meltwater sheet-flow (Shaw *et al.*, 1989; Rains *et al.*, 1990; Shaw *et al.*, 1996, Munro and Shaw, 1999).

The continued reluctance by many glacial scientists to revisit the primary assumption of an ice genesis for drumlins and flutings perhaps arises in part from the imposing volume of work that has been constructed on that assumption. The theory of subglacial meltwater sheet erosion and deposition has been shown, in many instances, to provide a more plausible and consistent explanation of the field evidence than do theories based on ice-substrate interaction.

1.2 Objectives

This study addresses the nature of drumlin genesis from basic principles of physical dynamics. The hypothesis is that Prince George drumlins are erosional in origin, that the erosional agent was subglacial meltwater, and that erosion was by turbulent sheet flow under a stagnating Cordilleran Ice Sheet during the waning stages of the Late Wisconsin Fraser Glaciation. The assumptions are that a relationship exists between drumlin form, composition and genesis, and that a detailed analysis of form and composition will provide sufficient evidence to verify or negate the proposed mode of genesis. The objectives include (1) the measurement and modeling of glacial landforms and microrelief over varied substrates, elevations and slope conditions through precise elevation point surveys and digital surface interpolation, (2) the description of drumlin internal composition, stratigraphic relationships (where exposed), surficial sediments and related glacial markings (striations, grooves) through field observation and laboratory analysis, and (3) the integration of these results with those from other regional studies to infer a probable mode of drumlin genesis in north-central British Columbia, with potential implications for the reinterpretation of Fraser Glaciation features throughout the Cordillera.

1.3 Importance of this Study

The determination of the genetic agents and the dynamics involved in drumlin genesis will enhance our understanding of the inherent properties of these landforms and how they have interacted (and continue to do so) with the larger earth system. The results of this study hold deep implications for glacial geology, as summarized below:

1.3.1 Relationships between form and process

Some of the first models of drumlin formation were constructed around the idea of till deposition by glacial ice onto and around existing obstacles. More recently a number of workers have explained drumlin structure, orientation and distribution in terms of ice interaction with a variably-deforming substrate (Smalley and Unwin, 1968; Rose and Letzer, 1977; Boulton, 1987; Hart, 1997). They consider the characteristics of the internal sediments (strong fabrics, dilated till) to be indicative of the external formation process, and have explained a suite of observed landforms as products of ice-molding and deformation processes. Other workers have cited the similarity of form between drumlins and small-scale bedrock erosional bedforms as evidence for subglacial meltwater erosion of drumlins from the substrate, or subglacial meltwater erosion of the overlying basal ice and subsequent subglacial cavity infill (Shaw and Kvill, 1984; Shaw *et al.*,1989). This study will add to the body of knowledge relating to drumlin form, internal composition, surface microstructure, stratigraphy, and physiographic context. The results could help refine more than one form-process model.

1.3.2 Ice-sheet reconstruction

If meltwater is concluded to be the formative agent of the Prince George drumlins, then reconstruction of ice-flow characteristics from landform surface properties in glaciated regions must be reconsidered. If meltwater is found not to be the genetic agent, then much can be inferred about ice interaction with the substrate and local topography. Kleman (1994) has suggested that only relatively large 'robust' drumlins have survived prolonged warm-based ice-sheet coverage without significant morphological alteration.

1.3.3 Climate change studies

General circulation models (GCM's) are used to predict future climate trends based on past paleoclimate proxy indicators. Therefore, it is important to ascertain the nature of early Holocene meltwater release (i.e., catastrophic, pulsed or steady-state) and the effects on sea level, sea surface temperature and ocean circulation patterns (Anderson *et al.*, 1997). Workers reconstructing the relationships between sea level and isostatic uplift on the coast of British Columbia during Fraser deglaciation have detected pulsations with strong, shortlived submergence dated about 11.5 ka BP (Clague, 1989). Further evidence for an extreme fluctuation in early Holocene freshwater input, potentially from this study area, exists in Ocean Drilling Program drill cores taken from an anoxic marine basin near the mouth of the Fraser River. The 100+ m cores provide a continuous record of sedimentation to ~14,500 BP (Bornhold and Firth, 1997). Early Holocene, Late Glacial mm-thick laminated mud is interrupted by a 40 cm, massive layer of grey silty clay, dated ~11,000 BP. Marked by an extremely sharp basal contact, it was interpreted as representing an 'abrupt discharge event' (Bornhold and Firth, 1997).

1.3.4 Mineral exploration

The interest in mineral exploration in the study area has been high since the Cariboo placer gold discoveries of the 1860s, when placer deposits were found near the upper surface of preglacial gravels (Tyrrell, 1955; Clague, 1991). A clear understanding of the mode of glacial landform genesis will improve the interpretations of sedimentary sequences, with significant implications for placer mineral exploration in the area.

1.4 The Study Area

This study was undertaken in the vicinity of Prince George, British Columbia, within the northwestern portion of the Interior Plateau. Physiographic regions include portions of the Nechako Plateau, Cariboo Mountains and Rocky Mountain Trench (Fig. 1-2). The bedrock formations are Precambrian, Paleozoic and Mesozoic in age, and mountain peaks rise to elevations of 3,500 metres asl. The Rocky Mountains are comprised of folded and faulted sedimentary rocks; the Omineca Mountains to the north contain both sedimentary and volcanic rocks, while the Cariboo Mountains contain metamorphic and sedimentary rocks (Tipper, 1971b). The Nechako and Fraser plateaus are primarily low-relief, rounded hills at elevations from 600 masl to 1200 masl, underlain by Paleozoic and Mesozoic volcanic and sedimentary rocks, with some low-lying areas blanketed by Tertiary volcanic extrusions (Campbell and Charlesworth, 1970; Tipper, 1971a). Most of the Nechako Plateau is covered by Pleistocene till deposits (Armstrong and Tipper, 1948).

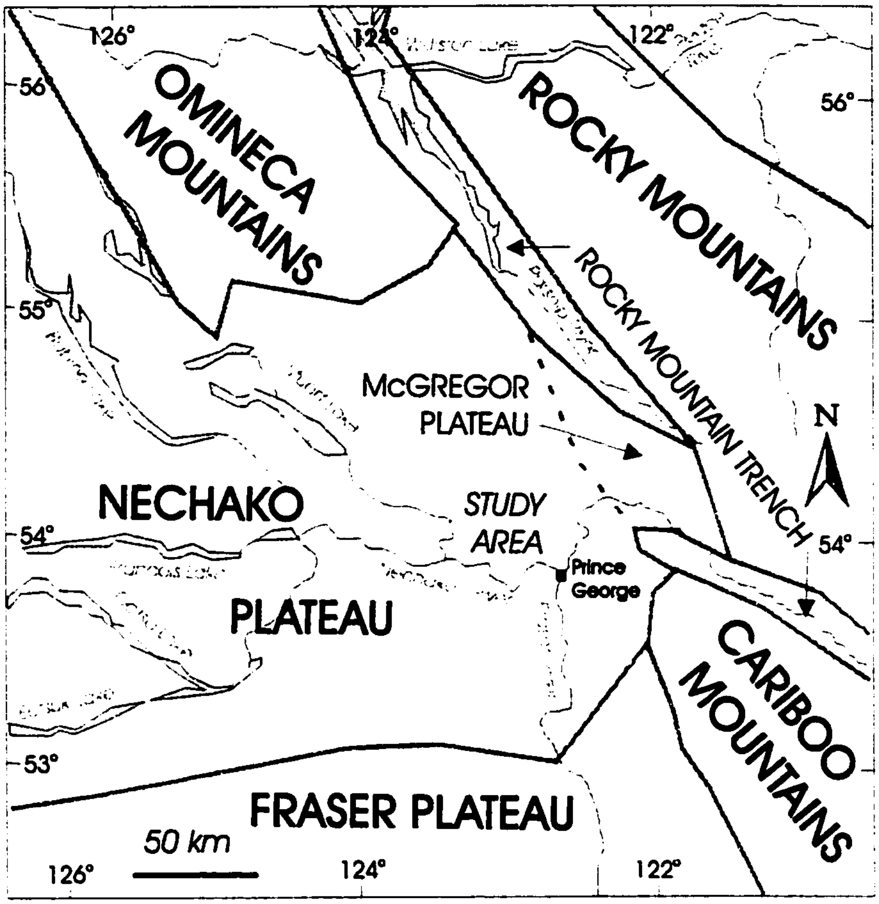


Figure 1-2. Physiographic regions of central British Columbia (after Tipper, 1971).

The Rocky Mountain Trench is a nearly flat-bottomed depression extending 1,000 km to the south between the Rocky and Cariboo ranges, and 700 km to the north between the Rocky and Omineca ranges. The McGregor Plateau, a relatively high, irregular subregion of the Nechako Plateau, provides the only physiographic interruption of the Trench. Low-lying, interconnected areas covered by Quaternary glacio-lacustrine sediments were referred to by Armstrong and Tipper (1948) as the Nechako Plain, comprised primarily of large, discrete glacial lake drainage basins near Fort. St. James, Vanderhoof, Prince George and Quesnel (Fig. 1-3). The study area includes the confluence of the Nechako and Fraser River systems. Tipper (1971b) cited fossiliferous sedimentary evidence that the Nechako and southeast Fraser drainage channels have been in place since the Cretaceous. The Fraser drainage basin from Prince George to the southwest is less well-developed: the valleys are narrow, with northward-flowing tributaries flowing into the southward-flowing main channel, and Miocene river gravels indicate paleoflow to the north, suggesting that the Fraser River once continued northward up the Rocky Mountain Trench and eastward into the Peace River system (Tipper 1971b).

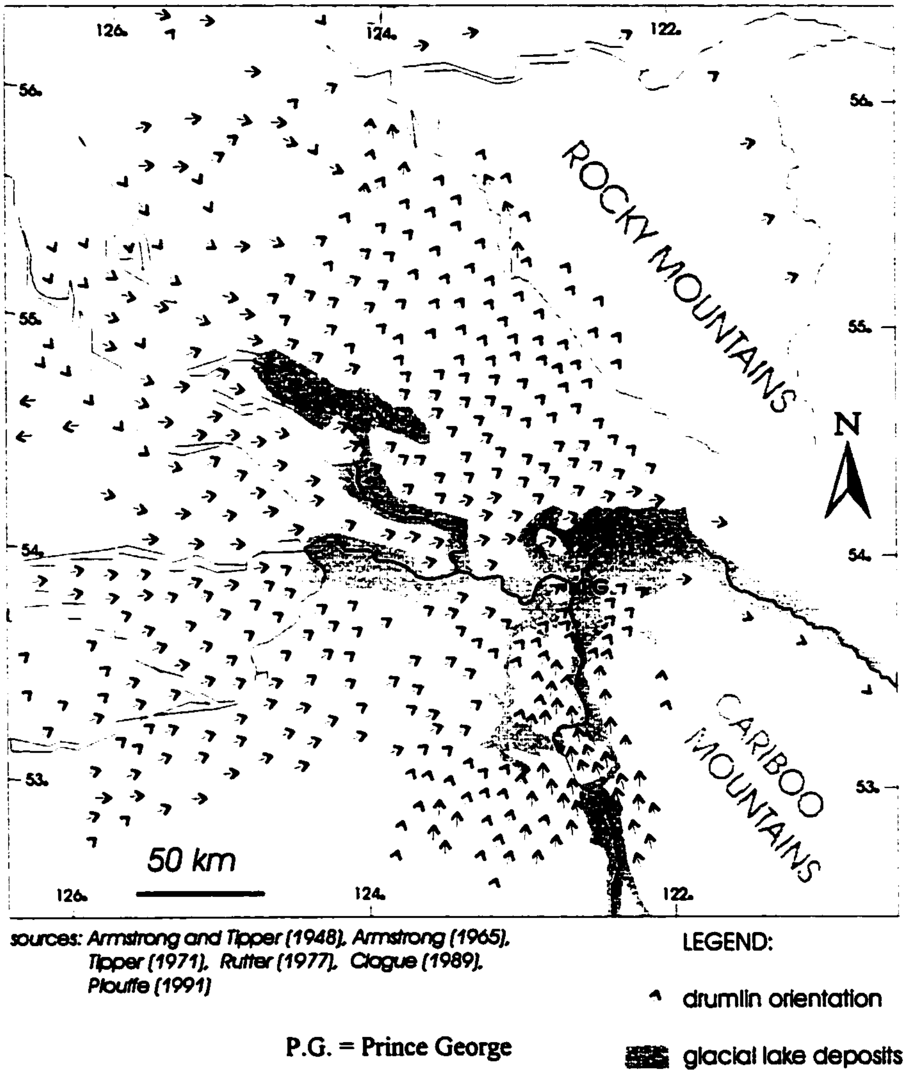


Figure 1-3. Regional drumlins and glacial lake deposits.

1.5 Previous Work

Past studies in north-central British Columbia have concluded that most glacial features and surficial deposits are the product of a Late Wisconsinan Fraser Glaciation. Cooling is estimated to have started ca. 29 ka BP, with the Cordilleran Ice Sheet at glacial maximum extending south into Washington State, west into the Coast Mountains, north into the Yukon and east through the Rocky Mountains to join the Laurentide Ice Sheet (Rutter, 1977; Fulton *et al.*, 1984; Clague, 1989). The timing of initial glacial retreat has been estimated at 16 ka BP in the Coast Mountains and on the plains east of the Rocky Mountains, and at 14 ka BP in the Yukon Territory and southern British Columbia (Clague, 1981; Fulton,1984). Many workers have lamented the relative paucity of Quaternary research in north-central British Columbia (Tipper, 1971b; Clague, 1981; Fulton, 1984). Much of the published work consists of observations gathered incidentally during bedrock studies, stratigraphic description and feature nomenclature are inconsistent, the mapping scale is variable, and an interpretive synthesis remains to be achieved. However, a considerable amount of data on Pleistocene surficial features and sediments has been acquired over the past 100 years; coverage of the study area is shown in Figure 1-4. The following summary provides the historical context within which this study was undertaken, and includes selected observations and interpretations that will be discussed further in this study.

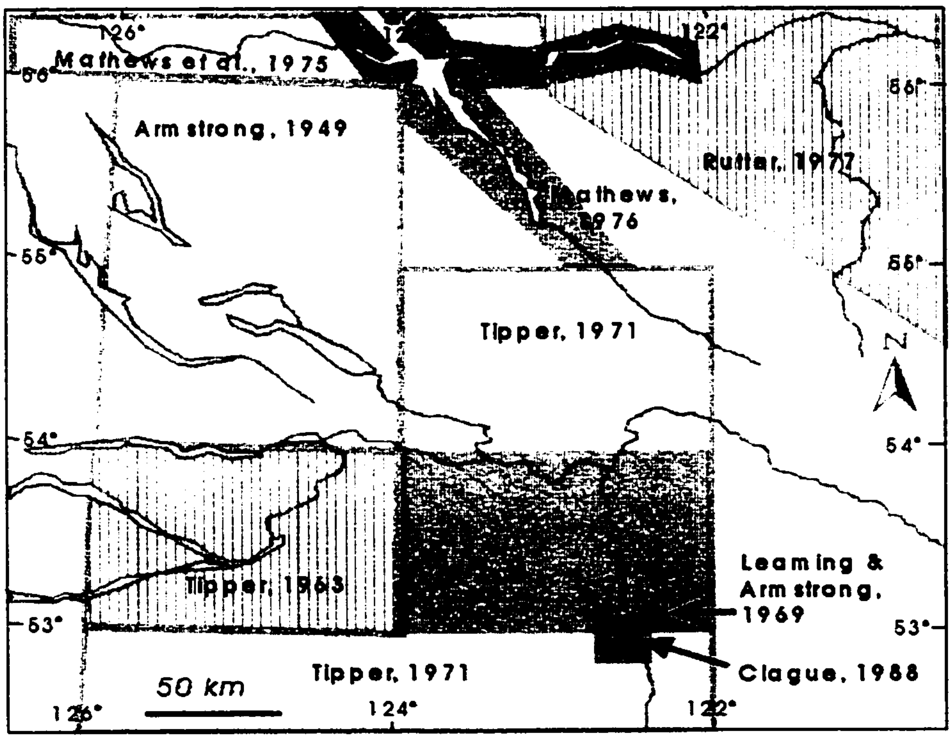


Figure 1-4. Quaternary geology studies in central British Columbia.

Dawson (1890) was the first geologist to observe and explain the widespread glacial features of north-central British Columbia as products of a Pleistocene Cordilleran glaciation. He noted numerous parallel ridges in the area which he termed 'moraines', and proposed that ice accumulated to cover all but the highest peaks in north-central British Columbia and eventually flowed outward in all directions.

Kerr (1934) studied the Coast, Cassiar and Omineca ranges, and distinguished between alpine glacial features and continental ice sheet features in northern British Columbia. In the Omineca Mountains he found exposures of a reddish 'drift sheet' overlain by two later, gray till sheets, all separated by 'well-bedded water-lain deposits', which he attributed to multiple advances and retreats. He noted the occurrence of erratics, eskers and 'buried rock channels' in the Omineca Mountains northwest of the study area, mostly on valley floors but also on mountain sides at higher elevations. In the Interior Plateau he found an abundance of 'drift' from the Coast Mountains, indicating northeast ice movement. From his observations Kerr (1934) proposed that Cordilleran ice built to a thick dome covering the Central Interior, from which it eventually flowed radially outwards. He also suggested that tremendous volumes of ice-dammed meltwater may have been trapped in the Interior Plateau during melting stages, depositing glacial lake sediments in low-lying areas before being suddenly released through outlets north to the Yukon and south to Idaho and Washington.

Armstrong and Tipper (1948) mapped much of north-central British Columbia from 10 years of field observations and thousands of U.S. military air photographs, providing the first comprehensive description of glacial features in the study area. They observed widespread parallel drumlins and intervening depressions or 'groovings' in till over much of the Nechako Plateau to an elevation of 1500 masl. The till was described as a clay and sand matrix containing well-rounded pebbles and boulders, grading upwards to poorly-sorted, till-derived sand and gravel with occasional lenses of well-sorted sand and gravel. Armstrong and Tipper (1948) noted that till on the east side of an extensive granite batholith contains granite boulders, which are absent in till west of the batholith. The drumlins display a wide variety of shapes (circular to elongated oval) and sizes, up to 3 km long and 50 m high, with the stoss (upstream) end and sides typically steeper than the lee (downstream) end (Fig. 1-5). They found that drumlins usually occur in groups and are often separated by valleys up to 800 m wide, 50 m deep and 10 km long. Shallow groovings (or flutings) are common on the drumlins or are found alone at elevations above 1500 m. Rock drumlins (or crag-and-tails) and drumlinized bedrock ridges are more uniformly parallel than till drumlins, with narrower intervening troughs. Armstrong and Tipper (1948) also noted three compound eskers, two of which lie on the Nechako Plain (Fig. 1-6).

The Stuart River compound esker emerges from 'hummocky' terrain (more rounded, less linear than drumlinized terrain) in the Stuart River Valley and ends on the bank of the Nechako River north of Prince George. The visible base of the esker is relatively constant at an elevation of 760 m, coinciding with the upper elevation of Glacial Lake Prince George deposits. The smaller Bednesti compound esker west of Prince George also extends from a drumlinized till plain onto (or into) glaciolacustrine sediments. Armstrong and Tipper (1948) observed that the esker slopes gently from west to east (into the glaciolacustrine deposits), so assumed the esker deposits rest on underlying till. They also suggested that emergent drumlins in the glaciolacustrine sediments were 'islands' in the lakes, with coarser sediment at the margin representing beach sediments. Armstrong and Tipper (1948) concluded from the general eastward flow direction, indicated by glacial features, that ice at glacial maximum moved east from the Coast Mountains across the Nechako Plateau.

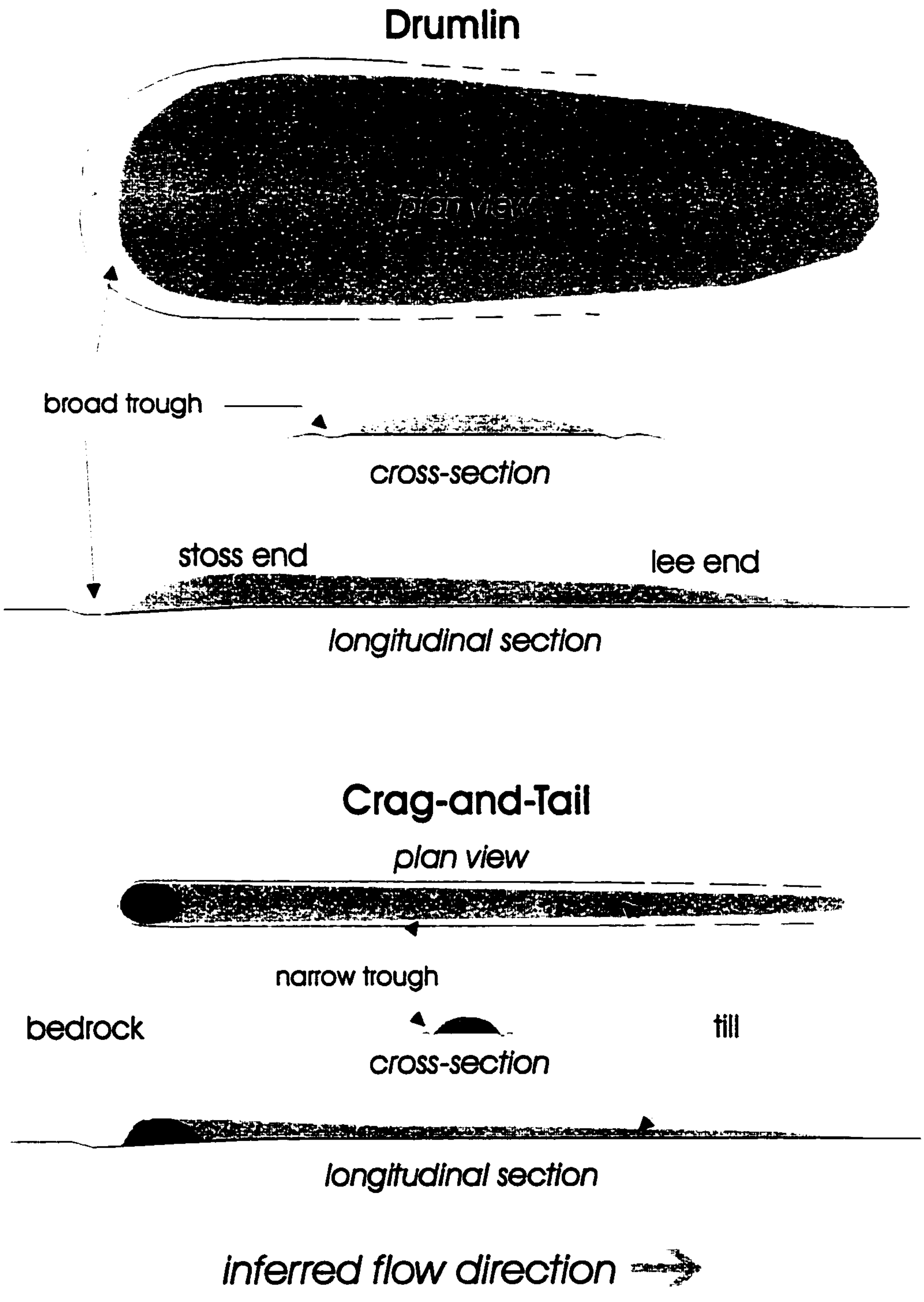


Figure 1-5. Typical drumlin forms (schematic, after Armstrong and Tipper, 1948)

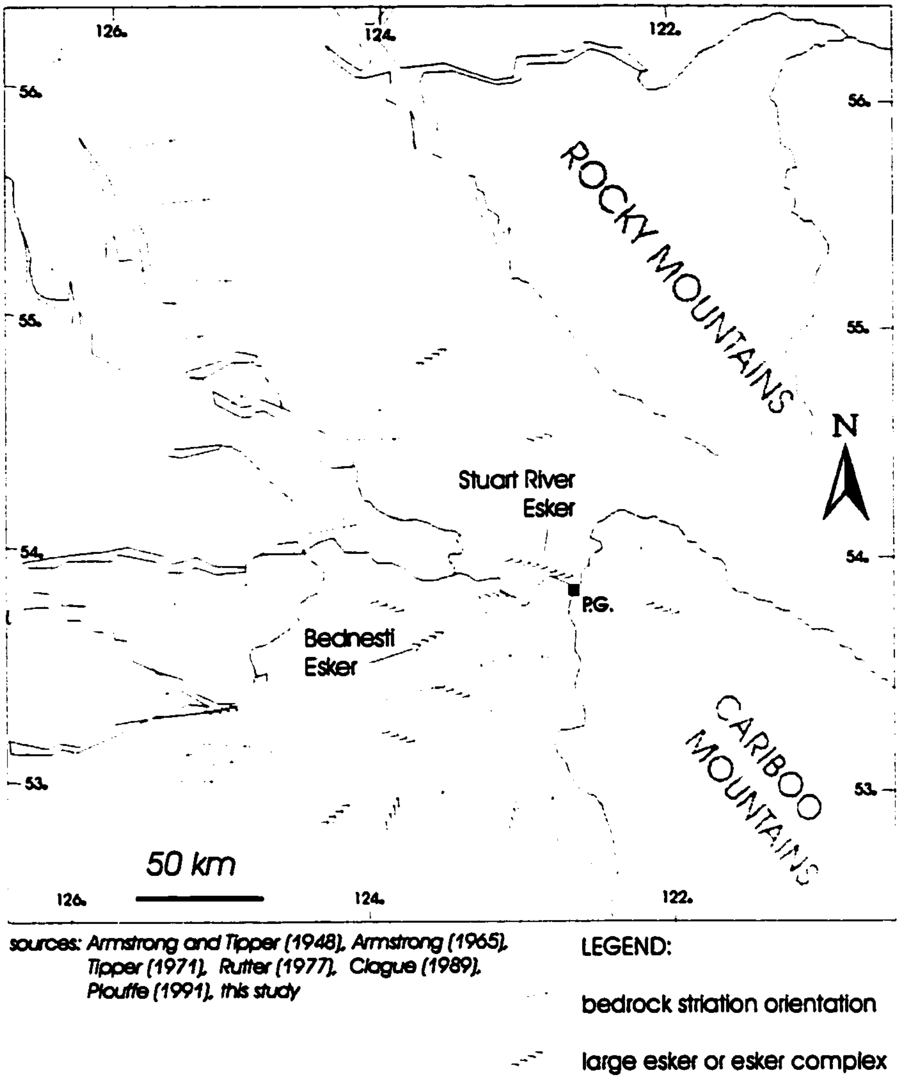


Figure 1-6. Regional eskers and glacial striae.

Tyrrell (1955) briefly surveyed glacial features along the Fraser River from Prince George to Quesnel. He observed numerous exposures of 'bouldery clay', all of similar composition, overlying stratified silts. He noted the relatively youthful character of the Fraser River, which had cut and maintained a deep, narrow, meandering gorge through soft Miocene sandstone, its form being atypical of known glaciated valleys. The only glacial striae he found were east of Quesnel, preserved on a quartz vein at 45° orientation, and on granite at 15°; in both cases oriented parallel to the local Cottonwood River valley. No other exposures of igneous bedrock showed evidence of glaciation, and the only moraines he found were small valley end moraines. On the basis of these observations collected over a few weeks, Tyrrell (1955) concluded that Pleistocene glaciation had been restricted to mountain valleys, and believed he had conclusively refuted the idea of a continental Cordilleran Pleistocene glacier.

Tipper (1963) studied the bedrock and surficial geology of the Nechako Plateau east of the study area. He found glacial striae at seven sites on Mesozoic volcanics and Tertiary rhyolite oriented between 70° and 90°. Till drumlins, rock drumlins and drumlinized bedrock ridges are much more common and display greater variability of orientation, from 40° to 95°, while glacial grooves show the greatest variability, oriented from 350° to 90° (Tipper, 1963). Glaciolacustrine deposits from Glacial Lake Vanderhoof, on the Nechako Plain, are contorted and pebble-rich near the top, with an undulating surface grooved in parallel with 'the known direction of ice movement'. Individual beds range in thickness from 0.5 cm to 20 cm, and are composed of silt and clay. Irregular areas of hummocky terrain, interpreted as ablation moraine and pitted outwash deposits, were mapped primarily on the northeast side of hills and mountains. Tipper (1963) noted that hummocky terrain and drumlinized terrain do not occur together.

Armstrong (1965) studied the geology of the Fort St. James region west of the study area. He observed one till, up to 120 m thick, covering much of the Nechako Plateau to elevations of 1500 masl, and occasionally to 1800 masl. He found drumlins to be limited to <1200 masl, to be best-developed in till-covered, low-lying plains and valleys, and to commonly display shallow longitudinal surface grooves, which he interpreted as ice-embedded boulder gouges. The drumlins are commonly topped by massive, poorly-sorted gravel, interpreted by Armstrong (1965) as glacial till washed free of fines by post-glacial runoff processes. 'Groovings' in till were observed to 1800 masl elevation; two sets of obliquely intersecting groovings were interpreted as evidence of two advances. Armstrong (1965) identified two glacial lake basins in the area as the Fort St. James and Vanderhoof basins. The associated glaciolacustrine deposits range in elevation from 670 to 795 masl. The Fort St. James basin sediments are predominantly cross-bedded sand (fine to coarse) and silt, with typical total thicknesses of about 30 m. Vanderhoof Basin sediments are thin, parallel laminae of clay (alternating bands of brown and grey-blue) and silt (cream to brown), accumulating to more than 100 m thick. The margins of both lakes are characterized by sand, gravel and boulders, interpreted as delta deposits and wave-reworked till beaches.

Leaming and Armstrong (1969) compiled a comprehensive surficial geology map of the Prince George area. Their map was prepared independently from that of Tipper (1971b), yet drumlin orientations and major geological units are in remarkable agreement. While Tipper (1971b) limited his surficial sediment mapping to glaciolacustrine sediments and pitted terrain, Leaming and Armstrong (1969) delineated Pre-Fraser deposits, Fraser glaciofluvial, glaciolacustrine and till deposits. Numerous additional subunits were interpreted, based on the degree of sediment stratification, consolidation, stratigraphic position, physiographic context and surface texture. Explanatory notes on their map include a caution that some sand/gravel units were arbitrarily assigned a unit designation based on little or no evidence of origin. Of particular interest were their observations of poorly-sorted sand and gravel at the margins of Glacial Lake Prince George deposits (interpreted as beach deposits) and of sand outwash deposits overlying glaciolacustrine silts from the Bednesti Lake Esker to the Nechako River valley.

Quaternary glacial features of the Prince George region were mapped at a scale of 1:250,000 by Tipper (1971b). This publication summarized the author's field observations over 20 years of regional bedrock studies, supplemented with air photo interpretations. He mapped glacial features more comprehensively than did Leaming and Armstrong (1969), including drumlins, rock drumlins (or crag and tail), glacial grooves (trough-like depressions), meltwater channels, glaciolacustrine deposits, eskers (and esker complexes) and pitted terrain (or kettle deposits). These maps provided invaluable reconnaissance data for this study. Tipper (1971b) observed that Vanderhoof Basin glaciolacustrine sediments had been drumlinized, providing a significant precursor to the findings of this study.

Mathews (1976) mapped the surficial sediments of the Parsnip, Finlay and Peace River valleys prior to the flooding of Williston Lake upstream from the W.A.C. Bennet Dam. He interpreted a complex sequence of sediments as evidence for multiple glacial advances, based primarily on the stratigraphic discontinuity of the till and a small number of till fabrics. Textural and lithological analyses of tills that he attributed to separate advances revealed no significant differences. The lowest sediments in the sequence are oxidized and contorted sand and gravel beds, containing organic materials radiocarbon dated as older than 28 ka BP. Above these lie well-sorted stratified gravel and poorly-sorted massive gravel interbedded with four till deposits. The uppermost deposits in the Rocky Mountain Trench consist primarily of coarsening-up glaciolacustrine sand, silt and clay beds to thicknesses of 90 m (a few metres of till overlies these deposits in the northernmost Finlay River valley). In the Peace River valley the upper deposits are primarily silt grading upwards to gravel. The so-called Portage Mountain end moraine consists of more than 90 m of coarsening-upwards, well-sorted sand and gravel, fining eastwards to sand; with eastward-dipping foresets (interpreted as deltaic deposits). Mathews (1976) found glacial striae to elevations of 1970 masl in the Rocky and Omineca Mountains.

Rutter (1977) described surface features and sediments in northeastern British Columbia apparently resulting from Cordilleran Ice flowing through the Rocky Mountains to join the Laurentide Ice Sheet. His observations of Cordilleran glacial features on the east side of the Rocky Mountains include erratics, drumlins, flutings and surficial sediments, indicating that Cordilleran ice from the study area flowed northward and eastward through numerous mountain valleys. A northwest-southeast boundary in the foothills marks the termination of Cordilleran surficial sediments and the truncation of southerly-trending flutings (presumed to have been created under Laurentide ice) by easterly-trending drumlins and flutings (Rutter, 1977).

Clague (1981) summarized the Quaternary geochronology of coastal British Columbia based on radiocarbon dating, and of the interior of British Columbia based on glacial sediments and 'ice flow patterns'. In south-central British Columbia, Fraser Glaciation deposits had been interpreted as a single lithostratigraphic unit called the Kamloops Lake Drift. Further north the interbedding of till and glaciolacustrine deposits had been interpreted as evidence for stades and interstades, although no corroborating chronological evidence had been found. Only one radiocarbon date, of 25,940 ± 380 ^{14}C years, was obtained from Fraser till, providing only a maximum limiting date to the glacial advance. Clague (1981) argued that high elevation striae in the Rocky Mountains were evidence of an ice dome, with surface flow uncontrolled by basal topography, and that low elevation glacial features are a product of topographically-controlled ice flow, overprinted by interstadial and deglaciation processes.

Clague (1988) studied late Quaternary valley-fill sediments near Quesnel, south of the study area. Above pre-Fraser fluvial and colluvial deposits (massive red-brown gravels and diamict) he found up to 20 m of well-sorted, stratified, clast-supported gravel with a sand matrix, overlain by up to 180 m of glacio-lacustrine sediments of interbedded sand, mud and diamicton. The silt and sand units grade from non-stony fine laminae (< 1 cm thick) at the bottom to stony, massive, often deformed (sheared and folded, with striated clasts) beds in the top 10-20 m of the unit. The upper contact is a sharp, sometimes deeply scoured erosion surface, overlain by up to15 m of gravel, diamict and rhythmically bedded clay and silt. Clague (1988) interpreted the sequence from bottom to top as pre-Fraser fluvial deposits, subaqueous debris flow deposits, distal ice-advance proglacial lake deposits, proximal ice-rafted and ice-overridden deposits, stagnant-ice basal meltout till, and retreat-stage ice-dammed glaciolacustrine deposits. No datable organics were found in the sequence, but the upper laminae were dated at 12-13 ka BP by thermoluminescence.

Plouffe (1991) studied a large region north of Fraser Lake. In some areas he mapped drumlins and groovings not included on Armstrong's (1965) map, with a greater variability of orientation. In the Omineca Mountains they align closely with both large and small local valleys. In the Fort St. James area they are evident in the glacial lake basin and are closely aligned with Stewart Lake; Armstrong (1965) had mapped drumlins aligned across the lake and ending at the margin of the basin. Plouffe (1991) found very few bedrock striations, noting that two sets he found north of Pinchi Lake crossed at an oblique angle, which he interpreted as evidence for the shifting flow of coalescing piedmonts. At Fraser Lake a 6 m sequence of sand, gravel, diamict, gravel and sand was interpreted by Plouffe (1991) to represent pre-Fraser and Fraser deposits. In valleys below 725 masl silt and clay laminae form sequences as thick as 30 m; generally thinning-upwards, they are interpreted as increasingly distal ice-retreat glaciolacustrine deposits.

Clague (1991) described Quaternary sediments in nine valleys southwest of Quesnel. Thick deposits (>80 m at some sites) of stratified gravel, sand, silt and diamict displayed internal structures (intertonguing lithologies, folds, faults and vertical dykes) indicating 'gravitational foundering', post-deposition deformation and porewater expulsion. A high-relief unconformity truncates this unit, followed by stratified sand and gravel (fining to sand and mud at some sites) and another erosional unconformity beneath Fraser till of 10-20 m thickness. The till is overlain by a sequence of stratified gravel, sand, silt and diamict, similar to the lowest deposits, though without the complex internal architecture. Clague (1991) attributed the sequence to an Early Wisconsinan glaciation, Middle Wisconsinan valley incision, pre-Fraser fluvial and pre-advance outwash deposition, ice erosion and till deposition, and ice-dammed retreat-stage glaciolacustrine deposition.

Shaw (1994) cited the occurrence of hairpin scours wrapped around the stoss and sides of both till and bedrock drumlins in the Prince George region as evidence for turbulent erosion by 'horseshoe vortices'. He likened their pattern and form to small-scale erosional marks wrapped around cm-scale chert nodules in Ontario Ordovician carbonates. He challenged Armstrong and Tipper's (1948) suggestion that glacial 'grooves' in the Prince George area were carved by boulders protruding downwards from the flowing ice. He asserted that the grooves are too large to be etched by a single boulder or multiple clasts in a debris-rich basal layer, and that bifurcated, crescentic scours common at the stoss end of drumlins cannot be explained by such a process.

Clague (1989) released preliminary maps of the surficial geology southwest of Prince George at 1:100,000 scale. He observed thick deposits of fine-grained rhythmites underlying undulating, hummocky surfaces to an elevation of 760 masl, interpreted as Glacial Lake Vanderhoof deposits. Sand and gravel deposits with a thin, discontinuous veneer of clay and silt between 760 and 800 masl grade into till at higher elevations. Clague (1989) noted that the sand and gravel occurs at the basin margins; and mapped them as beach deposits. Drumlins are limited to <1200 masl; their orientations show more variability at this scale than on Tipper's (1971b) 1:250,000 maps, often diverging around local topographic highs. In a low-relief area southwest of Pelican Lake, drumlins within 1 km of each other converge at an angle of 15° under no apparent topographic influence.

In summary, the few large-scale Quaternary studies in the region reveal more variability of glacial lineations than the regional trends reported in earlier reconnaissance-scale studies. Interpretations of the growing body of stratigraphic evidence (derived primarily from valley bottoms) rely heavily on assumptions that the glacial sediment record remains basically intact, so the observed sequences must represent multiple Fraser Glaciation advance and retreat stages. Interpretations of advance outwash are unsupported by evidence of upward thickening of beds or coarsening texture; advance proglacial sediments are identical to upper sequences except for internal deformation; gravel on top of drumlins and at the margins of glacial lake basins is assumed to be from reworked till; eskers are assumed to have been deposited after the glaciolacustrine deposits. This Prince George area survey tests these assumptions, complements the recent work of Clague, Plouffe and others in adjacent regions, and builds on the comprehensive body of early work completed by Armstrong, Tipper and others.

CHAPTER 2. METHODOLOGY

The primary goal of this study is to complement past regional Quaternary work by focusing on landform morphology and sedimentology at a few representative localities in the Prince George region. Particular aspects under scrutiny include the local variability of drumlin form and orientation, the stratigraphic relationship between drumlins, eskers, and glaciolacustrine sediments, and the reinterpretation of the Fraser Glaciation sediment record as the product of late-glacial, catastrophic meltwater erosion and deposition.

A number of specific objectives were established to provide the basis for a thorough assessment of the meltwater hypothesis:

1. Drumlins were studied in a variety of locales sufficient to delineate regional variability, especially along the apparent glacial flow path;
2. Drumlin form was surveyed using a Gobal Positioning System (GPS) at a resolution sufficient to quantify the range and variability of size, shape, surface texture and microfeatures;
3. The composition of drumlins was ascertained from surficial sediment sampling in dig pits and stratigraphic mapping at road and creek exposures;
4. The stratigraphic record of other glacial deposits was recorded as a contextual framework for reconstruction of the Fraser Glacial record.

2.1 Site Selection

Initial site selection for 1997 fieldwork was based on Tipper's (1971) maps, air photo imagery, and the recommendations of local expert Dr. A. Gottesfeld (University of Northern British Columbia). The Stone Creek Forestry Road, 25 km south of Prince George, provided access to a recently burned and logged area. The exposed group of drumlins occupied canopy-free terrain ideal for unobstructed GPS satellite reception, and smaller cutblocks nearby exposed a suite of individual features. Subsequent sites for 1998 fieldwork expanded the survey into gravel and lacustrine sediments in the Fraser and Nechako Plateaus, drumlinized bedrock in the Rocky Mountain Trench, and diamict on the McGregor Plateau.

2.2 Global Positioning System (GPS) Data Collection

This study incorporated high-resolution GPS transect surveys to map the form and microtopography of drumlins. Location data were collected continuously by a backpack 'rover' receiver as the worker walked transects over the terrain of interest. In addition to recording GPS time signals and calculating positions, the receiver downloaded information on the 'health' of GPS satellites in visible range; a combination of satellite signals was automatically selected to provide the most accurate locations based on geometry. The two rover receiver models used in this study were a 1994 Trimble Basic Plus and a 1997 Trimble ProXL. The Basic Plus receiver, capable of utilizing up to 6 satellite channels at any one time, operated consistently during two days of testing but was inconsistent in field use. Vertical errors ranged from sub-metre to more than ten metres, so data from this receiver were used sparingly to fill gaps in the ProXL database. Anomalous data points were identified by graphing in Excel and removed from the transect data. The Basic Plus did not retain satellite information for each file, so the source of the error remains uncertain. The ProXL system used 8 channels, and provided consistent results of <1 m error throughout the two field seasons.

Survey operation was limited to time periods when at least five satellite signals were being recorded (the minimum for high-resolution 3D location acquisition), with an elevation mask of 15° above the horizon, to reduce the potential for signal blockage or multipath error from trees or high-relief terrain. The minimum Predicted Dilution-of-Precision threshold (based on the geometry of the satellite configuration being used – the closer together the satellites, the poorer the triangulation accuracy) was set to 6, as was the Signal to Noise Ratio, as recommended in Trimble operation manuals (Trimble Navigation Ltd., 1997). In 1997 GPS base data were purchased from TerraPro GPS Surveys Ltd., which maintains a permanent 12-channel Trimble GPS base station in Prince George. For the 1998 field season a portable 12-channel Trimble base station was set up at the University of Northern British Columbia to collect base data.

Base and rover GPS data were synchronously recorded every 5 seconds, providing a data point every 2-10 metres along the transect (depending on walking speed, which was dependent on terrain slope, deadfall obstructions, thick vegetation, and the distraction of ripe fieldberries). Transect spacing ranged from 5 m to 60 m, depending on the feature scale, so along-transect resolution was considerably higher than across-transect resolution. The transects were originally intended to be oriented in two directions, with two rover receivers being used at the same time by two field workers, resulting in a grid of GPS points. It was reasoned that this would result in more complete coverage of the feature, with only 25% potential redundancy (data overlap after interpolation between transects), while ensuring sufficient data acquisition if one of the receivers failed (Fig. 2-1). The redundancy was beneficial, as the Basic Plus data were of minimal use. The ProXL receiver was used most often for across-feature transects, which was (in hindsight) less effective for describing the continuity of linear features during the surface interpolation process. Additional transects were taken along sharp slope breaks and over small features that required closer grid spacing (Fig. 2-2).

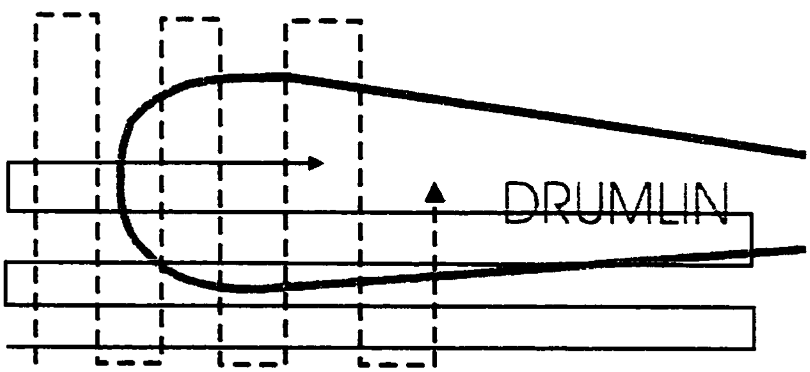


Figure 2-1. GPS transect grid for a two-rover system.

2.3 GPS Differential Correction

GPS post-processing was undertaken in Trimble Pathfinder Pro software. A differential-correction process removed the apparent lateral and vertical drift recorded at the stationary base station (at a known exact location) from the time-synchronous rover data.

Data points from the ProXL receiver retained non-spatial attributes, including the exact time of data collection, dilution-of-precision value, and the health of each satellite used, all of which were useful in culling anomalous data points. The portable Trimble base station data were retroactively calibrated to the permanent station location established by TerraPro GPS Surveys Ltd. A number of tests throughout the two field seasons showed the system resolution to be sub-metre in both the horizontal and vertical planes for sites within 100 km of Prince George. The corrected transects were amalgamated for each discrete drumlin feature or group of features in preparation for the production of digital elevation models (Fig. 2-2). The final output consisted of a space-delimited ASCII x,y,z file containing UTM northing, easting and elevation to the nearest centimetre, based on a UTM projection, WGS-84 datum.

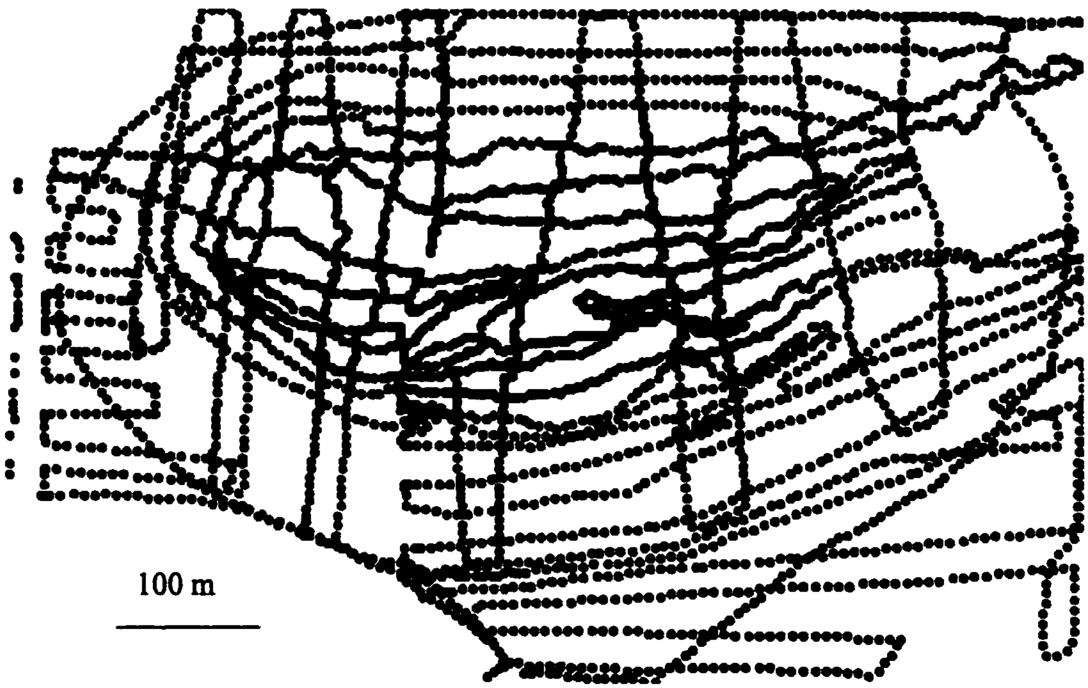


Figure 2-2. Example of corrected, amalgamated GPS transect data prior to DEM interpolation.

2.4 Interpolation of Digital Elevation Models

The ASCII files were imported into IDRISI GIS as vector points on a one-metre grid. Digital elevation models were interpolated using Inverse Distance Weighting, with a weighting exponent of two and a six-point search radius. Grid resolution was generalized to 2 m or 5 m, depending on feature scale and transect separation. Interpolation artifacts were filtered out using two passes of a 7x7 (or 5x5 for small features) mean convolution kernel. Figure 2-3. illustrates the effect of the filtering process; data loss from the upper and lower ends of the elevation range is 1-2 metres at the upper and lower extremes, but noise has been significantly lessened.

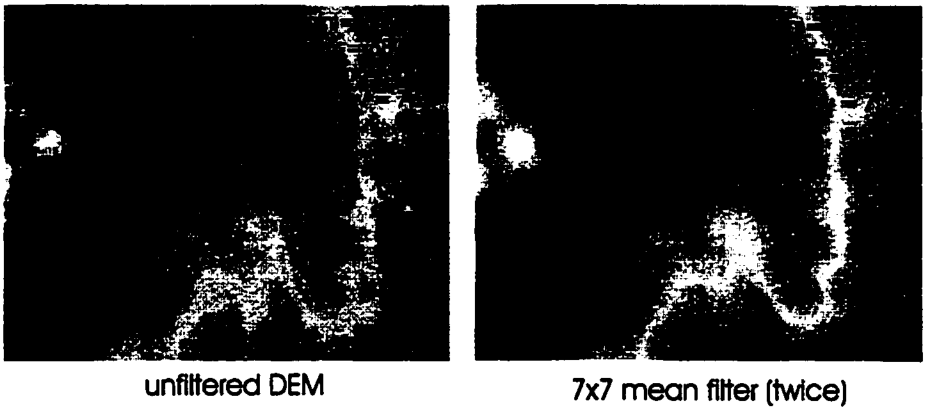


Figure 2-3. Effects of DEM mean filtering.

In some cases the interpolation process introduced objectionable spikes or troughs between transects that were separated by 50 m or more (the result of a stepwise interpolation of local trends into a no-data zone). In these cases artificial data points were inserted into the initial raster grid, based on trends observed in the field, to minimize the interpolation error. The filtered DEM's were exported to ArcView for generation of derivative slope and aspect maps, and Triangular Irregular Networks (TIN) to be viewed in three dimensions. A digital dataset was prepared to accompany this thesis, including Excel files of the original corrected GPS positions, the DEM grid, sediment sample and fabric data, and selected JPEG images of the drumlins.

2.5 Surficial Sediment and Fabric Analysis

At each GPS survey site, observations were recorded on the composition of the underlying features and surface sediments. For rock drumlins, the lithology and structure of the bedrock was noted, as were the orientations of striations and flutings and the nature of surface veneers, including gravel or boulders. For rock-cored and diamict drumlins, clast fabric orientations were recorded from exposures or pits. Sample size was 25 to 50 clasts, collected from below the C horizon. This horizon was usually marked by the termination of roots and disturbed sediment, a layer of cobbles at 20 cm to 50 cm depth, and undisturbed sediment below. Fabrics were measured at road exposures to depths of 10 metres to test for vertical consistency. RockWorks 98 was used to generate rose diagrams, stereonets and eigenvalues for each fabric. Sediment samples were gathered at most sites for grain size analysis. Hand sieving was utilized to remove clasts larger than 2 mm; sandy samples were further sieved to 0.0625 mm diameter, and clayey samples were analyzed using hydrometry to 0.001 mm diameter (Folk, 1980; Catto, 1987). Results were plotted as texture histograms and ternary diagrams, based on a Wentworth phi scale. Roundness was assessed from the granule fraction as rounded, subrounded, subangular, or angular. Cobbles and boulders were assessed in the field for size, location, lithology, roundness and the presence of striations or percussion marks.

2.6 Stratigraphic analysis

Exposed sediments in drumlins and related features were recorded to interpret the sedimentary environment prior to formation of the drumlinized surface. Many diamict features displayed no obvious contacts and minimal stratigraphic variability to a depth of up to 10 metres. The quarried MacLeod Lake rock drumlin exposed two apparently distinct overlying tills in the lee end. Other stratigraphic information was recorded from sediment sequences at two Hixon river-cut gravel exposures, a gravel pit in Prince George, a slump in the Stuart River esker complex, a BC Rail exposure along the banks of the Fraser River and a number of small highway embankment exposures in silt, sand and gravel throughout the study area. Exposures of glaciolacustrine silts overlying gravelly diamict were studied in the greatest detail. At College Heights, a subdivision of Prince George, steps were dug into a fresh road exposure. Rhythmite beds were described and measured to the nearest cm from the contact with underlying gravels to the drumlin surface. At Cale Creek, a sequence of more than 100 rhythmites was logged and sampled. At the Strathnever site steps were dug into the rhythmites, the sequence was logged and sampled, and the exposure was photographed along part of its profile.

2.7 Diamict Consolidation

Sediment on the top of Stoner Creek diamict drumlins was harder to penetrate (apparently more highly consolidated) than on the drumlin sides or any of the adjacent low-lying areas. A simple penetrometer was employed to test this observation, comprised of a cone-tipped (5 cm diameter) metal rod marked at 5 cm depth intervals. A 2.2-kg sledge hammer was used to drive the calibrated pole into sediment below the C-horizon. The number of blows required to penetrate 5, 10 and 15 cm was recorded at numerous sites on the two drumlins. The force of the blows was kept as consistent as possible, and the number of blows was normalized using observed mean values to compensate for the apparent strength differential between the two workers. The technique was imprecise, but the results were relatively consistent.

2.8 Regional Observations

Initial observations of till fabrics, bedrock striations and flutings at Stone Creek and sites to the north revealed an apparent divergence in their orientations, so additional fabrics and sediment samples were collected east and west of Prince George and as far north as Williston Lake to verify the regional fabric trend and variability, and topographic high points were examined for evidence of remnant bedrock striations and flutings.

The following chapters examine the glacial landforms of the Prince George area, grouped by composition. Chapter Three includes bedrock drumlins, drumlinized bedrock ridges and crag-and-tail features. Chapter Four includes diamict (interpreted as till) composition and variations of diamict drumlin morphology and internal stratigraphy. Chapter Five includes a general discussion of Fraser gravels, lacustrine rhythmites, and drumlins comprised of silt overlying gravel.

CHAPTER 3. BEDROCK DRUMLINS

Rock drumlins and drumlinized ridges are common at higher elevations of the Fraser Plateau, Nechako Plateau and McGregor Plateau, and as igneous extrusions and hillside outcrops at lower elevations. Figure 3-1 shows the relevant localities in the study area. All these features have some superficial sediment visible in surface depressions and at the lee end. Individual rock drumlins are rounded knobs of local bedrock, elongated in the direction of the formative flow, with steep stoss ends and sedimentary tails at their lee ends. Larger drumlinized ridges are incised with flutings in the direction of flow, leaving rows of bedrock remnants similar in shape to till drumlins. There was no observed lower size limit for bedrock drumlin morphology, but features smaller than a few metres in relief were not surveyed. These landforms are comprised of Tertiary or older bedrock; it is evident that they are erosional remnants.

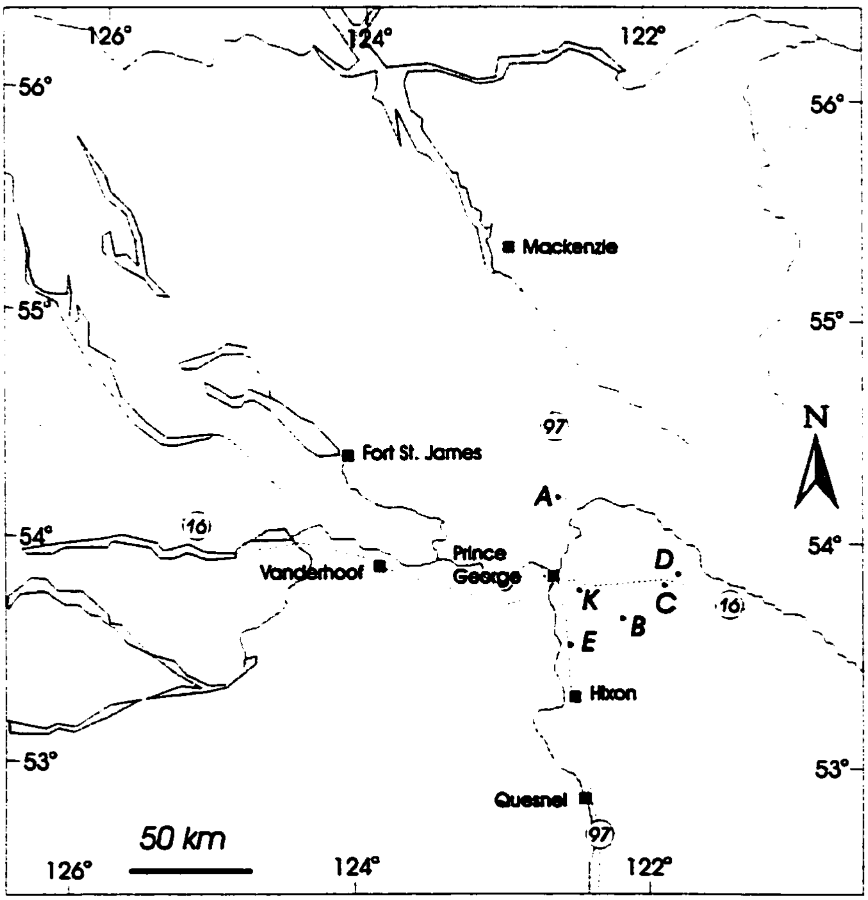


Figure 3-1. Bedrock localities of the study area.

3.1 Summit Lake (Locality A)

Two rock-cored drumlins at this site north of Prince George (elevation 750 masl) have been partially quarried for columnar basalt, providing excellent exposures of the crag-and-tail structure (Fig. 3-2). The basalt is vertically faulted, and the quarrying process has littered the southeast side with angular blocks. The stoss end and much of the southeast side of the largest feature remain intact, providing a sufficient basis to reconstruct its original surface form. The drumlin is 850 m long, 250 m wide and 50 m high. The stoss end of the drumlin (SW) is very steep, with a slope >40°; the lee end of the bedrock core slopes at 20°. The diamict tail (NE) slopes more gently, terminating 15 m higher in elevation than the base of the stoss end base.

The diamict fabric (#69, 70) is oriented north-south, oblique to the drumlin central axis by 30°, and two of three fabrics collected within 6 km of the site (#119, 135, 145) are also oriented oblique to the local drumlins (Fig. 3-3). The southeast side is convex in cross-section, with slopes of up to 30° and a shallow trough along the slope break; the terrain is relatively flat further to the east. The southwest side is concave in cross-section, with slopes of up to 40°; the ground rises to a smaller adjacent drumlin on the northwest side. The bottom slope break on the southwest side is undulatory, suggesting some bedrock control of the surface erosion.The smaller drumlin to the west has been quarried at the stoss end, providing a cross-section view of its form (Fig. 3-4). The upper surface of this small drumlin forms a smooth, even curve, with no steps or surface depressions.

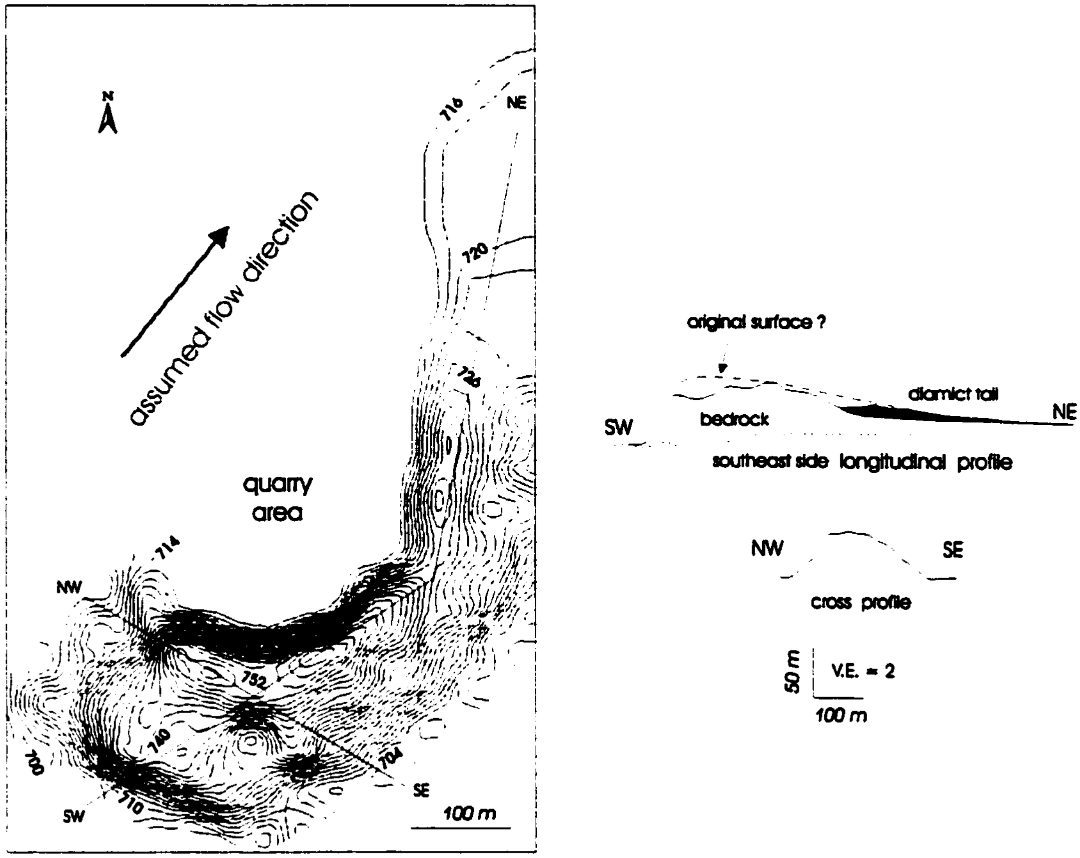


Figure 3-2. Contour map and profiles of quarried rock drumlin, locality A.

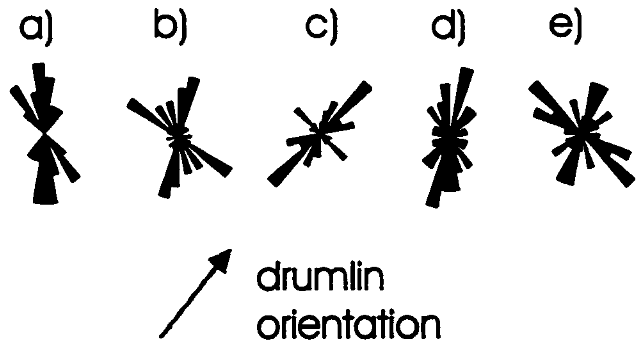


Figure 3-3. Fabric orientations from within Summit Lake drumlin (a, b), and sites 5 km to the northwest (c), and 5 km to the north (d, e). Arrow indicates long-axis orientations of local drumlins.

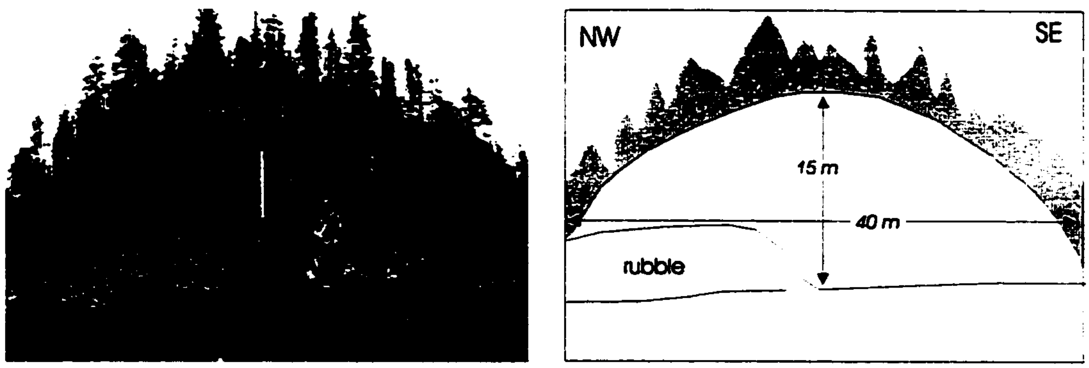


Figure 3-4. Quarried stoss end of a small rock drumlin, locality A.

3.2 Willow Road shale ridge (Locality B)

Streamlined features are visible near the junction of Willow and Willow North Forest Service Roads as a series of low-profile drumlins draped over the crest and east shoulder of a rounded shale ridge (Fig. 3-5). The shale bedding dips south at a near vertical 85°. A thin veneer of sandy diamict at the stoss end displays angular clasts of schist and shale, with a dark-coloured matrix. Near the top of the ridge (elevation 1000 masl) a number of rounded granite boulders are perched on the surface. The orientation of the drumlins is east-west, parallel with the local trend as mapped by Tipper (1971b). There are no drumlins on the steeper, west (stoss) side of the ridge. Figure 3-6 depicts the scale of the ridge and drumlins. The two drumlins are 30 m wide, 60-90 m long and 5 m high, the most prominent of a dozen similar forms aligned along the crest of the ridge. Their description as drumlins is subjective: whereas on the crest of the hill the remnant knobs are prominent, the eroded terrain on the downflow (northeast) side is more subtly fluted. Such low-relief features are muted or hidden completely by forest cover, but were commonly observed in deforested areas at high elevations throughout the study area. The minor east-west trending pattern in the detail of Fig. 3-6 is an artifact of the interpolation process and is not evident on the ground.

Maximum slopes on the larger drumlins are 10-20° on stoss and lee ends, up to 30° on the sides. At this scale smaller features are shown to be nested with larger features (Fig. 3-

7). Sinuous furrows run between remnant knobs and cross over their lee ends at oblique angles. Shale bedrock is exposed on the crest of the ridge; granite boulders as much as 1m in diameter are evident on the stoss side of the ridge but absent on the lee side.

Figure 3-5. Photograph, lee side of drumlinized shale ridge, locality B. Flow was from right to left.

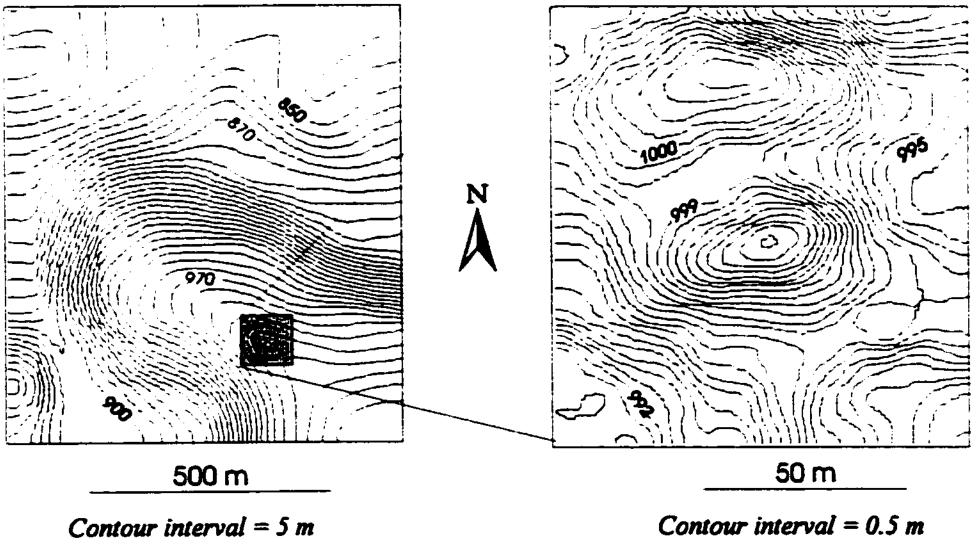


Figure 3-6. Contour maps of bedrock ridge (left) and drumlins (right), locality B.

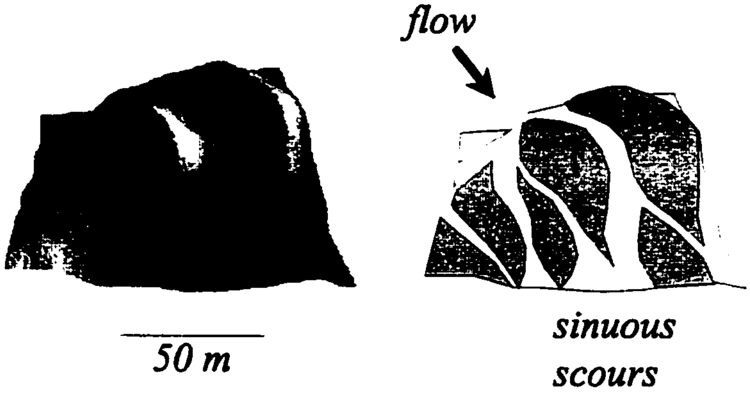


Figure 3-7. Modeled oblique view of drumlins on shale ridge, looking west, locality B.

3.3 Purden Lake (Locality C)

This is a recently logged bedrock hill west of Purden Lake, composed of jadeite (554744E, 5968241N, elevation 865 masl). The hill is slightly oblong and oriented northeast-southwest. Many smaller elongated drumlins are superimposed on it, oriented closer to east-west. Much of the GPS data acquired for these small features was corrupted, so survey details are minimal. Figures 3-8 and 3-9 show the shape of the hill and two smaller areas, but poorly represent the details of their form. The larger feature is comprised of three rows of smaller drumlins (each 50 m long and 1-3 m in relief) cascading up and over the crest of the hill. A thin veneer of sand, gravel and rounded quartzite cobbles covers a few protected areas near the top.

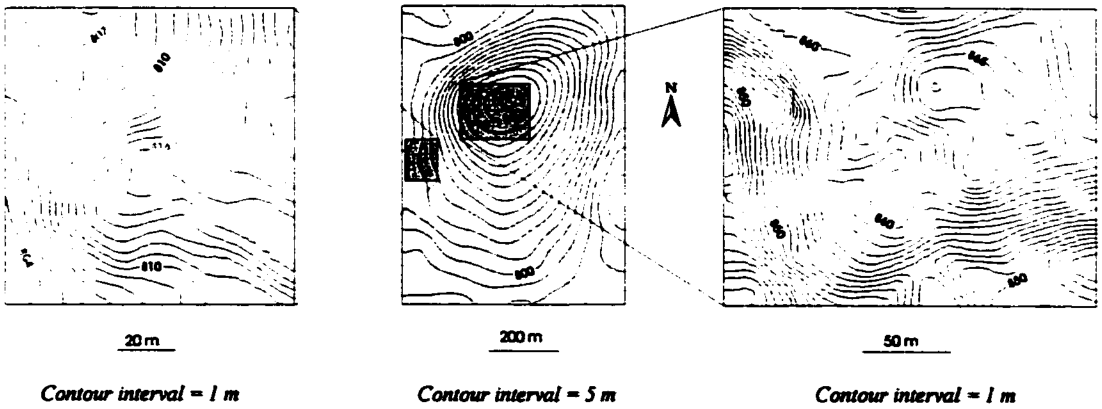


Figure 3-8. Contour maps of drumlinized bedrock hill, locality C

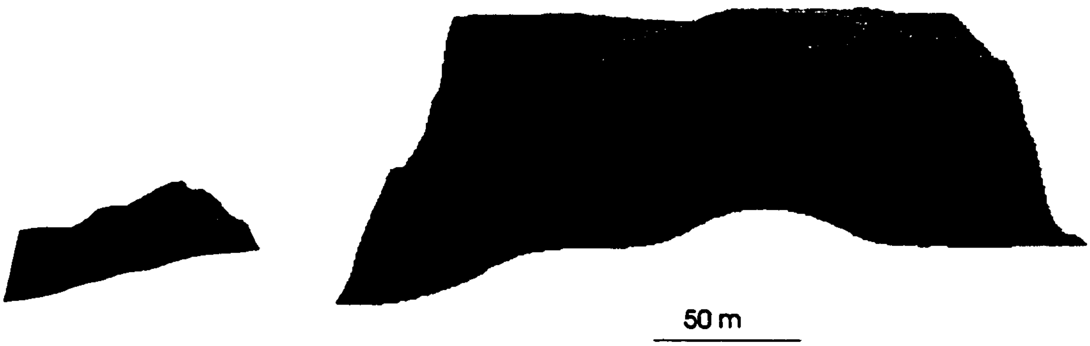


Figure 3-9. Oblique views of drumlins, looking north, locality C.

3.4 Bowron Road (Locality D)

A drumlinized limestone ridge was surveyed east of Purden Lake (58036E, 5977035N, elevation 800 masl), oriented northwest-southeast in the Rocky Mountain Trench. More than a kilometre long and 250 m wide, its sides and southwest end are relatively steep and featureless (Fig. 3-10). Systematic surveying was limited to the top and northeast side of the ridge, which are covered with flutings and small remnant ridges. The top of the ridge is cut by a large trough, 50 m wide and 500 m long, flat-bottomed with steep sides, oriented slightly oblique to the ridge. The trough originates from the northwest and exits to the southeast. The steep southwest side of the ridge is smooth, with slopes to 45°. The northeast side is covered in small drumlins cascading down a slope that rarely exceeds 25°. Many smaller flutings cross the ridge in an east-west direction, perhaps indicating a secondary or subsequent flow direction. The smallest drumlins portrayed are 15 m wide, 30 m long and 2-3 m high, but many smaller features occur within the largest fluting. Bedrock fractures were evident at the highest exposed surfaces; orientations were varied, from 70-80° southward at one location to 60° westward in another. A bedrock exposure on the southwest side displayed cavitation pock marks on the lee side, and many exposures on top of the ridge exhibit flutings at a scale of metres or centimetres. The photographs in Figure 3-11 illustrate a common field observation that flutings on flat areas are more linear than those on slopes, which are commonly horizontal at their stoss ends and curve gently downslope at their lee ends. These small flutes or furrows are most often closely aligned with the larger drumlins and flutings on the ridge; their orientations are generally along-slope rather than downslope, so they are unlikely to be Holocene karst features. They are similar to aeolian ventifacts, which are commonly much older features. Shallower cracks that crosscut the flutes at oblique angles are associated with local fracturing.

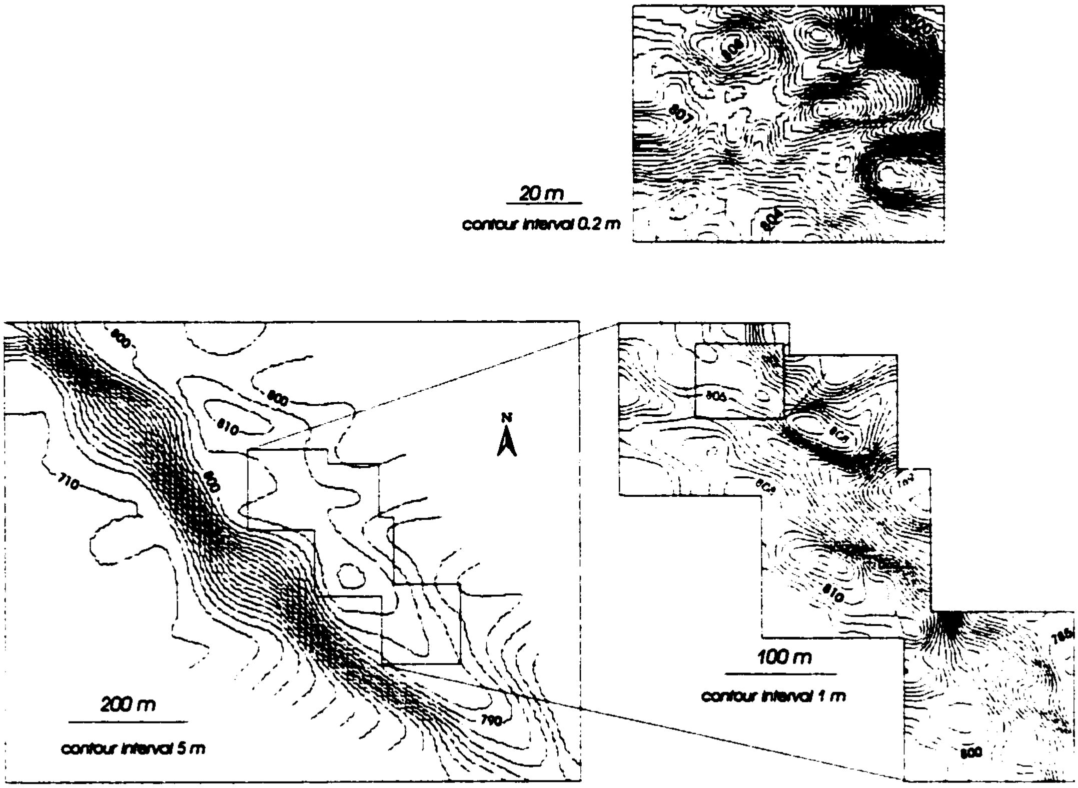


Figure 3-10. Contour maps of limestone ridge, locality D (flow was left to right).

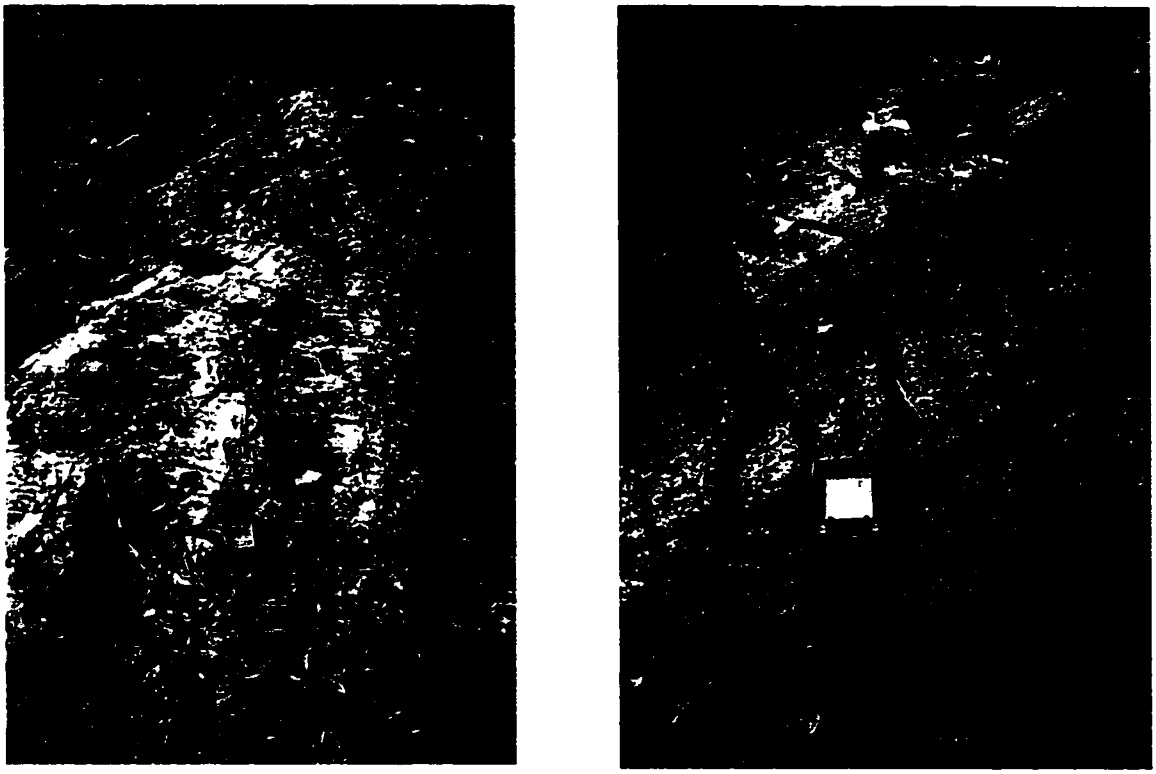


Figure 3-11. Flutings in limestone (compass is 5 cm wide), locality D.

3.5 Stoner dump (Locality E)

The Stoner dump 20 km south of Prince George is the site of a small rock drumlin 250 m long, 70 m wide, and 10 m high (630 masl). Oriented north-south, it is slightly asymmetrical, curving gently downslope at the lee end (Fig. 3-12). The west side slopes more steeply (30°) than the east side (20°); the stoss end slopes at 10-15° and the lee end at 5°. The surface is irregular, interrupted by protuberances of schist bedrock and depressions containing diamict and silt rhythmites. The longitudinal profile illustrates that the eastern base of the drumlin rises by 7 m from stoss to lee end. Situated downslope from an area of larger diamict drumlins, this feature is comprised of schist, as are many local outcrops. An apron of intact bedded silts (8-11 cm couplets) is evident on all sides of the landform.

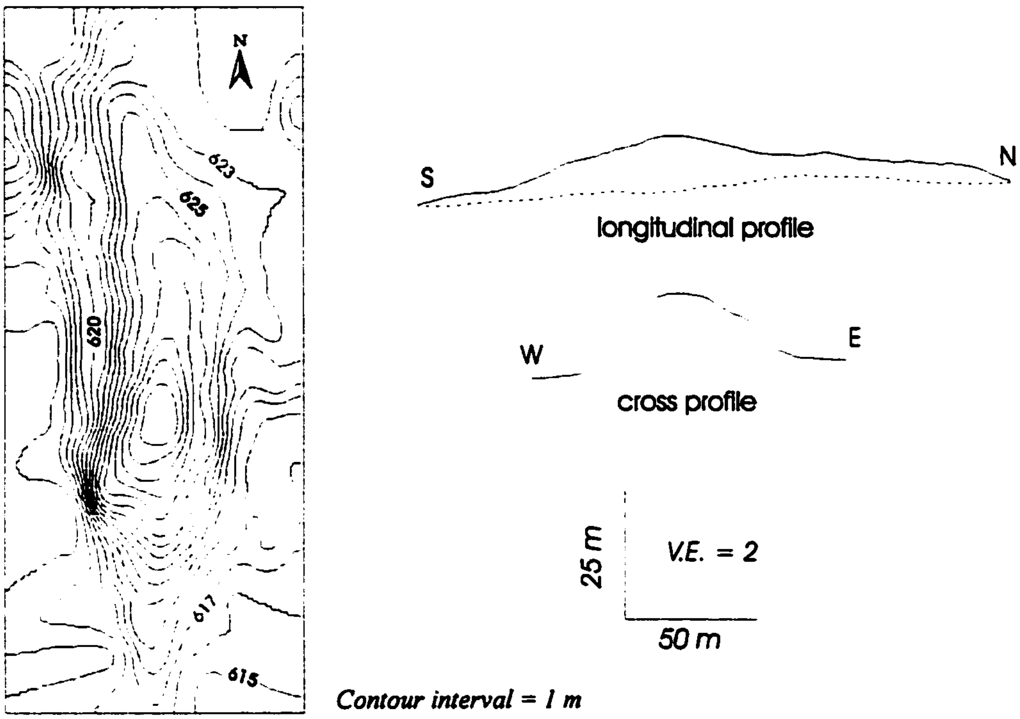


Figure 3-12. Contour map and profiles of rock drumlin, locality E.

3.6 Tabor Mountain (locality K)

At Tabor Mountain a series of drumlinized ridges strikes northwest-southeast, while the drumlins are oriented northeast-southwest (Fig. 3-13). The photograph detail shows a range of smaller features to the north oriented in the same direction. Single transects at locality K were surveyed on the stoss end of two drumlins and the trough between, as thick brush elsewhere prohibited signal reception and access. The stoss end of the drumlins is steep and rounded, with slopes ~20°, rising from 910 to 1035 masl. The two drumlins are separated laterally by 650 m, yet their stoss end profiles are well-matched in terms of slope and roughness (Fig. 3-14, black dashed line and solid grey line). The lee ends extend as tails, at slopes less than 5°. The floor of the furrow between them rises at a 10° slope to 990 m elevation, flattens abruptly and drops again eastward where it contains a narrow lake. The trough also contains diamicton (site #71). Many small flutings are evident on exposures at the lookout above (east) of the ridge, striking between 55-69°, parallel to the drumlins (Fig. 3-13 and Fig. 3-15). Striations at the lookout strike between 52-90° (Fig. 3-16).

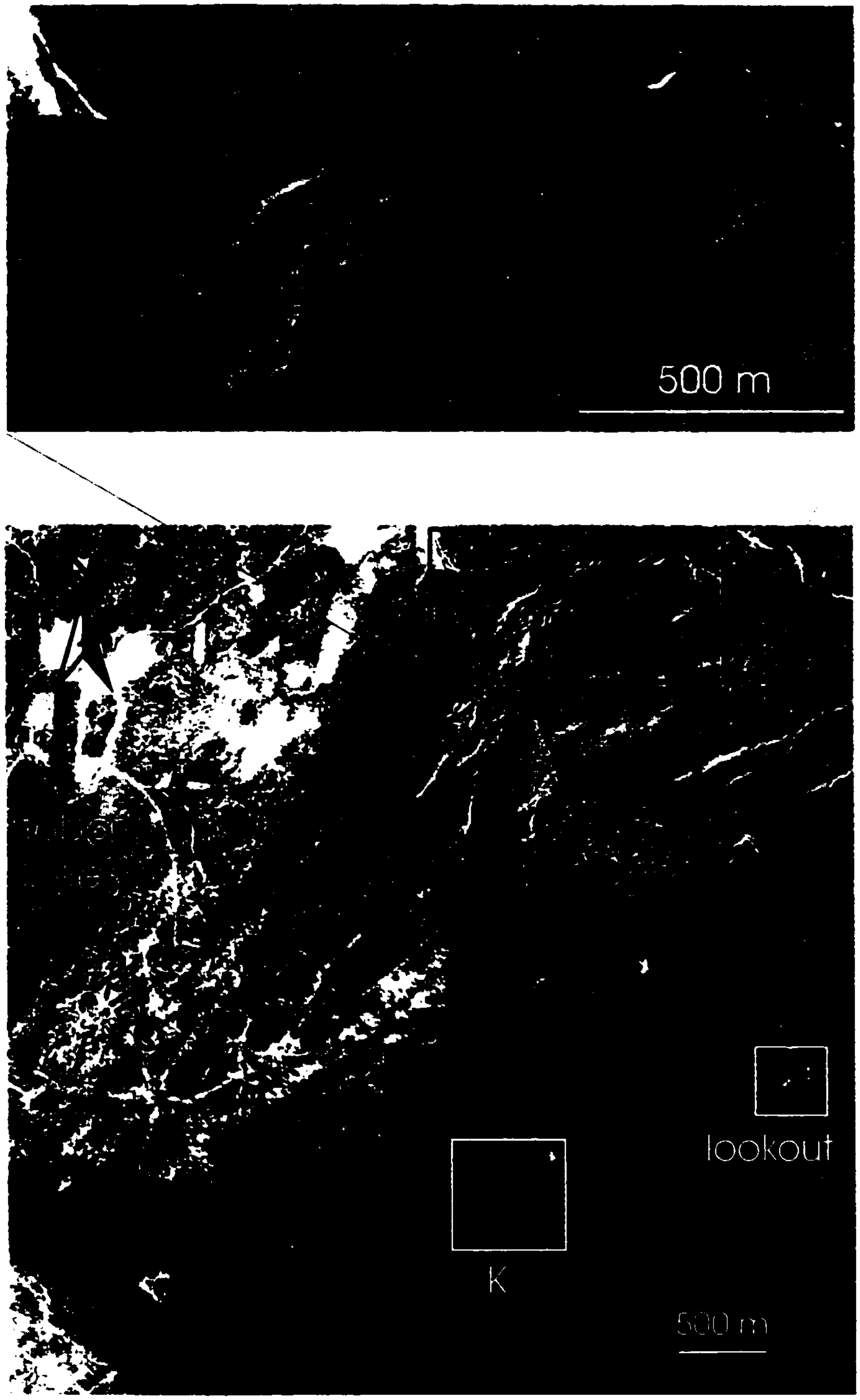
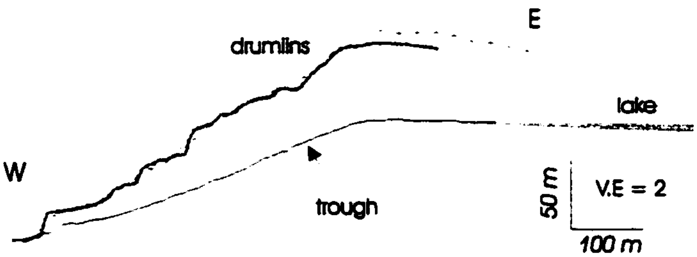


Figure 3-13. Tabor Mountain drumlinized bedrock ridges, locality K (flow was northeast). (air photograph A-13959-43 reproduced with permission of Natural Resources Canada)



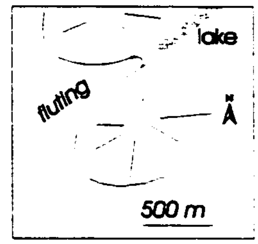
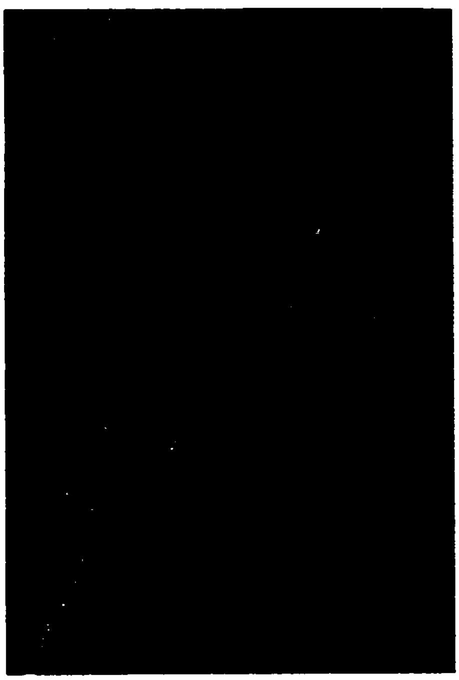


Figure 3-14. Profiles and schematic of drumlinized ridge, locality K.



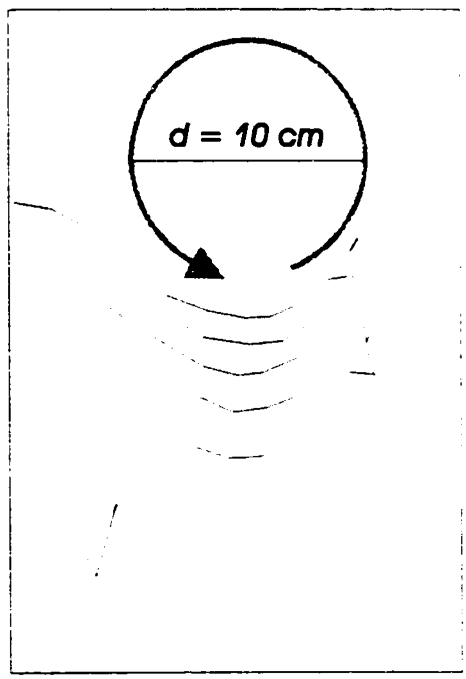


Figure 3-15. Small fluting, oriented southwest-northeast, locality K.

Figure 3-16. Bedrock striations, locality K (penny for scale).

3.7 Interpretations of Bedrock Drumlins

As noted by previous workers (Armstrong and Tipper, 1948; Tipper, 1971b) rock drumlins follow the same regional trends as till drumlins and flutings, and it is logical to assume a common origin. They have been eroded at scales from tens of metres to kilometres long, and vary in shape from low-relief undulations to prominent crag-and-tails. Large-scale rock drumlins at Summit Lake (locality A) demonstrate the power of the eroding agent to reduce a vertical extrusion of columnar basalt to a smoothly convex shape. The preferred orientation of clasts in the local diamict diverge by up to 15° from drumlin orientations, evidence that till-deposition and drumlin-formation processes were distinct and separate. Alternating flutings and drumlins in bedrock ridges such as Tabor Mountain (locality K) corroborate an erosive flow from the southwest sufficient to scour 50 m into bedrock.

Medium-scale sinuous flutings were observed on bedrock ridges at Willow Road and Bowron Road (Figs. 3-7, 3-10) The flutings bifurcate to wrap over and around drumlin stoss ends, much as stream channels separate and rejoin around midstream bars. At these sites, as at locality D (Fig. 3-17), the ridges are relatively featureless at the stoss end, with drumlins on the crest of the ridges evolving to flutings cascading down the lee side of the ridges. The erosional flow may have locally exploited bedding weaknesses in the bedrock, but in none of the three cases is the smaller fluting parallel to fracture or bedding strike, so the surface relief is not bedrock-controlled.

At the low end of the scale are the meter- and centimeter-scale flutings and striations observed on many bedrock outcrops (Figs. 3-11, 3-15). The striations are shallow and infrequent, rarely covering more than 25% of an exposed surface. Their crossing at oblique angles is evidence of separate ice flow directions, and attests to the minimal erosion caused by ice-borne clasts. The deeper, wider flutes were obviously eroded after the larger bedforms on which they are superimposed, and in the same general direction. They are evident on even the highest points of land, such as the top of Sinkut Mountain south of Vanderhoof (Figs. 3-17, 3-18). Such small-scale features attest to the low viscosity of the erosive agent. They would be unlikely to have been preserved in the regional diamict discussed in the next chapter. However, the distribution, morphology and composition of diamict drumlins will be shown to be consistent with the evidence for widespread, pervasive erosion of bedrock drumlins by a turbulent fluid.

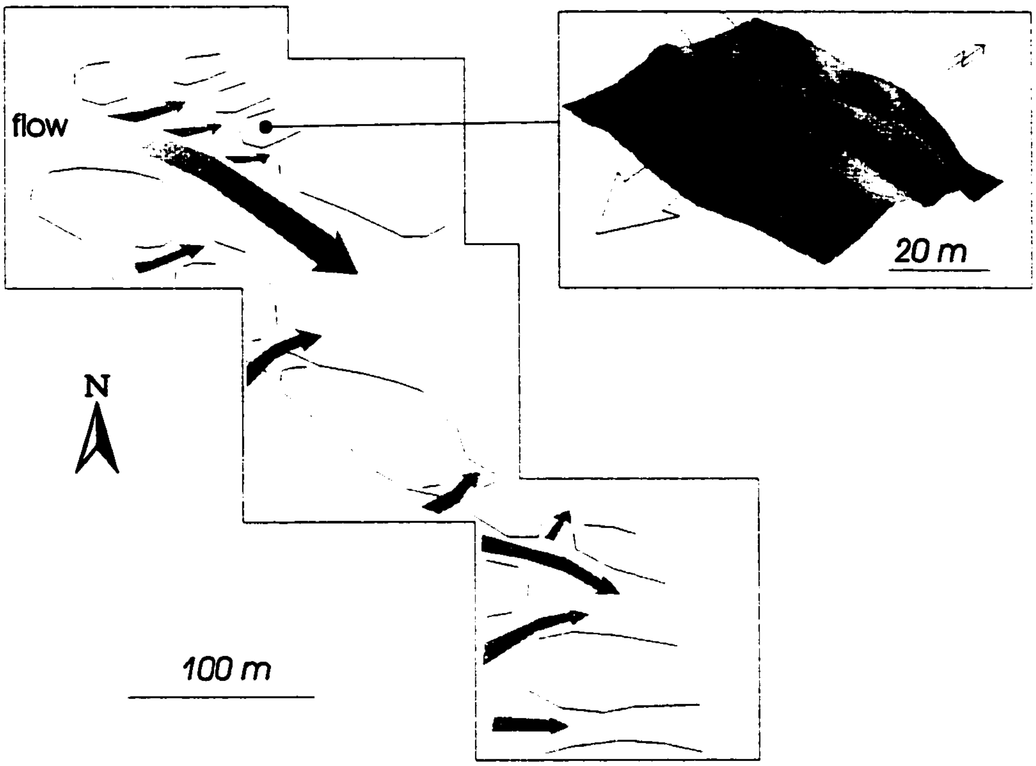


Figure 3-17. Drumlins, flutings and suggested flow paths, bedrock ridge, locality D.

Figure 3-18. Fluting atop Sinkut Mountain, oriented east-west.

Figure 3-19. Sinkut Mountain, looking south from Vanderhoof area.

CHAPTER 4. DIAMICT DRUMLINS

Drumlinized diamict covers most of the Nechako Plateau to elevations of 1500 m (Armstrong and Tipper, 1948). Diamict was collected from many sites along a 300 km transect that roughly parallels the south to north direction of flow from 50 km south of Prince George to where the drumlins converge at Williston Lake (Fig. 4-1).

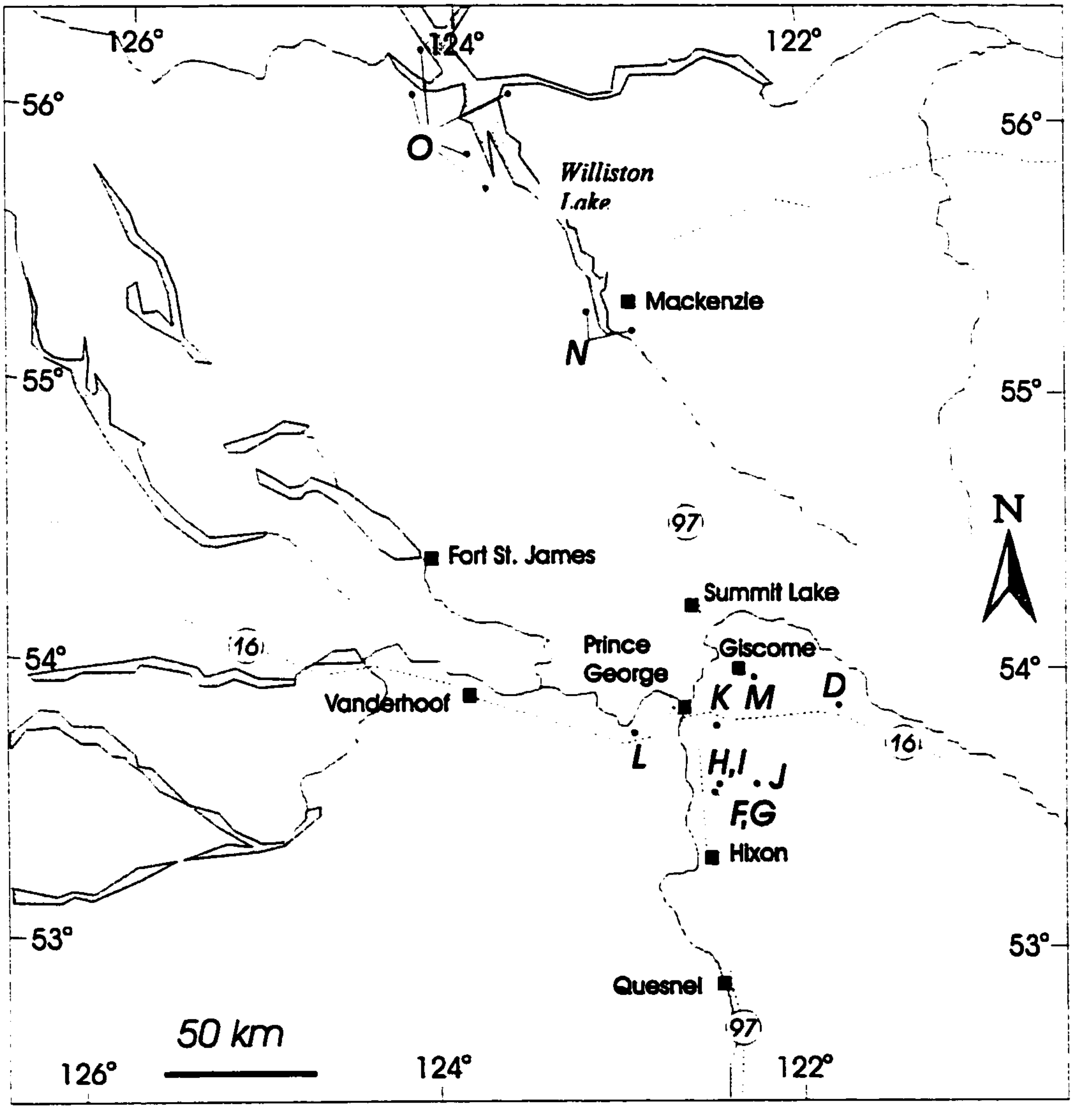


Figure 4-1. Diamict drumlin localities.

Figure 4-2 depicts the grain size of diamict from five regions along this transect. Diamict from each region is represented by mean values derived from four or more sediment samples, and no obvious regional variability is apparent from the aggregated values. The grain size standard deviation values for all diamicts are 13.2% for gravel, 5.3% for sand and 11.3% for fines. The relatively uniform grain size variability of the regional diamict is reflected in ternary sediment diagrams (Fig. 4-3).

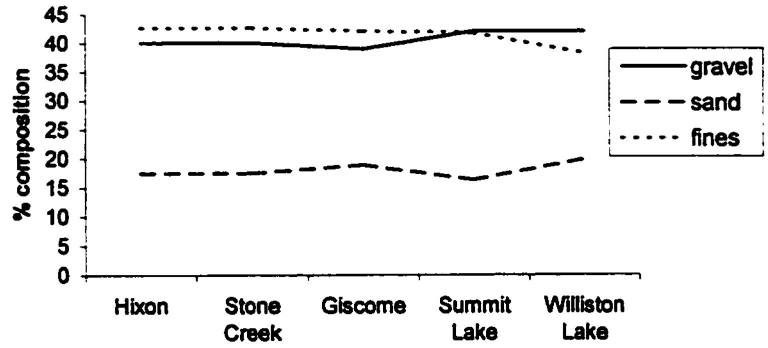


Figure 4-2. Grain size of diamict from Hixon (south) to Williston Lake (north).

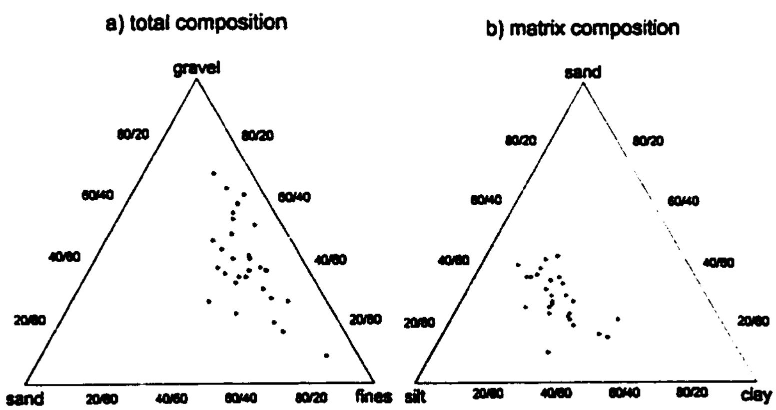


Figure 4-3. Grain size of a) total sediment and b) matrix components of regional diamict.

4.1 Stone Creek Drumlins (Locality F)

The most intensively studied drumlins occur in a 2 km x 3 km recently burned area 20 km south of Prince George (53° 37'N, 122° 35'W). The area had been recently logged and the surface scraped of debris, so it was necessary to ascertain the depth of sediment disturbance below which to sample grain size and till fabric. Tree roots and other evidence of bioturbation terminated at depths of 0.2 - 0.5 m in excavations, often coinciding with an oxidized zone or a layer of rounded cobbles (Fig. 4-4). Diamict was sampled at a road exposure on the lee end of a drumlin two km east of the Stone Creek drumlins, to test composition variability from the surface to a depth of 6 m (Table 1, Appendix A). The matrix shows little variability in grain size with depth, with standard deviations less than 15% of mean values. The proportion of gravel varies little except for the clast-poor layer at 0.7 m depth. The fabric azimuth, plunge and strength are consistent with depth, except for a weaker fabric at the 1.2 m cobble layer, and reversed plunge at 6 m. These results imply that diamict collected from a depth of one-half metre has not been significantly disturbed by post-glacial processes, and can be assumed to represent the grain size characteristics and fabric of the diamict as originally deposited.

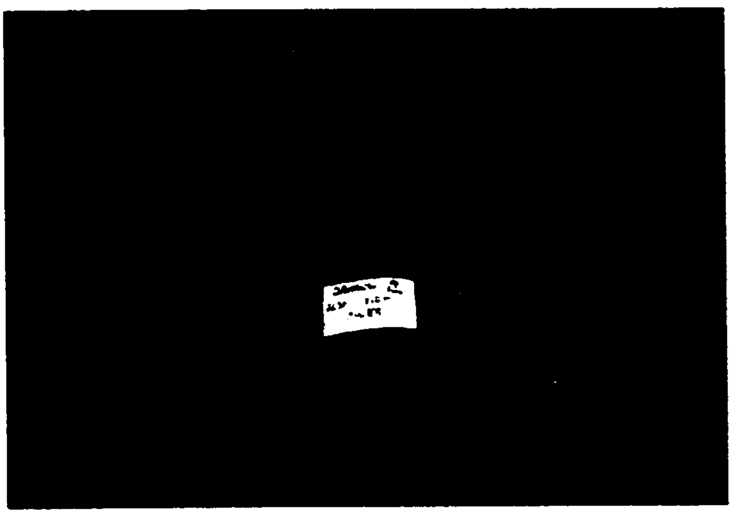


Figure 4-4. Cobbles extracted from a diamict dig pit, Stone Creek (3"x5" card for scale).

The vertical homogeneity of diamict grain size and fabric are not reflected in the lithology at this site, nor are the sediments entirely without structure. Shale is common throughout, but mica-rich schist occurs only in the top metre, and soft, crumbly granite occurs only at 6 m. A thin layer of rounded gravel occurs at 1.2 m, and a layer of rounded cobbles at 1.5 m. Boulders, cobbles and rounded pebbles are common at 4 m, while at 6 m the only clasts are subangular pebbles and granules. From these observations it is clear that structure and lithology vary considerably, that the generally massive diamict contains thin interbeds of sorted sediment, and that no one sample typifies the overall nature of the diamict.

Table 2 includes the grain size of sediment gathered from thirty-three one-metre-deep excavations, presented as mean values for each of the four surveyed sectors. The sectors are comprised of morphologically dissimilar surface features across an area of five km^2 and over an elevation range of 50 m. Their mean sediment grain size varies little, except for more gravel and a coarser matrix in the eastern sector.

Ternary diagrams of the total sediment grain size and matrix proportions from all pits in the Stone Creek area indicate a relatively uniform population with a few outliers from the easternmost drumlin, which represent glaciofluvial or glaciolacustrine interbeds in the diamict (Fig. 4-5). Fabrics generally trend northwest-southeast, but it was observed that fabrics near the tops of drumlins are more closely aligned with the central axes of the drumlins, and that fabrics taken from steep slopes often plunge downslope. It is possible that Holocene solifluction, slope creep or near-surface hydrological processes have influenced clast imbrication on steep slopes. Fabrics that plunge downslope were thus considered as being potentially disturbed from their original orientation, and are not discussed further. Mixed lithologies of both sedimentary and metamorphic clasts commonly occurred together in all four sectors. A comparison of twelve samples containing shale and seventeen not containing shale revealed a difference of only 1% in mean grain size.

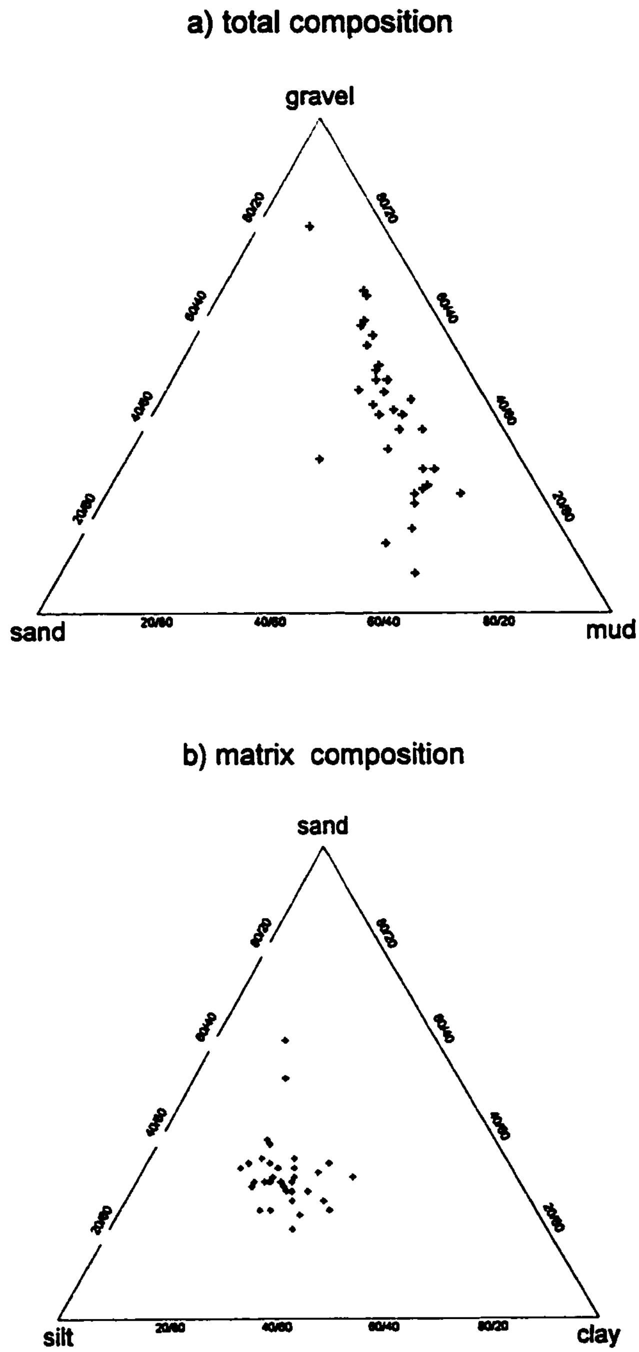


Figure 4-5. Grain size of a) total sediment and b) matrix components of Stone Creek diamict.

The distribution of surface boulders in the Stone Creek drumlins is non-uniform. Forty-six isolated clasts were recorded in the central and western sectors; the east sector contains boulder fields and the north sector a boulder mound, each with countless clasts up to 1.5 m diameter. The eight largest clasts found in the area are granitoid, 2-2.5 m in diameter, well-rounded with percussion chips, often faceted on one or more sides. These large clasts are isolated in the bottoms of channels or are found at the base of steep slopes. Smaller boulders are typically rounded granitoid or angular basalt, most common at the lower stoss end of drumlins and along the sides, and rarely found on the crest of the drumlin or the lee end.

Surveying of the Stone Creek drumlins was undertaken in four sectors, each focusing on a particular feature or group (Fig. 4-6).

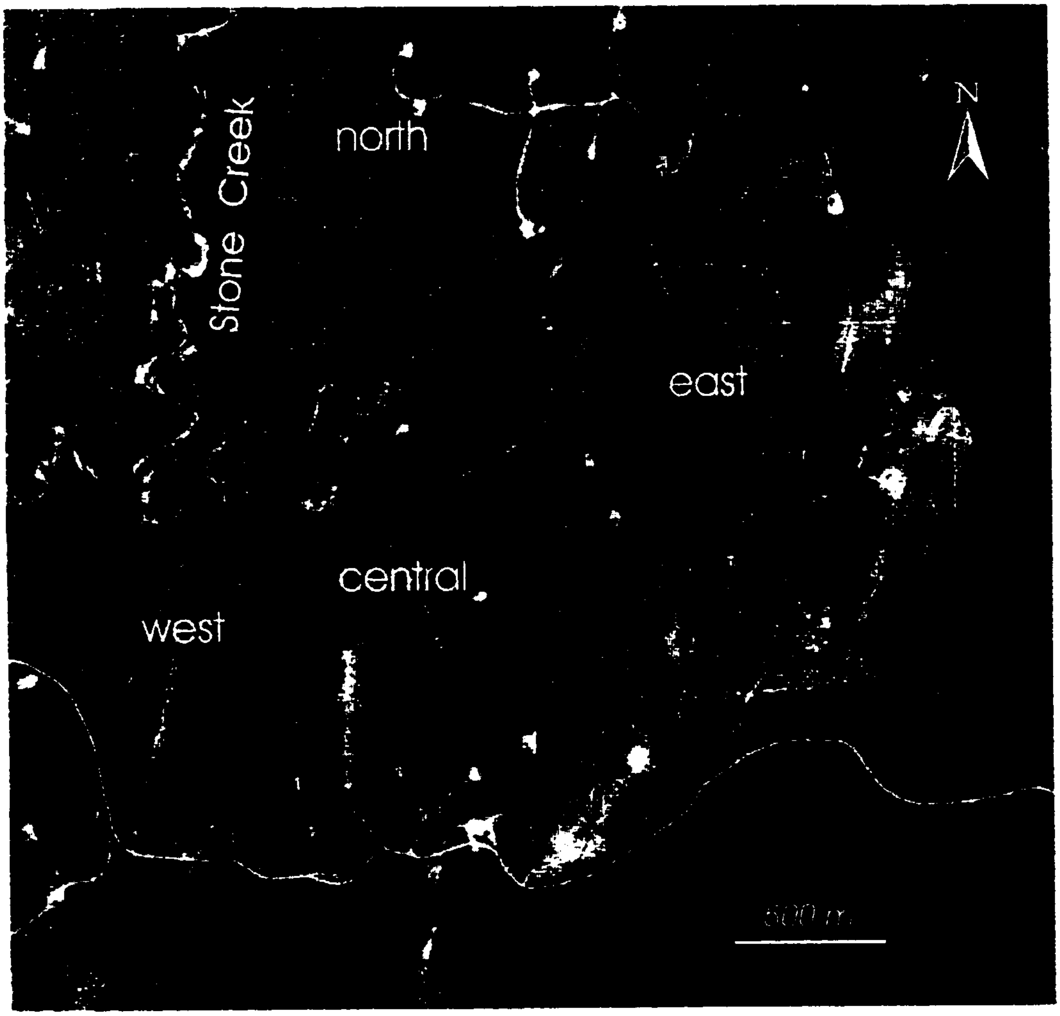
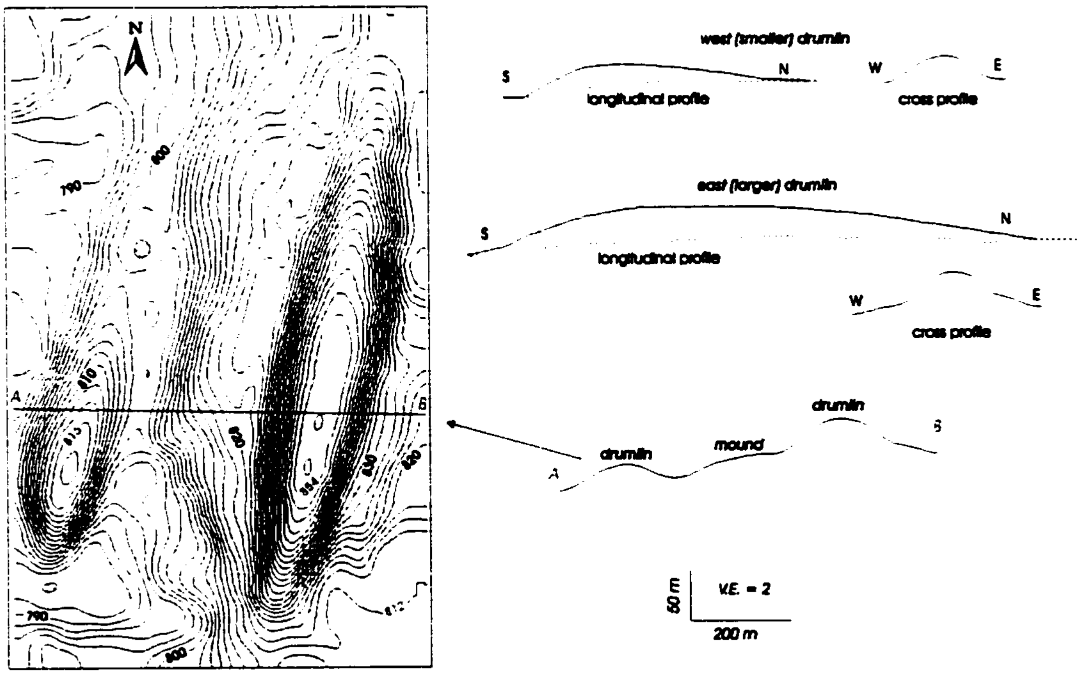


Figure 4-6. The four surveyed sectors of the Stone Creek drumlins (locality F).
(air photograph BCB96003-5 reproduced with permission of BC Ministry of Environment)

4.1.1 Central Stone Creek Sector

This sector contains one large drumlin, a smaller one of similar shape, and a low mound separating them (Figs. 4-6, 4-7). The smaller drumlin is 220 m wide, 650 m long and 20 m high; the larger is 250 wide, 1200 m long and 30 m high. The base of both features rises gently in elevation from stoss to lee ends by 7-10 m. The mound between is similar in shape and orientation, differing only in its vertical relief. A shaded relief oblique image (Fig. 4-8) highlights multiple smaller ridges and flutings oriented parallel to the drumlins. The small-wavelength, small-amplitude transverse features are artifacts of the survey transect orientation and data interpolation processes, and do not represent real landforms. The filtering necessary to reduce the effect of between-transect interpolation artifacts also eliminates small-scale along-transect features. An illustration of this loss of resolution is a profile across the apex of the larger drumlin (Fig. 4-9): the modeled surface is smoothly rounded at the top and base, but the original survey transect (and a photograph of the stoss end) shows a flatter top and sides, and the trough at the east base is deeper and narrower. The flattened top and sides are not evident on the smaller drumlin.



Contour interval = 2 m

Figure 4-7. Contour map and profiles of Stone Creek drumlins, central sector.

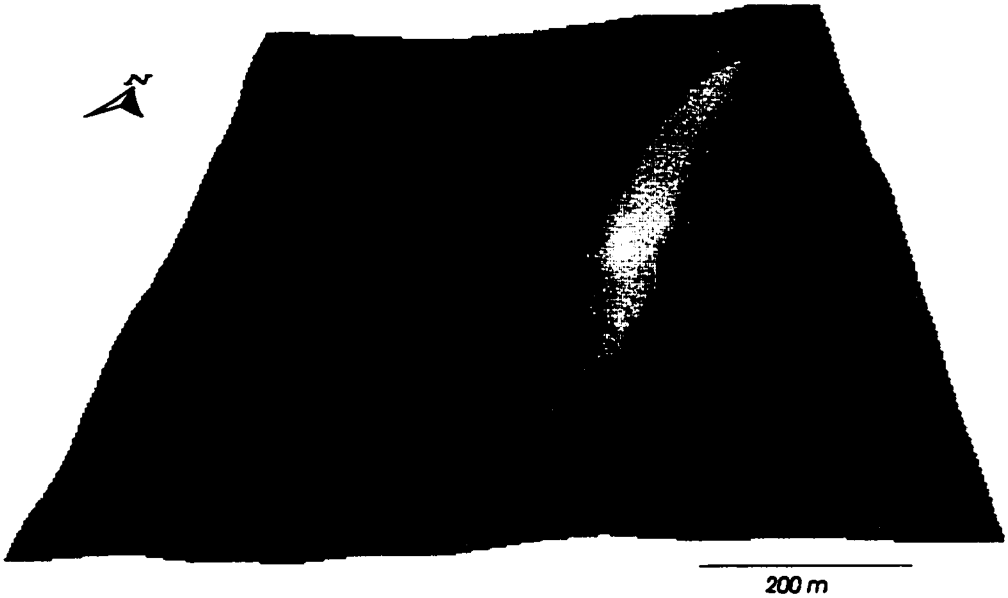


Figure 4-8. Oblique view of Stone Creek drumlins, central sector, looking north (V.E. = 2).

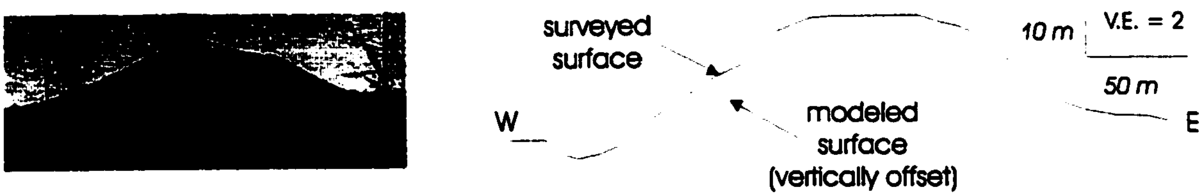


Figure 4-9. Photograph of flat-topped drumlin, with surveyed and modeled cross profiles.

In the central sector, diamict commonly contains subangular pebbles, rounded to angular cobbles, and is commonly a light grey colour. Quartzite, siltstone and shale are common, while pure quartz was observed at three sites and coal at two sites. A distinct layer of cobbles was noted at eight of sixteen sites, from 20-55 cm depth. In this sector diamict fabrics #4, 7, 10, 11, 15 and 25 were collected from relatively flat sites, while fabrics #6, 9 and 24 were collected from slopes, but do not plunge downslope; preferred orientations are oblique to the drumlin central axis (Fig. 4-31).

Figure 4-10 portrays a detailed grain size survey in the central sector. The high concentration of sand in the low trough probably results from reworking by the nearby Stone Creek at flood stages during the Holocene; the proportion of sand elsewhere on the drumlins is consistent with the regional mean of about 20%. However the high proportion of gravel and paucity of fines on top of the small drumlin (20 m above the trough) cannot be attributed to the creek. The gravel distribution closely follows the shape of the drumlin, as does the trend of sediment compactness as shown in Figure 4-11. Penetrometry tests were conducted on both drumlins; units measured are hammer blows required to drive a 2 cm cone 15 cm into sediment below C horizon with a 5-lb sledge. Results indicate that compactness is highest at the stoss end and near the top of both drumlins in the central sector. The coincidence of a high proportion of gravel with high compactness on the smaller drumlin is significant, considering that gravel is difficult to compact.

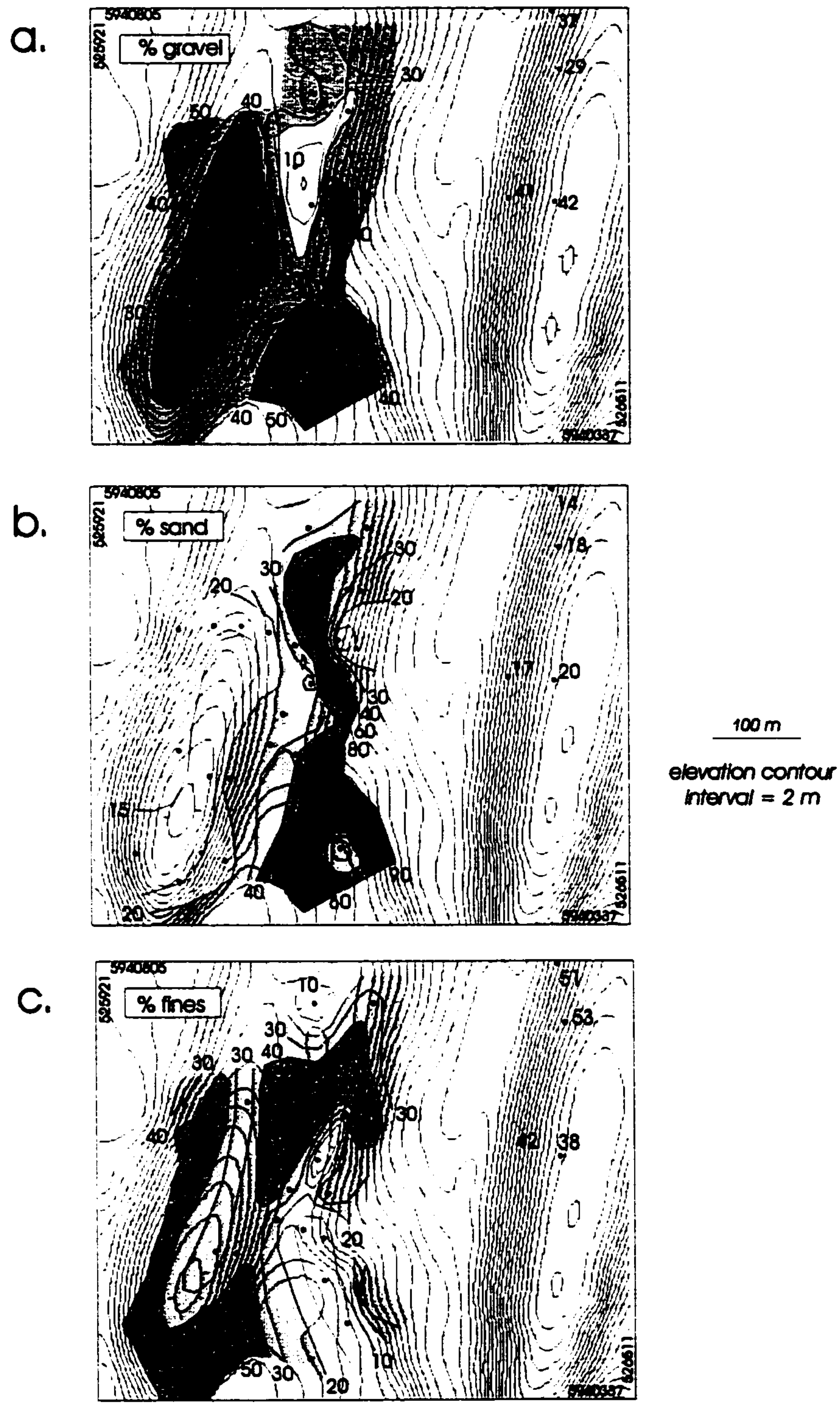


Figure 4-10. Distribution of a) gravels, b) sands and c) fines, central sector Stone Creek drumlins, shown as percentage of surficial sediment.

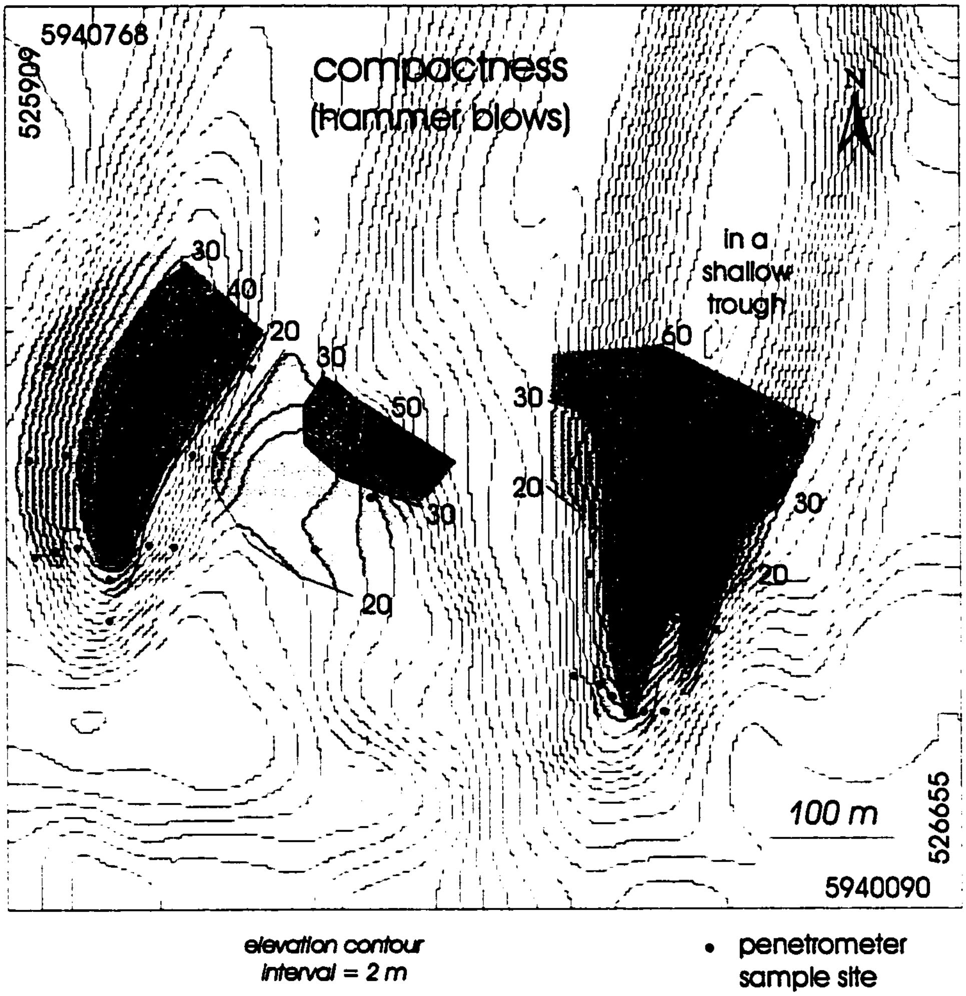


Figure 4-11. Compactness of Stone Creek drumlins, central sector (units are hammer blows).

4.1.2 Western Stone Creek Sector

This sector of the Stone Creek study area is dominated by a large drumlin with a scour along its central axis (Figs. 4-6, 4-12). The drumlin is 850 m long, 300 m wide and 40 m high. The drumlin is steep on the east side (25° slope), less so on the west side (15-20°); stoss and lee ends slope at about 10°. A low adjoining mound on the west side is similar in profile to the main drumlin (white dashed line on longitudinal profile). The base drops by 12 m from stoss to lee end. The central trough is less striking in the filtered DEM than originally surveyed; Figure 4-13 shows the actual cross profiles at various points along the drumlin. The bottom of the trough can be described in cross-section by an arc of radius 3-4 m at the stoss end; at the lee end the trough bifurcates, broadens and shallows (Fig. 4-13). An oblique view from the stoss end shows a broad, flat area to the east of the drumlin, covered by sand deposits (Fig. 4-14). The tail of an upflow drumlin is visible in the lower right part of the image, cut obliquely by a trough. Stone Creek flows from right to left nearby, and a Holocene flood event probably accounts for both the sandy sediments and the cross-cutting trough.

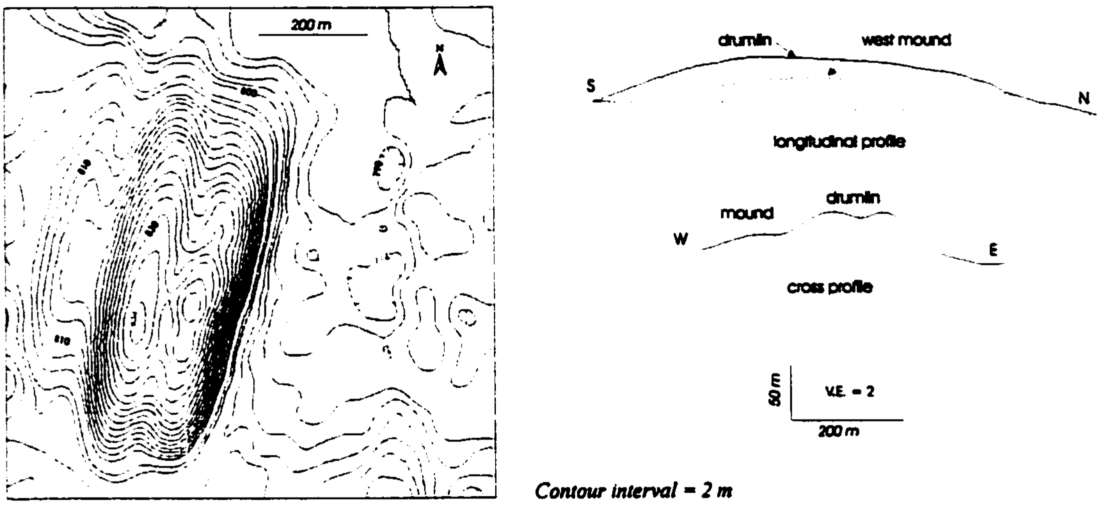


Figure 4-12. Contour map and profiles, Stone Creek drumlins, western sector.

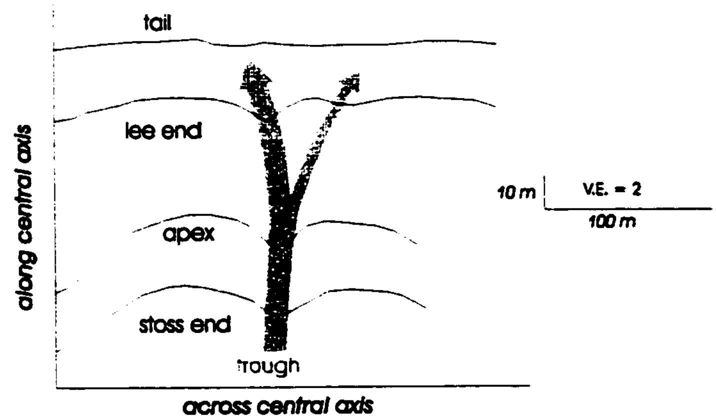


Figure 4-13. Profiles of a bifurcating trough, Stone Creek drumlins, western sector.

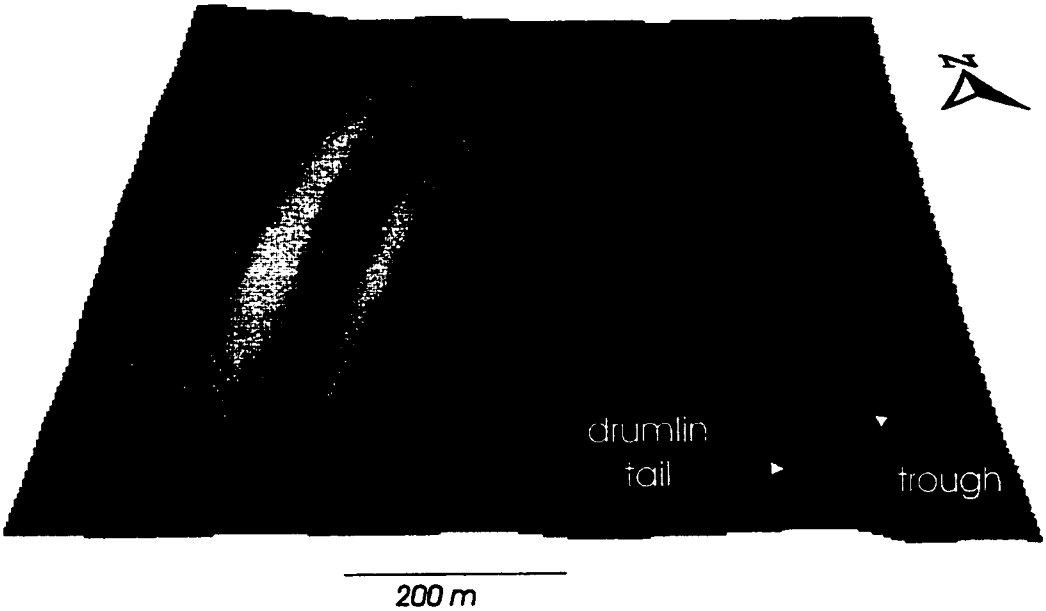


Figure 4-14. Oblique view of Stone Creek drumlin, western sector, looking north.

Diamict in the western sector contains angular to subangular pebbles with rounded quartzite cobbles and a relatively high proportion of clay. Shale and charcoal pieces were observed at one site. A cobble layer was noted at all sites, from 50-70 cm depth. All fabrics were collected from slopes; the three that do not point downslope (#17, 18, 19) are oriented east-west (Fig. 4-31).

4.1.3 Eastern Stone Creek Sector

This sector of the Stone Creek survey area is dominated by a broad, relatively low-profile drumlin etched by a series of parallel north-south flutings (Figs. 4-6, 4-15). The feature is 1200 m long, 750 m wide and 40 m high. Slopes reach 20° on the west side, 10° on the east side, stoss end and lee end. The base of the drumlin rises 25 m from stoss to lee end. The central axis of the feature is oriented north-south, but the flutings that cross it and mark its outer boundaries are oriented northeast-southwest. The stoss end is markedly steeper on the east half of the drumlin than on the west half. The flutings that comprise the surface of the drumlin are evident in an oblique image illuminated from the northwest (Fig. 4-16). The flutings are superimposed on the broad channel (flat bottom, steep sides) at the lee end of the drumlin. Also visible are the stoss end of a drumlin to the north, the lee end of a 'rat tail' drumlin and numerous smaller channels cross-cutting the terrain. The easternmost drumlin contains a boulder field on top and boulder/cobble pavement on the southeast side, in the same stratigraphic position as the gravel bed sample sites (Fig. 4-17). Small (subglacial) channels running up the side of the drumlin and back down are littered with boulders at their northernmost outlets.

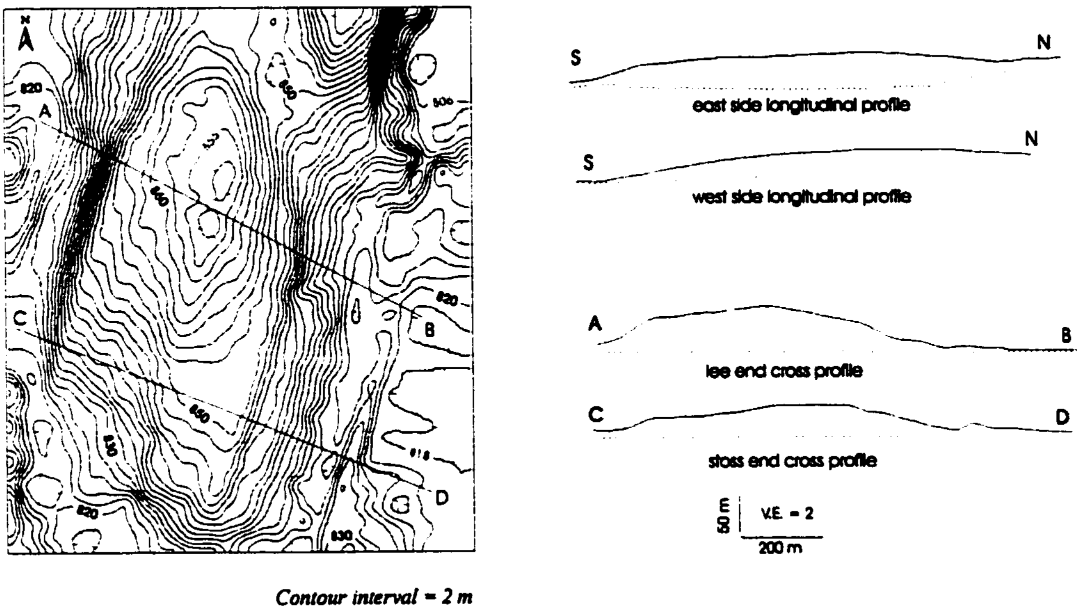


Figure 4-15. Contour map and profiles of Stone Creek drumlins, eastern sector.

Figure 4-16. Oblique view of Stone Creek drumlin, eastern sector, looking west.

Figure 4-17. Boulder/cobble pavement, eastern Stone Creek drumlin (largest boulder shown is 2.5 m across).

Diamict in the east sector contains angular to subangular pebbles, colour is generally darker than other sectors, shale and coal were observed at one site. A layer of rounded cobbles was observed at two sites, from 30-40 cm depth. Fabrics obtained from four diamict sites (#21, 22, 30, 35) trended northwest-southeast (Fig. 4-31). This drumlin also contains interbedded non-diamict sediments. Deposits at sites #34, 35 and 147, located at the east stoss end, are comprised primarily of laminated silt and clay with a few boulders, stacked cobbles and pebbles; overlying shale bedrock. Pebble fabrics plunge to the west. Sediment at site #36, located near the east base of the drumlin is comprised of four poorly sorted clast-supported gravel beds dipping 15° northward; overlying a layer of rounded, imbricated cobbles. Site #37, located near the crest of the drumlin contains two beds of oxidized sand and gravel, dipping 10° southward, overlying a layer of angular cobbles. Sediment site #148, on the extreme west slope of the drumlin, is comprised of silt overlying a layer of cobbles at 80 cm depth.

4.1.4 Northern Stone Creek Sector

This sector of the Stone Creek drumlins contains a number of drumlins arranged 'en echelon' (Figs. 4-6, 4-18). An incised stream crosses the area in a northeast-southwest direction; the breadth of the stream valley and the drumlins located in it suggest the valley predates the Holocene stream.

A small, low relief drumlin in the southwest corner of the north sector is comprised primarily of cobbles and boulders. It is 250 m long, 75 m wide, 5 m high, perched on the side of a larger hill; the base rises 10 m from stoss to lee end (Fig. 4-19).

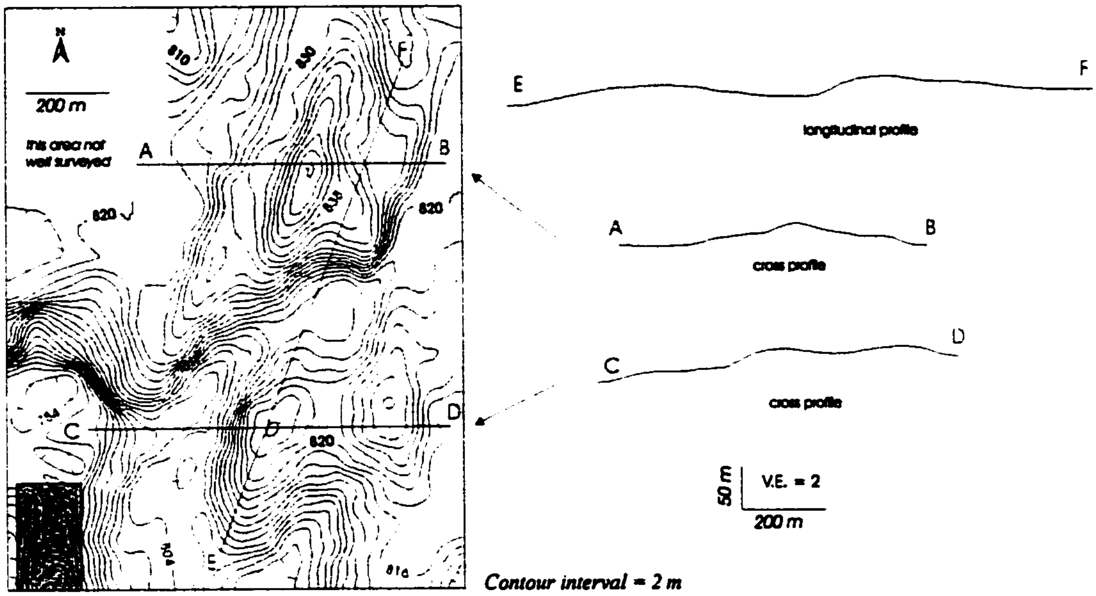


Figure 4-18. Contour map and profiles of Stone Creek drumlins, northern sector.

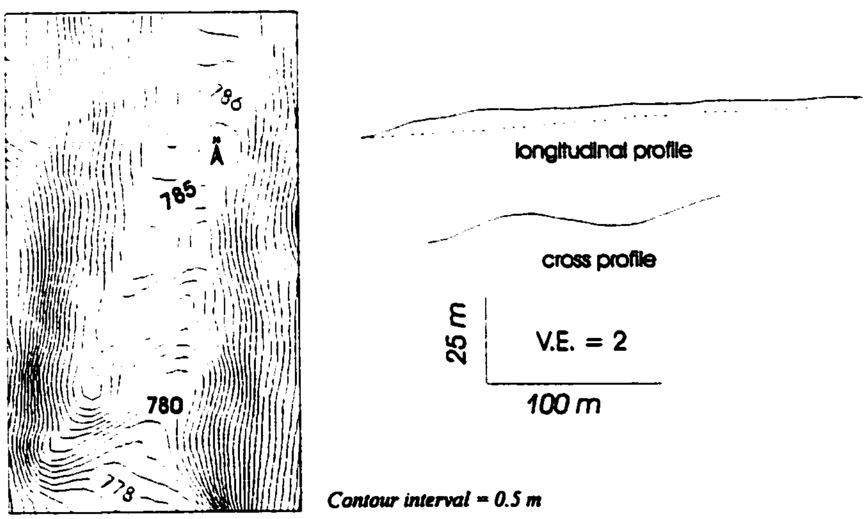


Figure 4-19. Contour map and profiles of boulder drumlin, Stone Creek, northern sector.

4.2 Channel drumlin (locality G)

This drumlin, located two km northeast of the Stone Creek study area, is 750 m long, 350 m wide, and 30 m high (Figs. 4-20, 4-21). It is steepest near the base at the stoss end, where slopes reach 30°. The lee end is marked by two 'arms' that slope at 5° and a bowl-shaped scour between in which slopes reach 10°. The sides of the drumlin are steepest near the base, reaching 20° slope. At the south (stoss) end a flat-bottomed, steep-sided channel is oriented in line with the drumlin central axis (Fig. 4-22). A similar channel is visible leading to a drumlin in the southwest corner of Figure 4-20.

Figure 4-20. Air photograph, Channel drumlin, locality G (centre).
(air photograph BCB96004-8 reproduced with permission of BC Ministry of Environment)

The channel is 40 m wide, 5 m deep, and runs straight for 200 m. Its upflow end connects to two smaller scours entering obliquely; at the downflow end it bifurcates around the drumlin. The scour in the lee end starts abruptly near the drumlin crest and curves downward northwest toward a broad channel (Fig. 4-23). Closed contours mark a round depression in the middle of the scour; the depression was probably deeper prior to this area having been flattened and partly filled as a logging staging area. Grain size from eight samples (#47-55) showed less gravel (36% mean) than fines (48% mean). A layer of cobbles was observed at all sites, from 30-50 cm depths. Boulders were observed on the stoss end and east side of the drumlin, the largest (2 m) in the narrow channel adjacent to the east side. Two fabrics on top of the drumlin are oriented parallel to the central axis (fabrics #50, 52); seven other fabrics were taken from steep slopes; they display an east-west trend, but are generally oriented downslope, so may be from disturbed materials.

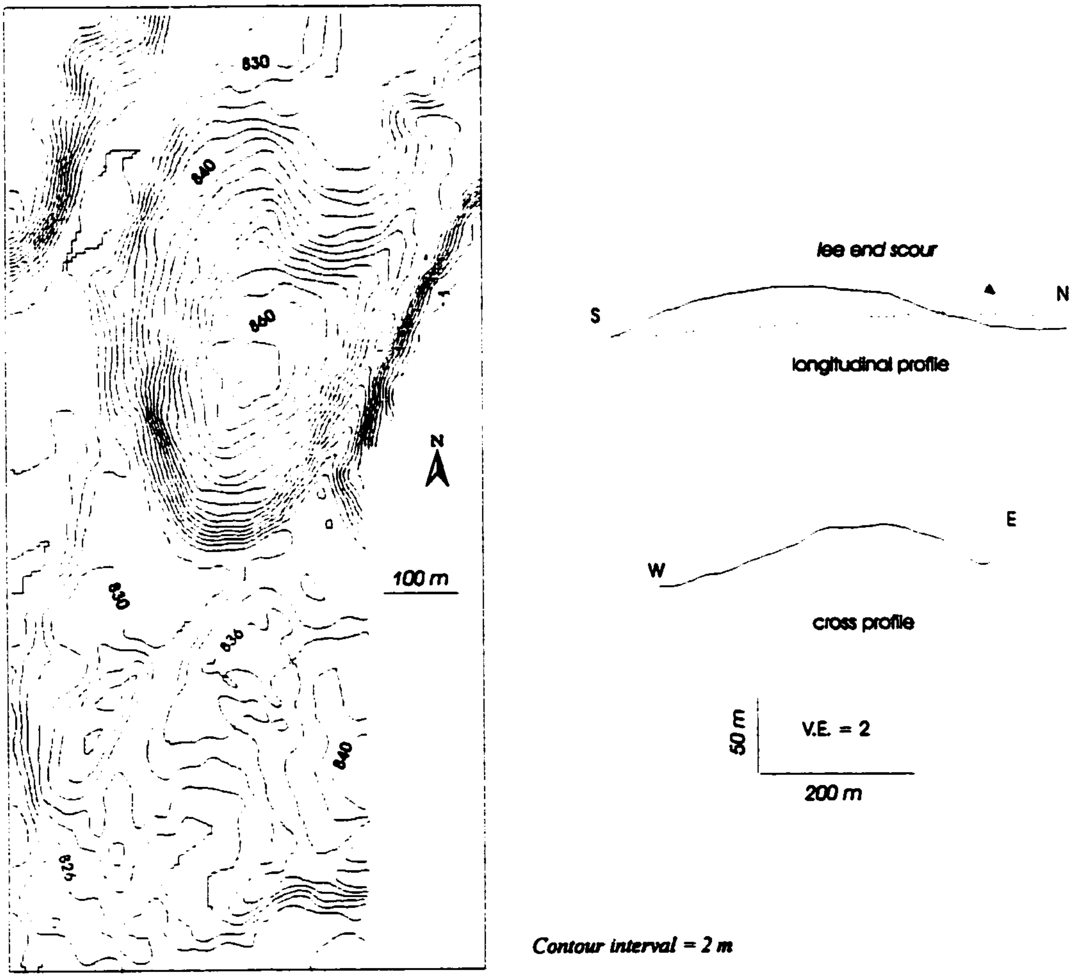


Figure 4-21. Contour map and profiles of Channel drumlin, locality G.

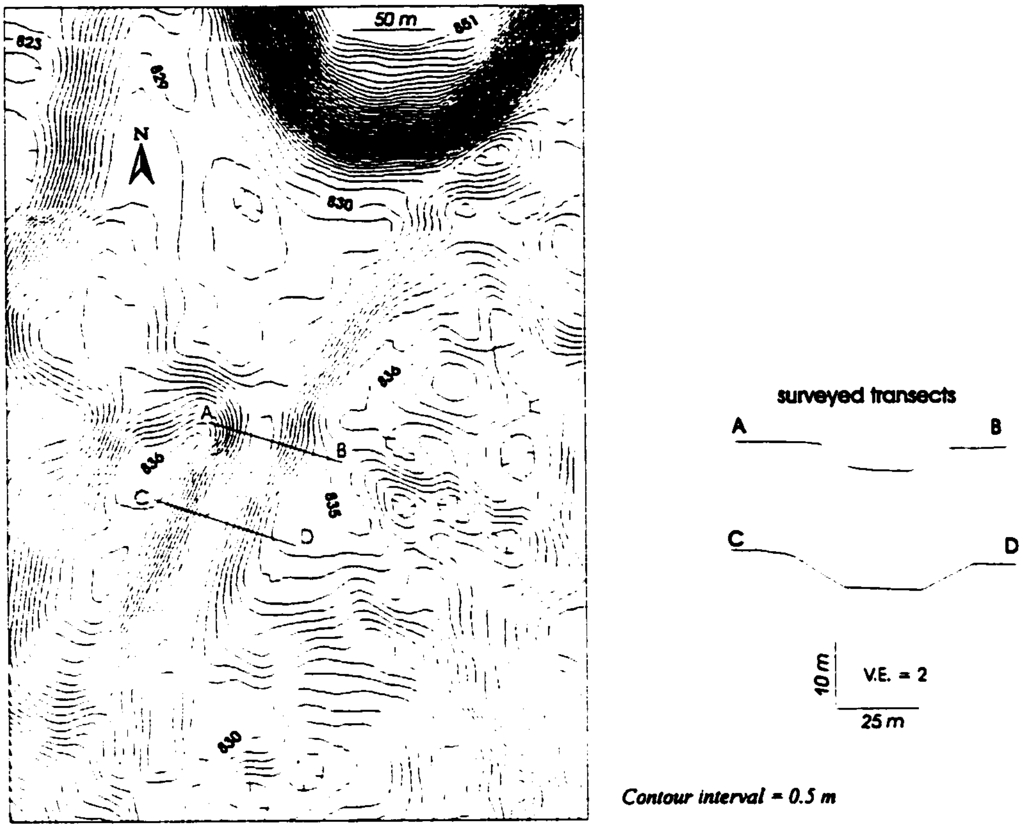


Figure 4-22. Contour map and profiles of stoss-end channel, locality G.

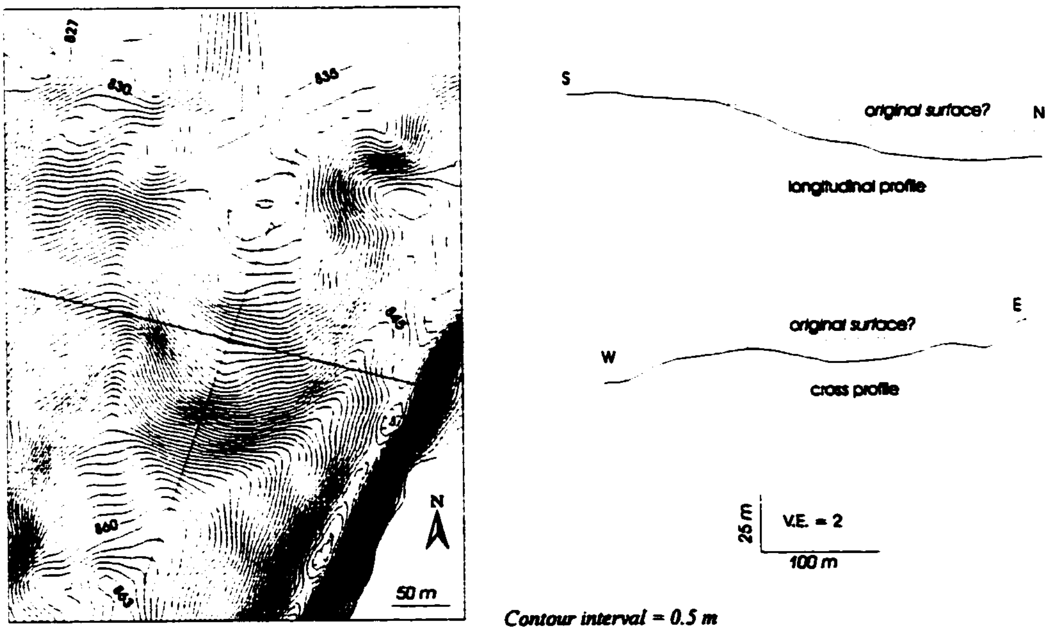


Figure 4-23. Contour map and profiles of lee end scour, locality G.

4.3 Right-Angle Channel Drumlin (Locality H)

This drumlin is located six km north of the Stone Creek area. It is similar in form to other diamict drumlins, but the right-angle scour that delineates its west side is unusual in shape and orientation (Figs. 4-24, 4-25, 4-26). The drumlin is 700 m long and 200 m wide; it is slightly curvilinear, its central axis convex to the southeast. The east base rises 25 m from stoss to lee end (5° slope); the base-to-crest relief is no more than 10 m. The maximum slope is 20° at the base of the stoss end, except for the scour on the west side where sides slope 25-35°, and a large portion of the scour wall has slumped. The scour is 70 m wide and 15-20 m deep. The south end of the scour is oriented parallel with the drumlin. The north end of the scour is deeper and perpendicular to the drumlin central axis. The scour originated above the slope break at the west base of the drumlin, therefore is not contemporaneous with the drumlin, but is consistent with an origin as a sub-glacial tunnel channel. No sediment samples were collected from this drumlin.

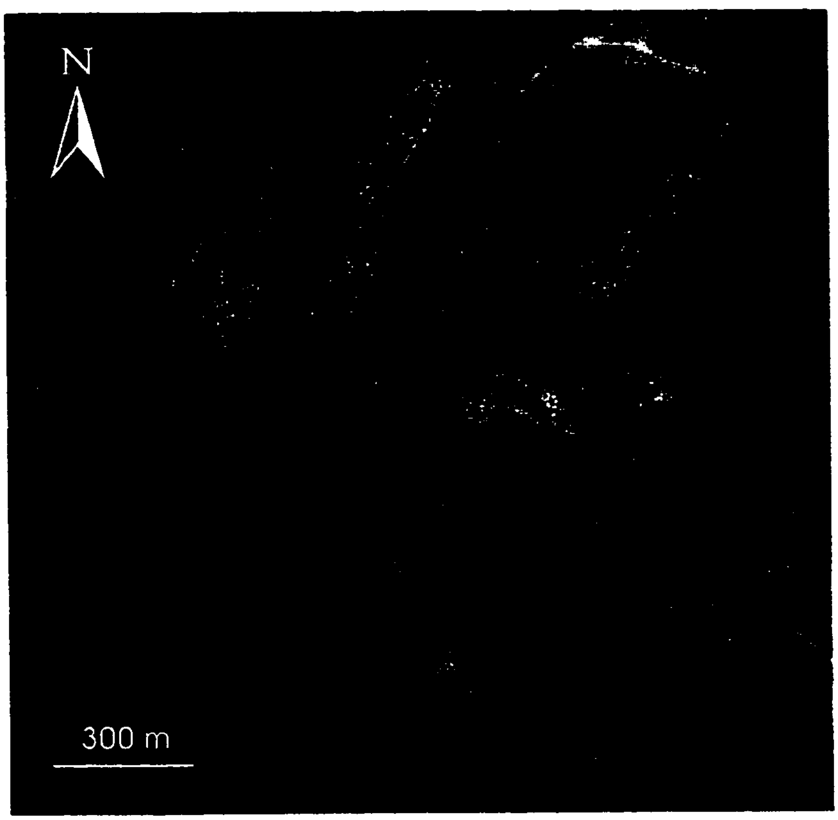


Figure 4-24. Air photograph, Right-Angle-Channel drumlin, locality H (centre).
(air photograph BCB96004-7 reproduced with permission of BC Ministry of Environment)

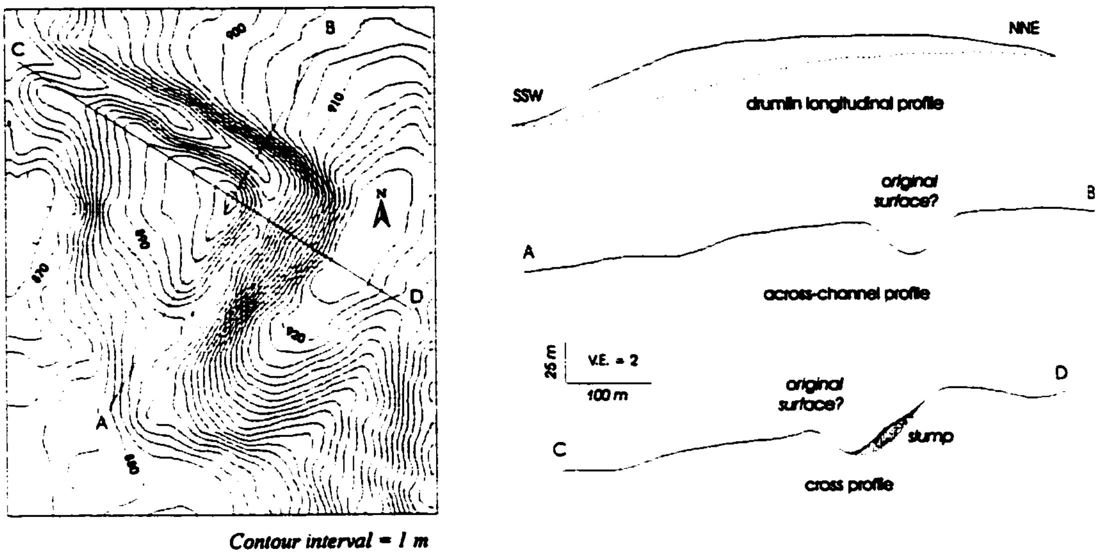


Figure 4-25. Contour map and profiles of drumlin and right-angle scour, locality H.

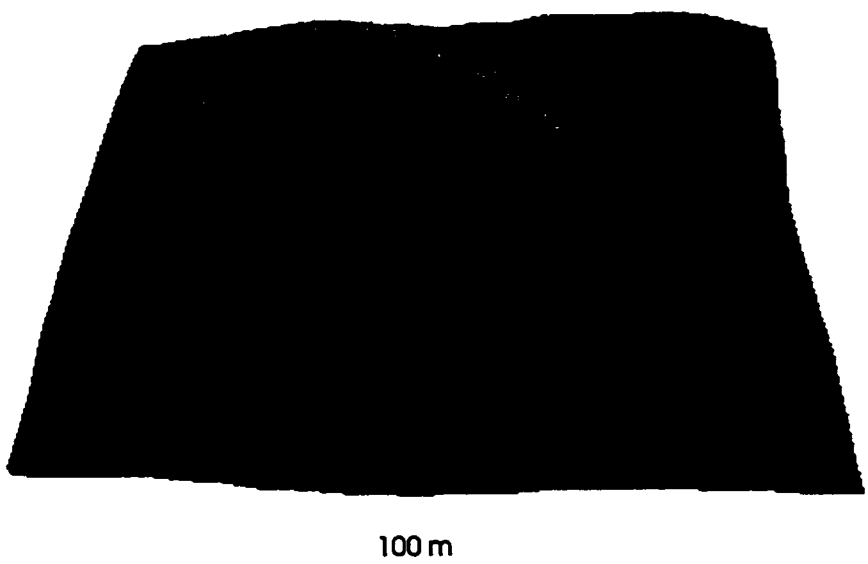
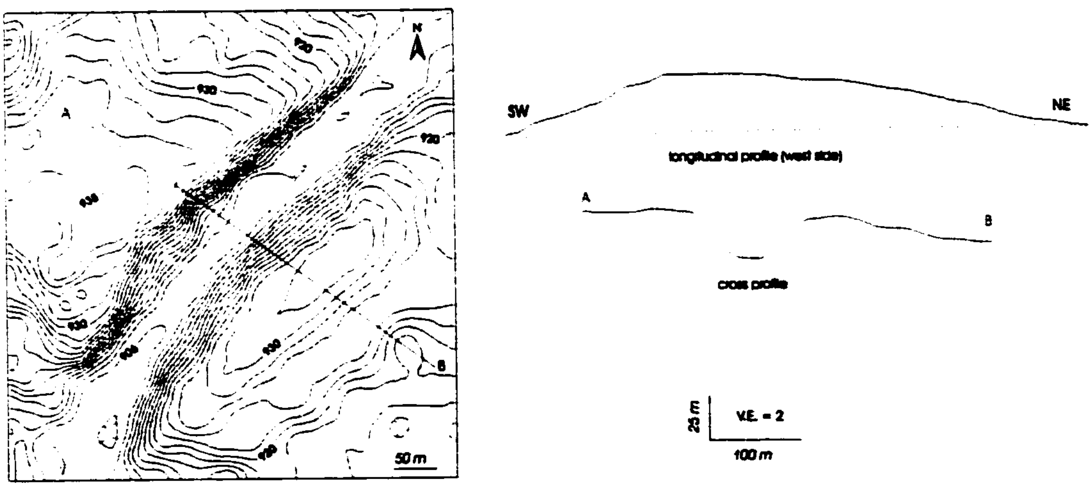


Figure 4-26. Oblique view, right-angle scour, locality H, looking east.

4.4 Split Drumlins (locality I)

These features, located 8 km northeast of the Stone Creek area, are notable less for the drumlins than for the scour that bisects them; it is 650 m long, 150 m wide and 30 m at its deepest point (Figs. 4-25, 4-26, 4-27). The longitudinal profile is similar to other drumlins, but the cross profile shows the scour to be steeper-walled and flatter-bottomed than typical troughs. The scour starts and ends in low-lying areas to the north and south, with its highest point midway between the stoss and lee ends. The scour is slightly curved; slopes on the inside wall reach 25°, on the outside wall 35°. The maximum slope on the stoss end of the drumlin is 15-20°. The proportions of the drumlin are continuous across the scour, indicating that the scour post-dates the drumlin as a tunnel channel.

Sedimentary characteristics from three samples are typical of the Stone Creek diamict. A fourth sample revealed bedded sediment as depicted in Figure 4-30. Finely-laminated clay is overlain by a layer of gravel and cobbles, imbricated to the north (fabric #58). This layer is followed by alternating beds of sand (up to 10 cm thick) and clay with pebbles (2-3 cm thick). The sequence was eroded unevenly and draped with coarsening-upwards beds. The sample was taken near the top of the drumlin. A diamict fabric taken from the top of the lee end is oriented in parallel with the drumlins at 45° (fabric #57). Two other fabrics were taken from steep slopes, and are oriented downslope (#56, 59).



Contour interval = 2 m

Figure 4-27. Contour map and profiles of Split drumlins and scour, locality I.

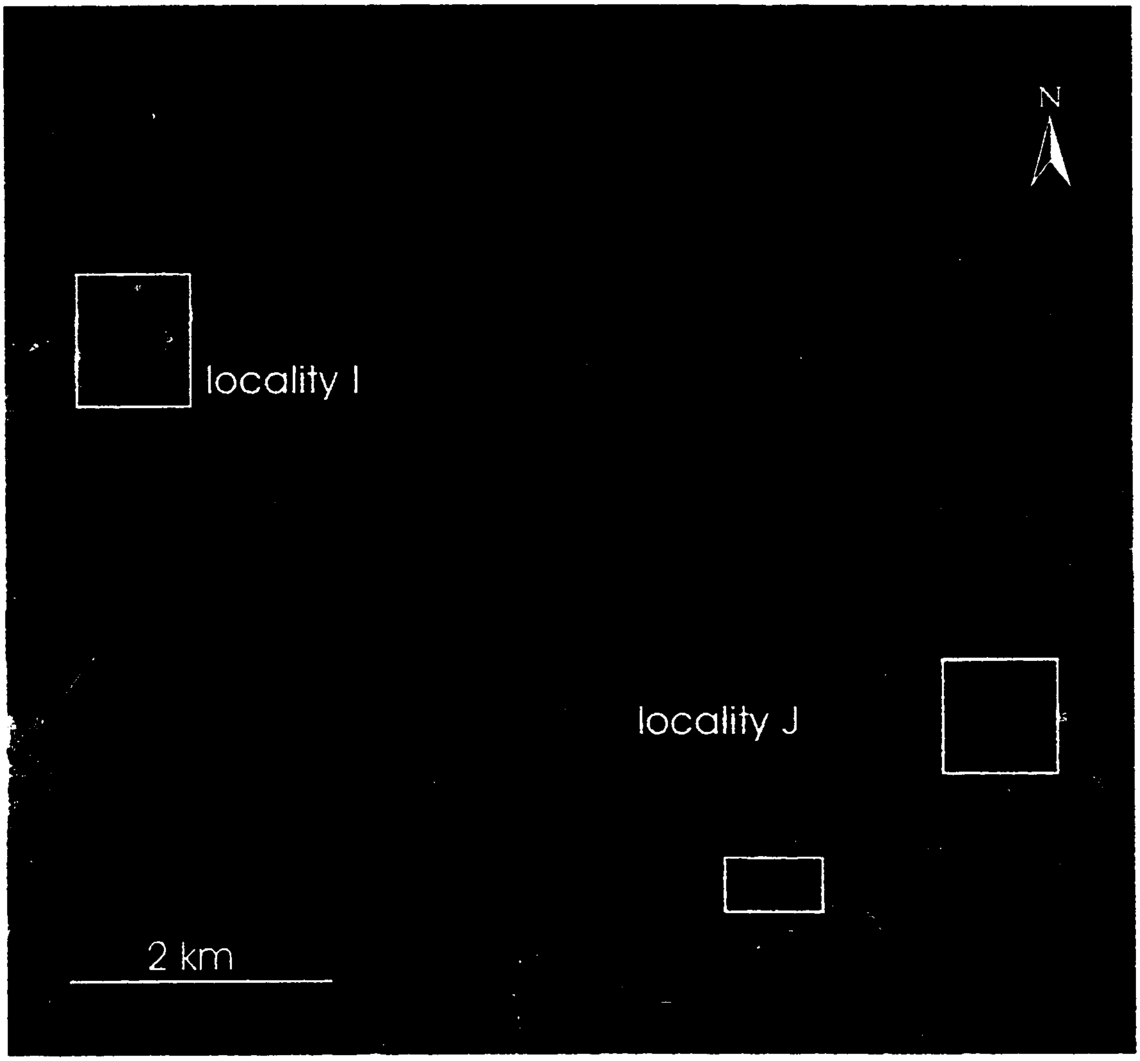


Figure 4-28. Air photo, localities I, J.

(air photograph BCB96004-5 reproduced with permission of BC Ministry of Environment)

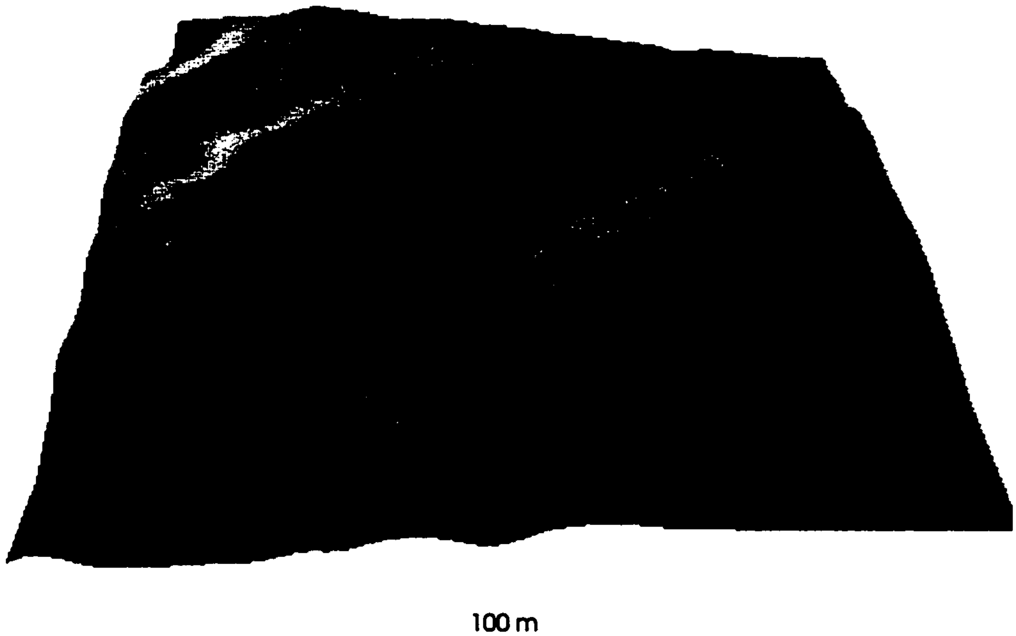


Figure 4-29. Oblique view of the scouring dividing the Split drumlins, locality I.

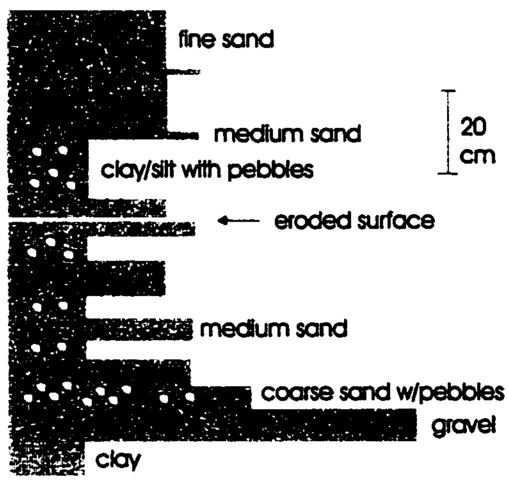


Figure 4-30. Sediment from site E3, Split drumlins.

4.5 Montagne drumlin (locality J)

This feature is located in a narrow mountain valley 8-10 km east of the Stone Creek area at 1050 masl (Figs. 4-28, 4-31, 4-33). Oriented parallel to the valley, it is 500 m long, 250 m wide and 10-20 m high (depending on which end it is viewed from). The steepest slope, on the northwest side, is 15°, which is partially a result of the gradient of the hill on which it sits. Elsewhere slopes rarely exceed 7°. This is the most prominent drumlin in a line of low-relief features along the valley floor. At a higher elevation (1200 masl), to the northeast in the same valley, flutings on a drumlinized ridge are oriented in the same direction (Fig. 4-28); fluting cross-sections show 10 m wavelengths and 1-2 m amplitudes. Drumlinized bedrock ridges are also visible in Figure 4-28, west of locality J and east of locality I. The diamict at the lower site (#65-67) underlies red clay from 25-70 cm thick, suggesting the clay was draped over the drumlin. A bed of granite and shale cobbles was observed at 70 cm depth at one site, a quartzite boulder at the same depth at a second site. Pebbles were generally subrounded. Two of three fabrics (#66, 67) are strongly orientated parallel to the drumlin central axis, plunging southwest (Fig. 4-33). Two excavations in the higher feature revealed shale and granite cobbles and boulders in diamict from 20-40 cm, overlying fissile shale bedrock. Most pebble clasts were subangular shale or mudstone. Two of three fabrics at this site (#63, 64) showed preferred orientation northeast-southwest, parallel with the drumlin axis (Fig. 4-33).

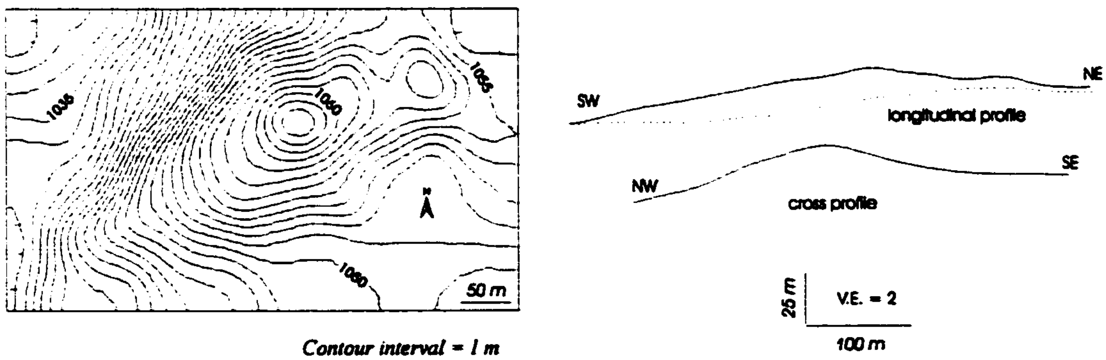


Figure. 4-31. Contour map and profiles of Montagne drumlin, locality J.

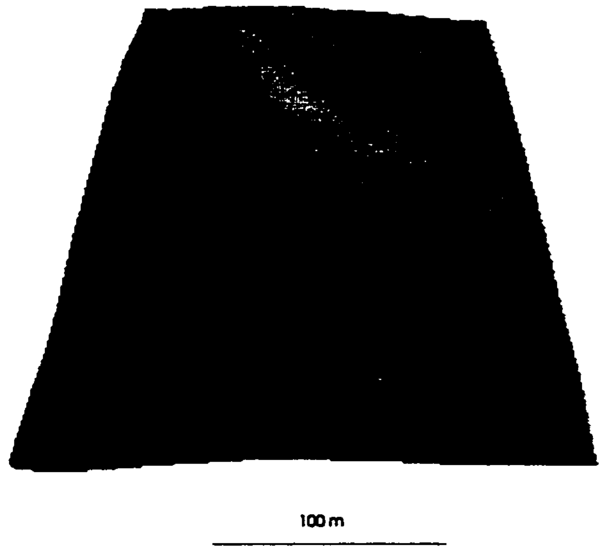


Figure 4-32. Oblique view, Montagne drumlin, looking east.

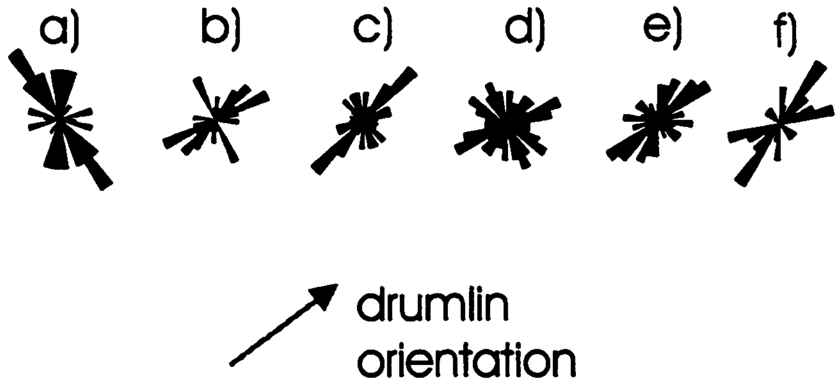


Figure 4-33. Clast orientations, Montagne drumlin (a, b, c) and nearby drumlinized ridge (d, e, f).

4.6 Other diamict sample sites

In the Prince George area diamict fabrics (#120, 131, 132, 133, 134) show preferred orientation northeast-southwest oblique to drumlin central axes (Fig. 4-34). The divergence between fabrics and drumlins is most pronounced east of Prince George, where drumlins turn east and southeast down the Rocky Mountain Trench, but fabrics maintain a north-south orientation. Clasts are primarily igneous, including basalt and quartz, with some conglomerate.

As discussed in the section on Summit Lake, fabrics there are oriented obliquely to drumlin axes; fabrics in the Bear Lake region to the north are oriented more closely to drumlin axes.

In the McKenzie area diamict is relatively dark in colour, containing basalt, schist and quartz clasts. Two fabrics are oriented north-south, oblique to local drumlin central axes (locality N, #124, 126). Both plunge steeply to the south.

In the Williston Lake area diamict was sampled at four sites along the west side of the lake (#127, 128, 129, 130), and one on the east side (#123). Clasts are of igneous and metamorphic lithology, angular to subangular at pebble size. Fabrics are generally oriented towards the apex of the two arms of Williston Lake, where drumlins converge and glacial flow presumably proceeded east through the Peace River Valley. Four fabrics plunge away from the apex, and one toward it.

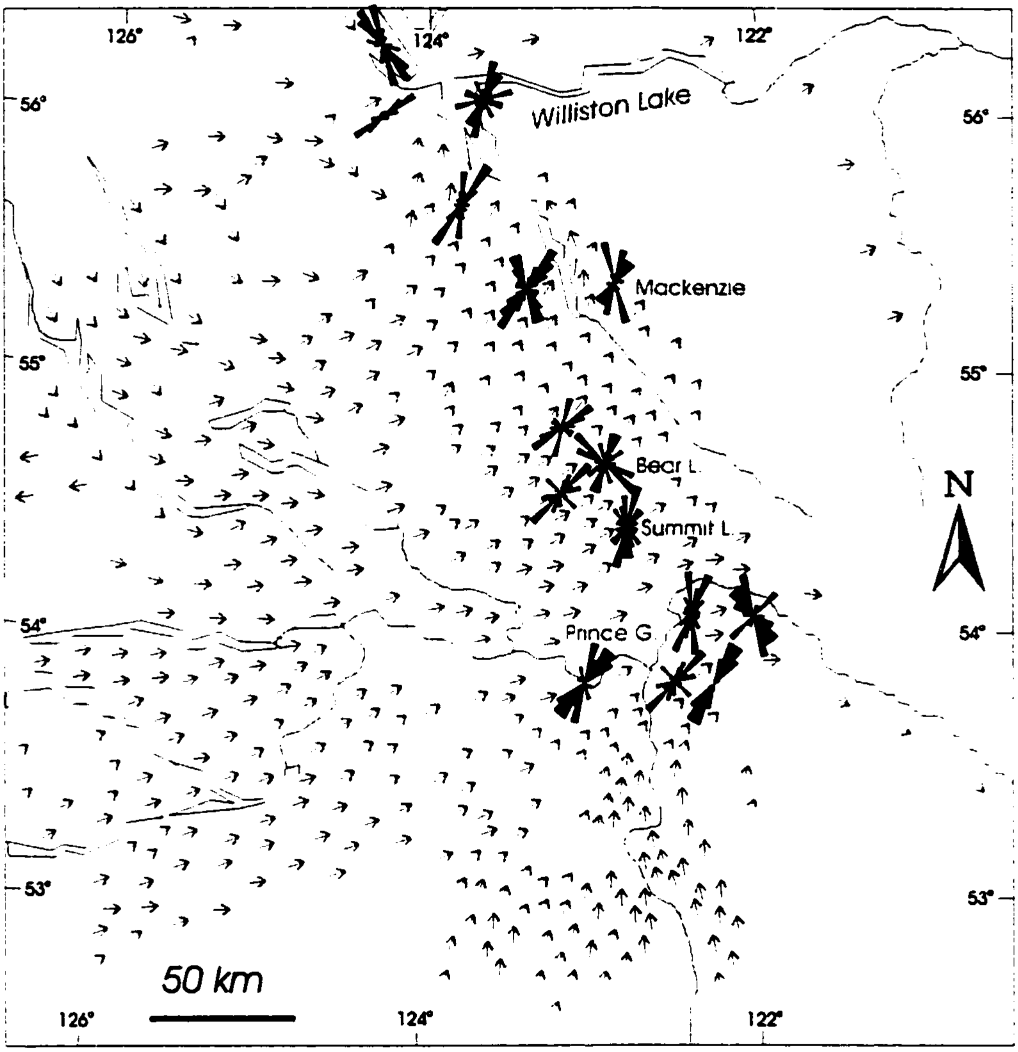


Figure 4-34. Diamict clast and drumlin orientations, Prince George to Williston Lake.

4.7 Interpretations of diamict drumlins

Diamict drumlins cover most of the flat-lying terrain of the study area, and local variation of their long-axis orientation is minimal, as noted by Armstrong and Tipper (1948). The Stone Creek drumlins provide evidence that diamict drumlin internal composition and external form arise from distinct and separate processes. The regional extent, composition and fabric of the diamict, and the imposition of subglacial tunnel channels on the drumlins, supports the interpretation of the diamict as till and the drumlins as subglacial landforms.

A distinction between lodgement, flow, deformation or basal melt-out till cannot be conclusively supported on the basis of the sediment characteristics. Figure 4-35 displays the isotropy of Stone Creek diamict as a function of S_1 vs. S_3 eigenvectors, with genetic groupings as proposed by Dowdeswell and Sharp (1986).

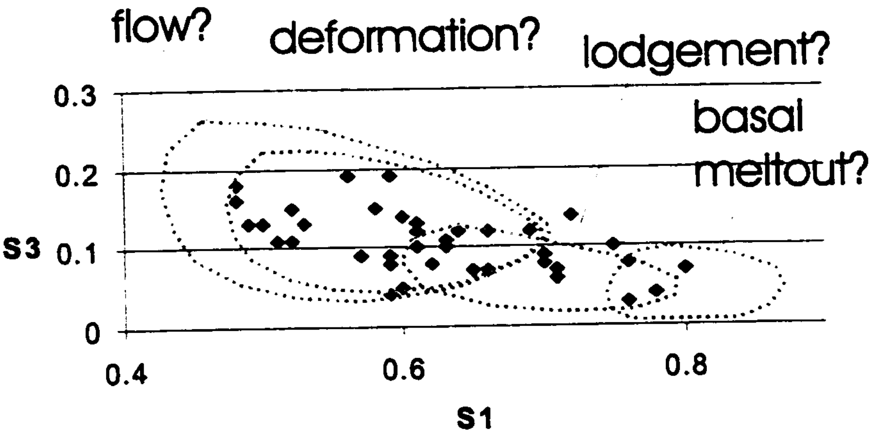


Figure 4-35. Isotropy of Stone Creek diamict fabrics.

Hicock *et al.* (1996) discussed the interpretation of till genesis on the basis of fabric eigenvectors and modality. They concluded that till interpretation based solely on eigenvector strength is too simplistic, that bimodality and polymodality of the clast fabric orientations infer secondary or subsequent genetic influences. They suggested that subglacial flow or deformation would, in most cases, reduce the fabric strength of lodgement or meltout till. The fabric orientations in the southern half of the Stone Creek area (Fig. 4-36) are weaker, and display an east-west mode that is absent from diamict fabrics in the northern half.

The Stone Creek till is highly variable in lithology and fabric orientation. Shale was evident in some samples and absent from others; fabrics change from east-west in the southern sections to north-south in the north section (Fig. 4-36). This variability of surficial sediment characteristics suggests that internal bedding may have been truncated at the surface, or that local sedimentation was highly variable. Erosional surfaces at the base of gravel and sand interbeds on the slopes of the largest eastern sector drumlin further attest to the truncation. The beds are interpreted as representing minor subglacial glaciofluvial events that interrupted the deposition of the till in this region. The preferred orientation of till clasts in the east sector is more east-west than those in the central sector. The interpretation is that this large eastern Stone Creek feature represents a local remnant of meltout till that was initially of regional extent but has been removed elsewhere. The overall surface of the Stone Creek drumlins, then, resulted from differential erosion of heterogeneous glacigenic deposits. The flutings represent the most recent flow paths, the drumlins are resistant erosional remnants, and the low mounds between them are transitional forms.

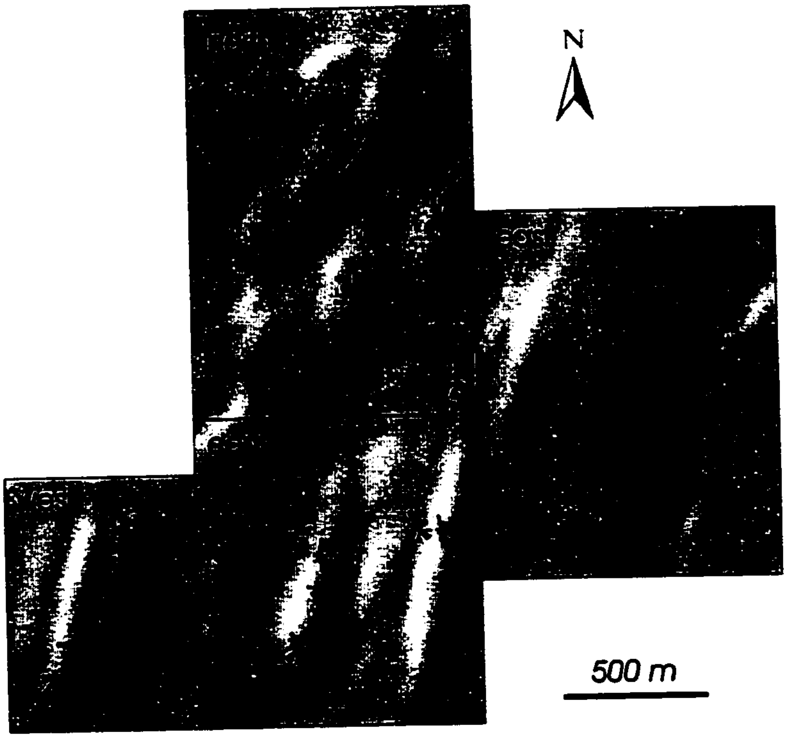


Figure 4-36. Clast orientations of Stone Creek diamict

The right-angle scour at locality H and deep, sinuous scour at locality I are similar to late-stage scours following sheet flow described by Brennand and Shaw (1994) in south-central Ontario. They suggested that ice-bed recoupling may have resulted in flow channelization into the ice and substrate, resulting in secondary tunnel channels (some with undulating long profiles and others exhibiting sharp turns in direction) connecting larger channels. The right-angle scour at locality H is deep and straight, indicating a substantial and focused erosive power, yet the flow was apparently prevented from flowing up and over the drumlin by a seal created by the pinned ice sheet. The sinuous scour at Locality I has steep slopes and sharp slope breaks that are incongruous with the drumlin it bisects; the centre of the scour is higher than its ends, and it joins two low-lying areas upflow and downflow of the drumlin. Such scours are consistent with meltwater channelization, under hydrostatic pressure, connecting two broader cavities as the ice sheet lowered (Brennand and Shaw, 1994).

The internal architecture of diamict drumlins has not been well-documented, given the lack of good exposures and subtlety of the stratification. Where stratified sediments were found, they were truncated by the surface. The preferred orientation of clasts varies from the drumlin axes in many cases. Thus, a depositional or 'plastering on' process is unlikely as a genetic origin for these landforms. Deformation of the internal sediments by the ice sheet cannot be ruled out, but deformation of the landforms would require a consistency of orientation between landforms and sediments, which is not the case. The landforms are more consistent with an erosional genesis, and the *en echelon* scour patterns evident in air photographs (Figs. 4-6, 4-20, 4-24, 4-28) provide a record of turbulent flow vortices splitting, expanding, reforming and resplitting. Such small-scale turbulence is unlikely to occur in a thick, highly viscous ice sheet. Remnant boulder fields attest to an erosional agent of limited competence, as does the regional cobble lag. Thus, diamict drumlins provide evidence for turbulent sheet flow wide enough and deep enough to cover them by at least tens of metres, and of a strength and duration sufficient to remove large tracts of presumed meltout till. Superimposed channels and flutings provide evidence for waning-stage subglacial channel flow. The conclusion is that the ice sheet was lifted by subglacial meltwater flow sufficient to erode the landforms; the ice was lowered quickly during the waning flood stage, compacting the till and concentrating meltwater flow into confined channels. The argument for subglacial erosion and ice-sheet letdown is further supported by the drumlinization, compaction and deformation of glaciolacustrine silt beds, to be discussed at length in the next chapter.

CHAPTER 5. GRAVEL AND SILT DRUMLINS

Gravel and silt drumlins consist of two distinct structural elements: an underlying bed of gravel or diamict with a gravel veneer and an overlying cap of silt rhythmites. Located in the Prince George and Vanderhoof glacial lake basins, they have been mapped by previous workers (Armstrong and Tipper, 1948; Tipper, 1971; Clague, 1988) as sites of thick glaciolacustrine sediments. All site localities for this study are shown in Fig. 5-1. Some general observations on the sediments are pertinent to their depositional context prior to a discussion of the landforms.

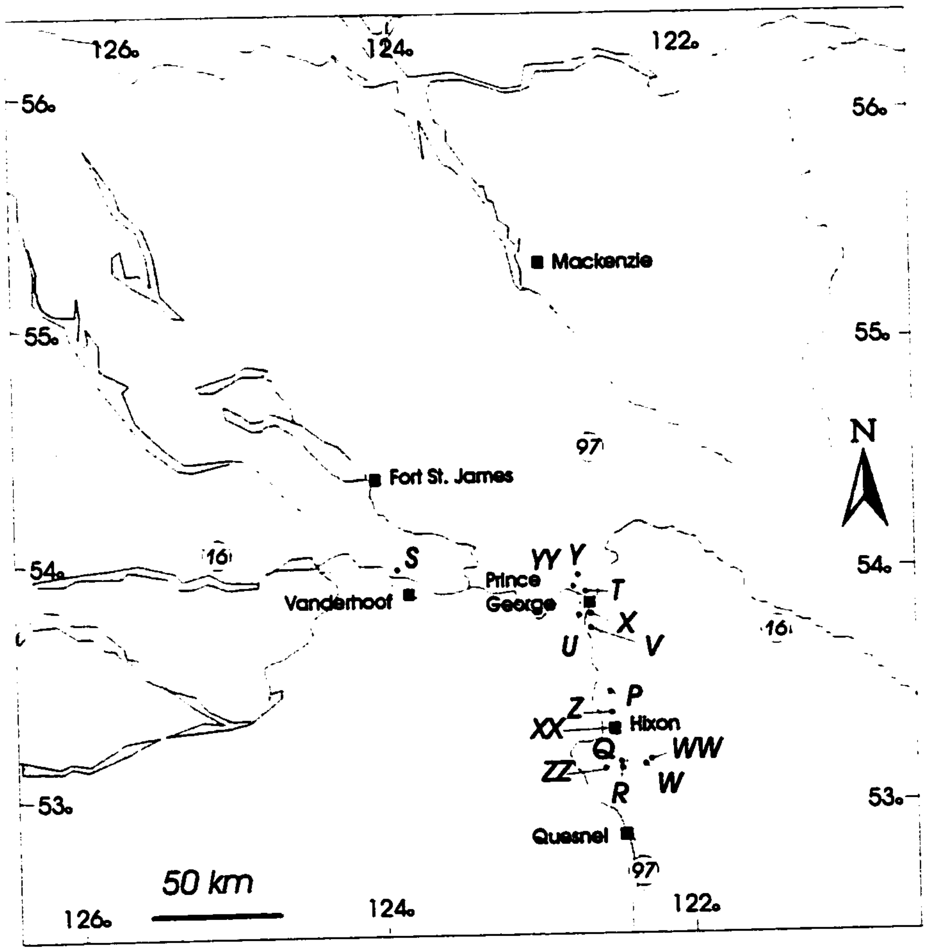


Figure 5-1. Gravel/silt site locality map.

5.1 Fraser Gravel Exposures

The composition of the gravel unit in drumlins is distinguished from diamict by a predominance of gravel (>50%) and low proportion of fines compared to diamict. The matrix is sandy, the clasts commonly exhibit bedding. The thickness of the gravel unit is highly variable, as evidenced from road and creek exposures in the Hixon area. In low-lying areas cross-bedded sand and gravel comprise sequences up to 50 m thick, while on higher promontories gravel units, only a few metres thick, overlie diamict and are truncated at the surface.

5.1.1 College Heights (locality U)

This site in a Prince George subdivision is a commercial aggregate pit, 200 m north of locality U (Fig. 5-1). The pit is located on the low-slope western (downflow) side of a local topographic high. The owner, Mr. Ed Kovach, excavated a large pocket of well-sorted sand in 1979, and has extracted poorly-sorted coarse gravel ever since. The gravel contained a chunk of what he described as 'hardpan' clay, measuring 10' x 10' x 20'. What is visible today are three exposed faces, up to 15 m high, of cross-bedded sand and gravel. The lowest deposits are foresets of coarse gravel dipping eastwards at 20°, with contorted medium sand interbeds and sand rip-up clasts as large as 3 m x 10 m in cross-section. A cobble lag lies on an undulating eroded surface (2 m amplitude, 30 m wavelength). Above the lag, 8 m of cross-bedded coarse sand and gravel beds dip at 10° east and north, fine upwards and are truncated by another erosional surface. Above the second erosional surface, 3 m of horizontal coarse sand and gravel foresets dip north, fine up to medium sand, overlain by 3 m of diamict, 1 m of silts (4-5 beds), and 2 m of diamict.

5.1.2 BC Rail right-of-way, Prince George

This Fraser River exposure faces the city centre from the south (locality X, Fig. 5-1). Access was limited, so heights and thicknesses are rough estimates only. The lowest beds are alternating beds of beige coarse, planar-bedded sand and gravel, and grey, medium sand beds with foresets dipping to the east, totaling 17 m in thickness. Lying above these beds thick units of planar, coarse brown sand beds and cross-bedded grey sand show foresets dipping to the east. This upper sequence is 5 to 10 m thick. Above this lies 3-5 m of grey diamict or gravels, topped by 3-5 m of silt rhythmites and, occasionally, a thin layer of diamict. Much of the internal bedding is laterally discontinuous, interrupted by erosion surfaces. In many places along the exposure the upper units have been truncated by a steeply undulating surface similar in scale to the surface of the McMillan Bluffs north of the city (Fig. 5-2). A thin layer of diamict over much of this eroded surface implies that it is of glacial origin.

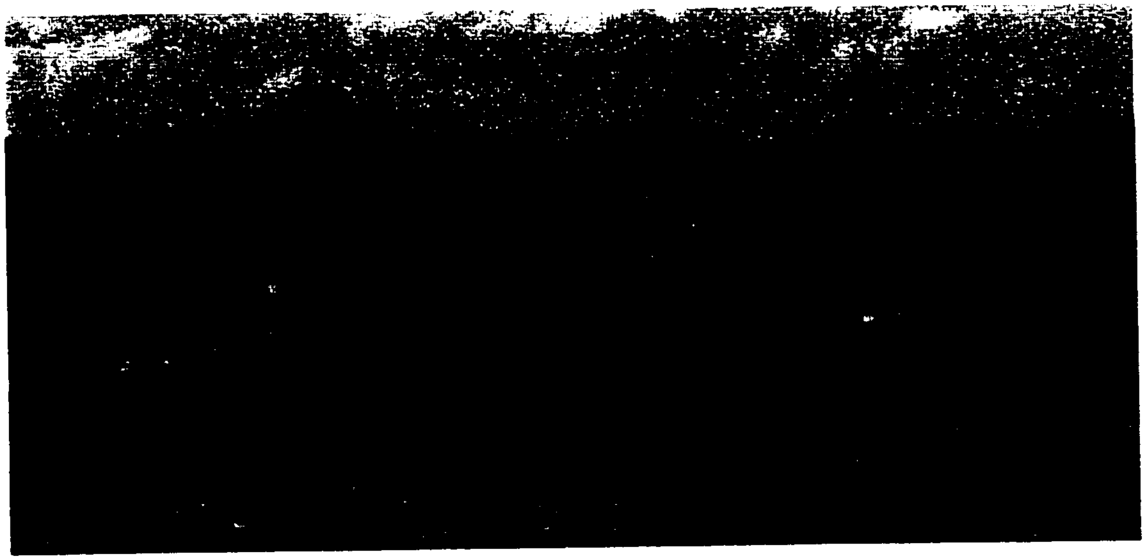


Figure 5-2. Macmillan Bluffs, Prince George

5.1.3 Hixon Creek (locality XX)

This site is 1 km south of Hixon along Hixon Creek (Fig. 5-1). Twelve metres of coarsening-upward sand and gravel beds with internal erosion surfaces point to cut-and-fill processes. The sands and gravels are truncated by an undulatory erosion surface with a wavelength ~15 m. Above the erosion surface lie 8 m of finer, coarsening up planar sand and gravel beds, which are in turn truncated by an erosional surface. Thick silt (4 m) rests on the upper erosional surface. A nearby site along the creek displays a large clastic dyke cutting through 15 m of cross-stratified sand and gravel beds and diamict (Fig. 5-3).

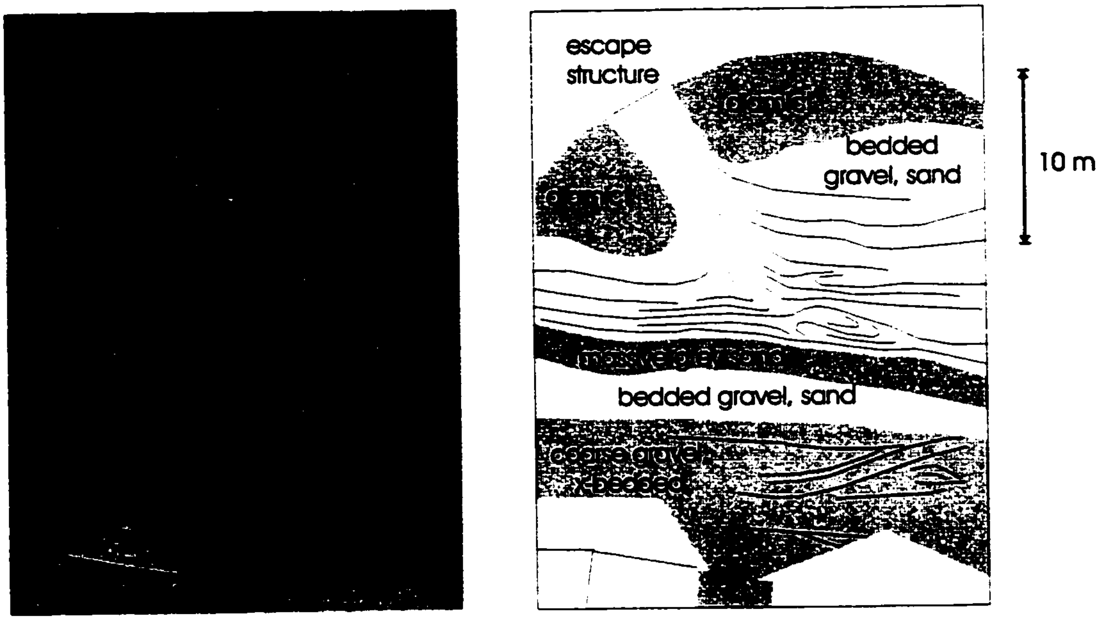


Figure 5-3. Diapiric escape structure in bedded gravel, Hixon townsite.

5.1.4 Naver Creek

Exposure at this site, 2 km northeast of locality XX (Fig. 5-1), contains 14 m of well-sorted coarse sand and gravel at the bottom of the exposure with foresets dipping to the south. An overlying 6 m bed of coarser red gravel is marked at the top by cobbles with an undulatory surface (wavelength 10m, amplitude 2m). Above the contact the sequence is as follows: 1 m of well-sorted white sand, 6 m of planar beds of beige sand and grey gravel (large-scale foresets dipping to the north), 5 m of red gravel, 5 m of grey gravel and 5 m of diamict.

5.2 Silt Rhythmites

Fining-upward silt rhythmite units in the study area are commonly draped over a sharp, undulating contact with the Fraser gravels. Above the contact the first deposits are often disturbed, distorted or partially eroded, evolving upward to thicker couplets of light silt and dark clay with a few isolated pebbles. Individual rhythmite beds are thickest on the lee (downflow) side of larger features. The upper beds are truncated by the modern surface .

5.2.1 'White Silts' of McMillan Bluffs (locality T)

The most visible exposure of rhythmite deposits occurs along the banks of the Nechako River north of the Prince George city centre (Fig. 5-2). They are comprised in the basal sequence of fining upward silt and sand beds, light buff in colour, ranging in thickness from centimetres to metres, truncated by an undulating surface. The upper beds are silt, a meter or more thick, separated by thin clay interbeds (Fig. 5-4). The lowest visible beds are comprised of well-sorted sand, below which an apron of sand obscures the exposure. Two medium sand beds are visible, the lower with climbing ripples indicating paleoflow to the northeast, the upper one cross-bedded, with pebbles and rip-up clasts. Cross-laminae climbing ripple sequences in sand and silt dip to the northeast.

5.2.2 College Heights (Locality U)

This road exposure is located on the east (downflow) side of a local topographic high in a new southwest Prince George suburb (Fig. 5-1). Silt and clay laminae up to 1 cm thick overlie a cobble lag, and are overlain in turn by two rhythmites each 20 cm thick and a sequence of alternating fine and medium sand beds (Fig. 5-4). The lower sands are cross-bedded, in places contorted, and contain pebbles and rip-up clasts. The upper sands are horizontally bedded, fining upwards into silt/clay rhythmites, 5-15 cm thick, similar to those below the sand unit. Fig. 5-3 presents possible correlating contacts between the College Heights and McMillan Bluff sediments. The upper units are thick silt and clay rhythmites, the middle units are thin sand and silts beds, and the lower units are thicker fine sand beds with medium sand interbeds. If the proportions of the two sections are consistent in the lower units, then the silt/gravel contact below the McMillan Bluff sediments is close to the modern day Nechako River valley bottom.

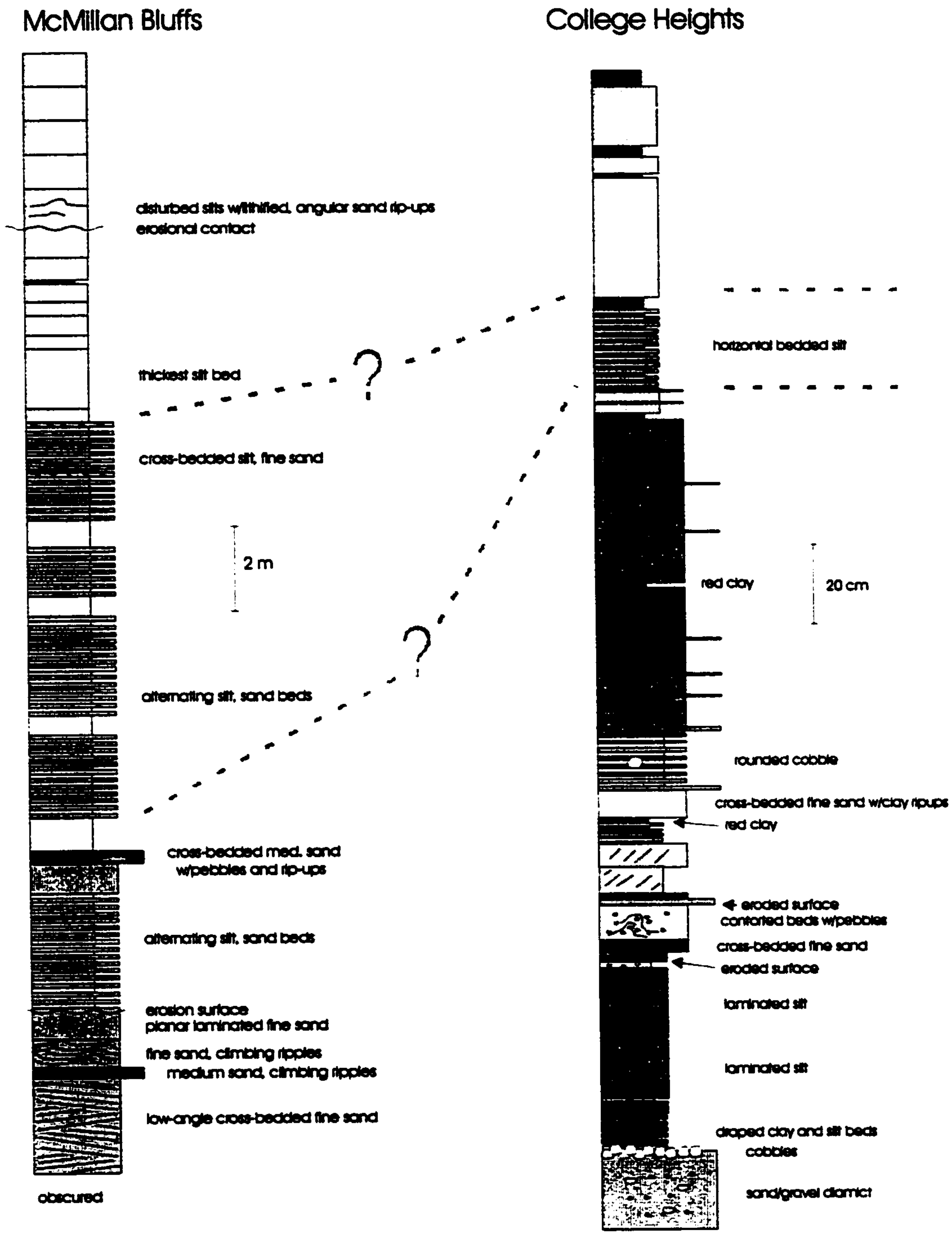


Figure. 5-4. Stratigraphy of McMillan Bluff and College Heights rhythmites.

5.2.3 Cale Creek (locality V)

This site is located 15 km south of Prince George, 100 m north of the Cale Creek railway trestle (Fig. 5-1). The site (between 630-645 masl) lies in the lee of a topographic high to the south (upflow). More than 120 rhythmite couplets are preserved, surpassing the upper limit of 100 suggested by Clague (1988). Cale Creek rhythmite thicknesses decrease exponentially with height (Fig. 5-5). The thickest beds near the base of the unit consist of light-coloured silt to darker silt to dark, reddish clay. The light and dark silts are of approximately equal proportions (~10 cm thick); the red clay is 1 cm or less thick. The silts near the top of the rhythmite sequence are mostly light-coloured with a thin, dark interbed. The rhythmites overlie sand and gravel, and rounded cobbles are prevalent just below the contact. The contact between the silt and gravel undulates, with an amplitude of 0.3 m and wavelength of 5 m.

An exposure 200 m north of locality V is 15 m lower in elevation, and only a few beds were preserved above the contact with gravel. The couplets are ~10 cm thick, the undulatory contact with gravel is 0.2 m amplitude and 2 m wavelength.

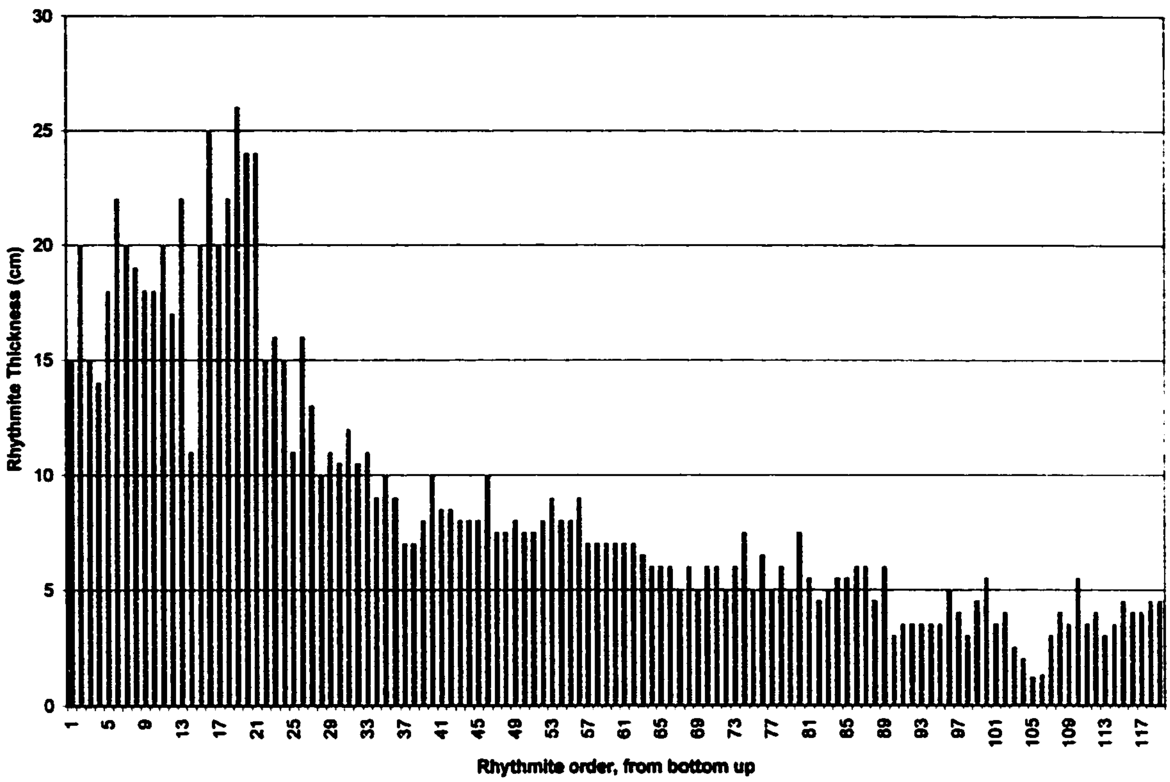


Figure 5-5. Rhythmite thicknesses, Cale Creek exposure.

5.2.4 Naver Forestry Road (Locality W)

This site is located in the hills above and east of Strathnever (5905195N, 534849E), situated on the steep north (downflow) side of a hill. The basal units consist of thick disturbed clay and silt beds (Fig. 5-6). The silt in the rhythmites at the top of the exposure are 60 cm to 1.4 metres in thickness, while the clay laminae are 1 cm or less. At an elevation of 731 masl, the site is only 25 m below the upper limit of rhythmites mapped by Tipper (1971b). The thickness of the rhythmites is unexpected for deposition in a shallow water column, yet Tipper (1971b) interpreted gravels at 757 masl as beaches marking the upper limit of the glacial lake. Other exposures on local forestry roads include 1.5 m of massive silt over massive fine sand at 806 masl (5905052N, 536656E) and 2.5 m of massive silt over diamict at 830 masl (locality WW, 5906675N, 539682E).

Interpretation: The gravel unit was eroded by high-energy fluid flow, and the cobble lag was deposited as flow waned. The thick, massive silts are backflow eddy deposits. The elevation and thickness of the deposits indicates a lake level much higher than 800 masl.

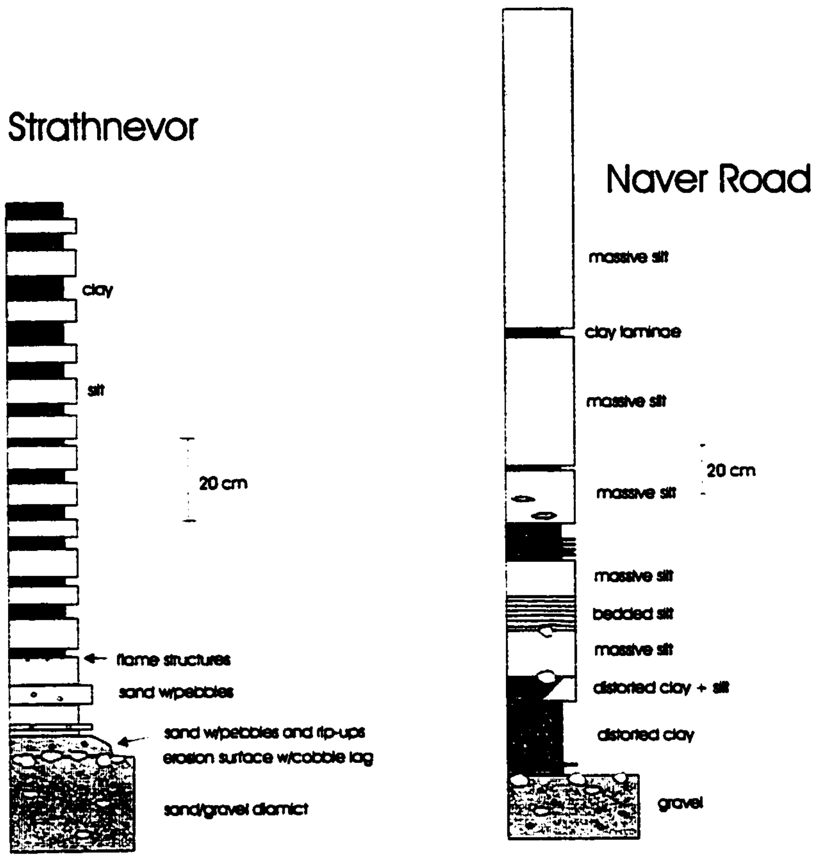


Figure 5-6. Stratigraphy of the Strathnever and Naver Road exposures.

5.3 Powerline Drumlins (Locality P)

North of Hixon a group of relatively broad drumlins, separated by narrow flutings, are oriented beneath and parallel to a cleared powerline allowance (Figs. 5-1, 5-7, 5-8). Only the stoss ends were systematically surveyed, as the lee ends were covered with thick brush where a large bear had been sighted. The westernmost drumlin is the largest, being more than a km long, 300 m wide and 40 m high (Figs. 5-7, 5-8). It is also the steepest, with slopes reaching 25° on its stoss end and on the west side, where a slope failure is evident. The features to the east become progressively smaller, shallower, and displaced northwards. A series of flutings 1-2 m in relief lie between, and parallel to, the two eastern drumlins. The easternmost drumlin is 500 m long, 200 m wide and 15 m high, with a stoss end and eastern side slope of 15°. The surface of these drumlins is rougher than that observed on diamict drumlins: there are many small depressions and bumps, and the axial crest on the highest drumlin is sharply peaked. The drumlins are bounded to the west by a deep, narrow channel, to the east by a broad, shallow channel, to the north and south by more drumlins arranged *en echelon*.

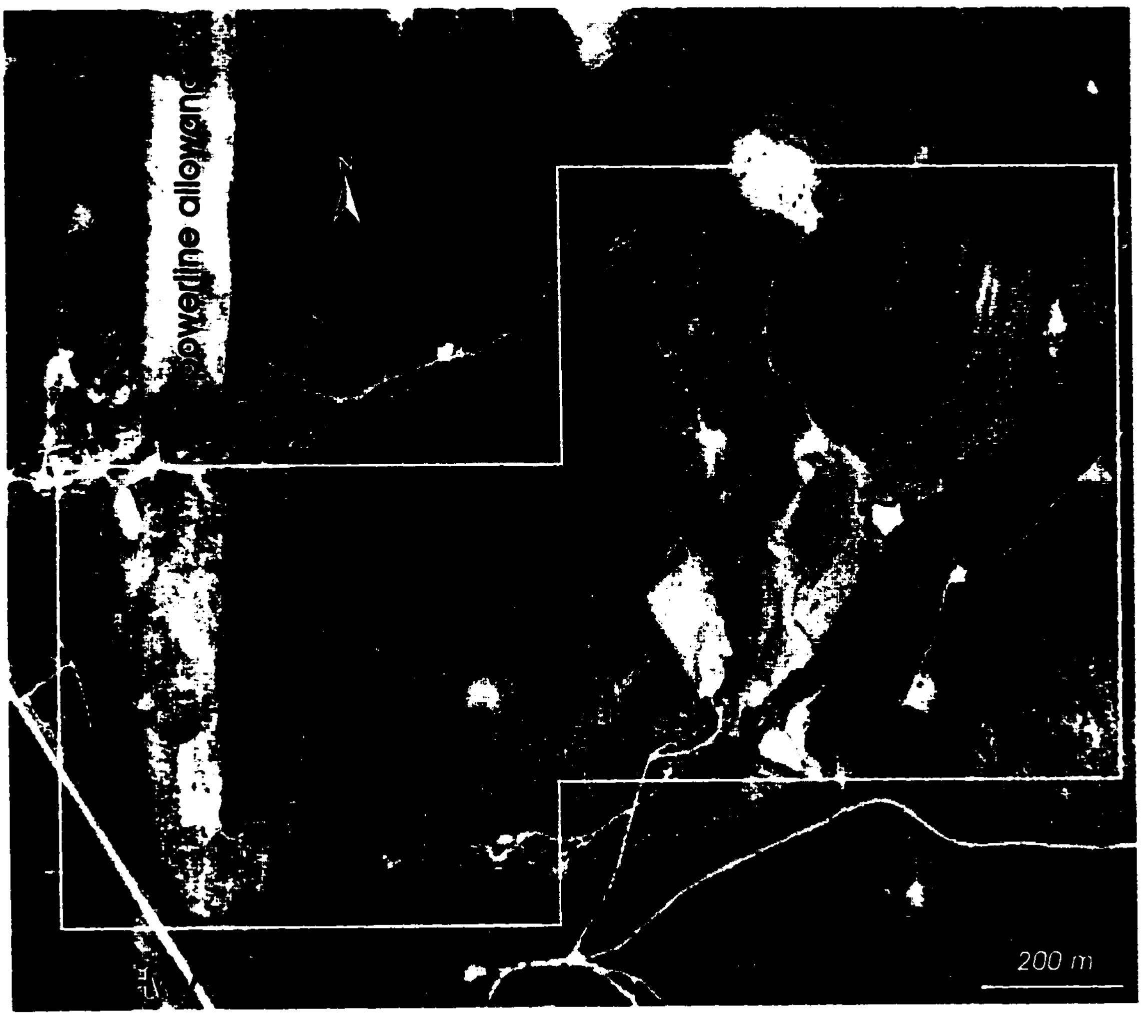


Figure 5-7. Air photograph, Powerline Drumlins (flow direction is bottom to top).
(air photograph BCB96003-143 reproduced with permission of BC Ministry of Environment)

Sediment at the westernmost base of the features is typical diamict (#72), progressing to clast-supported gravel at higher levels (#73). On the east side, gravelly diamict is found low on the drumlin (#74, 78), grading to sand and gravel (pebble matrix) higher up (#76).

The contact with finer sediment (#75, silt/clay with pebbles) above is sharp and near the top of the drumlin are silt/clay rhythmites with no pebbles (#77). The vertical sedimentary sequence recorded from an adjacent drumlin is similar, in that sand and gravel (#79, 80) and gravelly diamict (#81) underlie fines with pebbles, which in turn underlie fines with no pebbles (#83). The lack of consolidation in the gravel is evidenced by a large slump on the west side of the drumlin.

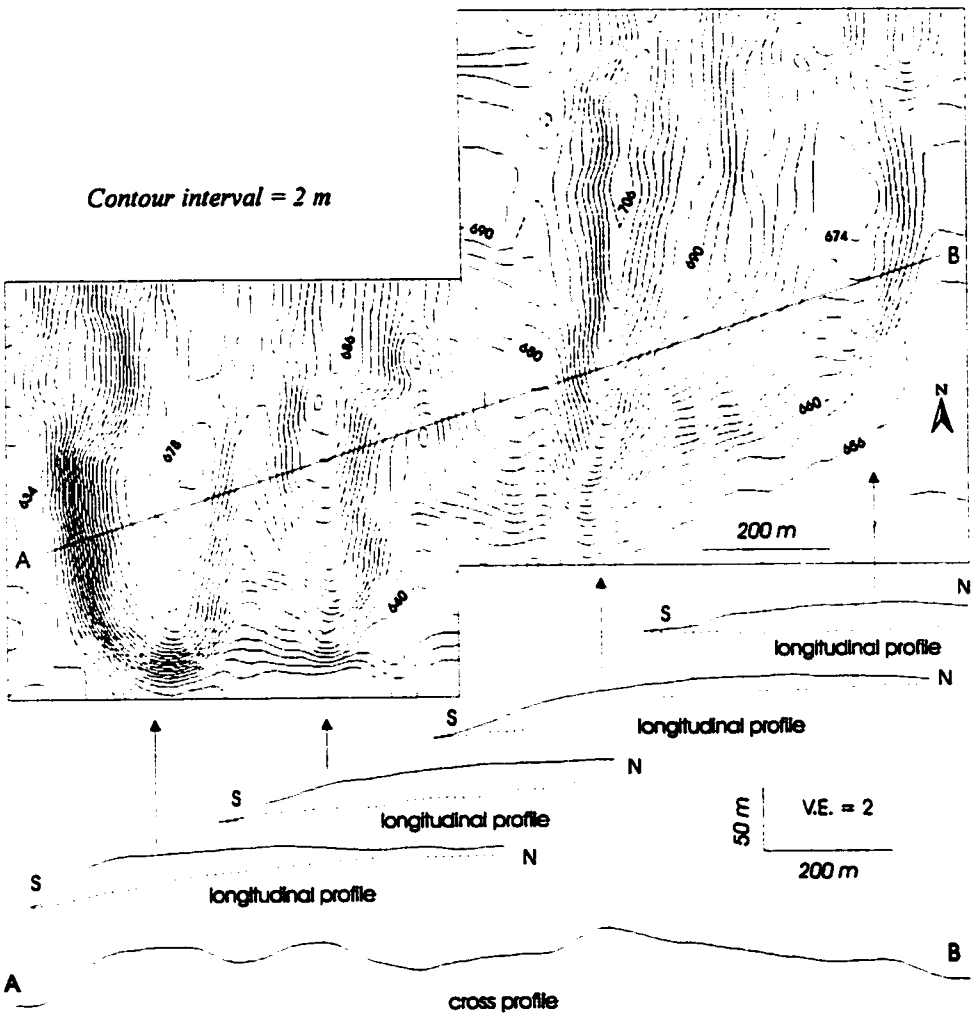


Figure 5-8. Contour map and profiles of Powerline drumlins, locality P.

The low-lying areas around this drumlin are covered with thick silts. The drumlins next to it display numerous surface exposures of the contact between overlying fines and underlying gravel. Sites #79 and 89, just below the contact on the drumlin to the east, are primarily sand; these sites are located stratigraphically between the gravel and the silt. Sites #88 and 90 are clay and silt beds with no gravel clasts. Site #90 sits high on a narrow drumlin; the silt/clay is more compact and the bedding is distorted. Immediately below this silt unit is a cobble pavement. Further east, site #91 is gravel and site #92 is diamict. Figure 5-9 presents representative fabric orientations from all sediments; most are oblique to the drumlin central axes.

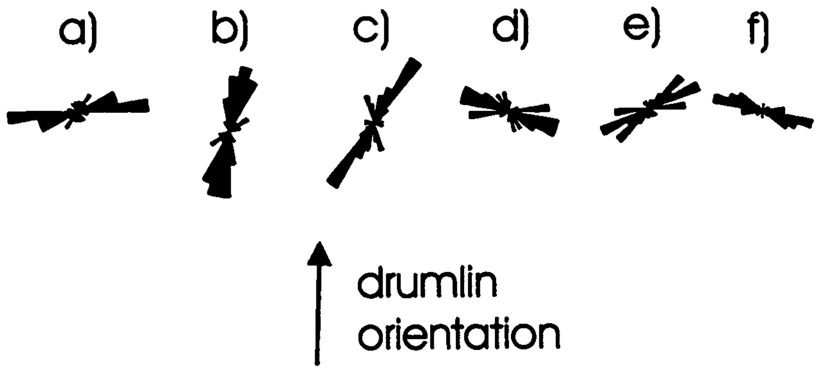
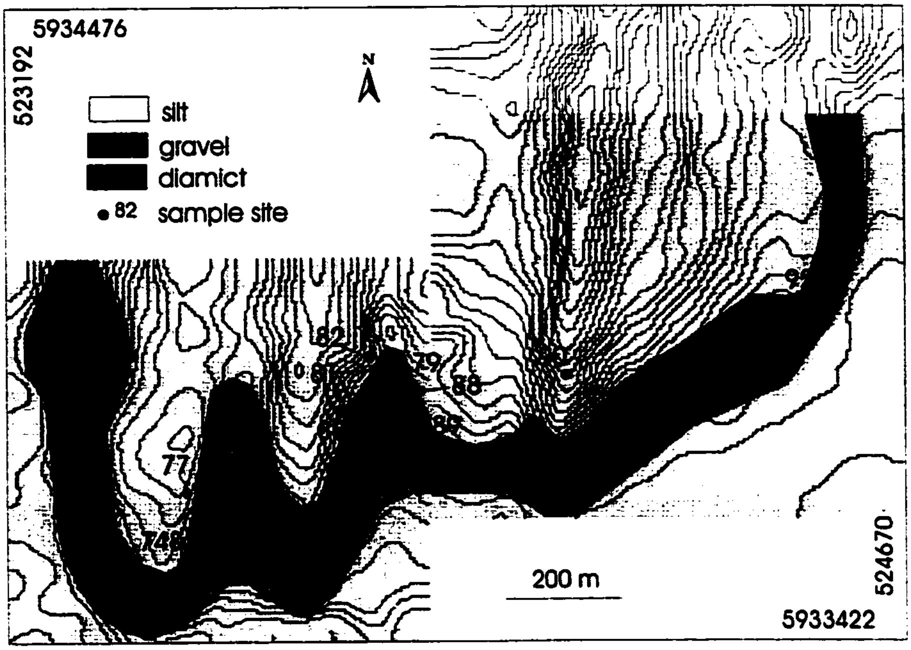


Figure 5-9. Fabric clast orientations, Powerline drumlins, from diamict (a, b), gravel (c,d) and silt (e, f).

Figure 5-10 summarizes the surface sediment of all four Powerline drumlins interpolated from sediment samples and field observations. Silt rhythmites cover most low-slope surfaces; silts on the top of drumlins are more compact and bedding is distorted. The silt/gravel contact occurs at the base of all drumlins and again at various higher elevations on the drumlins. This contact is marked at the surface by an abundance of cobbles and boulders at the upper limit of the gravel. Diamict is exposed on the stoss ends and the steepest sides of the drumlins. Boulders are found at bottom slope breaks and in the troughs between drumlins.



Contour interval = 2 m

Figure 5-10. Surficial sediment of Powerline drumlins, locality P.

5.4 Strathnever drumlins (locality Q)

These low-relief features are located on the stoss end of a broad hill 10 km south of Hixon (Fig. 5-1), downflow from a relatively flat plain, and upflow from more drumlins arranged *en echelon* (Figs. 5-11, 5-12). They average 700 m long, 300 m wide and 15 m high. The surface of the two southern drumlins is smooth, and the trough between them is broad and steep. The silt plain to the south gently undulates at a wavelength of 200-250 m and amplitude of 2-5 m; the undulations along the eastern margin of the surveyed area comprise linear waveforms transverse to the flow direction.

A nearby highway exposure reveals a complex relationship between diamict, gravel and overlying silt (Fig. 5-13). The diamict (#143) is either distorted or unevenly eroded; the upper limit of its surface undulates at a wavelength of 50-70 m and amplitude of 5-10 m. The overlying gravel is composed of equal proportions of gravel and sand (#142), with a 2-3 m thick lens of coarse sand overlying 50 m of the unit. The gravel has an undulating upper surface, at a wavelength of over 100 m and amplitude of 5-10 m. The silt beds lie conformably over this surface, and all units are truncated by the upper surface. This exposure is at the northeast end of the Strathnever drumlins.

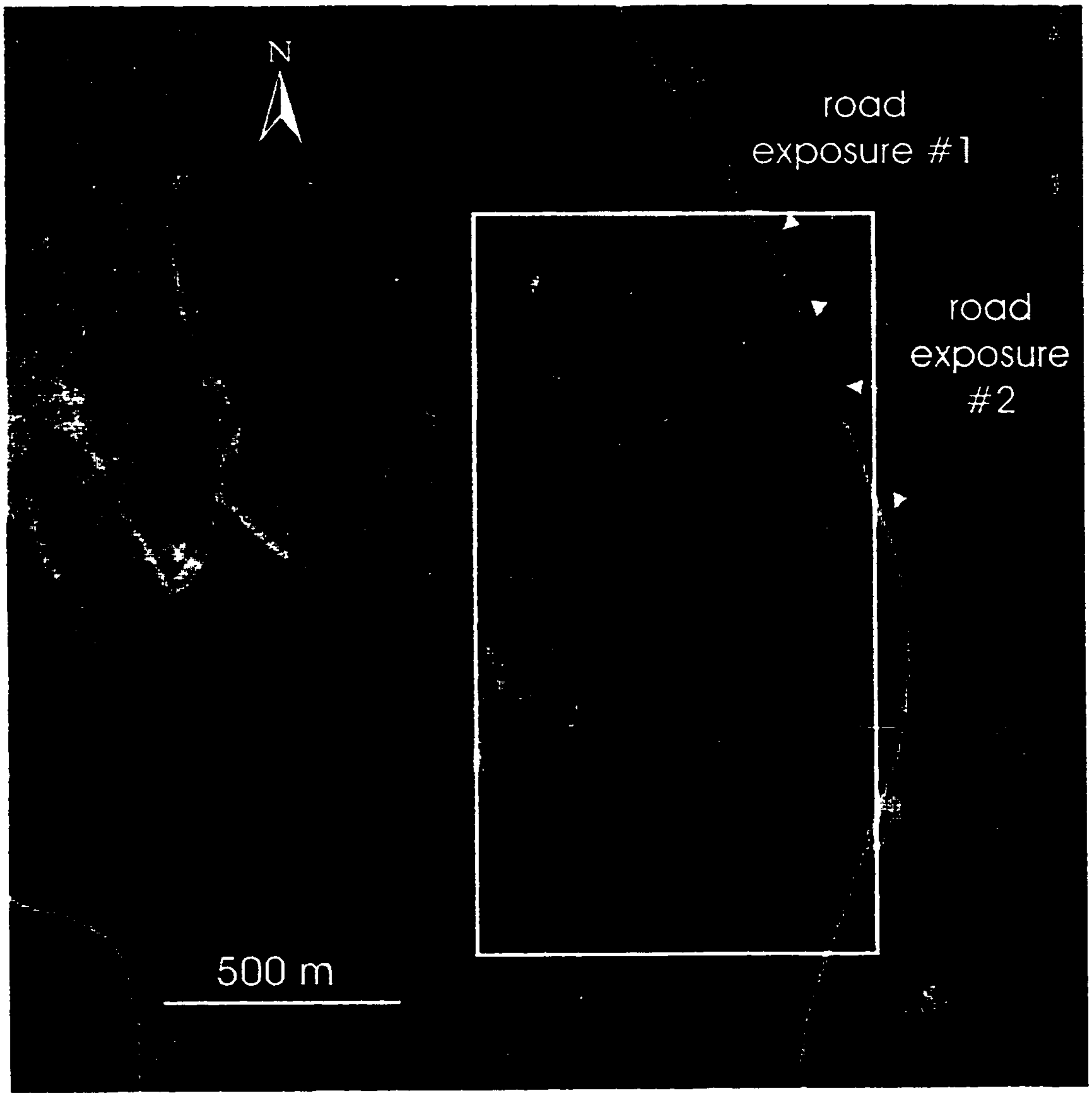


Figure 5-11. Air photo of Strathnever drumlins and highway exposure, locality Q.
(air photograph BCB960005-171 reproduced with permission of BC Ministry of Environment)

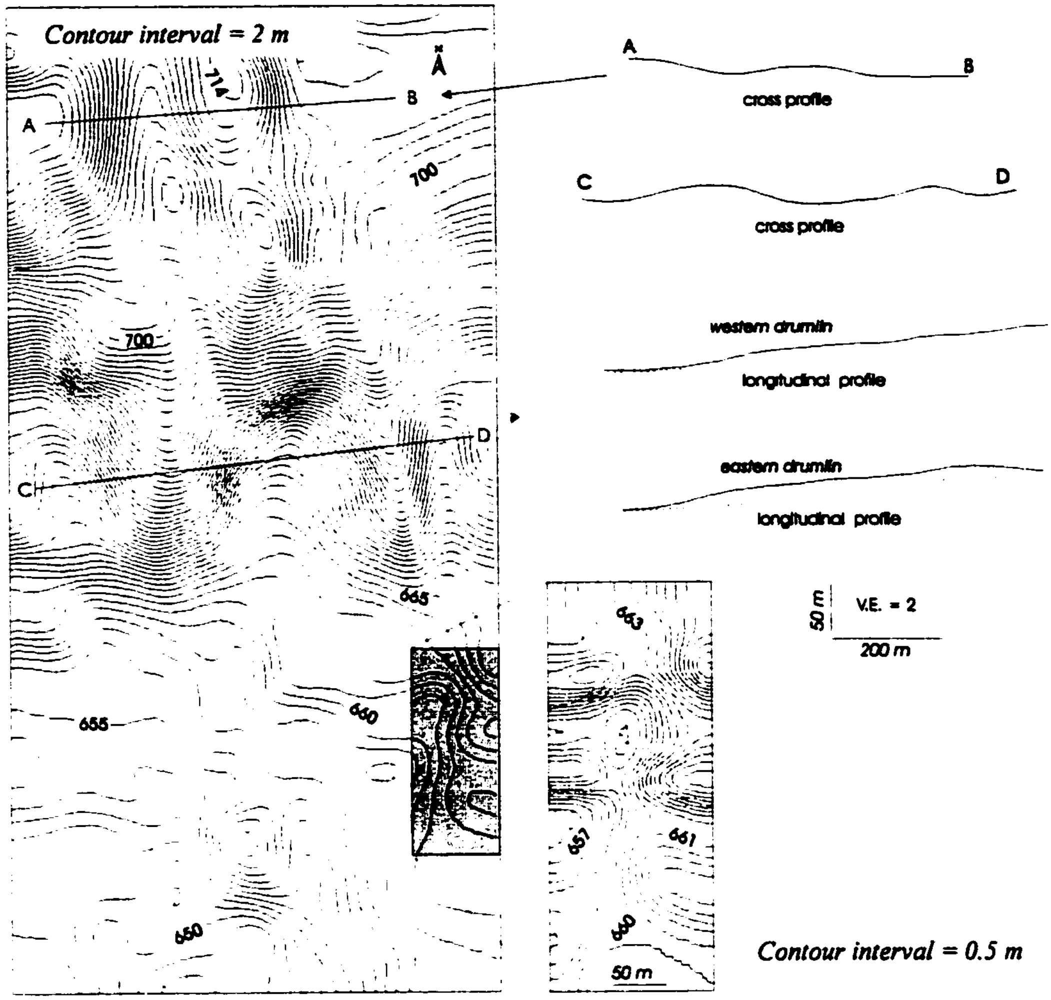


Figure 5-12. Contour map and profiles of silt-gravel drumlins, locality Q.

The Strathnever drumlins are lower in relief than till drumlins, with surface sediment comprised of silt rhythmites on low-slope surfaces (#94) and gravel or diamict (#93) on the steeper slopes. The silt/gravel contact at both the upper and lower slope breaks are marked at the surface by an abundance of cobbles. The total thickness of the rhythmites on the open field south of the drumlins is unknown, but individual couplets in a shallow gully are 7 cm thick (5 cm silt, 2 cm clay). A farm road on the west side of the surveyed area exposed silt beds overlying gravel on the nose of the drumlin. The silt unit is 1-2 m thick on lower slopes and at the top, but beds are truncated entirely on the steeper slope. Gravel was observed on the stoss end and steeper sides of all drumlins. There is no indication of slumping , subaerial erosion or redeposition of the silt beds to explain their absence from the stoss end slopes.

5.4.1 Strathnever highway exposures

These exposures are the result of Highway 97 widening operations south of Hixon, at an elevation of 675-705 masl (Figs. 5-1, 5-11). The cobble lag at the top of the diamict unit is overlain by sand with pebbles and clay rip-ups and conformably-overlying medium sand beds (Figs. 5-6, 5-13). An irregular contact separates the sand from silt above, followed by alternating beds of sand (with pebbles) and silt. The contact between a clay bed and silt below is irregular, with flame structures. From this point the beds are typical rhythmites of light-coloured silt grading upward to darker clay, from 7-9 cm in total thickness. The lower beds are comprised of thicker silts than clays, but at the top of the exposure silt and clay thicknesses are approximately the same. Other exposures north and south along the highway reveal similar rhythmite beds overlying gravel. The beds are truncated by the ground surface, numbering up to 20 on the south (downflow) side of larger landforms (Fig. 5-14).

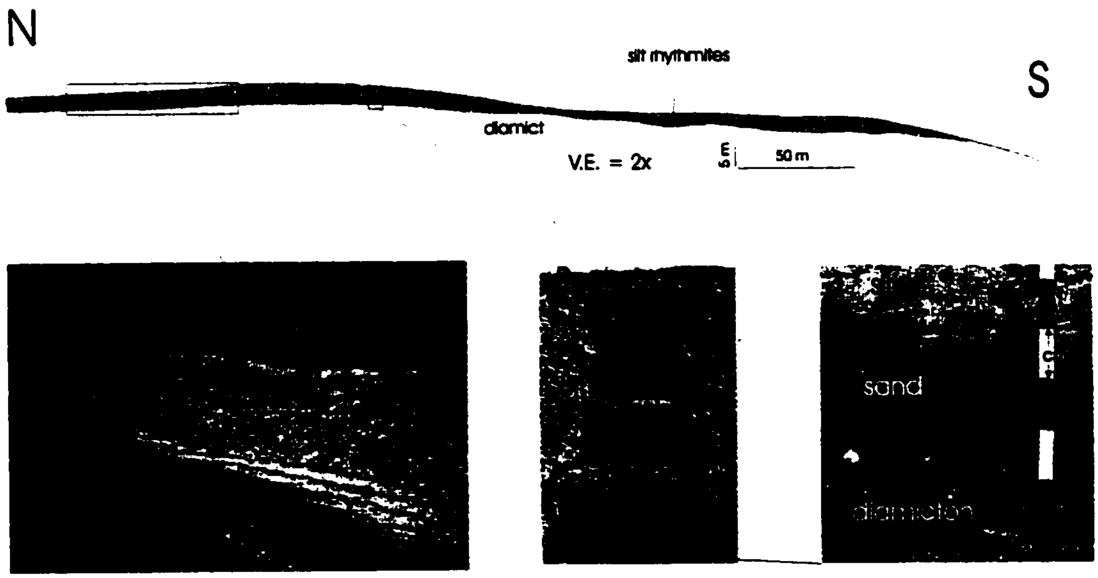


Figure 5-13. Strathnever road exposure #1.

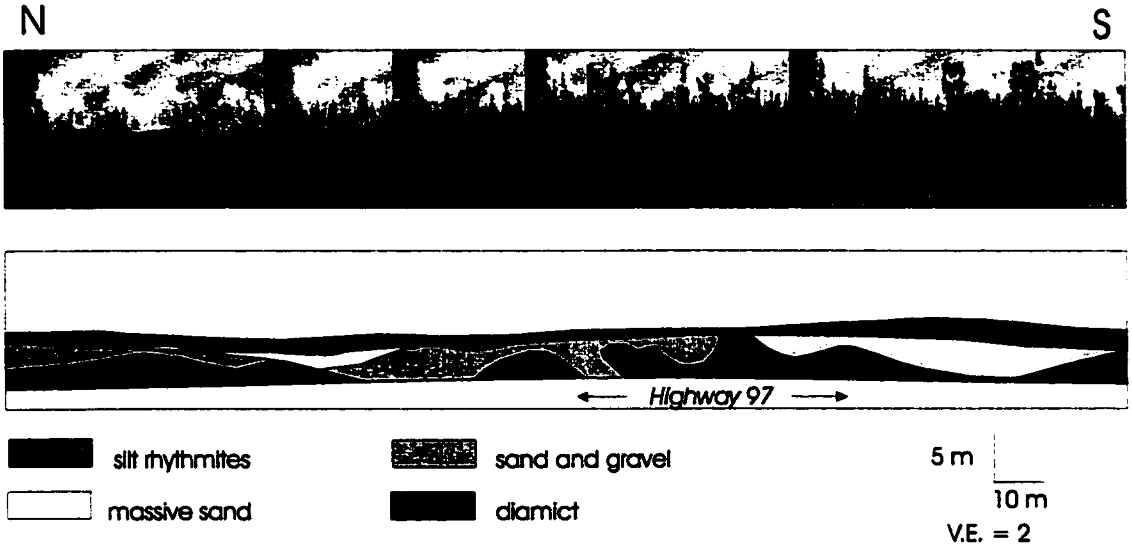


Figure 5-14. Strathnever road exposure #2.

Interpretation: The sand/gravel unit has been eroded by high-energy fluid flow (long wavelength undulation). The cobble lag was deposited as flow waned; sand units with coarser clasts and rip-ups may have been local debris flows under unstable conditions. Escape structures in the overlying silt indicate that deposition was rapid. The rhythmites were eroded at the surface by high-energy fluid flow.

5.5 Chubb Lake Road flutings (locality R)

These small features are located 2 km south of the Strathnever site (Fig. 5-1). They are the smallest features surveyed, at 200 m long, 70 m wide and 2-5 m high (Figs. 5-15, 5-16). These flutings are located on the southeast, stoss end of a large hill, oriented parallel to the flow. In an adjacent area on the lee end of the hill the undulations are similar in scale, but oriented transverse to the flow direction. Similar features are evident in silts throughout the Prince George and Vanderhoof basins.

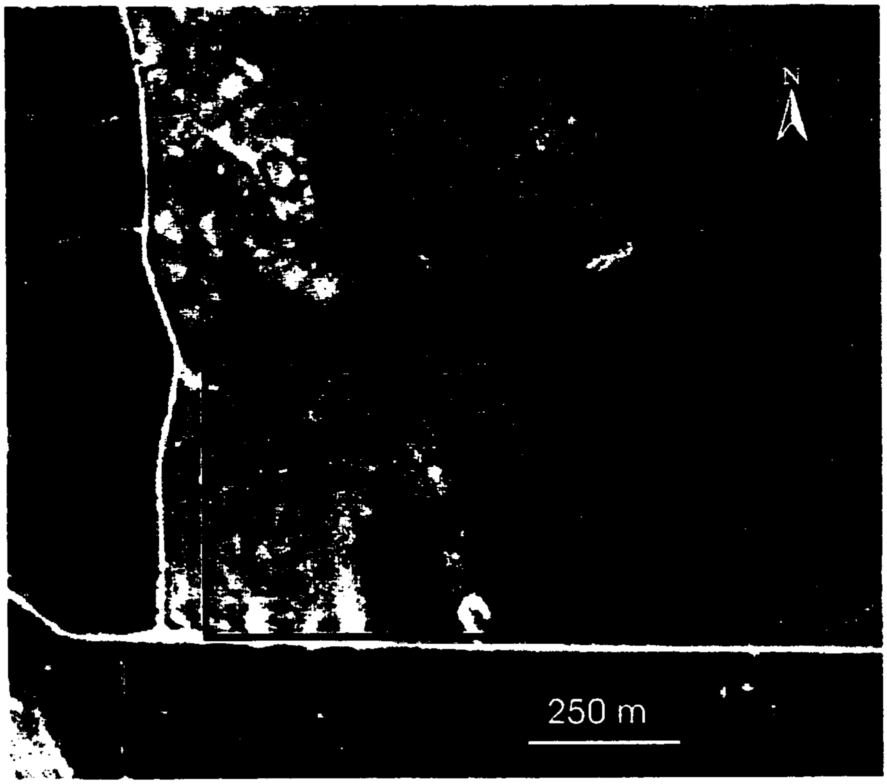


Figure 5-15. Air photograph, Chubb Lake Road flutings, locality R.
(air photograph BCB960005-171 reproduced with permission of BC Ministry of Environment)

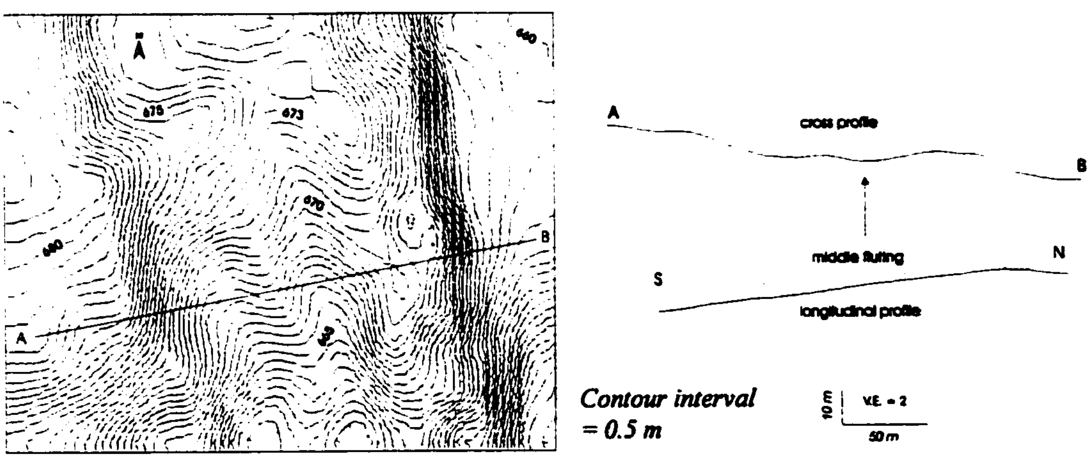


Figure 5-16. Contour map and profiles of Chubb Lake flutings, locality R.

Two road exposures reveal a shallow accumulation of rhythmites over diamict, bedded sand and gravel. At the top of a 2 m thick rhythmite unit, the couplets are 5-6 cm thick; at the base they are 9-10 cm thick. The red/black portion of the couplets is almost pure clay (#141), and comprises half the thickness of each couplet. The contact with the gravel below is sharp and undulatory. One exposure under the crest of a drumlin shows diamict underlying the gravel. A lower exposure under the trough of a fluting 50 m to the west reveals a cobble lag and alternating beds of well-sorted gravel (10 cm thick) and sand with gravel (50 cm thick) under the contact.

5.6 Vanderhoof drumlin (locality S)

This feature, situated in the Vanderhoof Glacial Lake basin (Fig. 5-1), is comprised of two distinct morphological forms: a high-relief drumlin and the low-relief hill on which it is perched, separated by a distinct slope break (Figs. 5-17, 5-18). The central axis is slightly curvilinear, convex to the south, and parallels the east-west regional orientation of other glacial features in the Vanderhoof area. The drumlin slopes at 15-20° at its stoss end and on the south side (the southwest face is the steepest); the north side slopes at 10-15°, the lee end at 5-10°. The underlying hill slopes at 4 -12°, again steepest in the southwest quadrant. The upper drumlin is 600 m long, 200 m wide and 25 m high; the hill is about 1 km long, 450 m wide and 5-10 m high. The steeper south wall is marked by two slope failures, the largest being 160 m along-slope and 80 m up-slope in dimension. The rotational slump blocks have left depressions in the drumlin side, in which thick silt deposits were observed. The feature sits isolated on a gently rolling silt plain on which low-relief bedforms, both parallel and transverse to the flow direction, were observed to the west (Fig. 5-19).

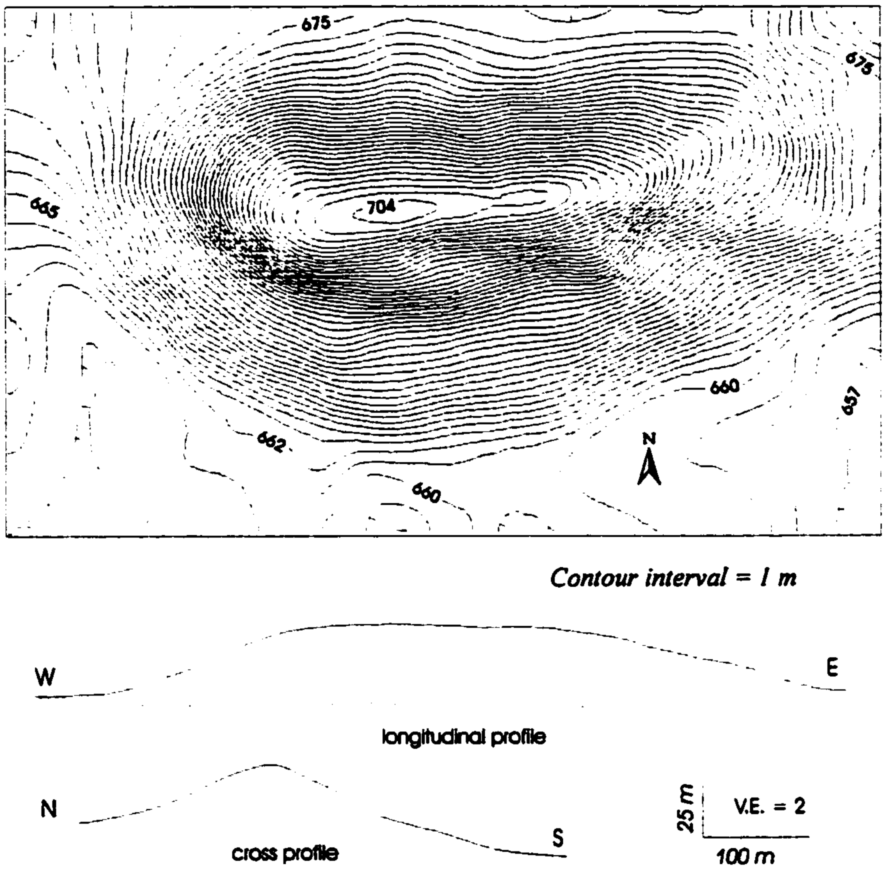


Figure 5-17. Contour map and profiles, Vanderhoof gravel drumlin, locality S.

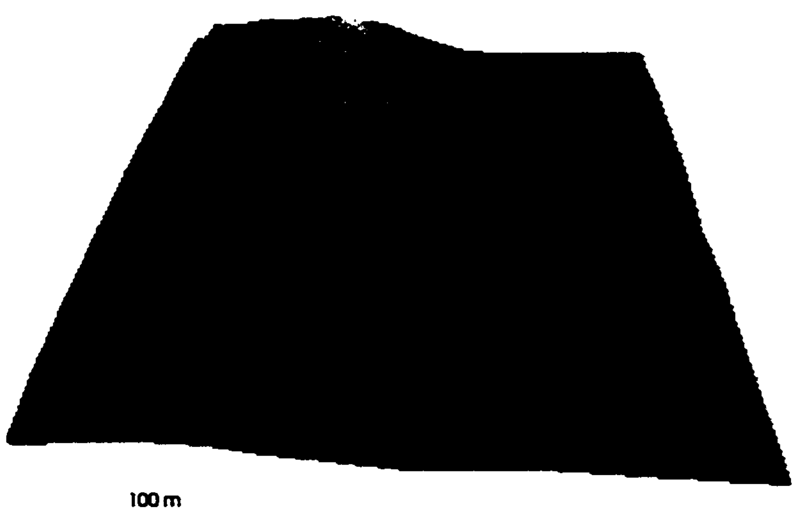


Figure 5-18. Oblique view of Vanderhoof gravel drumlin, looking east.

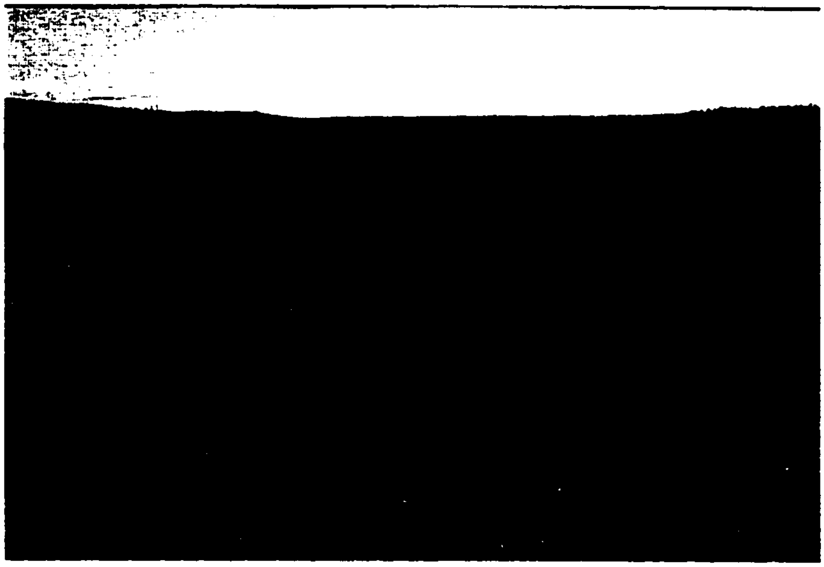


Figure 5-19. Rolling topography on glaciolacustrine silts, Fraser Lake area.

Figure 5-20 depicts the general distribution of sediments on the Vanderhoof drumlin, which is surrounded by silt rhythmites. Couplet thickness varies from 12 cm in the lowland to the south, to 8 cm on the northwest side (#96), and 6 cm on the lee end (#98), all dipping away from the drumlin. The southern rhythmites contained a 20 cm rounded clast with one flat side; bedding is compressed under the clast and draped over it. On the lee end of the drumlin three couplets overlie 15 cm beds of medium sand (#97) and coarse sand with pebbles. On top of the drumlin silt is only 5 cm in total thickness (#144), overlying cobbles in a sand matrix. The southern slope has been block faulted, leaving a crescent-shaped, protected hollow containing rhythmite couplets 30 cm thick. Surface sediments on the drumlin stoss end and sides are in a gravel-matrix diamict (#100). A low-slope apron below the slope break at the stoss end is comprised of cobble-rich diamict; the proportion of cobbles decreases away from the slope break. Boulders are common at slope breaks on the stoss end and sides. As observed on other drumlins, the contact between silt and gravel/diamict is marked by a high proportion of larger clasts at the surface. In 1997 a Vanderhoof engineering firm excavated the north side of the drumlin with heavy machinery to investigate the potential for a commercial aggregate pit.

Three exploratory holes revealed a shallow covering of gravel over a clay-rich core (presumably diamict).

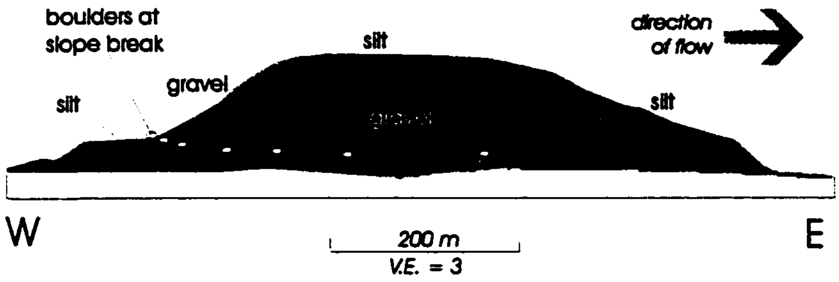


Figure 5-20. Distribution of surficial sediments, Vanderhoof gravel drumlin.

5.7 Eskers and Ice-Contact Deposits

Eskers were mapped by previous workers on the Nechako Plateau, commonly (but not always) oriented parallel to local drumlins and glacial striations in bedrock (Fig. 1-5). Eskers and ice-contact deposits observed during this study are herein described briefly, primarily in relation to underlying glaciolacustrine sediments. This evidence provides support for a subglacial, rather than proglacial, genesis of the silt rhythmites.

5.7.1 North Nechako (locality YY)

A slope failure on the lower part of the Stuart River Complex Esker system is visible behind a trailer court on North Nechako Road (elevation 630 masl). Planar beds of fine beige sand (2 m total thickness) overlie coarse grey sand, and coarsen upwards to coarse grey sand with silt rip-up clasts and bi-directional festoon bedding.

5.7.2 Hart Highlands (locality Y)

A number of small hills on the plateau north of Prince George (elevation 650 masl), part of the Stuart River Complex esker system, are comprised of alternating beds of coarse sand, medium sand, and silt. Some foresets to the northeast are visible in the coarse sand, but most structure is either contorted or massive. These hills occur at a higher elevation than nearby glaciolacustrine sediments, but it is not certain that they contain sediment at a higher stratigraphic level than the silts.

5.7.3 Kolling Road (locality Z)

At the junction with Highway 97, 6 km south of Stoner, the southern end of a small ridge is exposed (elevation 600 masl). The lowest visible unit consists of highly-contorted silts with numerous ball-and-pillow structures intruding into the overlying sand (Fig. 5-21). A medium sand unit above contains a normal fault dipping southwest, which has vertically displaced a silt interbed by almost 1 m. Above this lie 2 cm beds of fine sand, silt, and coarse sand with pebbles and rounded clay ripups, topped by an erosional contact, 3 m of planar sands, and another erosional contact. Above the contact lie contorted silt beds, 3 m of planar-bedded medium sand, with interbeds of fine sand, pebbles or coal-rich sand, and another erosional contact. Above this lies 2 m of fine sand with large ripup inclusions of contorted silt. The uppermost beds consist of alternating laminae of fine and medium sand. These laminae thin upwards from 2 cm to 2 mm in thickness. Limited cross-bedding indicates flow to the west.

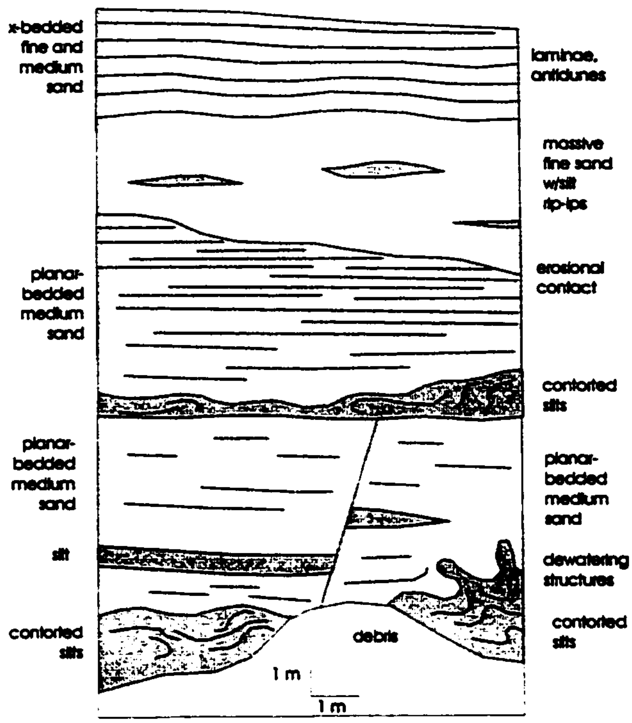


Figure 5-21. Exposed deposit at Kolling Road, locality Z.

5.7.4 Chubb Lake Road (locality ZZ)

South of Hixon and four km west of Highway 97 and locality R, a series of long hills are oriented north-south, parallel with the Fraser River valley (Fig. 5-22, approximately 650 masl). The hills, which were observed but not surveyed, are estimated to be 5 m high, 20 m wide and hundreds of metres long. Composed of sand and gravel, the northernmost hill is an oblong mound being excavated by the owner as a source of road aggregate. The internal structure is chaotic, with cross-bedding, climbing ripples, and faults truncated by internal erosion surfaces. The adjacent fields are comprised of silt, and the slope break at the base of the hills is sharp, consistent with deposition of the sand and gravel in a constrained tunnel channel. Other hills in the area are also being excavated for road aggregate (Fig. 5-21).

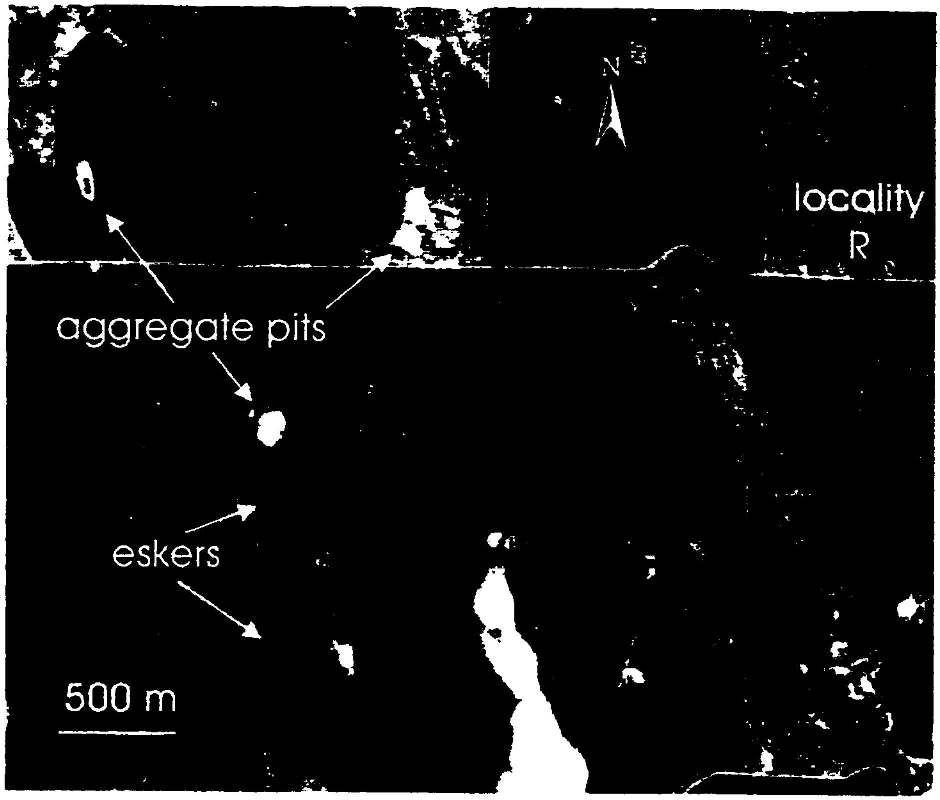


Figure 5-22. Esker deposits and aggregate pits, locality ZZ.
(air photograph BCB960005-172 reproduced with permission of BC Ministry of Environment)

5.7.5 Hixon Townsite

Another potential ice contact site is located 500 m south of locality XX (590 masl). The remnants of an excavated hummock next to a railway track show alternating beds of gravel and sand that have been eroded to a small dome (Fig. 5-23). The dome is draped with massive sand that was eroded preferentially from the east side. Alternating beds of silt and gravel were deposited with a westward dip, similar to foresets. A layer of pebbles lies conformably over the unit, followed by >10 silt rhythmites. Two metres of diamict cap the feature.

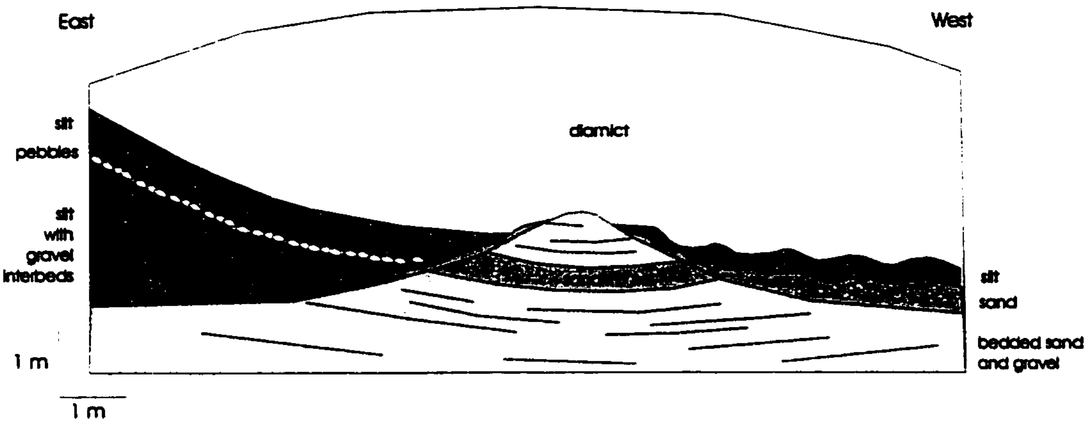


Figure 5-23. Internal sediments of an exposed hummock near locality XX.

5.7.6 Bednesti Compound Esker

This esker west of Prince George begins at the outlet of an erosional channel occupied by Cluculz and Bednesti Lakes and terminates in glaciolacustrine deposits south of the Nechako River (Tipper, 1971b). Leaming and Armstrong (1969) mapped the sediment between the esker and the Nechako River Valley as a sandy outwash plain. Tipper (1971b) mapped the same deposits as pitted terrain. Clague (1998) mapped the esker and associated ice-contact gravel overlying the glaciolacustrine sediments for a distance of 5 km. Their maps support the findings of this study that eskers and ice-contact gravels overlie the glaciolacustrine sediments, corroborating other evidence for a subglacial origin of the glaciolacustrine sediments.

5.8 Interpretation of silt and gravel deposits and drumlins

Gravel deposits 30-40 m thick were found in the lee of topographic highs and in valley bottoms. The Fraser River exposure (locality X) demonstrates significant lateral variability over very short distances; units vary in thickness and in some cases disappear completely; oxidized deposits can appear anywhere in the sequence as thick red beds or thin, discontinuous streaks.

I suggest that stratigraphic evidence for separate glacial events or local readvances (Mathews, 1976; Clague, 1981) is refutable. The lowest Fraser gravels record high-velocity, erosive northeasterly flow. The interbedding of non-oxidized sediments with thin or discontinuous oxidized beds high in the sequence indicates that Pre-Fraser sediments were eroded from nearby and redeposited in a high-energy environment (the greater the distance transported the more dispersed the oxidized sediments would have become). The discontinuities represent highly erosive regional flow events, and the cobble lags above indicate an agent of limited competence, such as water. Dewatering features, such as dykes observed at Quesnel and Hixon, indicate that sediments were deposited so quickly as to be hydraulically unstable, resulting in what Clague (1991) termed 'gravitational foundering'. The inability of porewater to adjust to changing pressures in relatively porous sediments is in keeping with deposition over a period of hours or days, not years or centuries. The presence of diamict in the Quesnel sequence (Clague, 1991) indicates that ice was present during or after deposition of the sequence; the rapid lowering of the ice could account for the deformation of the lower sediments, and may have initiated the dewatering process. The diamict could be late-stage basal meltout, representing brief time intervals in the subglacial deposition of the stratified sediments.

In cross-sections where the lower contact of a glaciolacustrine silt unit was observed, gravel commonly underlies the contact. The prevalence of coarse clasts at the margins of glaciolacustrine deposits was observed at many sites from Hixon north to Williston Lake, but it is suggested that they constitute a previous gravel lag rather than till reworked into a beach as suggested by Tipper (1971b) and Clague (1988). It was found that the drumlinization of silt beds is more prevalent than Tipper (1971b) observed. The surface expression of the contact between silt beds and gravel is vertically and laterally discontinuous: the two units can alternate going up the stoss ends and sides of hills, which is, again, difficult to reconcile with beach wave action.

The upper elevation limit of the glaciolacustrine deposits in the Prince George region was determined by Tipper (1971b) to be 760 masl. It is probable that he mapped this limit based on a limited number of observations, considering his admission that shorelines are indistinct. In fact, the upper elevation limit of Tipper's (1971b) silt unit sometimes rises well above 760 masl (e.g., Pilot Mountain, 5 km north of Prince George, over 800 masl) and more often drops below 760 masl (e.g. Fraser River valley, near Chrysdale, under 650 masl). In this study the thickness of rhythmites at locality W (1.4 m thick, elevation 731 masl) is incongruous with a water column only tens of metres deep. Thick deposits of massive silt at elevations of 806 masl and 830 masl (locality WW) were likely reworked from beds deposited at those elevations or higher. It is clear that further work is required to delineate the true upper limit of the lake basins.

The thickness of individual rhythmite beds is shown to be highly variable between localities. The Cale Creek sediments establish the minimum number of rhythmites couplets as 120 at elevations between 620-635 masl, with the lowest beds 20-25 cm thick. The McMillan Bluffs contain beds up to 1 m thick at elevations between 650-680 masl. The College Heights site (elevation 650 masl) has silt beds up to 30 cm thick within metres of the lower contact. At Strathnever (elevation 680 masl) the lower beds are less than 10 cm thick. Naver Road (elevation 731 masl) is nearby and higher, yet has 1.4 m beds over a contact with diamict. Thus, the thickest beds occur at the highest elevations, which is consistent with a depositional response to local sediment supply and flow conditions in a deep subglacial lacustrine environment, but difficult to explain as a response to a shallowing subaerial lacustrine environment.

Gravel drumlins were found only in low-lying areas of the Nechako and Fraser Plateaus, where local gravel would have been available as pre-glacial valley-bottom fluvial deposits. The drumlins were found to be diamict-cored, overlain by a gravel veneer of variable thickness, in turn partially overlain by silt rhythmite beds. Two of the three gravel drumlins surveyed (localities P and S) include massive slope failures of the poorly consolidated gravel; these features would clearly have been unable to resist the high shear stresses of an active ice sheet. Road exposures show the gravel to be a veneer on many of the drumlins, as confirmed by the commercial excavation of the Vanderhoof drumlin. Silt rhythmites have been preferentially eroded from the stoss end and tops of drumlins to expose gravel, indicating erosive flow to the north and east. Small-wavelength bedforms on the silt plains indicate a turbulent fluid. Deformed silt beds occur at local high points of the drumlins, which is consistent with the temporary concentration of the weight of a falling ice sheet on local topographic high points.

Finally, the existence of eskers, ice-contact deposits and glacial outwash *overlying the silt rhythmites* further supports their formation in a lake *underneath* the ice sheet, rather than in front of it. If the 120 rhythmites at Cale Creek are used as a baseline for the number of beds deposited, then it is evident from other exposures that most of the original silt beds are missing. The thickest remnant deposits were found in topographic lows and hollows that were protected from northeasterly flow. The evidence is consistent with the subglacial erosion of the silts contemporaneous with regional erosion of till and bedrock drumlins.

CHAPTER 6. DISCUSSION, CONCLUSIONS and IMPLICATIONS

6.1 General discussion of findings

A significant achievement of this study was the measurement and modeling of drumlin form over an array of physiographic settings in central British Columbia. Drumlins vary in size, relative relief, elevation and contiguity. Isolated drumlinized bedrock outcrops, such as the Summit Lake crag-and-tails, displayed the highest relative relief. Drumlinized bedrock ridges such as those at Willow Road and Purden Lake preserved numerous low-relief drumlins and sinuous flutings on their lee sides. These features occur in groups, superimposed on the larger ridges, with the smallest drumlin being 10 m long and less than a metre high. Till drumlins displayed a more limited size range, with none observed less than 200 m long. Till and rock drumlins commonly display finely-etched furrows at the base of the stoss end and along the sides. Only on till drumlins were dish-shaped depressions observed on the lee side, and the 'channel' drumlin featured a straight, steep-walled channel on its downflow approach. Gravel/silt drumlins are lower in elevation and relative relief than till or rock drumlins, and have more uneven surfaces. The upvalley orientation of the Montagne drumlin and nearby drumlinized bedrock ridge indicate that the last glacial event to impact this high-elevation environment was the same regional flow that drumlinized the lowlands.

The variability displayed by the landforms does not, in itself, provide definitive evidence for a preferred mode of drumlin genesis. However, their orientation, composition and distribution of surficial sediments provide additional clues. Armstrong and Tipper (1948), Armstrong (1965), Tipper (1971b) and others have observed the remarkable parallelism of drumlins and flutings across topographic features and varying substrates. There is an upper elevation limit beyond which these features are not found, but flow was relatively unhindered by local topographic relief between 650 masl and 1500 masl. The regional continuity of the features led to the logical assumption that they were formed contemporaneously, and the findings of this thesis do not contradict that assumption. However, the supposed genetic agent and process bear further examination.

6.1.1 Bedrock drumlins

Bedrock drumlins have obviously been eroded, as opposed to being deposited or deformed by glacial processes. The shape and size of the inter-drumlin flutings at Tabor Mountain (locality K) indicate a powerful flow vortex radius in the order of 100 m, at an elevation of 1,000 masl. An equally large fluting is evident on top of the Bowron Road limestone ridge (locality D, 800 masl), yet so are drumlins as small as 10 m long, and cm-scale flutings. The formation of turbulent vortices at such small scales attests to the low viscosity of the erosive agent. Kor *et al.* (1991) found erosional bedforms in bedrock resulting from the interaction of local relief and turbulent meltwater flow. The 's-forms' ranged in scale from metres to tens of kilometres; their geometry and distribution provide evidence of flow strength, direction, separation and vorticity. Shaw (1994) discussed the differential erosion of 'hairpin scours' at many scales and in many substrates resulting from bifurcating horseshoe vortices in turbulent fluids. He demonstrated that glacial ice Reynolds numbers are far too small (by 19-25 orders of magnitude, depending on feature scale) for a transition from laminar to turbulent flow. The properties of water, however, at a velocity of 5 m/s, allow turbulent flow and erosive vortices at scales as small as a few mm in diameter (Shaw, 1994).

6.1.2 Bedrock striations and flutings

The relationship between small flutings and striations observed at Tabor Mountain and other high elevation bedrock sites bears further discussion. They have both traditionally been interpreted as subglacial features carved by ice or by clasts embedded in ice, yet in this study they were found to possess distinct morphological characteristics. Flutings occur as rounded linear troughs with smoothed surfaces. If the bedrock surface of the fluting is uneven, cavitation marks can occur downflow of a local depression (Fig. 6-1). Cavitation marks are more commonly found in rock eroded by streams, where flow has separated from and reattached to the bed, and small percussion cavities pock-mark the surface. Another indication of flow direction across uneven surfaces of flutings are smooth stoss ends and rough or 'plucked' lee ends, similar to *roches moutoneés* (Fig. 6-2). Flutings range in diameter from centimetres to kilometres; larger flutings are commonly remarkably straight, while small flutings are often sinuous. Striations are commonly superimposed on bedrock flutings, implying a subglacial origin for both. Only millimetres in diameter, striations occur as parallel, laterally discontinuous scratches; they usually interrupt only a small portion of the original surface, their orientation is highly variable (Armstrong and Tipper, 1948), and they often cross at oblique angles on the same exposure (Fig. 3-14).

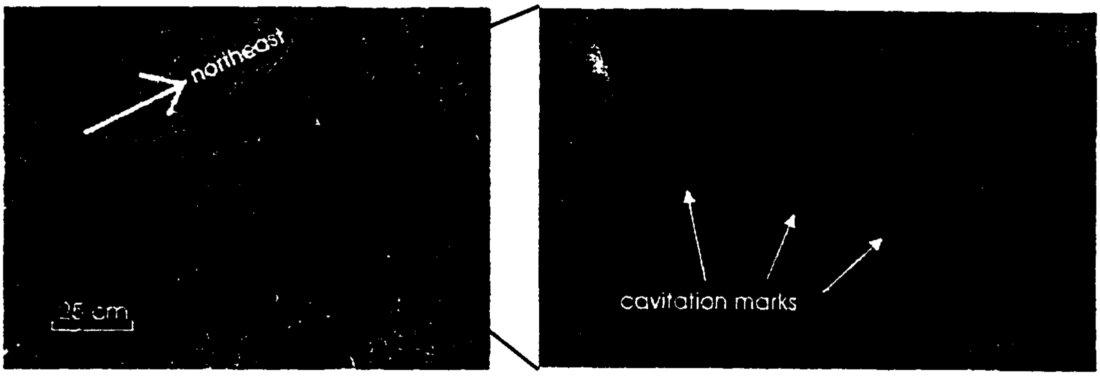


Figure 6-1. Shallow fluting near MacKenzie with cavitation marks (arrow at left points downflow).

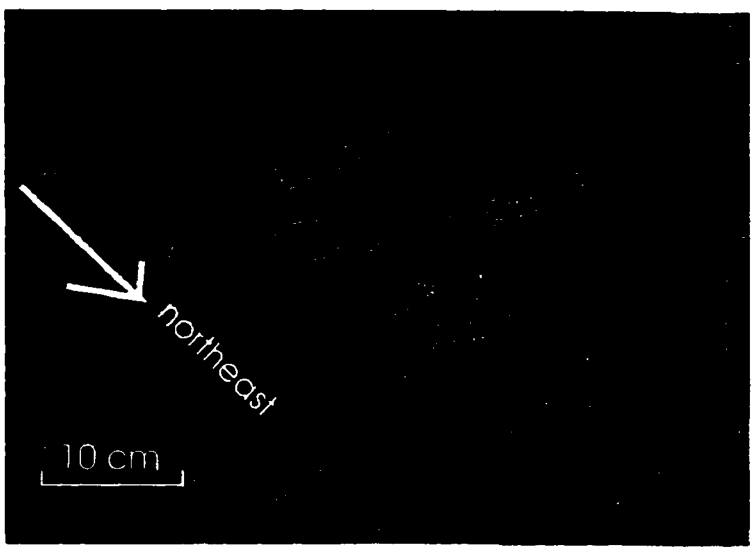


Figure 6-2. Shallow fluting near MacKenzie, with a downflow *roche moutonée* (arrow points downflow).

Some workers have interpreted crossing striations as evidence for multiple glacial advances separated by considerable lengths of time (Tipper, 1971a,b); if this is so, the shallow scratches also attest to the minuscule erosive power of rock-laden ice. There is not a continuum of scale between striations and flutings. Striations are straight, parallel, rarely exceed 2 mm in cross-section, and are uniformly deep along their length, all consistent with being gouged by rock-laden basal ice. Small flutings are sinuous, locally non-parallel, shallow along their length, and are rarely smaller than 2 cm in cross-section, all consistent with erosion by turbulent water. Sinuous flutings in bedrock were found on the highest points of land near Prince George (Tabor lookout, elev. 1250 m) and Vanderhoof (Sinkut Mountain lookout, elev. 1475 m), indicating that erosive water reached those elevations. Kerr (1934) observed channels and eskers on mountainsides high above valley floors in the Omineca Mountains, and Armstrong (1965) found till flutings (which he called groovings) at elevations to 1800 m in the fort. St. James area.

6.1.3 Till drumlins

If the regional till was deposited under a thick ice sheet, whether as lodgement, deformation or melt-out, it is reasonable to assume that the deposition occurred as an extensive sheet with little local across-flow or downflow variability. Glen's Law ($E = A\tau^n$) relates strain rate (E) to the coefficient of hardness (A) and shear stress (τ). The shear stress (τ) at the base of the ice sheet can be described as $\tau = pgh \sin \alpha$, where p = ice density, g = gravity, h = ice thickness and α = ice surface slope. The shear stress regime is thus primarily controlled by ice thickness and surface slope, and the strain rate is unlikely to change significantly with minor changes in bed topography. However, the drumlins and flutings display significant changes in relief over tens of metres, which is incongruous with erosion by the basal laminar flow of an ice sheet. The landforms are more likely to represent the response of the diamict to a locally turbulent erosion agent such as meltwater. Stokes' Law relates the drag of an object to the speed of the flow, the viscosity of the fluid and the size of the object. Ice sheets are highly viscous and highly competent (capable of transporting very large masses of rock and sediment). The distribution of boulders on the stoss ends of drumlins and in channels, and the common presence of a cobble lag near the surface attests to an erosion agent of limited competence, such as water.

The compacted till on top of the two penetrometry-tested drumlins (and other compacted hills observed while digging) provides evidence that the landforms were altered by compaction or erosion. If the weight of the overlying ice sheet was concentrated on the top of the features for a short period of time, either the ice was uplifted and let down or the intervening lows were eroded very quickly. In either case, the subglacial hydrological conditions require a steep hydrostatic pressure gradient and high-velocity, turbulent meltwater flow. There is ample evidence that subglacial water played a role in etching small-scale and large-scale scours at many localities. The bifurcating scours at the lee end of the western Stone Creek drumlin and the stoss end of the Channel drumlin (locality G) indicate erosion by a turbulent, low-viscosity fluid capable of splitting into multiple vortices over distances of 100 m or less.

Kor *et. al.* (1991) described a broad suite of bedform erosional marks arising from high-angle or vertical flow structures. Muschelbrüche are mussel-shaped depressions with sharp upflow rims and shallower downflow margins. The circular scour in the lee end of the locality G drumlin (Figs. 4-23, 6-4) indicates erosion in a backflow environment that was not vertically constrained. Similar, but smaller, depressions were also observed at the lee ends of drumlins at localities H and I. These depressions are interpreted as incomplete erosional forms initiated after the main drumlins were formed, based on their relative shallowness. They are attributed to the erosive action of a meltwater flow vortex resulting from reconnection with the substrate following flow separation, or as a backflow eddy, or in combination with expanding horseshoe vortices along the sides of the drumlin (Fig. 6-3). The circular lee side scour at locality G is both broader and deeper than the scours along the drumlin sides, indicating a flow vortex 200 m wide. The shallow walls of the scour are consistent with turbulent, erosive flow that continued vertically, unobstructed by ice, for at least tens, if not hundreds of metres.

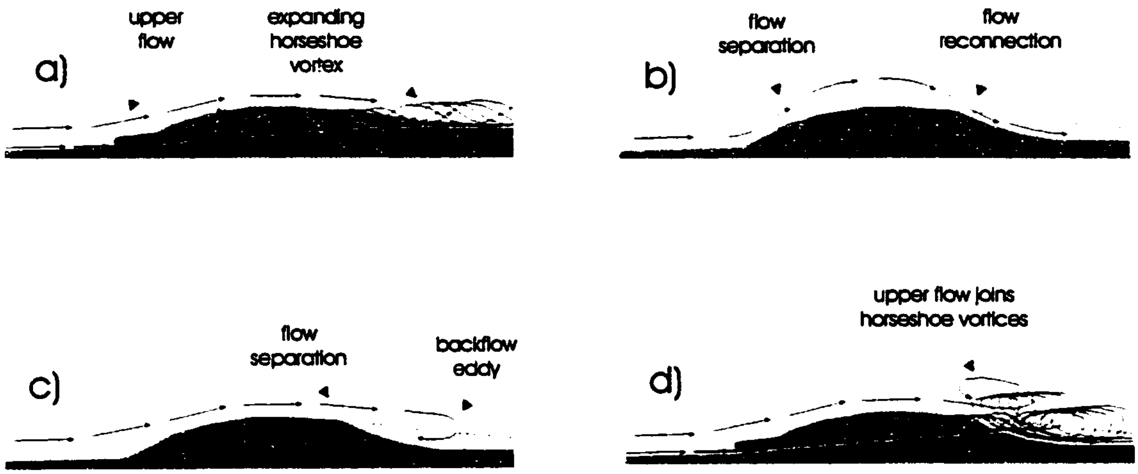


Figure 6-3. Hypothetical (a) development of Channel drumlin, and erosion of lee side depression by (b) upper flow separation and reconnection, (c) back-eddy erosion, or (d) a complex horizontal or vertical vortex.

Other workers have described depressions formed on the lee side of a sinusoidal surface by glacier flow. Röthlisberger and Iken (1981) and Kamb (1987) postulated that decreased effective pressure in a subglacial water-filled lee-side cavity resulted in the 'plucking' of the substrate (bedrock), resulting in steps or troughs oriented transverse to ice flow. Dardis and Hanvey (1994) invoked similar processes to explain 'wave cavities' on the lee side of soft-sediment drumlins. They found roughly stepped transverse features (roches moutonées) and smooth, rounded conduits parallel with ice flow. However, none of the features was bowl-shaped, or as round as the 'channel' drumlin scour.

6.1.4 High elevation diamict

The Montagne drumlin (locality J, 1050 masl) and drumlinized ridge (1200 masl) are of interest for a number of reasons. The occurrence of clay rhythmites just below the surface indicates that still water was trapped in the valley for a considerable length of time after the diamict drumlin formed. The stoss end of the drumlin faces down-valley, indicating up-valley flow; the dip and preferred orientation of the diamict fabrics indicate deposition by up-valley flow. The diamict beneath the clay is almost exclusively locally derived angular shale and schist, except for a lag of subrounded granite and quartzite cobbles and boulders (Fig. 6-4). This lag contains only larger clasts, with none of the smaller fraction that would be expected from basal meltout deposition. Holocene fluvial erosion of the finer fraction is highly unlikely, considering the overlying clay. The upvalley orientation of these features precludes their formation by late-stage montagne ice, which would have flowed downvalley. The cobble/boulder lag attests to subglacial water driven by a hydrostatic head sufficient to erode landforms at 1200 masl elevation. The draped clay is evidence that, at some point, deep, still water filled this high valley for an extended period of time. The conclusion is that the drumlin and ridge were eroded from *in situ* sediments by an agent of limited competence (water) flowing upvalley, depositing a lag of cobbles from the plateau as flow waned. The subsequent effect on the landform by late-stage valley ice flowing downslope has been minimal.

Figure 6-4. Near-surface igneous and metamorphic cobbles and boulders, locality J.

6.1.5 Regional diamict

A regional argument that drumlin form and composition were genetically distinct is based on the observation that till fabrics are locally variable but regionally consistent. In a transect from Hixon north to Williston Lake, fabrics indicate that ice flowed north into the Rocky Mountain Trench and took a sharp turn eastward into the Peace River Valley. Fabrics in the trench trend parallel to it, corroborating the findings of Matthews (1976). Topography of the Rocky Mountains apparently limited the eastward flow of the ice sheet from central British Columbia.

However, drumlins cross-cut the trench into the west side of the Rocky Mountains, as mapped by Tipper (1971b), and exit the Rocky Mountains on the east side, as mapped by Rutter (1976, 1977). Their orientations on the Nechako Plateau also commonly diverge significantly from local fabric orientations, as observed in the Summit Lake crag-and-tail and Stone Creek drumlins, and this disparity occurs often enough to refute a depositional or deformational genesis. The marked difference between northern and southern Stone Creek fabric orientations, and the exposure of gravel interbeds in the easternmost Stone Creek drumlin, are evidence that those sediments were deposited at different times and by distinctly separate processes, perhaps as a combination of lodgement, meltout and subglacial meltwater flow processes. The drumlinized surface has exposed these sediments unevenly, depending on the degree to which they have been eroded. The question remains as to where and how these eroded sediments were transported and redeposited. The volume of sediment is large, yet there are no significant Fraser moraines have been mapped in central British Columbia. If ice was responsible for the erosion, then it would be reasonable to expect significant till deposits downflow of the plateau region in the Rocky Mountain Trench. Instead, numerous exposures along Highway 16 in the trench display little or no diamict over an undulating bedrock surface (Fig. 6-5).

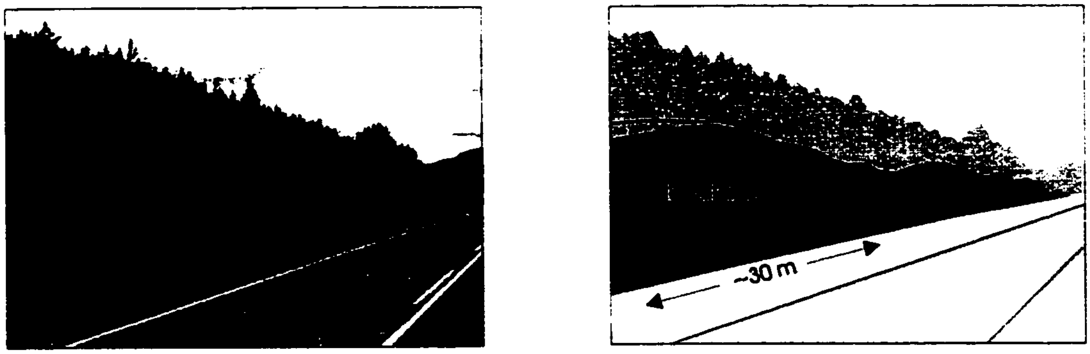


Figure 6-5. Eroded bedrock surface, looking southeast, Highway 16 near locality D.

Evidence of voluminous meltwater flow exists east of the trench. Tipper (1971b), Mathews (1976, 1980) and Rutter (1977) mapped drumlins and flutings in a number of small Rocky Mountain valleys, indicating northeast flow at elevations of 1500 masl. Mathews (1976) interpreted the "Portage Moraine' in the Peace River Valley as deltaic sediments deposited in standing water at a minimum elevation of 855 masl, and also noted silt deposits above the moraine on Bull Mountain at an elevation of 949 masl. He suggested that lake drainage partially eroded the moraine before being 'diverted' to erode the Peace River Canyon. It is here agreed that the 'moraine' may well represent a subaqueous deposit of some of the eroded sediment from central British Columbia. However, it is suggested that the Peace River Canyon could not have been eroded by the overflow drainage of the lake trapped behind the Peace River Moraine, as the elevation of the delta deposit's upper limit is below that of the canyon. The steep-sided, narrow cross-section of the bedrock canyon attests to rapid downcutting by water under pressure (Fig. 6-6). The inclusion of suspended sediments would have enhanced the erosive capability of the flow, similar to sandblasting. A sudden and overwhelming surge of meltwater, constrained from above by ice, could have provided the hydraulic head necessary to drive erosive flow through the higher valleys to accomplished this work. If this was the case, it provides evidence that the regional flood was a response to a sudden influx of meltwater, rather than a sudden decrease in hydraulic pressure at the outlet(s) on the east side of the Rocky Mountains.

Figure 6-6. The Peace River Canyon, near the Peace Canyon Dam.

6.1.5 Fraser gravel

Thick sequences of silt, sand, gravel and diamict in central British Columbia have been interpreted as evidence for multiple advances by Kerr (1934), Mathews (1976) and Clague (1981). Massive red gravel at the base of many exposures has been interpreted as oxidized pre-Fraser deposits (Kerr, 1934; Clague, 1988). Clague (1988) interpreted a 200 m Quesnel sequence of gravel, silt, and diamict as a record of preglacial debris flow, distal advance, proximal advance, active ice deformation, stagnant meltout, and retreat stages. Clague (1991) interpreted an 80 m Quesnel sequence of stratified deposits as early-Wisconsinan on the basis of internal deformation, two overlying erosional unconformities and a diamict unit. He attributed vertical dykes cutting through the sequence to porewater expulsion. A similar dyke 3-4 m in width, visible in a near-surface exposure at Hixon Creek (locality XX), provides evidence that porewater expulsion occurred in Fraser Glaciation sediments. Exposures at two other Hixon sites show two erosional unconformities in the stratified sediments, overlain by more stratified sediments and a thin diamict unit. The College Heights gravel pit (locality U) also displays two erosional unconformities separating stratified sediments. The lowest beds (above the oxidized pre-Fraser deposits) are coarse gravels with large sand rip-up clasts, and the lower erosional unconformity is 20-30 m in wavelength. According to the pit owner's observations of sediments he removed, huge clay rip-ups were also transported from the west. The structure and grain size of these sediments indicate a highly energetic erosional/depositional flow on a massive scale, more intense than glacial outwash flow and more stratified than a debris flow. The two erosional unconformities and finer stratified sediments observed by Clague (1991) in Quesnel are evident at both localities, but the intervening diamict unit is not. He noted that the stratified sequences he was interpreting as preglacial and late glacial differed only in their degree of deformation. Similarly, Mathews (1976) interpreted four sequences of diamict separated by stratified gravel units as evidence for four advances, but noted that the diamicts were virtually indistinguishable. The interbedded gravel and diamict sequences more likely record alternating late-stage meltout periods and subglacial flood events. The paleodirections in gravels above the regional unconformities indicate northeastward flow, into the Rocky Mountains.

6.1.6 Glaciolacustrine Sediments

Armstrong and Tipper (1948) observed upper limits of stratified sand, silt and clay deposits from 790 m elevation at Fort St. James to 760 m elevation at Prince George, also noting that sediments fine eastward. Their evidence for shorelines in the Fort St. James basin included a prevalence of coarser clasts (pebbles to boulders) in the clay and silt beds near the margins, which they attributed to reworked till. Armstrong and Tipper (1948) noted, but did not explain, the absence of glaciolacustrine sediments from till drumlin 'islands' in the basin, with anomalously sharp contacts at the base of the drumlins. Tipper (1963) observed that upper glaciolacustrine deposits in the Vanderhoof basin are distorted, pebble-rich and grooved. Tipper (1971) revised his earlier interpretation of those deposits, attributing their drumlinization and deformation of the upper silt beds to a late readvance. He reduced the extent of 'well-developed shorelines' to a small region between Tabor and Prince George.

A few commonalities observed in the present study are worth reviewing:

1. where the underlying contact is visible, it is erosional and undulatory, over gravel or diamict, with a cobble lag; wavelengths of the erosional surface range from 2m to 100 m;
2. an irregular sequence of thin, deformed and cross-bedded fine sediments precedes the rhythmites; thin clay or sand interbeds with rip-up clasts appear intermittently higher in the sequence;
3. foresets, climbing ripples and cross-bedding show northeastward paleocurrents, confirming Tipper's (1971) observation of eastward-fining sediment towards the Peace River Valley;
4. surface rhythmites are truncated by an undulatory erosional surface at wavelengths of 10-100 m; surface beds show no indication of significant Holocene erosion; eroded silt beds are sometimes overlain by thin diamict units or small eskers.

The general absence of faulting is evidence that the lacustrine sediments were not deposited supraglacially and let down during meltout. The occurrence of overlying diamict and esker deposits is further evidence that the deposition and erosion of the rhythmites was subglacial. The Naver Road deposits revise the upper limit of silt deposits to at least 830 masl, and their thickness suggests a deep, ice-blocked water column. The cobble lag at locality J provides evidence that water was flowing at an elevation of 1200 masl, and clay deposits were found at an elevation of 1050 masl at the same site. It is concluded that subglacial water reached elevations greater than 1000 masl for a period of time sufficient to deposit the silt beds, and that eventual northeast drainage of this pressurized reservoir eroded the upper beds from all but a few protected areas. The duration of rhythmite deposition is not resolved – climbing ripples in the sands and silts indicate relatively rapid sedimentation (Allen, 1970) but the clay laminae represent unknown, perhaps seasonal, periods of negligible flow.

Thus, there is evidence that the Fraser Glaciation ice sheet deposited thick till over much of central British Columbia. There is also evidence that a regional erosion event removed much of the till and redeposited gravel in a few protected, low-lying areas. The absence of significant moraines in the Cordillera supports the hypothesis that most of the mobilized sediment was carried in suspension, to be deposited far beyond glacial limits, in accordance with Mathews (1976) view of the Peace River moraine as a delta. There is evidence that the study area glaciolacustrine beds were deposited over the gravels, which were partially removed by a second regional erosion event, explaining Armstrong and Tipper's (1948) lacustrine 'islands' and Tipper's (1971) drumlinized lake sediments. Armstrong and Tipper's (1948) gravel 'beaches' may simply represent the predominant local sediment in low-lying areas prior to, and just beyond the limits of, lacustrine deposition. Tipper's (1971) 750 masl upper limit of glaciolacustrine deposits in the Prince George area is shown to be only a general limit, as massive silts at higher elevations are evidence of much deeper water. The inclusion of gravel-silt drumlins in the regional suite of drumlinized landforms has shed new light on the glacial history of central British Columbia.

Datable deposits from the retreat of the Laurentide Ice Sheet have established that deglaciation in central Canada progressed at a very rapid rate (Young *et al.* 1994). It is reasonable to assume that the Cordilleran Ice Sheet, responding to similar climate conditions, also underwent rapid melting, trapping large volumes of water in the topographically constricted and ice-choked lowland between the Coast and Rocky Mountains. The plausibility of subglacial meltwater frequently scouring the landscape under high pressure and at high velocity is no more fantastic than the prospect of glacial readvances during a time of rapid regional deglaciation.

6.2 Conclusions

This survey of drumlin form and composition has demonstrated that Prince George drumlins are more variable in composition than in form. Exposures have shown that the drumlinized surface is not conformable with internal sedimentary structures; gravel, sand and silt beds are truncated at the surface. Bedrock, till and stratified sediment have all been eroded by regional flow to the northeast. The parallelism of the drumlins noted by Armstrong and Tipper (1948) and Tipper (1971) attests to the regional scale of the flow, and their interpretation of an ice sheet genesis was in accord with long-held assumptions about linear features recording the direction of glacial flow. The interpretations by Mathews (1976), Rutter (1977), Clague (1988) and others of the central British Columbia sedimentary record have been, likewise, based on assumptions that widespread waterlain sediments were deposited in subaerial, and not subglacial environments. However, the observations in this study of diamict-interbedded gravels and deformed silts are more in accord with erosion, deposition and compaction under an ice sheet intermittently rising and falling in response to fluctuating hydraulic pressures.

There is strong evidence for a subglacial erosional genesis of the drumlins. Bedrock drumlins are obviously erosional remnants. Tunnel channels superimposed on till drumlins attest to their subglacial origin, and the discordance between till fabrics and drumlin orientation precludes an ice-depositional or ice-deformational genesis. Stratified glaciofluvial sediments include two internal regional erosional discontinuities, their upper surface is terminated by a third, and overlying glaciolacustrine sediments have been eroded by a fourth.

The evidence for sediment-laden, subglacial meltwater sheet flow as the erosion agent is equally compelling. Regional discontinuities and dewatering structures in the gravels are consistent with pulsating sheet flow and rapid deposition; the drumlinization of glaciolacustrine deposits in both the Vanderhoof and Prince George basins, and the undisturbed nature of the remaining beds, makes erosion by active ice highly unlikely. The occurrence of small-diameter, sinuous, bifurcating flutings and lee-side eroded bowls indicates a turbulent, low-viscosity fluid. The presence of a cobble and boulder lag in all environments attests to a transport agent of limited competence, which rules out an ice sheet. The partial erosion of poorly-consolidated gravel features indicates a flow of limited force and duration, again precluding the ice sheet as the agent. The direction of the erosive flow is the same direction indicated by flow structures in the glaciofluvial and glaciolacustrine sediments, consistent with a unidirectional waxing (erosional) and waning (depositional) flow. The glaciolacustrine sediments comprise part of the eroded surface, and they are superimposed by eskers, so the ice sheet was still present when they formed and were eroded. Thus, the hypothesis that subglacial meltwater eroded the

Fraser Glaciation landforms in central British Columbia is supported by the evidence collected in this study, and is in accord with observations from previous work.

6.3 Implications

A large volume of Cordilleran meltwater evidently flowed rapidly eastward through the Rocky Mountains towards a lower-pressure regime under or over the Laurentide Ice Sheet. The regional nature of the flow, and multiple apparent outlets, indicate a dramatic increase in pressure at the meltwater source west of the central British Columbia study area. Glacial lineations in the rest of the Cordillera indicate that great volumes of water flowed from northern British Columbia to the Yukon and from south-central British Columbia into Washington, where the erosive effects of meltwater sheet flow are dramatically evident in the Scablands (Baker, 1978, Shaw, *et. al.*, 1999). The sudden influx of sediment-laden fresh water to ocean reservoirs will have affected Late Wisconsinan seafloor sedimentation and sea surface temperatures, with impacts for climate change modeling.

Tipper (1971) took great pains to map and differentiate disparate drumlin groupings as products of separate glacial stages or advances. Mathews (1976), Clague (1988) and others have interpreted interbedded till and glaciolacustrine sediments as evidence for multiple glaciations. This study supplements the wealth of information provided by their work, and the meltwater erosion model provides an elegant explanation for aspects of drumlin morphology and composition that are difficult to reconcile with an ice-deposition or deformation genesis. Shaw (1999) has demonstrated that transverse Rogen features can be eroded by subglacial meltwater flow; Munro and Shaw (1997) and Munro-Stasiuk (1999) have shown that the genesis of some hummocky terrain is erosional. The possibility of a meltwater origin for entire suites of glacial landforms elsewhere in the world must be considered and factored into ice sheet reconstruction models.

The questions remaining are not whether meltwater eroded the drumlins but when, how often and from what sources. The timing must have been late glacial, as the landforms themselves show no evidence of active ice deformation. Drumlin orientations indicate a meltwater source to the west in the Coast Mountains, and regional sedimentary discontinuities indicate multiple flood events. Further stratigraphic work is necessary to establish sedimentary correlations with southern and northern parts of the Cordillera. Remotely sensed imagery will soon provide a platform for regional mapping of surface features at high resolution, and for quantification of relationships between landform, elevation, slope, surface roughness and other attributes to further test the meltwater model. A new synthesis of the evidence is called for, and the seed of this synthesis has been planted and persistently nurtured by proponents of the meltwater flood hypothesis. The weight of evidence from this study clearly falls in their favour.

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APPENDIX A: Sediment data

The following pages include sediment data for samples sites mentioned in the thesis. Each site was sampled for grain size, clast fabric orientation, or both. GPS locations and elevations are provided where available. Sediment was processed for grain size according to Catto (1987). Grain size percentage and accompanying graph refer to the complete sample, while roundness refers to granules between –2 and –1 phi. 'Other notes' generally refer to laboratory observations of lithology or roundness of larger clasts. Fabric orientations are graphically presented as unidirectional roses and Schmidt equal area stereonets. Field notes are variable in content, but were included for completeness.

sample #	1	northing	5940390	easting	526053
field ID	a1	collected	13/6/97	elevation (masl)	802

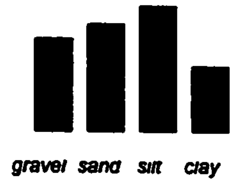
sieved

Phi	%
<-2	18
-2 to -1	5.6
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

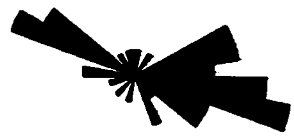
Phi	%
<3.6	29
3.6-4.0	7
4.0-4.5	3
4.5-5	6
5.0-5.6	5
5.6-6.2	5
6.1-6.4	4
6.4-6.9	2
6.9-7.3	6
7.3-7.6	4
7.6-7.8	2
7.8-8.3	3
8.8-8.8	2
8.8-9.6	4
>9.6	18

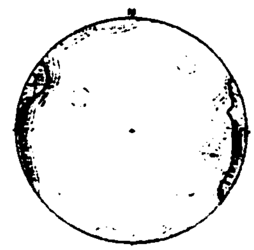
grain size	%
gravel	24
sand	27
silt	32
clay	17



clast roundness subangular to angular
other notes some shale

fabric, n= 51
mean azimuth 108
mean plunge 1
eigenvalue, S 0,73
S2 0.22
S3 0.04





field notes angular shale cobbles point downhill
middle Stone Creek drumlins

---

sample #	2	northing	5940399	easting	526027
field ID	a2	collected	13/6/97	elevation (masl)	812

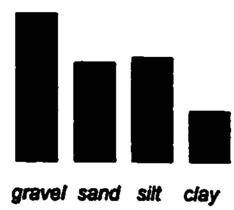
sieved

Phi	%
<-2	25
-2 to -1	12
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

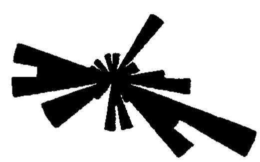
Phi	%
<3.6	29
3.6-4.0	10
4.0-4.5	5
4.5-5	2
5.0-5.6	9
5.6-6.2	7
6.1-6.4	5
6.4-6.9	4
6.9-7.3	2
7.3-7.6	2
7.6-7.8	3
7.8-8.3	1
8.8-8.8	1
8.8-9.6	2
>9.6	18

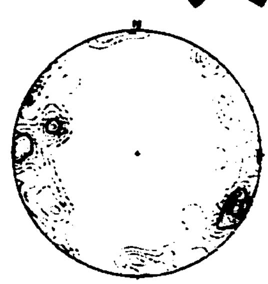
grain size	%
gravel	37
sand	25
silt	26
clay	13



clast roundness subangular
other notes some angular large clasts

fabric, n= 51
mean azimuth 287
mean plunge 3
eigenvalue, S 0.62
S2 0.31
S3 0.07





field notes 7.5YR 5/4
middle Stone Creek drumlins

sample # 3 | field ID a3 | northing 5940398 | collected 13/6/97 | easting 525950 | elevation (m) 810

sieved

Phi	%
<-2	40
-2 to -1	2.8
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

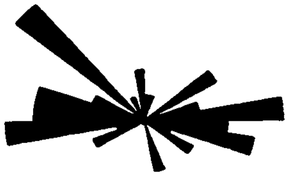
Phi	%
<3.6	23
3.6-4.0	9
4.0-4.5	3
4.5-5	6
5.0-5.6	8
5.6-6.2	5
6.1-6.4	4
6.4-6.9	6
6.9-7.3	4
7.3-7.6	3
7.6-7.8	1
7.8-8.3	4
8.8-8.8	1
8.8-9.6	4
>9.6	19

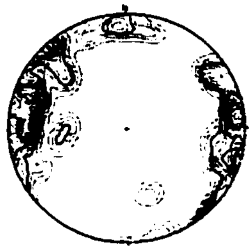
grain size

	%
gravel	43
sand	18
silt	26
clay	13

clast roundness subangular
other notes some angular large clasts

fabric, n= 51
mean azimuth 281
mean plunge 4
eigenvalue, S1 0.71
S2 0.22
S3 0.07





field notes 2.5Y 5/3
middle Stone Creek drumlins

---

sample # 4 | field ID a4 | northing 5940364 | collected 13/6/97 | easting 525998 | elevation (m) 814

sieved

Phi	%
<-2	25
-2 to -1	12
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

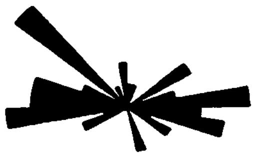
Phi	%
<3.6	27
3.6-4.0	6
4.0-4.5	3
4.5-5	7
5.0-5.6	4
5.6-6.2	4
6.1-6.4	4
6.4-6.9	6
6.9-7.3	4
7.3-7.6	3
7.6-7.8	2
7.8-8.3	3
8.8-8.8	3
8.8-9.6	3
>9.6	21

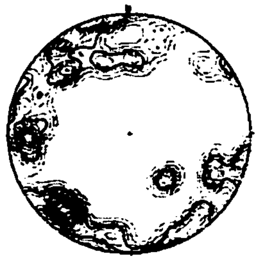
grain size

	%
gravel	37
sand	21
silt	27
clay	15

clast roundness subangular
other notes some rounded large clasts

fabric, n= 51
mean azimuth 332
mean plunge 3
eigenvalue, S1 0.51
S2 0.38
S3 0.11





field notes 2.5Y 5/3, siltstone, quartzite, quartz,
feldspar, fissile shale
middle Stone Creek drumlins

sample # 5 | northing 5940312 | easting 526004
field ID a5 | collected 17/6/97 | elevation (masl) 799

sieved

Phi	%
<-2	25
-2 to -1	12
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

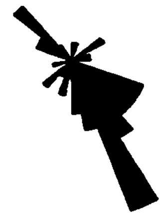
hydrometry

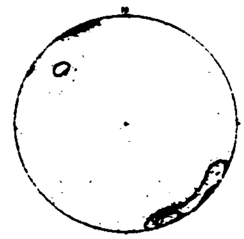
Phi	%
<3.6	23
3.6-4.0	8
4.0-4.5	4
4.5-5	3
5.0-5.6	3
5.6-6.2	6
6.1-6.4	2
6.4-6.9	5
6.9-7.3	3
7.3-7.6	3
7.6-7.8	1
7.8-8.3	4
8.8-8.8	4
8.8-9.6	3
>9.6	28

grain size	%
gravel	37
sand	20
silt	24
clay	20

clast roundness subangular
other notes

fabric, n= 57
mean azimuth 147
mean plunge 5
eigenvalue, S1 0.66
S2 0.23
S3 0.12





field notes 2.5Y 4/2, cobble layer at 40 cm
middle Stone Creek drumlins

---

sample # 6 | northing 5940486 | easting 526065
field ID a6 | collected 15/6/97 | elevation (masl) 811

sieved

Phi	%
<-2	37
-2 to -1	7.2
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

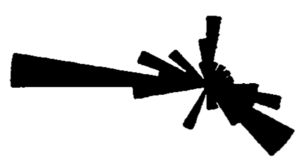
hydrometry

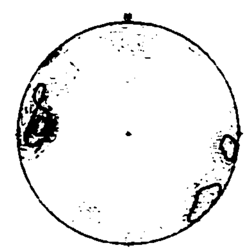
Phi	%
<3.6	38
3.6-4.0	8
4.0-4.5	2
4.5-5	2
5.0-5.6	6
5.6-6.2	9
6.1-6.4	2
6.4-6.9	4
6.9-7.3	4
7.3-7.6	3
7.6-7.8	2
7.8-8.3	3
8.8-8.8	3
8.8-9.6	4
>9.6	10

grain size	%
gravel	44
sand	26
silt	22
clay	8

clast roundness subangular
other notes dark colour

fabric, n= 51
mean azimuth 296
mean plunge 5
eigenvalue, S1 0.66
S2 0.27
S3 0.07





field notes 2.5Y 4/3, unconsolidated, cobble layer of granite & siltstone at 20 cm, some fissile shale
middle Stone Creek drumlins

sample #	7	northing	5940491	easting	526035
field ID	a7	collected	15/6/97	elevation (masl)	817

sieved Phi	%
<-2	60
-2 to -1	5.6
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

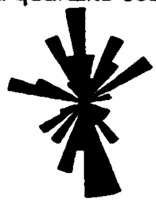
hydrometry Phi	%
<3.6	28
3.6-4.0	6
4.0-4.5	4
4.5-5	6
5.0-5.6	6
5.6-6.2	8
6.1-6.4	5
6.4-6.9	5
6.9-7.3	6
7.3-7.6	2
7.6-7.8	2
7.8-8.3	3
8.8-8.8	2
8.8-9.6	3
>9.6	14

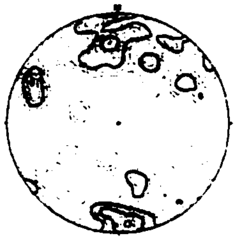
grain size	%
gravel	65
sand	12
silt	17
clay	6

clast roundness subangular

other notes shale & quartzite
s/a quartzite cobble

fabric, n= 51
mean azimuth 358
mean plunge 5
eigenvalue, S1 0.56
S2 0.25
S3 0.19





field notes 2.5Y
middle Stone Creek drumlins

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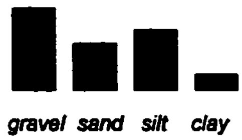
sample #	8	northing	5940518	easting	525999
field ID	a8	collected	15/6/97	elevation (masl)	814

sieved Phi	%
<-2	30
-2 to -1	10
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry Phi	%
<3.6	34
3.6-4.0	4
4.0-4.5	4
4.5-5	6
5.0-5.6	7
5.6-6.2	5
6.1-6.4	3
6.4-6.9	7
6.9-7.3	5
7.3-7.6	2
7.6-7.8	2
7.8-8.3	4
8.8-8.8	4
8.8-9.6	4
>9.6	9

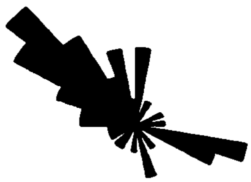
grain size	%
gravel	40
sand	23
silt	29
clay	8

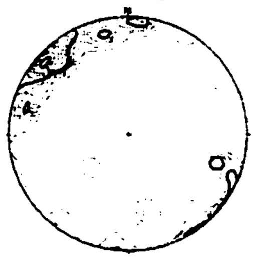


clast roundness angular to subangular

other notes light colour

fabric, n= 50
mean azimuth 313
mean plunge 3
eigenvalue, S1 0.67
S2 0.26
S3 0.07





field notes 2.5Y 5/3, mudstone, long shale clasts at 310 degrees,
cobble layer at 20 cm
siltstone at 20 cm, some fissile shale
middle Stone Creek drumlins

sample # 9 | northing 5940670 | easting 526041
field ID a9 | collected 15/6/97 | elevation (masl) 805

sieved

Phi	%
<-2	31
-2 to -1	5.9
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

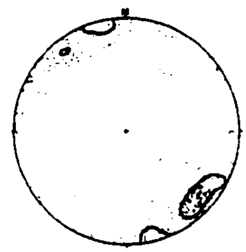
hydrometry

Phi	%
<3.6	29
3.6-4.0	7
4.0-4.5	3
4.5-5	5
5.0-5.6	5
5.6-6.2	6
6.1-6.4	3
6.4-6.9	3
6.9-7.3	5
7.3-7.6	3
7.6-7.8	2
7.8-8.3	4
8.8-8.8	2
8.8-9.6	3
>9.6	20

grain size	%
gravel	37
sand	23
silt	26
clay	15

clast roundness subangular
other notes some rounded large clasts

fabric, n= 50
mean azimuth 142
mean plunge 9
eigenvalue, S1 0.70
S2 0.21
S3 0.09



field notes 2.5Y 5/3, cobble layer at 20 cm
middle Stone Creek drumlins

---

sample # 10 | northing 5940669 | easting 526075
field ID a10 | collected 15/6/97 | elevation (masl) 807

sieved

Phi	%
<-2	51
-2 to -1	8
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

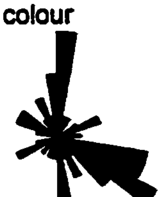
hydrometry

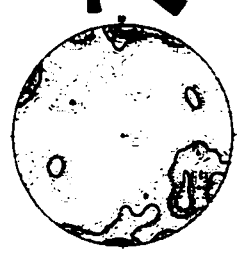
Phi	%
<3.6	32
3.6-4.0	8
4.0-4.5	7
4.5-5	5
5.0-5.6	7
5.6-6.2	7
6.1-6.4	4
6.4-6.9	4
6.9-7.3	5
7.3-7.6	1
7.6-7.8	2
7.8-8.3	3
8.8-8.8	2
8.8-9.6	4
>9.6	9

grain size	%
gravel	59
sand	17
silt	19
clay	5

clast roundness subangular
other notes some angular large clasts, light colour

fabric, n= 52
mean azimuth 146
mean plunge 11
eigenvalue, S1 0.55
S2 0.30
S3 0.15





field notes 2.5Y 5/1, grey colour, cobble layer at 20 cm
middle Stone Creek drumlins

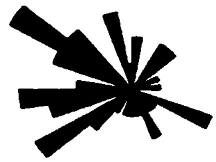
sample # 11 northing 5940660 easting 526111
field ID a11 collected 17/6/97 elevation (masl) 805

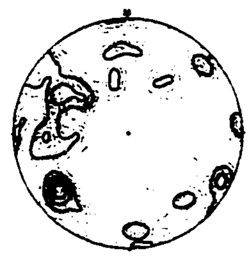
sieved Phi	%	**hydrometry** Phi	%
<-2	16	<3.6	29
-2 to -1	6.5	3.6-4.0	12
-1 to 0		4.0-4.5	3
0 - 1		4.5-5	3
1 - 2		5.0-5.6	6
2 - 3		5.6-6.2	6
3 - 4		6.1-6.4	2
>4		6.4-6.9	4
		6.9-7.3	6
		7.3-7.6	3
		7.6-7.8	1
		7.8-8.3	4
		8.8-8.8	1
		8.8-9.6	3
		>9.6	17

grain size	%
gravel	22
sand	32
silt	30
clay	16

clast roundness
other notes

fabric, n= 51
mean azimuth 290
mean plunge 21
eigenvalue, S1 0.49
S2 0.33
S3 0.18





field notes cobble layer at 40 cm
middle Stone Creek drumlins

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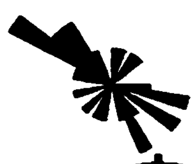
sample # 12 northing 5940664 easting 525998
field ID a12 collected 17/6/97 elevation (masl) 797

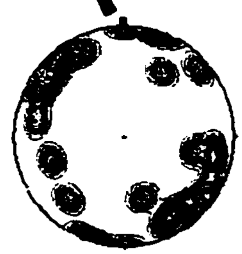
sieved Phi	%	**hydrometry** Phi	%
<-2	43	<3.6	32
-2 to -1	11	3.6-4.0	7
-1 to 0		4.0-4.5	3
0 - 1		4.5-5	3
1 - 2		5.0-5.6	8
2 - 3		5.6-6.2	6
3 - 4		6.1-6.4	2
>4		6.4-6.9	4
		6.9-7.3	7
		7.3-7.6	2
		7.6-7.8	1
		7.8-8.3	3
		8.8-8.8	3
		8.8-9.6	4
		>9.6	15

grain size	%
gravel	54
sand	18
silt	19
clay	9

clast roundness subangular
other notes some shale
light colour

fabric, n=
mean azimuth 304
mean plunge 5
eigenvalue, S1 0.5
S2
S3





field notes pebble layer at 20 cm, cobble layer at 40 cm
middle Stone Creek drumlins

sample #	13	northing	5940638	easting	526207
field ID	a13	collected	17/6/97	elevation (masl)	811

sieved

Phi	%
<-2	21
-2 to -1	7.4
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

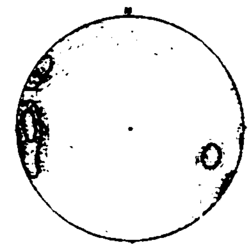
hydrometry

Phi	%
<3.6	23
3.6-4.0	9
4.0-4.5	5
4.5-5	7
5.0-5.6	5
5.6-6.2	6
6.1-6.4	4
6.4-6.9	4
6.9-7.3	6
7.3-7.6	2
7.6-7.8	3
7.8-8.3	3
8.8-8.8	2
8.8-9.6	3
>9.6	18

grain size	%
gravel	29
sand	23
silt	34
clay	15

clast roundness subangular to subrounded
other notes some angular large clasts

fabric, n= 51
mean azimuth 284
mean plunge 2.2
eigenvalue, S1 0.71
S2 0.22
S3 0.07



field notes
cobble layer at 55 cm
long cobbles point 220 degrees
middle Stone Creek drumlins

---

sample #	14	northing	5940589	easting	526500
field ID	a14	collected	17/6/97	elevation (masl)	837

sieved

Phi	%
<-2	31
-2 to -1	11
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

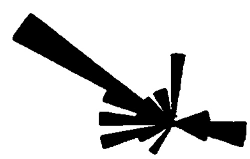
hydrometry

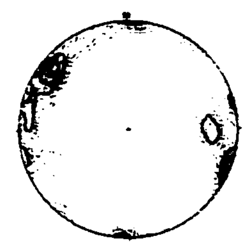
Phi	%
<3.6	34
3.6-4.0	4
4.0-4.5	3
4.5-5	4
5.0-5.6	6
5.6-6.2	5
6.1-6.4	3
6.4-6.9	5
6.9-7.3	7
7.3-7.6	1
7.6-7.8	1
7.8-8.3	3
8.8-8.8	2
8.8-9.6	6
>9.6	16

grain size	%
gravel	42
sand	22
silt	23
clay	13

clast roundness subangular
other notes shale, sedimentary

fabric, n= 26
mean azimuth 290
mean plunge 3
eigenvalue, S1 0.71
S2 0.24
S3 0.05





field notes
compact, grey colour
middle Stone Creek drumlins

sample #	15	northing	5940599	easting	526457
field ID	a15	collected	20/6/97	elevation (masl)	855

sieved

Phi	%
<-2	38
-2 to -1	3.4
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

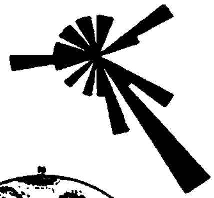
Phi	%
<3.6	29
3.6-4.0	7
4.0-4.5	5
4.5-5	4
5.0-5.6	7
5.6-6.2	5
6.1-6.4	4
6.4-6.9	6
6.9-7.3	3
7.3-7.6	3
7.6-7.8	3
7.8-8.3	3
8.8-8.8	3
8.8-9.6	2
>9.6	16

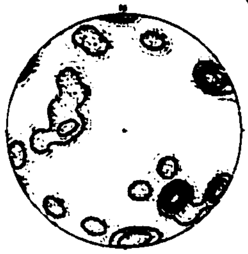
grain size	%
gravel	41
sand	21
silt	27
clay	11

clast roundness subangular to subrounded

other notes some coal
some large rounded clasts

fabric, n= 26
mean azimuth 149
mean plunge 1
eigenvalue, S1 0.48
S2 0.34
S3 0.18





field notes unconsolidated
middle Stone Creek drumlins

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sample #	16	northing	5940400	easting	525094
field ID	a16	collected	08/07/97	elevation (masl)	820

sieved

Phi	%
<-2	37
-2 to -1	12
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

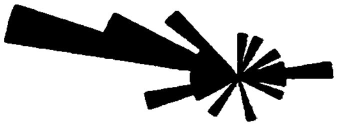
Phi	%
<3.6	32
3.6-4.0	5
4.0-4.5	4
4.5-5	3
5.0-5.6	8
5.6-6.2	6
6.1-6.4	2
6.4-6.9	5
6.9-7.3	4
7.3-7.6	4
7.6-7.8	2
7.8-8.3	3
8.8-8.8	3
8.8-9.6	4
>9.6	15

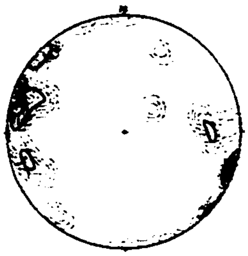
grain size	%
gravel	49
sand	19
silt	23
clay	10

clast roundness subangular to angular

other notes largest clast s/r, light colour

fabric, n= 26
mean azimuth 283
mean plunge 2.9
eigenvalue, S1 0.7
S2 0.21
S3 0.09





field notes 2.5Y 4/3, rounded cobble-gravel layer at 60-70 cm,
clay below
middle Stone Creek drumlins

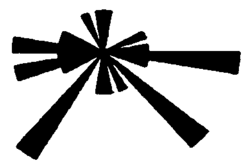
sample # 17 | northing 5940398 | easting 525126
field ID a17 | collected 08/07/97 | elevation (masl) 830

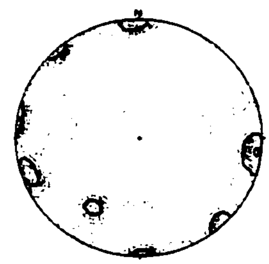
sieved		**hydrometry**	
Phi	%	Phi	%
<-2	40	<3.6	30
-2 to -1	10	3.6-4.0	5
-1 to 0		4.0-4.5	3
0 - 1		4.5-5	2
1 - 2		5.0-5.6	5
2 - 3		5.6-6.2	3
3 - 4		6.1-6.4	2
>4		6.4-6.9	4
		6.9-7.3	2
		7.3-7.6	2
		7.6-7.8	2
		7.8-8.3	3
		8.8-8.8	4
		8.8-9.6	6
		>9.6	27

grain size	%
gravel	50
sand	17
silt	16
clay	16

clast roundness angular
other notes largest clasts rounded
light colour

fabric, n= 26
mean azimuth 278
mean plunge 3.3
eigenvalue, S1 0.53
S2 0.33
S3 0.14





field notes 2.5Y 4/3, 90% fines, cobble layer at 50 cm
middle Stone Creek drumlins

---

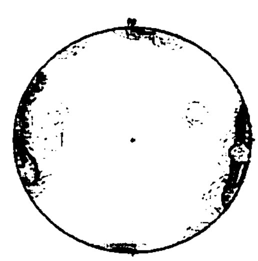
sample # 18 | northing 5940394 | easting 525177
field ID a18 | collected 08/07/97 | elevation (masl) 832

sieved		**hydrometry**	
Phi	%	Phi	%
<-2	41	<3.6	30
-2 to -1	15	3.6-4.0	5
-1 to 0		4.0-4.5	2
0 - 1		4.5-5	4
1 - 2		5.0-5.6	7
2 - 3		5.6-6.2	5
3 - 4		6.1-6.4	3
>4		6.4-6.9	5
		6.9-7.3	5
		7.3-7.6	2
		7.6-7.8	3
		7.8-8.3	2
		8.8-8.8	3
		8.8-9.6	5
		>9.6	19

grain size	%
gravel	56
sand	15
silt	18
clay	10

clast roundness angular
other notes fissile shale
dark colour

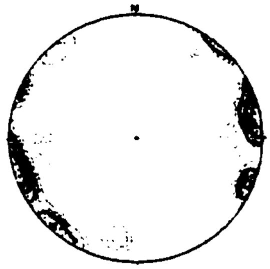
fabric, n= 26
mean azimuth 275
mean plunge 0.3
eigenvalue, S1 0.74
S2 0.2
S3 0.06



field notes charcoal at 20 cm,
rounded quatrtzite cobble layer at 50 cm
middle Stone Creek drumlins

sample # 19 | northing | easting
field ID a19 | collected 08/07/97 | elevation (masl)

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6		sand	0
-2 to -1		3.6-4.0		silt	0
-1 to 0		4.0-4.5		clay	0
0 - 1		4.5-5			
1 - 2		5.0-5.6		**clast roundness**	n/a
2 - 3		5.6-6.2		**other notes**	
3 - 4		6.1-6.4			
>4		6.4-6.9		**fabric,** n=	26
		6.9-7.3		mean azimuth	124
		7.3-7.6		mean plunge	1.8
		7.6-7.8		eigenvalue, S1	0.76
		7.8-8.3		S2	0.21
		8.8-8.8		S3	0.03
		8.8-9.6			
		>9.6			



field notes fabric only
middle Stone Creek drumlins

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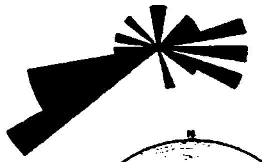
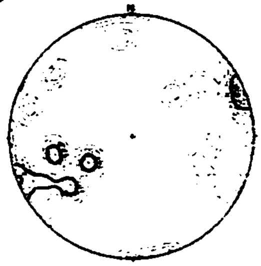
sample # 20 | northing 5941133 | easting 527229
field ID a20 | collected 12/07/97 | elevation (masl) 848

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	47
<-2	32	<3.6	32	sand	20
-2 to -1	15	3.6-4.0	6	silt	21
-1 to 0		4.0-4.5	3	clay	12
0 - 1		4.5-5	5		
1 - 2		5.0-5.6	5	**clast roundness**	angular to subangular
2 - 3		5.6-6.2	3	**other notes**	fissile shale
3 - 4		6.1-6.4	4		dark colour
>4		6.4-6.9	4	**fabric,** n=	26
		6.9-7.3	4	mean azimuth	307
		7.3-7.6	3	mean plunge	6.3
		7.6-7.8	3	eigenvalue, S1	0.59
		7.8-8.3	2	S2	0.22
		8.8-8.8	3	S3	0.19
		8.8-9.6	4		
		>9.6	19		

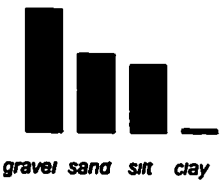




field notes 2.5Y 3/2, layer of rounded cobbles at 40 cm
eastern Stone Creek drumlins

sample # 21 | northing 5941148 | easting 527349
field ID a22 | collected ? | elevation (masl) 833

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	45
<-2	32	<3.6	30	sand	29
-2 to -1	13	3.6-4.0	8	silt	25
-1 to 0		4.0-4.5	3	clay	2
0 - 1		4.5-5	5		
1 - 2		5.0-5.6	7	**clast roundness**	angular to subangular
2 - 3		5.6-6.2	5	**other notes**	dark colour
3 - 4		6.1-6.4	4		
>4		6.4-6.9	3	**fabric,** n=	n/a
		6.9-7.3	5	mean azimuth	
		7.3-7.6	2	mean plunge	
		7.6-7.8	3	eigenvalue, S1	
		7.8-8.3	4	S2	
		8.8-8.8	4	S3	
		8.8-9.6	3		
		>9.6			



field notes cobble layer at 30 cm
eastern Stone Creek drumlins

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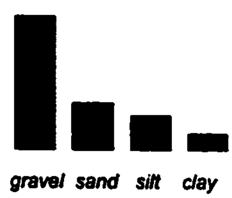
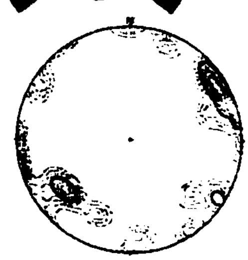
sample # 22 | northing 5941143 | easting 527412
field ID a23 | collected 12/07/97 | elevation (masl) 825

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	58
<-2	52	<3.6	33	sand	20
-2 to -1	5.8	3.6-4.0	15	silt	15
-1 to 0		4.0-4.5	5	clay	7
0 - 1		4.5-5	4		
1 - 2		5.0-5.6	5	**clast roundness**	subangular
2 - 3		5.6-6.2	3	**other notes**	some coal
3 - 4		6.1-6.4	3		some angular large clasts
>4		6.4-6.9	4	**fabric,** n=	23
		6.9-7.3	4	mean azimuth	117
		7.3-7.6	2	mean plunge	0.8
		7.6-7.8	3	eigenvalue, S	0.63
		7.8-8.3	0	S2	0.31
		8.8-8.8	2	S3	0.07
		8.8-9.6	2		
		>9.6	15		





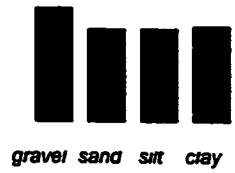
field notes glaciofluvial or mudflow?
eastern Stone Creek drumlins

sample # 23 | northing 5940763 | easting 526463
field ID a24 | collected 18/7/97 | elevation (masl) 844

sieved Phi	%
<-2	20
-2 to -1	8.9
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry Phi	%
<3.6	25
3.6-4.0	8
4.0-4.5	2
4.5-5	3
5.0-5.6	5
5.6-6.2	4
6.1-6.4	2
6.4-6.9	4
6.9-7.3	4
7.3-7.6	4
7.6-7.8	2
7.8-8.3	2
8.8-8.8	1
8.8-9.6	4
>9.6	30

grain size	%
gravel	29
sand	23
silt	23
clay	24



clast roundness subangular
other notes angular large clasts

fabric, n= n/a
mean azimuth
mean plunge
eigenvalue, S1
S2
S3

field notes 2.5Y 3/2, cobbles to 90 cm, none below,
quartz common
western Stone Creek drumlins

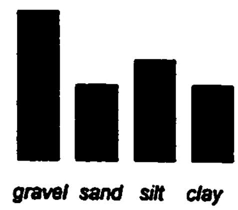
---

sample # 24 | northing 5940852 | easting 526539
field ID a25 | collected 18/7/97 | elevation (masl) 850

sieved Phi	%
<-2	21
-2 to -1	16
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

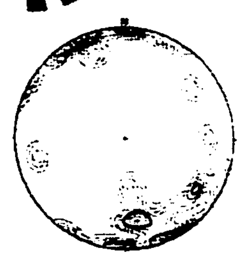
hydrometry Phi	%
<3.6	22
3.6-4.0	8
4.0-4.5	4
4.5-5	3
5.0-5.6	7
5.6-6.2	4
6.1-6.4	2
6.4-6.9	5
6.9-7.3	6
7.3-7.6	2
7.6-7.8	3
7.8-8.3	1
8.8-8.8	3
8.8-9.6	3
>9.6	27

grain size	%
gravel	37
sand	19
silt	25
clay	19



clast roundness subangular
other notes some ang. large clasts

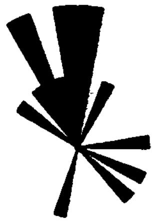
fabric, n= 26
mean azimuth 160
mean plunge 11
eigenvalue, S 0.68
S2 0.22
S3 0.09

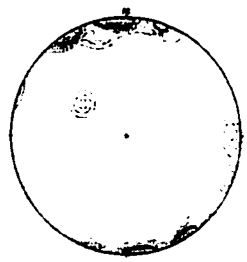


field notes coarser than a24 (sample #23)
western Stone Creek drumlins

sample # 25 northing 5941273 easting 526782
field ID a26 collected 18/7/97 elevation (masl) 845

sieved		**hydrometry**		**grain size**	**%**
Phi	%	Phi	%	gravel	17
<-2	12	<3.6	31	sand	31
-2 to -1	4.7	3.6-4.0	6	silt	28
-1 to 0		4.0-4.5	4	clay	24
0 - 1		4.5-5	3		
1 - 2		5.0-5.6	4	**clast roundness**	subangular
2 - 3		5.6-6.2	5	**other notes**	
3 - 4		6.1-6.4	3		
>4		6.4-6.9	3	**fabric,** n=	13
		6.9-7.3	4	mean azimuth	338
		7.3-7.6	3	mean plunge	4
		7.6-7.8	1	eigenvalue, S	0.73
		7.8-8.3	2	S2	0.21
		8.8-8.8	2	S3	0.06
		8.8-9.6	2		
		>9.6	27		





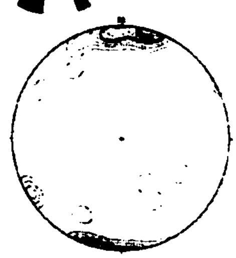
field notes cobble layer at 60 cm
western Stone Creek drumlins

---

sample # 26 northing ? easting ?
field ID a27 collected 06/08/97 elevation (masl) ?

sieved		**hydrometry**		**grain size**	**%**
Phi	%	Phi	%	gravel	0
<-2		<3.6		sand	0
-2 to -1		3.6-4.0		silt	0
-1 to 0		4.0-4.5		clay	0
0 - 1		4.5-5			
1 - 2		5.0-5.6		**clast roundness**	angular large clasts
2 - 3		5.6-6.2		**other notes**	
3 - 4		6.1-6.4			
>4		6.4-6.9		**fabric,** n=	25
		6.9-7.3		mean azimuth	2.3
		7.3-7.6		mean plunge	1.1
		7.6-7.8		eigenvalue, S	0.73
		7.8-8.3		S2	0.17
		8.8-8.8		S3	0.08
		8.8-9.6			
		>9.6			

gravel sand silt clay



field notes sandy diamict, charcoal at 60 cm,
cobble layer 70-90 cm
western Stone Creek drumlins

sample # 27 | field ID a28

northing	5940667	easting	525360
collected	06/08/97	elevation (masl)	817

sieved

Phi	%
<-2	30
-2 to -1	3.3
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

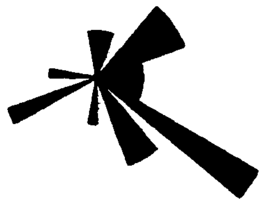
hydrometry

Phi	%
<3.6	33
3.6-4.0	10
4.0-4.5	4
4.5-5	5
5.0-5.6	6
5.6-6.2	4
6.1-6.4	3
6.4-6.9	4
6.9-7.3	5
7.3-7.6	2
7.6-7.8	1
7.8-8.3	2
8.8-8.8	2
8.8-9.6	1
>9.6	18

grain size	%
gravel	33
sand	29
silt	25
clay	13

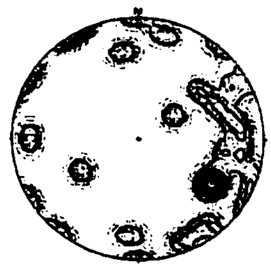
clast roundness angular to subangular

other notes



fabric, n= 25

mean azimuth	105
mean plunge	20
eigenvalue, S	0.53
S2	0.36
S3	0.11



field notes 2.5Y 4/3, red/green clay beds w/pebbles 5-50 cm, cobbles from 50-70 cm
western Stone Creek drumlins

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sample # 28 | field ID a29

northing	5940775	easting	525259
collected	06/08/97	elevation (masl)	816

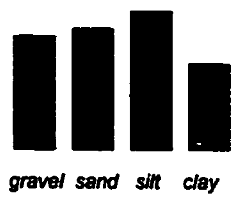
sieved

Phi	%
<-2	14
-2 to -1	11
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

Phi	%
<3.6	27
3.6-4.0	8
4.0-4.5	3
4.5-5	3
5.0-5.6	7
5.6-6.2	7
6.1-6.4	2
6.4-6.9	4
6.9-7.3	5
7.3-7.6	3
7.6-7.8	2
7.8-8.3	2
8.8-8.8	2
8.8-9.6	3
>9.6	22

grain size	%
gravel	25
sand	26
silt	30
clay	19

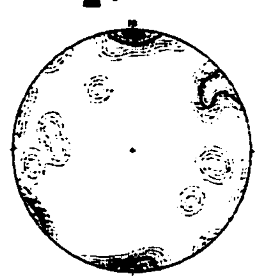


clast roundness subangular to subrounded

other notes

fabric, n= 26

mean azimuth	31
mean plunge	6.7
eigenvalue, S	0.51
S2	0.4
S3	0.09



field notes 2.5Y 5/3, compact clay w/cobbles 40-60 cm
western Stone Creek drumlins

sample # 29 | **field ID** a30 | northing ? | easting ? | collected 19/8/97 | elevation (masl) ?

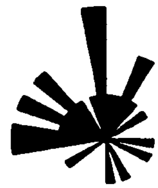
sieved Phi	%	**hydrometry** Phi	%
<-2	2.5	<3.6	
-2 to -1	7.9	3.6-4.0	
-1 to 0	6	4.0-4.5	
0 - 1	16	4.5-5	
1 - 2	12	5.0-5.6	
2 - 3	16	5.6-6.2	
3 - 4	16	6.1-6.4	
>4	24	6.4-6.9	
		6.9-7.3	
		7.3-7.6	
		7.6-7.8	
		7.8-8.3	
		8.8-8.8	
		8.8-9.6	
		>9.6	

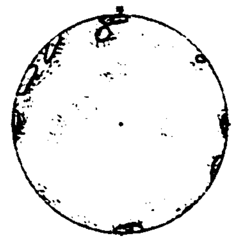
grain size	%
gravel	10
sand	69
silt	21
clay	0

clast roundness

other notes

fabric, n= 25
mean azimuth 332
mean plunge 8.4
eigenvalue, S1 0.52
S2 0.37
S3 0.11





field notes
boulder and stacked cobbles at 30 cm
20% clasts near surface increasing to 40% at 50 cm,
cobble layer at 60 cm
western Stone Creek drumlins

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sample # 30 | **field ID** a31 | northing ? | easting ? | collected 22/8/97 | elevation (masl) ?

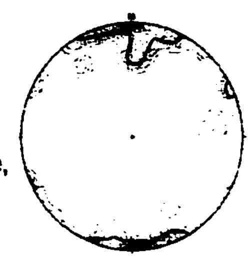
sieved Phi	%	**hydrometry** Phi	%
<-2	0	<3.6	25
-2 to -1	27	3.6-4.0	5
-1 to 0		4.0-4.5	3
0 - 1		4.5-5	3
1 - 2		5.0-5.6	6
2 - 3		5.6-6.2	6
3 - 4		6.1-6.4	3
>4		6.4-6.9	3
		6.9-7.3	4
		7.3-7.6	3
		7.6-7.8	1
		7.8-8.3	2
		8.8-8.8	2
		8.8-9.6	4
		>9.6	30

grain size	%
gravel	27
sand	22
silt	26
clay	25

clast roundness angular

other notes

fabric, n= 26
mean azimuth 2.4
mean plunge 4.4
eigenvalue, S1 0.71
S2 0.23
S3 0.05



field notes
in boulder field, angular boulders in sand matrix near surface,
rounded cobbles common at 50 cm
western Stone Creek drumlins

sample # 31 | northing 5942246 | easting 526303
field ID m1 | collected 10/07/97 | elevation (masl) 843

sieved

Phi	%
<-2	43
-2 to -1	11
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

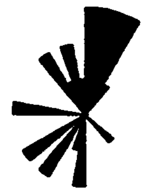
Phi	%
<3.6	32
3.6-4.0	7
4.0-4.5	3
4.5-5	3
5.0-5.6	8
5.6-6.2	6
6.1-6.4	2
6.4-6.9	4
6.9-7.3	7
7.3-7.6	2
7.6-7.8	1
7.8-8.3	3
8.8-8.8	3
8.8-9.6	4
>9.6	15

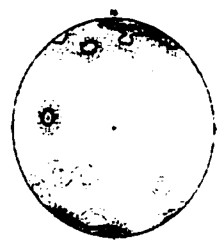
grain size

grain size	%
gravel	54
sand	18
silt	19
clay	9

clast roundness subrounded to subangular
other notes some shale, light colour

fabric, n= 26
mean azimuth 8
mean plunge 2.5
eigenvalue, S 0.7
S2 0.22
S3 0.07





field notes lots of pebbles
northern Stone Creek drumlins

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sample # 32 | northing 5941650 | easting 526203
field ID m2 | collected 10/07/97 | elevation (masl) 824

sieved

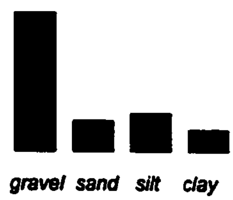
Phi	%
<-2	39
-2 to -1	22
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

Phi	%
<3.6	25
3.6-4.0	9
4.0-4.5	3
4.5-5	3
5.0-5.6	7
5.6-6.2	3
6.1-6.4	4
6.4-6.9	6
6.9-7.3	3
7.3-7.6	3
7.6-7.8	3
7.8-8.3	4
8.8-8.8	3
8.8-9.6	5
>9.6	19

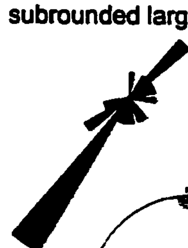
grain size

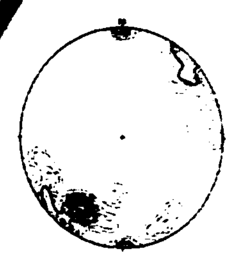
grain size	%
gravel	61
sand	13
silt	17
clay	9



clast roundness subangular
other notes some shale, some subrounded large clasts

fabric, n= 26
mean azimuth 218
mean plunge 7.1
eigenvalue, S 0.73
S2 0.2
S3 0.07





field notes red clay at 50 cm, lots of pebbles, shale, grey colour
northern Stone Creek drumlins

sample #	33	northing	5942087	easting	526602
field ID	m3	collected	10/07/97	elevation (masl)	821

sieved Phi	%
<-2	40
-2 to -1	6.8
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

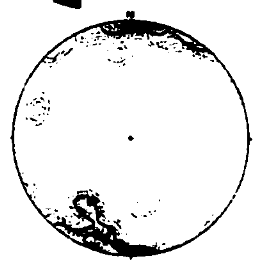
hydrometry Phi	%
<3.6	28
3.6-4.0	6
4.0-4.5	3
4.5-5	4
5.0-5.6	6
5.6-6.2	5
6.1-6.4	5
6.4-6.9	3
6.9-7.3	5
7.3-7.6	4
7.6-7.8	3
7.8-8.3	4
8.8-8.8	2
8.8-9.6	4
>9.6	18

grain size	%
gravel	47
sand	18
silt	23
clay	12

clast roundness subangular

other notes dark colour

fabric, n=	25
mean azimuth	193
mean plunge	5.6
eigenvalue, S	0.78
S2	0.17
S3	0.05



field notes lots of pebbles, grey colour
northern Stone Creek drumlin

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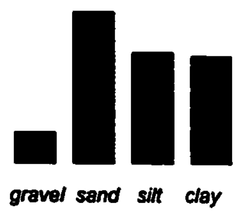
sample #	34	northing	5940913	easting	527152
field ID	L1	collected	09/07/97	elevation (masl)	847

sieved Phi	%
<-2	2.6
-2 to -1	5.1
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry Phi	%
<3.6	33
3.6-4.0	8
4.0-4.5	5
4.5-5	3
5.0-5.6	4
5.6-6.2	3
6.1-6.4	1
6.4-6.9	3
6.9-7.3	3
7.3-7.6	2
7.6-7.8	1
7.8-8.3	2
8.8-8.8	3
8.8-9.6	4
>9.6	25

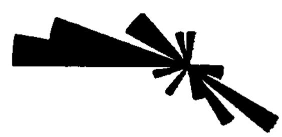
grain size	%
gravel	8
sand	38
silt	28
clay	27

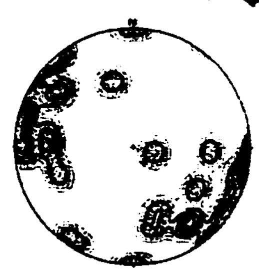


clast roundness subangular

other notes

fabric, n=	26
mean azimuth	117
mean plunge	0.5
eigenvalue, S	0.65
S2	0.22
S3	0.12



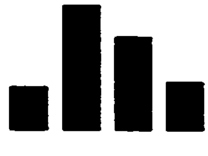


field notes 2.5Y 4/3, 30 cm boulder near surface,
cobble layer at 80 cm (some stacked)
eastern Stone Creek drumlin

sample # 35 northing 5940942 easting 527240
field ID L2 collected 09/07/97 elevation (masl) 841

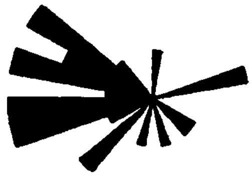
sieved		**hydrometry**	
Phi	%	Phi	%
<-2	8.8	<3.6	37
-2 to -1	5.1	3.6-4.0	10
-1 to 0		4.0-4.5	5
0 - 1		4.5-5	3
1 - 2		5.0-5.6	8
2 - 3		5.6-6.2	3
3 - 4		6.1-6.4	3
>4		6.4-6.9	3
		6.9-7.3	4
		7.3-7.6	1
		7.6-7.8	2
		7.8-8.3	1
		8.8-8.8	2
		8.8-9.6	2
		>9.6	16

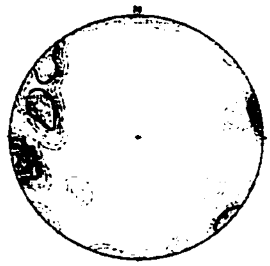
grain size	%
gravel	14
sand	40
silt	30
clay	15



clast roundness subangular
other notes one large clast

fabric, n= 26
mean azimuth 278
mean plunge 8.7
eigenvalue, S 0.69
S2 0.26
S3 0.06





field notes clay w/pebbles 30-65 cm, 2.5Y 2.5/1, includes fissile shale
eastern Stone Creek drumlins

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sample # 36 northing 5940970 easting 527350
field ID L3 collected 09/07/97 elevation (masl) 825

sieved		**hydrometry**	
Phi	%	Phi	%
<-2	69	<3.6	59
-2 to -1	8.9	3.6-4.0	4
-1 to 0		4.0-4.5	4
0 - 1		4.5-5	4
1 - 2		5.0-5.6	4
2 - 3		5.6-6.2	3
3 - 4		6.1-6.4	3
>4		6.4-6.9	2
		6.9-7.3	1
		7.3-7.6	2
		7.6-7.8	1
		7.8-8.3	0
		8.8-8.8	0
		8.8-9.6	1
		>9.6	12

grain size	%
gravel	78
sand	14
silt	5
clay	3

clast roundness subangular to subrounded
other notes schist common, some mica
some angular large clasts

fabric, n= n/a
mean azimuth
mean plunge
eigenvalue, S1
S2
S3

field notes 2.5Y 4/3, 4 gravel/sand beds, cobble layer at 60 cm dips 15 degrees north
eastern Stone Creek drumlins

sample #	37	northing	5941240	easting	526997
field ID	L5	collected	09/07/97	elevation (masl)	856

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	31
<-2	19	<3.6	51	sand	40
-2 to -1	12	3.6-4.0	7	silt	19
-1 to 0		4.0-4.5	6	clay	10
0 - 1		4.5-5	2		
1 - 2		5.0-5.6	4	**clast roundness**	subrounded to subangular
2 - 3		5.6-6.2	4	**other notes**	some angular large clasts
3 - 4		6.1-6.4	2		
>4		6.4-6.9	3	**fabric,** n=	n/a
		6.9-7.3	2	mean azimuth	
		7.3-7.6	1	mean plunge	
		7.6-7.8	1	eigenvalue, S1	
		7.8-8.3	1	S2	
		8.8-8.8	1	S3	
		8.8-9.6	1		
		>9.6	14		

field notes red sand/gravel bed 40-50 cm, dips 10 degrees south, angular cobble layer at 80 cm
eastern Stone Creek drumlin

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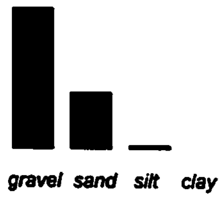
sample #	38	northing		easting	
field ID	x1	collected	23/8/97	elevation (masl)	

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	70
<-2	61	<3.6		sand	28
-2 to -1	8.7	3.6-4.0		silt	2
-1 to 0	4.3	4.0-4.5		clay	0
0 - 1	8.8	4.5-5			
1 - 2	4.7	5.0-5.6		**clast roundness**	
2 - 3	3.3	5.6-6.2		**other notes**	
3 - 4	2.9	6.1-6.4			
>4	6	6.4-6.9		**fabric,** n=	n/a
		6.9-7.3		mean azimuth	
		7.3-7.6		mean plunge	
		7.6-7.8		eigenvalue, S1	
		7.8-8.3		S2	
		8.8-8.8		S3	
		8.8-9.6			
		>9.6			



field notes massive, unconsolidated
Right-Angle drumlin

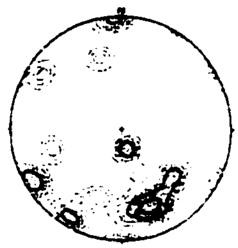
sample #	39	northing		easting	
field ID	g1	collected	23/6/97	elevation (masl)	

sieved Phi	%	**hydrometry** Phi	%
<-2	12	<3.6	25
-2 to -1	13	3.6-4.0	7
-1 to 0		4.0-4.5	3
0 - 1		4.5-5	6
1 - 2		5.0-5.6	6
2 - 3		5.6-6.2	7
3 - 4		6.1-6.4	2
>4		6.4-6.9	4
		6.9-7.3	6
		7.3-7.6	2
		7.6-7.8	3
		7.8-8.3	5
		8.8-8.8	3
		8.8-9.6	6
		>9.6	15

grain size	%
gravel	25
sand	24
silt	35
clay	16

clast roundness angular
other notes shale and schist

fabric, n= 26
mean azimuth 172
mean plunge 29
eigenvalue, S 0.62
S2 0.25
S3 0.13



field notes 60-90 cm below surface
Stone Creek forestry road

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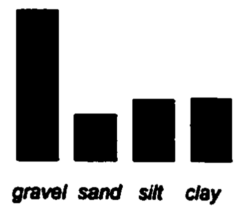
sample #	40	northing		easting	
field ID	g2	collected	23/6/97	elevation (masl)	

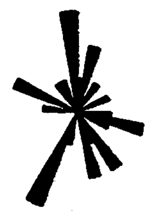
sieved Phi	%	**hydrometry** Phi	%
<-2	33	<3.6	21
-2 to -1	14	3.6-4.0	6
-1 to 0		4.0-4.5	4
0 - 1		4.5-5	2
1 - 2		5.0-5.6	6
2 - 3		5.6-6.2	4
3 - 4		6.1-6.4	4
>4		6.4-6.9	4
		6.9-7.3	4
		7.3-7.6	3
		7.6-7.8	2
		7.8-8.3	0
		8.8-8.8	3
		8.8-9.6	4
		>9.6	33

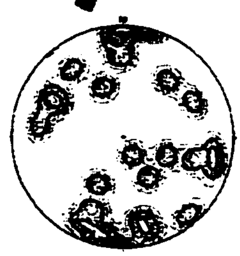
grain size	%
gravel	47
sand	14
silt	19
clay	20



clast roundness subangular
other notes some angular large clasts

fabric, n= 26
mean azimuth 169
mean plunge 5
eigenvalue, S 0.50
S2 0.27
S3 0.23





field notes 110-130 cm below surface
gravel and shale at 1.2 m
Stone Creek forestry road

sample # 41   northing ?   easting ?

field ID g3   collected 23/6/97   elevation (masl) ?

sieved

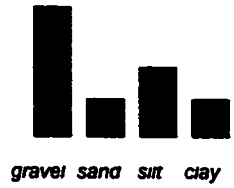
Phi	%
<-2	39
-2 to -1	8.4
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

Phi	%
<3.6	18
3.6-4.0	8
4.0-4.5	4
4.5-5	6
5.0-5.6	7
5.6-6.2	5
6.1-6.4	2
6.4-6.9	7
6.9-7.3	5
7.3-7.6	3
7.6-7.8	2
7.8-8.3	4
8.8-8.8	3
8.8-9.6	6
>9.6	20

grain size

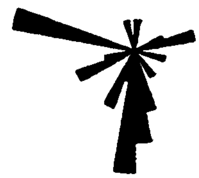
	%
gravel	47
sand	14
silt	25
clay	14

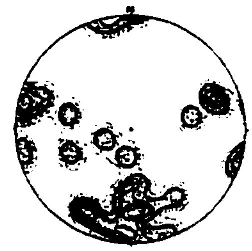


clast roundness angular

other notes large rounded cobble

fabric, n= 26
mean azimuth 185
mean plunge 27
eigenvalue, S 0.52
S2 0.32
S3 0.16





field notes

150-180 cm below surface
cobble layer at 1.5 m
Stone Creek forestry road

---

sample # 42   northing ?   easting ?

field ID g4   collected 23/6/97   elevation (masl) ?

sieved

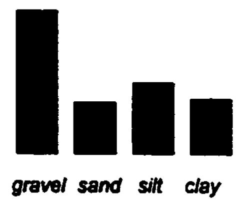
Phi	%
<-2	32
-2 to -1	13
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

Phi	%
<3.6	25
3.6-4.0	4
4.0-4.5	3
4.5-5	4
5.0-5.6	3
5.6-6.2	8
6.1-6.4	2
6.4-6.9	6
6.9-7.3	3
7.3-7.6	4
7.6-7.8	3
7.8-8.3	1
8.8-8.8	3
8.8-9.6	5
>9.6	26

grain size

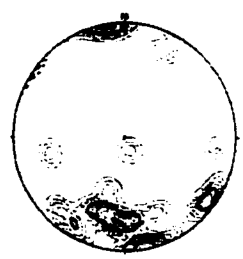
	%
gravel	45
sand	16
silt	22
clay	17



clast roundness subangular

other notes compact

fabric, n= 26
mean azimuth 179
mean plunge 19
eigenvalue, S 0.7
S2 0.20
S3 0.10



field notes

2-2.3 m below surface
some fissile shale
Stone Creek forestry road

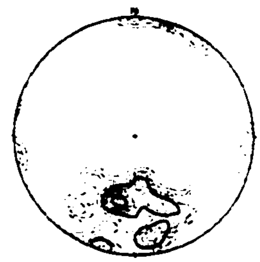
sample # 43 | northing ? | easting ?
field ID g5 | collected 23/6/97 | elevation (masl) ?

sieved Phi	%	hydrometry Phi	%
<-2	42	<3.6	18
-2 to -1	12	3.6-4.0	8
-1 to 0		4.0-4.5	4
0 - 1		4.5-5	4
1 - 2		5.0-5.6	8
2 - 3		5.6-6.2	5
3 - 4		6.1-6.4	3
>4		6.4-6.9	5
		6.9-7.3	5
		7.3-7.6	4
		7.6-7.8	2
		7.8-8.3	6
		8.8-8.8	3
		8.8-9.6	6
		>9.6	19

grain size	%
gravel	53
sand	12
silt	23
clay	12

clast roundness subangular
other notes dark colour

fabric, n= 26
mean azimuth 182
mean plunge 31
eigenvalue, S 0.76
S2 0.16
S3 0.08



field notes 2.8-3 m below surface
Stone Creek forestry road

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sample # 44 | northing ? | easting ?
field ID g6 | collected 23/6/97 | elevation (masl) ?

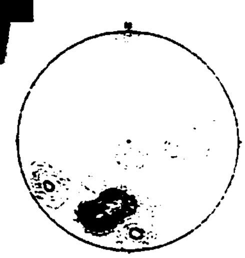
sieved Phi	%	hydrometry Phi	%
<-2		<3.6	
-2 to -1		3.6-4.0	
-1 to 0		4.0-4.5	
0 - 1		4.5-5	
1 - 2		5.0-5.6	
2 - 3		5.6-6.2	
3 - 4		6.1-6.4	
>4		6.4-6.9	
		6.9-7.3	
		7.3-7.6	
		7.6-7.8	
		7.8-8.3	
		8.8-8.8	
		8.8-9.6	
		>9.6	

grain size	%
gravel	0
sand	0
silt	0
clay	0

gravel sand silt clay

clast roundness subangular to subrounded
other notes compact, some angul. large clasts

fabric, n= 26
mean azimuth 198
mean plunge 35
eigenvalue, S 0.71
S2 0.22
S3 0.07



field notes 3.8-4 m below surface
lots of cobbles and boulders, fissile shale
Stone Creek forestry road

sample # 45 northing ? easting ?
field ID g7 collected 23/6/97 elevation (masl) ?

sieved

Phi	%
<-2	36
-2 to -1	14
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

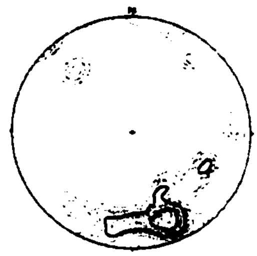
hydrometry

Phi	%
<3.6	18
3.6-4.0	8
4.0-4.5	4
4.5-5	3
5.0-5.6	7
5.6-6.2	7
6.1-6.4	4
6.4-6.9	5
6.9-7.3	6
7.3-7.6	4
7.6-7.8	1
7.8-8.3	4
8.8-8.8	3
8.8-9.6	7
>9.6	19

grain size	%
gravel	50
sand	13
silt	24
clay	13

clast roundness subangular
other notes some schist

fabric, n= 26
mean azimuth 166
mean plunge 21
eigenvalue, S 0.73
S2 0.20
S3 0.07



field notes 30-50 cm below surface
no cobbles, only pebbles

---

sample # 46 northing ? easting ?
field ID g8 collected 23/6/97 elevation (masl) ?

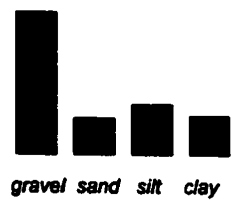
sieved

Phi	%
<-2	43
-2 to -1	9.8
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

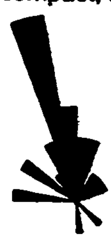
Phi	%
<3.6	21
3.6-4.0	8
4.0-4.5	5
4.5-5	3
5.0-5.6	6
5.6-6.2	4
6.1-6.4	2
6.4-6.9	6
6.9-7.3	4
7.3-7.6	2
7.6-7.8	2
7.8-8.3	4
8.8-8.8	2
8.8-9.6	5
>9.6	26

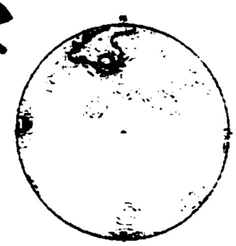
grain size	%
gravel	53
sand	14
silt	19
clay	15



clast roundness subangular
other notes compact, angul. lge. clasts

fabric, n= 26
mean azimuth 350
mean plunge 23
eigenvalue, S 0.67
S2 0.22
S3 0.11





field notes 6 m below surface
2.5Y 3/1, dark grey colour, no cobbles,
punky granite

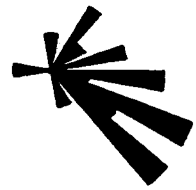
sample # 47 | northing 5943712 | easting 531286
field ID f1 | collected 21/6/97 | elevation (masl) 834

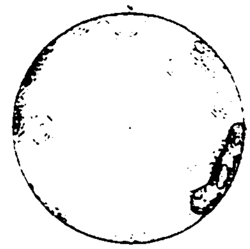
sieved Phi	%	**hydrometry** Phi	%
<-2	19	<3.6	21
-2 to -1	8.8	3.6-4.0	4
-1 to 0		4.0-4.5	5
0 - 1		4.5-5	5
1 - 2		5.0-5.6	8
2 - 3		5.6-6.2	5
3 - 4		6.1-6.4	2
>4		6.4-6.9	6
		6.9-7.3	4
		7.3-7.6	4
		7.6-7.8	1
		7.8-8.3	1
		8.8-8.8	3
		8.8-9.6	4
		>9.6	27

grain size	%
gravel	28
sand	18
silt	32
clay	22

clast roundness subangular to subrounded
other notes

fabric, n= 26
mean azimuth 111
mean plunge 9
eigenvalue, S 0.67
S2 0.30
S3 0.04





field notes 2.5Y 4/3, gravel layer at 45 cm, cobble layer at 60 cm
Middle drumlin

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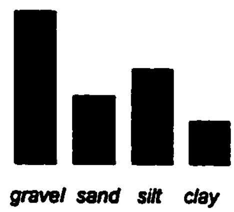
sample # 48 | northing 5943862 | easting 531429
field ID f2 | collected 21/6/97 | elevation (masl) 834

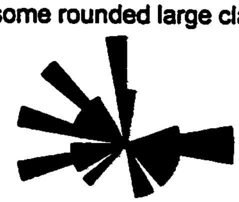
sieved Phi	%	**hydrometry** Phi	%
<-2	35	<3.6	25
-2 to -1	7.6	3.6-4.0	8
-1 to 0		4.0-4.5	3
0 - 1		4.5-5	5
1 - 2		5.0-5.6	7
2 - 3		5.6-6.2	6
3 - 4		6.1-6.4	5
>4		6.4-6.9	4
		6.9-7.3	5
		7.3-7.6	3
		7.6-7.8	2
		7.8-8.3	3
		8.8-8.8	3
		8.8-9.6	3
		>9.6	18

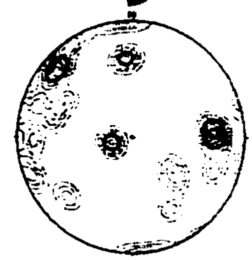
grain size	%
gravel	42
sand	19
silt	26
clay	12



clast roundness subangular
other notes some rounded large clasts

fabric, n= 26
mean azimuth 293
mean plunge 1
eigenvalue, S 0.54
S2 0.24
S3 0.22

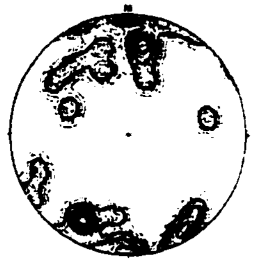




field notes gravel and cobble layer at 45 cm
Middle drumlin

sample #	49	northing	5943958	easting	531412
field ID	f3	collected	21/6/97	elevation (masl)	841

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	20
<-2	11	<3.6	23	sand	43
-2 to -1	8.6	3.6-4.0	10	silt	34
-1 to 0		4.0-4.5	3	clay	2
0 - 1		4.5-5	4		
1 - 2		5.0-5.6	10	**clast roundness**	subangular to subrounded
2 - 3		5.6-6.2	3	**other notes**	angular large clasts
3 - 4		6.1-6.4	1		
>4		6.4-6.9	4	**fabric,** n=	26
		6.9-7.3	3	mean azimuth	3
		7.3-7.6	3	mean plunge	5
		7.6-7.8	2	eigenvalue, S	0.63
		7.8-8.3	5	S2	0.24
		8.8-8.8	5	S3	0.13
		8.8-9.6	3		
		>9.6			



field notes 2.5Y 5/3, cobble layer at 30 cm
Middle drumlin

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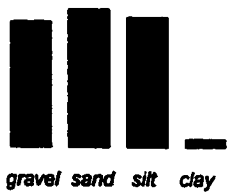
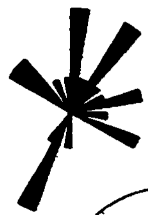
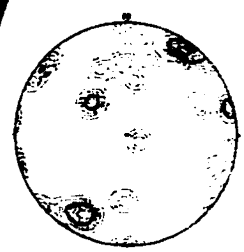
sample #	50	northing	5944180	easting	531460
field ID	f4	collected	21/6/97	elevation (masl)	862

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	31
<-2	25	<3.6	23	sand	34
-2 to -1	6.1	3.6-4.0	8	silt	32
-1 to 0		4.0-4.5	8	clay	2
0 - 1		4.5-5	5		
1 - 2		5.0-5.6	5	**clast roundness**	angular to subrounded
2 - 3		5.6-6.2	8	**other notes**	some rounded large clasts
3 - 4		6.1-6.4	3		
>4		6.4-6.9	4	**fabric,** n=	26
		6.9-7.3	5	mean azimuth	30
		7.3-7.6	2	mean plunge	10
		7.6-7.8	1	eigenvalue, S	0.54
		7.8-8.3	4	S2	0.28
		8.8-8.8	2	S3	0.18
		8.8-9.6	3		
		>9.6			







field notes 2.5Y 5/3, cobble layer at 30 cm
Middle drumlin

sample # 51 | northing 5944169 | easting 531583
field ID f5 | collected 21/6/97 | elevation (masl) 851

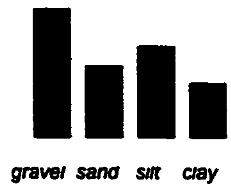
sieved

Phi	%
<-2	27
-2 to -1	11
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

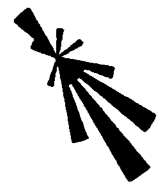
hydrometry

Phi	%
<3.6	27
3.6-4.0	6
4.0-4.5	4
4.5-5	4
5.0-5.6	7
5.6-6.2	7
6.1-6.4	2
6.4-6.9	6
6.9-7.3	5
7.3-7.6	3
7.6-7.8	2
7.8-8.3	0
8.8-8.8	2
8.8-9.6	4
>9.6	21

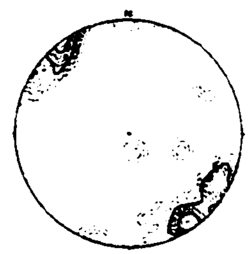
grain size	**%**
gravel	37
sand	21
silt	26
clay	16



clast roundness subangular to subrounded
other notes



fabric, n= 51
mean azimuth 140
mean plunge 9
eigenvalue, S 0.75
S2 0.16
S3 0.09



field notes cobble layer at 50 cm
Middle drumlin

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sample # 52 | northing 5944296 | easting 531518
field ID f6 | collected 21/6/97 | elevation (masl) 851

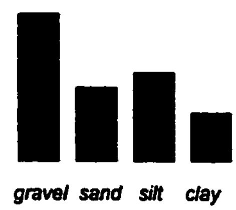
sieved

Phi	%
<-2	32
-2 to -1	9.4
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

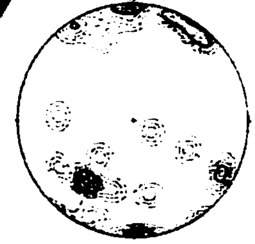
Phi	%
<3.6	33
3.6-4.0	2
4.0-4.5	4
4.5-5	6
5.0-5.6	7
5.6-6.2	6
6.1-6.4	3
6.4-6.9	3
6.9-7.3	6
7.3-7.6	2
7.6-7.8	1
7.8-8.3	2
8.8-8.8	2
8.8-9.6	3
>9.6	20

grain size	**%**
gravel	41
sand	21
silt	25
clay	14



clast roundness subangular
other notes some angular large clasts

fabric, n= 26
mean azimuth 190
mean plunge 11
eigenvalue, S 0.59
S2 0.25
S3 0.16



field notes cobbles from surface down
Middle drumlin

sample # 53 — **northing** 5944294 — **easting** 531361
field ID f7 — **collected** 21/6/97 — **elevation (masl)** 844

sieved

Phi	%
<-2	27
-2 to -1	10
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

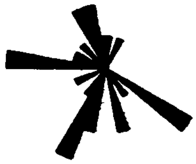
Phi	%
<3.6	19
3.6-4.0	7
4.0-4.5	6
4.5-5	5
5.0-5.6	6
5.6-6.2	6
6.1-6.4	2
6.4-6.9	5
6.9-7.3	2
7.3-7.6	3
7.6-7.8	2
7.8-8.3	1
8.8-8.8	2
8.8-9.6	2
>9.6	32

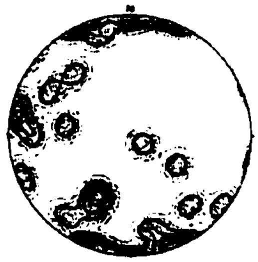
grain size

	%
gravel	37
sand	16
silt	25
clay	21

clast roundness subangular to subrounded
other notes some angular large clasts

fabric, n= 26
mean azimuth 168
mean plunge 9
eigenvalue, S 0.55
S2 0.33
S3 0.12





field notes compact, cobble layer at 35 cm
Middle drumlin

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sample # 54 — **northing** 5944282 — **easting** 531414
field ID f8 — **collected** 21/6/97 — **elevation (masl)** 851

sieved

Phi	%
<-2	
-2 to -1	
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

Phi	%
<3.6	
3.6-4.0	
4.0-4.5	
4.5-5	
5.0-5.6	
5.6-6.2	
6.1-6.4	
6.4-6.9	
6.9-7.3	
7.3-7.6	
7.6-7.8	
7.8-8.3	
8.8-8.8	
8.8-9.6	
>9.6	

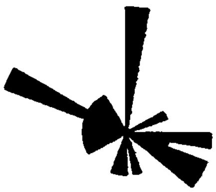
grain size

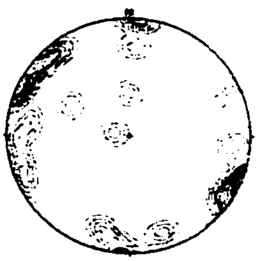
	%
gravel	0
sand	0
silt	0
clay	0

gravel sand silt clay

clast roundness n/a
other notes

fabric, n= 26
mean azimuth 298
mean plunge 4
eigenvalue, S 0.60
S2 0.28
S3 0.12





field notes Middle drumlin

sample # 55 | northing 5944304 | easting 531322
field ID f9 | collected 21/6/97 | elevation (masl) 848

sieved

Phi	%
<-2	41
-2 to -1	8.1
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

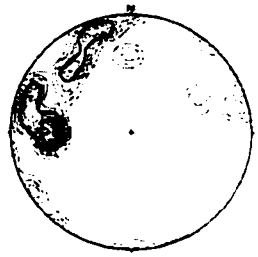
hydrometry

Phi	%
<3.6	31
3.6-4.0	10
4.0-4.5	6
4.5-5	3
5.0-5.6	8
5.6-6.2	3
6.1-6.4	4
6.4-6.9	6
6.9-7.3	3
7.3-7.6	2
7.6-7.8	1
7.8-8.3	2
8.8-8.8	2
8.8-9.6	2
>9.6	17

grain size	%
gravel	49
sand	21
silt	20
clay	10

clast roundness subangular to subrounded
other notes

fabric, n= 26
mean azimuth 292
mean plunge 23
eigenvalue, S 0.64
S2 0.30
S3 0.06



field notes cobbles from 20 cm to cobble layer at 50 cm
Middle drumlin

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sample # 56 | northing 5950551 | easting 536597
field ID e1 | collected 21/6/97 | elevation (masl) ~920

sieved

Phi	%
<-2	28
-2 to -1	6.9
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

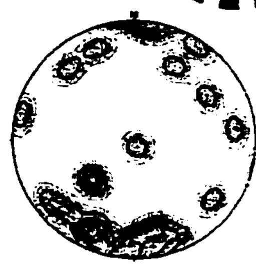
hydrometry

Phi	%
<3.6	29
3.6-4.0	10
4.0-4.5	3
4.5-5	2
5.0-5.6	4
5.6-6.2	6
6.1-6.4	3
6.4-6.9	5
6.9-7.3	5
7.3-7.6	1
7.6-7.8	2
7.8-8.3	1
8.8-8.8	4
8.8-9.6	2
>9.6	23

grain size	%
gravel	35
sand	25
silt	23
clay	16

clast roundness subangular
other notes rounded large clasts

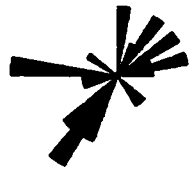
fabric, n= 27
mean azimuth 190
mean plunge 11
eigenvalue, S 0.64
S2 0.22
S3 0.14

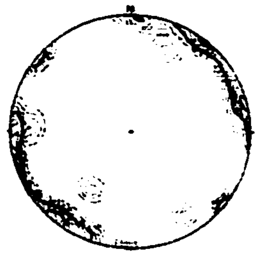


field notes 2.5Y 3/2, on main road to north of drumlins
Split drumlin

sample #	57	northing	5949661	easting	535366
field ID	e2	collected	25/6/97	elevation (masl)	912

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	35
<-2	28	<3.6	29	sand	25
-2 to -1	6.9	3.6-4.0	10	silt	23
-1 to 0		4.0-4.5	3	clay	16
0 - 1		4.5-5	2		
1 - 2		5.0-5.6	4	**clast roundness**	subrounded
2 - 3		5.6-6.2	6	**other notes**	some angular large clasts
3 - 4		6.1-6.4	3		
>4		6.4-6.9	5	**fabric,** n=	26
		6.9-7.3	5	mean azimuth	235
		7.3-7.6	1	mean plunge	1
		7.6-7.8	2	eigenvalue, S	0.68
		7.8-8.3	1	S2	0.28
		8.8-8.8	4	S3	0.04
		8.8-9.6	2		
		>9.6	23		





field notes no obvious A or B horizons
Split drumlin

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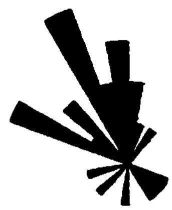
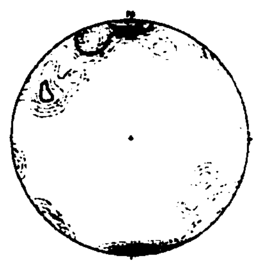
sample #	58	northing	5949586	easting	535586
field ID	e3	collected	?	elevation (masl)	919

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6		sand	0
-2 to -1		3.6-4.0		silt	0
-1 to 0		4.0-4.5		clay	0
0 - 1		4.5-5			
1 - 2		5.0-5.6		**clast roundness**	n/a
2 - 3		5.6-6.2		**other notes**	
3 - 4		6.1-6.4			
>4		6.4-6.9		**fabric,** n=	26
		6.9-7.3		mean azimuth	336
		7.3-7.6		mean plunge	6
		7.6-7.8		eigenvalue, S	0.7
		7.8-8.3		S2	0.25
		8.8-8.8		S3	0.05
		8.8-9.6			
		>9.6			

gravel sand silt clay



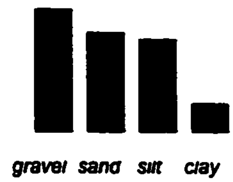


field notes plit drumlin

sample # 59 | northing 5949530 | easting 535638

field ID e4 | collected 25/6/97 | elevation (masl) 914

sieved		hydrometry		grain size	%
Phi	%	Phi	%	gravel	36
<-2	25	<3.6	38	sand	29
-2 to -1	11	3.6-4.0	7	silt	27
-1 to 0		4.0-4.5	4	clay	8
0 - 1		4.5-5	4		
1 - 2		5.0-5.6	7		
2 - 3		5.6-6.2	6		
3 - 4		6.1-6.4	4		
>4		6.4-6.9	4		
		6.9-7.3	4		
		7.3-7.6	2		
		7.6-7.8	2		
		7.8-8.3	3		
		8.8-8.8	2		
		8.8-9.6	4		
		>9.6	9		



clast roundness angular

other notes light colour

fabric, n= 26

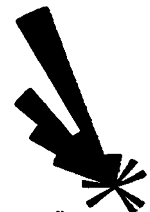
mean azimuth 323

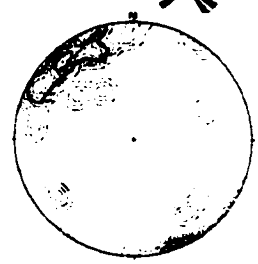
mean plunge 11

eigenvalue, S 0.74

S2 0.18

S3 0.08





field notes overlain by reddish fine
Split drumlin

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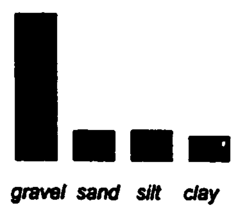
sample # 60 | northing ? | easting ?

field ID c1 | collected 21/6/97 | elevation (masl) ?

sieved		hydrometry		grain size	%
Phi	%	Phi	%	gravel	64
<-2	54	<3.6	27	sand	13
-2 to -1	10	3.6-4.0	8	silt	13
-1 to 0		4.0-4.5	4	clay	11
0 - 1		4.5-5	4		
1 - 2		5.0-5.6	5		
2 - 3		5.6-6.2	5		
3 - 4		6.1-6.4	4		
>4		6.4-6.9	2		
		6.9-7.3	4		
		7.3-7.6	2		
		7.6-7.8	2		
		7.8-8.3	3		
		8.8-8.8	1		
		8.8-9.6	3		
		>9.6	26		



clast roundness subrounded to subangular

other notes rounded large clasts

fabric, n= 26

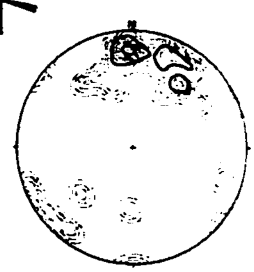
mean azimuth 14

mean plunge 21

eigenvalue, S 0.67

S2 0.21

S3 0.12

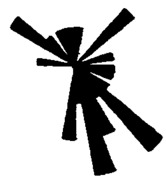


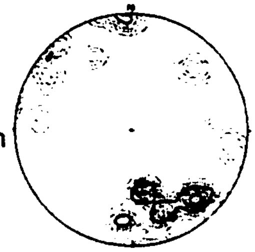
field notes 2.5Y 4/3, rounded quartzite cobbles throughout
near Stoner village

sample # 61 | northing ? | easting ?
field ID d1 | collected 17/6/97 | elevation (masl) ?

sieved Phi	%	**hydrometry** Phi	%	**grain size**	%
<-2		<3.6		gravel	0
-2 to -1		3.6-4.0		sand	0
-1 to 0		4.0-4.5		silt	0
0 - 1		4.5-5		clay	0
1 - 2		5.0-5.6		**clast roundness**	
2 - 3		5.6-6.2		**other notes**	
3 - 4		6.1-6.4			
>4		6.4-6.9		**fabric,** n=	26
		6.9-7.3		mean azimuth	149
		7.3-7.6		mean plunge	16
		7.6-7.8		eigenvalue, S	0.65
		7.8-8.3		S2	0.22
		8.8-8.8		S3	0.13
		8.8-9.6			
		>9.6			

gravel sand silt clay





field notes 2.5Y 4/4, boulders and cobbles from 10-40 cm depth
near Stoner village

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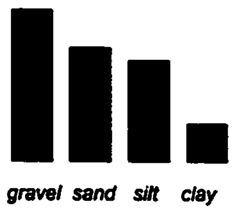
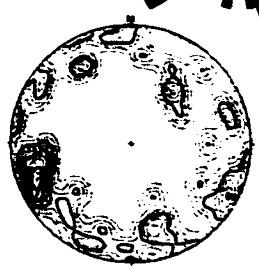
sample # 62 | northing ? | easting ?
field ID b1 | collected 17/6/97 | elevation (masl) ?

sieved Phi	%	**hydrometry** Phi	%	**grain size**	%
<-2	32	<3.6	41	gravel	38
-2 to -1	5.9	3.6-4.0	4	sand	28
-1 to 0		4.0-4.5	6	silt	25
0 - 1		4.5-5	6	clay	9
1 - 2		5.0-5.6	8	**clast roundness**	subangular
2 - 3		5.6-6.2	3	**other notes**	some argillite
3 - 4		6.1-6.4	3		some angular large clasts
>4		6.4-6.9	4	**fabric,** n=	48
		6.9-7.3	3	mean azimuth	259
		7.3-7.6	3	mean plunge	2
		7.6-7.8	1	eigenvalue, S	0.45
		7.8-8.3	1	S2	0.41
		8.8-8.8	2	S3	0.14
		8.8-9.6	1		
		>9.6	14		

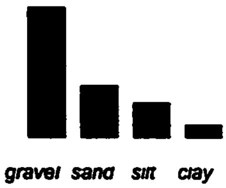


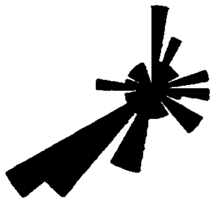


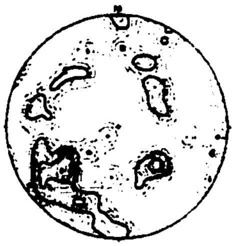
field notes 2.5Y 3/2, shale cobbles at 20 cm,
shale bedrock at 40 cm
high ridge above Montagne drumlin

sample # 63 northing ? easting ?
field ID b2 collected ? elevation (masl) ?

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	57
<-2	51	<3.6	45	sand	22
-2 to -1	6.1	3.6-4.0	7	silt	15
-1 to 0		4.0-4.5	5	clay	6
0 - 1		4.5-5	5		
1 - 2		5.0-5.6	5	**clast roundness**	
2 - 3		5.6-6.2	4	**other notes**	
3 - 4		6.1-6.4	4		
>4		6.4-6.9	3	**fabric,** n=	49
		6.9-7.3	5	mean azimuth	222
		7.3-7.6	2	mean plunge	26
		7.6-7.8	0	eigenvalue, S	0.47
		7.8-8.3	0	S2	0.27
		8.8-8.8	2	S3	0.26
		8.8-9.6	0		
		>9.6	13		







field notes high ridge above Montagne drumlin

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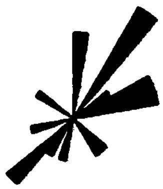
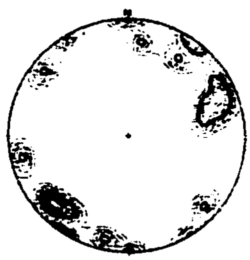
sample # 64 northing ? easting ?
field ID b3 collected ? elevation (masl) ?

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6		sand	0
-2 to -1		3.6-4.0		silt	0
-1 to 0		4.0-4.5		clay	0
0 - 1		4.5-5			
1 - 2		5.0-5.6		**clast roundness**	
2 - 3		5.6-6.2		**other notes**	
3 - 4		6.1-6.4			
>4		6.4-6.9		**fabric,** n=	18
		6.9-7.3		mean azimuth	46
		7.3-7.6		mean plunge	6
		7.6-7.8		eigenvalue, S	0.65
		7.8-8.3		S2	0.28
		8.8-8.8		S3	0.07
		8.8-9.6			
		>9.6			

gravel sand silt clay





field notes cobble layer from sample #62
high ridge above Montagne drumlin

sample # 65 northing ? easting ?
field ID j1 collected 25/6/97 elevation (masl) ?

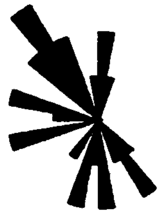
sieved Phi	%	**hydrometry** Phi	%
<-2		<3.6	
-2 to -1		3.6-4.0	
-1 to 0		4.0-4.5	
0 - 1		4.5-5	
1 - 2		5.0-5.6	
2 - 3		5.6-6.2	
3 - 4		6.1-6.4	
>4		6.4-6.9	
		6.9-7.3	
		7.3-7.6	
		7.6-7.8	
		7.8-8.3	
		8.8-8.8	
		8.8-9.6	
		>9.6	

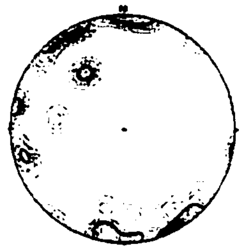
grain size	%
gravel	0
sand	0
silt	0
clay	0

gravel sand silt clay

clast roundness subrounded
other notes subangular large clasts

fabric, n= 26
mean azimuth 159
mean plunge 1
eigenvalue, S 0.65
S2 0.28
S3 0.06





field notes 2.5Y 4/2, underlying 25 cm clay (2.5Y 4/3)
Montagne drumlin

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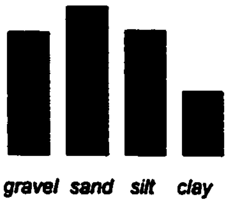
sample # 66 northing ? easting ?
field ID j2 collected 25/6/97 elevation (masl) ?

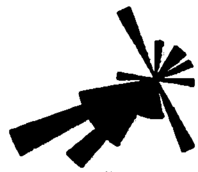
sieved Phi	%	**hydrometry** Phi	%
<-2	19	<3.6	33
-2 to -1	7.9	3.6-4.0	11
-1 to 0		4.0-4.5	3
0 - 1		4.5-5	4
1 - 2		5.0-5.6	6
2 - 3		5.6-6.2	7
3 - 4		6.1-6.4	2
>4		6.4-6.9	4
		6.9-7.3	4
		7.3-7.6	2
		7.6-7.8	1
		7.8-8.3	3
		8.8-8.8	1
		8.8-9.6	2
		>9.6	17

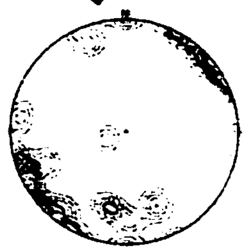
grain size	%
gravel	27
sand	32
silt	27
clay	14



clast roundness subangular to subrounded
other notes some shale
subangular large clasts

fabric, n= 27
mean azimuth 223
mean plunge 9
eigenvalue, S 0.67
S2 0.25
S3 0.08



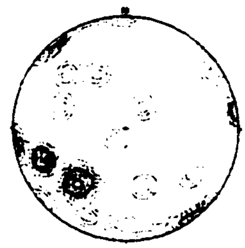


field notes red clay from 10-45 cm, 25 cm of silt below,
cobble layer at 70 cm
Montagne drumlin

sample # 67 | northing ? | easting ?
field ID j3 | collected 25/6/97 | elevation (masl) ?

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6		sand	0
-2 to -1		3.6-4.0		silt	0
-1 to 0		4.0-4.5		clay	0
0 - 1		4.5-5			
1 - 2		5.0-5.6		**clast roundness**	subrounded
2 - 3		5.6-6.2		**other notes**	
3 - 4		6.1-6.4			
>4		6.4-6.9		**fabric,** n=	26
		6.9-7.3		mean azimuth	226
		7.3-7.6		mean plunge	28
		7.6-7.8		eigenvalue, S	0.51
		7.8-8.3		S2	0.33
		8.8-8.8		S3	0.16
		8.8-9.6			
		>9.6			

gravel sand silt clay



field notes 70 cm clay w/20 cm quartzite clast, most clasts granite
Montagne drumlin

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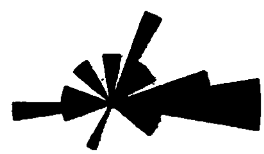
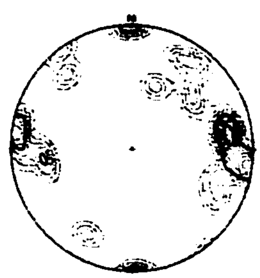
sample # 68 | northing ? | easting ?
field ID k1 | collected ? | elevation (masl) ?

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6		sand	0
-2 to -1		3.6-4.0		silt	0
-1 to 0		4.0-4.5		clay	0
0 - 1		4.5-5			
1 - 2		5.0-5.6		**clast roundness**	
2 - 3		5.6-6.2		**other notes**	
3 - 4		6.1-6.4			
>4		6.4-6.9		**fabric,** n=	26
		6.9-7.3		mean azimuth	86
		7.3-7.6		mean plunge	11
		7.6-7.8		eigenvalue, S	0.64
		7.8-8.3		S2	0.27
		8.8-8.8		S3	0.09
		8.8-9.6			
		>9.6			

gravel sand silt clay





field notes northeast of Stone Creek drumlins

sample # 69 northing ? easting ?

field ID n1 collected 13/7/97 elevation (masl) ?

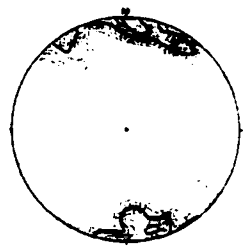
sieved Phi	%	**hydrometry** Phi	%
<-2	9.9	<3.6	21
-2 to -1	7.4	3.6-4.0	9
-1 to 0		4.0-4.5	4
0 - 1		4.5-5	5
1 - 2		5.0-5.6	8
2 - 3		5.6-6.2	4
3 - 4		6.1-6.4	4
>4		6.4-6.9	4
		6.9-7.3	3
		7.3-7.6	2
		7.6-7.8	1
		7.8-8.3	2
		8.8-8.8	3
		8.8-9.6	3
		>9.6	27

grain size	%
gravel	17
sand	25
silt	33
clay	25

clast roundness subangular

other notes subrounded large clasts

fabric, n= 26
mean azimuth 175
mean plunge 0
eigenvalue, S 0.82
S2 0.14
S3 0.04



field notes lower of 2 tills, lots of clay, few clasts
A. Gottesfeld observed more silt and quartzite clasts
Summit Lake quarried crag-and-tail

---

sample # 70 northing ? easting ?

field ID n2 collected 13/7/97 elevation (masl) ?

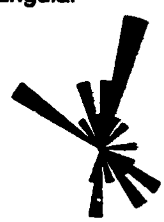
sieved Phi	%	**hydrometry** Phi	%
<-2	55	<3.6	22
-2 to -1	3.9	3.6-4.0	9
-1 to 0		4.0-4.5	4
0 - 1		4.5-5	5
1 - 2		5.0-5.6	5
2 - 3		5.6-6.2	6
3 - 4		6.1-6.4	3
>4		6.4-6.9	4
		6.9-7.3	5
		7.3-7.6	2
		7.6-7.8	1
		7.8-8.3	3
		8.8-8.8	3
		8.8-9.6	4
		>9.6	24

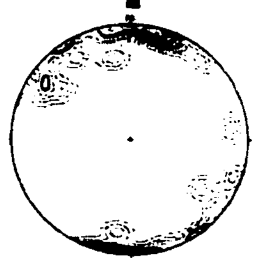
grain size	%
gravel	59
sand	13
silt	17
clay	12

clast roundness subangular

other notes

fabric, n= 26
mean azimuth 348
mean plunge 4
eigenvalue, S 0.7
S2 0.25
S3 0.05





field notes upper of 2 tills, coarser
Summit Lake crag-and-tail

sample # 71   northing ?   easting ?

field ID x2   collected 24/8/97   elevation (masl) ?

sieved

Phi	%
<-2	0
-2 to -1	41
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

Phi	%
<3.6	25
3.6-4.0	9
4.0-4.5	4
4.5-5	6
5.0-5.6	10
5.6-6.2	5
6.1-6.4	3
6.4-6.9	7
6.9-7.3	7
7.3-7.6	2
7.6-7.8	2
7.8-8.3	2
8.8-8.8	3
8.8-9.6	2
>9.6	13

grain size

	%
gravel	41
sand	20
silt	30
clay	9

clast roundness angular to subangular

other notes

fabric, n= 25

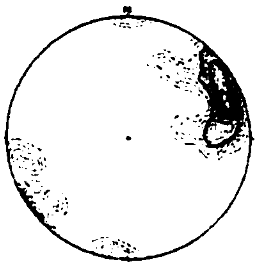
mean azimuth 63

mean plunge 14

eigenvalue, S 0.83

S2 0.11

S3 0.06



field notes 30-40% angular clasts, unconsolidated
Tabor Mountain rock drumlin tail

---

sample # 72   northing ?   easting ?

field ID i1   collected 24/6/97   elevation (masl) ?

sieved

Phi	%
<-2	0
-2 to -1	27
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

Phi	%
<3.6	15
3.6-4.0	12
4.0-4.5	4
4.5-5	2
5.0-5.6	3
5.6-6.2	3
6.1-6.4	2
6.4-6.9	2
6.9-7.3	5
7.3-7.6	1
7.6-7.8	2
7.8-8.3	4
8.8-8.8	4
8.8-9.6	6
>9.6	35

grain size

	%
gravel	27
sand	20
silt	23
clay	30

clast roundness subangular

other notes

fabric, n= 26

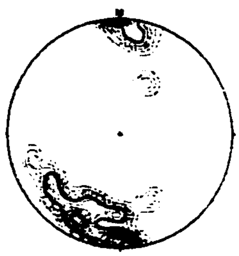
mean azimuth 197

mean plunge 15

eigenvalue, S 0.8

S2 0.12

S3 0.08



field notes 2.5Y 4/3, rounded gravel and cobbles throughout
Powerline drumlin

sample # 73 | northing ? | easting ?

field ID i2 | collected 24/6/97 | elevation (masl) ?

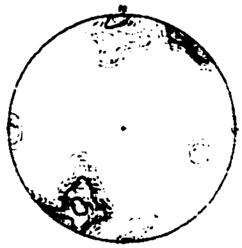
sieved Phi	%	hydrometry Phi	%
<-2	63	<3.6	
-2 to -1	8.5	3.6-4.0	
-1 to 0	4.4	4.0-4.5	
0 - 1	6.6	4.5-5	
1 - 2	8.6	5.0-5.6	
2 - 3	4.6	5.6-6.2	
3 - 4	3.1	6.1-6.4	
>4	1.6	6.4-6.9	
		6.9-7.3	
		7.3-7.6	
		7.6-7.8	
		7.8-8.3	
		8.8-8.8	
		8.8-9.6	
		>9.6	

grain size	%
gravel	71
sand	28
silt	0
clay	0

clast roundness

other notes

fabric, n= 26
mean azimuth 204
mean plunge 9
eigenvalue, S 0.75
S2 0.15
S3 0.10



field notes pebble matrix w/gravel and cobbles throughout
Powerline drumlin

---

sample # 74 | northing ? | easting ?

field ID i3 clay | collected 24/6/97 | elevation (masl) ?

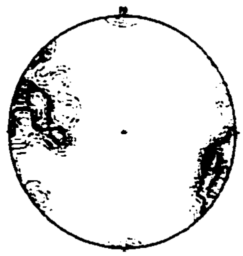
sieved Phi	%	hydrometry Phi	%
<-2	16	<3.6	3
-2 to -1	18	3.6-4.0	5
-1 to 0		4.0-4.5	4
0 - 1		4.5-5	1
1 - 2		5.0-5.6	2
2 - 3		5.6-6.2	5
3 - 4		6.1-6.4	3
>4		6.4-6.9	6
		6.9-7.3	7
		7.3-7.6	5
		7.6-7.8	7
		7.8-8.3	12
		8.8-8.8	8
		8.8-9.6	12
		>9.6	20

grain size	%
gravel	34
sand	5
silt	40
clay	21

clast roundness subangular to subrounded

other notes light colour, reddish

fabric, n= 26
mean azimuth 285
mean plunge 7
eigenvalue, S 0.78
S2 0.13
S3 0.09



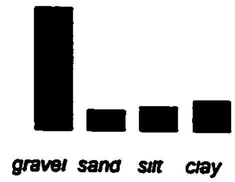
field notes 10YR 5/3, pebbles only
Powerline drumlin

sample # 75 northing ? easting ?
field ID i3 collected 24/6/97 elevation (masl) ?

sieved Phi	%
<-2	53
-2 to -1	9.1
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

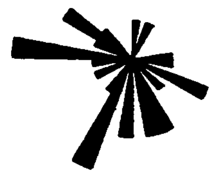
hydrometry Phi	%
<3.6	15
3.6-4.0	12
4.0-4.5	4
4.5-5	2
5.0-5.6	3
5.6-6.2	3
6.1-6.4	2
6.4-6.9	2
6.9-7.3	5
7.3-7.6	1
7.6-7.8	2
7.8-8.3	4
8.8-8.8	4
8.8-9.6	6
>9.6	35

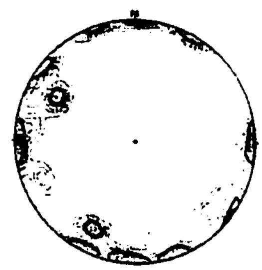
grain size	%
gravel	62
sand	10
silt	12
clay	15



clast roundness subrounded
other notes

fabric, n= 26
mean azimuth 137
mean plunge 2
eigenvalue, S 0.55
S2 0.42
S3 0.04





field notes 10YR 5/3, interbedded with clay
Powerline drumlin

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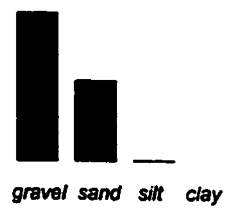
sample # 76 northing ? easting ?
field ID i4 collected 24/6/97 elevation (masl) ?

sieved Phi	%
<-2	58
-2 to -1	6.3
-1 to 0	8.8
0 - 1	12
1 - 2	1.9
2 - 3	7.5
3 - 4	4.2
>4	1.1

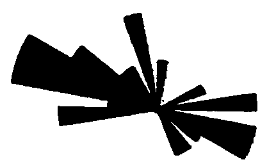
hydrometry Phi	%
<3.6	
3.6-4.0	
4.0-4.5	
4.5-5	
5.0-5.6	
5.6-6.2	
6.1-6.4	
6.4-6.9	
6.9-7.3	
7.3-7.6	
7.6-7.8	
7.8-8.3	
8.8-8.8	
8.8-9.6	
>9.6	

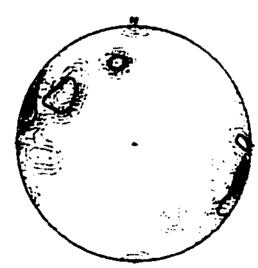
grain size	%
gravel	65
sand	35
silt	0
clay	0



clast roundness
other notes

fabric, n= 26
mean azimuth 295
mean plunge 7
eigenvalue, S 0.75
S2 0.17
S3 0.08





field notes cobbles throughout, some stacked
Powerline drumlin

sample # 77 northing ? easting ?
field ID i5 collected 24/6/97 elevation (masl) ?

sieved Phi	%	**hydrometry** Phi	%	**grain size**	%
<-2		<3.6		gravel	0
-2 to -1		3.6-4.0		sand	0
-1 to 0		4.0-4.5		silt	0
0 - 1		4.5-5		clay	100
1 - 2		5.0-5.6			
2 - 3		5.6-6.2			
3 - 4		6.1-6.4			
>4		6.4-6.9			
		6.9-7.3			
		7.3-7.6			
		7.6-7.8			
		7.8-8.3			
		8.8-8.8			
		8.8-9.6			
		>9.6			

clast roundness
other notes

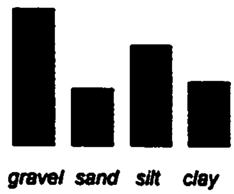
fabric, n=
mean azimuth n/a
mean plunge
eigenvalue, S1
S2
S3

field notes solid clay, no pebbles (estimated grain size, sample lost)
Powerline drumlin

---

sample # 78 northing ? easting ?
field ID i6 collected 19/8/97 elevation (masl) ?

sieved Phi	%	**hydrometry** Phi	%	**grain size**	%
<-2	0	<3.6	21	gravel	38
-2 to -1	38	3.6-4.0	4.6	sand	16
-1 to 0		4.0-4.5	2.4	silt	28
0 - 1		4.5-5	2	clay	18
1 - 2		5.0-5.6	1		
2 - 3		5.6-6.2	1		
3 - 4		6.1-6.4	4		
>4		6.4-6.9	2		
		6.9-7.3	5		
		7.3-7.6	5		
		7.6-7.8	3		
		7.8-8.3	10		
		8.8-8.8	10		
		8.8-9.6	9		
		>9.6	20		



clast roundness subangular
other notes subrounded large clasts

fabric, n=
mean azimuth n/a
mean plunge
eigenvalue, S1
S2
S3

field notes almost clast-supported, rounded cobble layer at 30 cm, clay lens below
Powerline drumlin

sample # 79 | northing ? | easting ?
field ID a32 | collected 23/8/97 | elevation (masl) ?

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	8
<-2	5.8	<3.6		sand	89
-2 to -1	2.6	3.6-4.0		silt	2
-1 to 0	2.5	4.0-4.5		clay	0
0 - 1	12	4.5-5			
1 - 2	54	5.0-5.6		**clast roundness**	subrounded to subangular
2 - 3	16	5.6-6.2		**other notes**	
3 - 4	4.3	6.1-6.4			
>4	2.4	6.4-6.9		**fabric,** n=	n/a
		6.9-7.3		mean azimuth	
		7.3-7.6		mean plunge	
		7.6-7.8		eigenvalue, S1	
		7.8-8.3		S2	
		8.8-8.8		S3	
		8.8-9.6			
		>9.6			

field notes between 2 middle drumlins, horizontal beds of sand
Powerline drumlins

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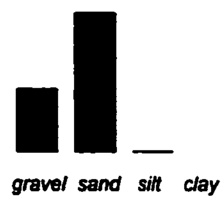
sample # 80 | northing ? | easting ?
field ID a33 | collected 23/8/97 | elevation (masl) ?

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	31
<-2	27	<3.6		sand	69
-2 to -1	4.2	3.6-4.0		silt	0
-1 to 0	3.1	4.0-4.5		clay	0
0 - 1	16	4.5-5			
1 - 2	36	5.0-5.6		**clast roundness**	
2 - 3	10	5.6-6.2		**other notes**	
3 - 4	2.5	6.1-6.4			
>4	0.6	6.4-6.9		**fabric,** n=	n/a
		6.9-7.3		mean azimuth	
		7.3-7.6		mean plunge	
		7.6-7.8		eigenvalue, S1	
		7.8-8.3		S2	
		8.8-8.8		S3	
		8.8-9.6			
		>9.6			



field notes 10Yr 4/3, sand/gravel beds dip west
Powerline drumlins

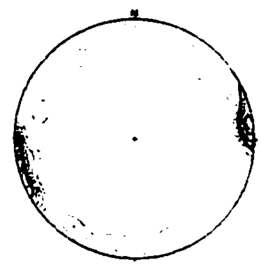
sample # 81 northing ? easting ?
field ID a34 collected 23/8/97 elevation (masl) ?

sieved Phi	%	**hydrometry** Phi	%
<-2	41	<3.6	16
-2 to -1	11	3.6-4.0	4
-1 to 0		4.0-4.5	3
0 - 1		4.5-5	3
1 - 2		5.0-5.6	6
2 - 3		5.6-6.2	5
3 - 4		6.1-6.4	4
>4		6.4-6.9	2
		6.9-7.3	5
		7.3-7.6	3
		7.6-7.8	3
		7.8-8.3	6
		8.8-8.8	10
		8.8-9.6	9
		>9.6	21

grain size	%
gravel	52
sand	10
silt	24
clay	14

clast roundness subangular to angular
other notes largest clast subrounded, light colour

fabric, n= 26
mean azimuth 69
mean plunge 2
eigenvalue, S 0.75
S2 0.22
S3 0.03



field notes rounded gravels
Powerline drumlins

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sample # 82 northing ? easting ?
field ID a35 collected 23/8/97 elevation (masl) ?

sieved Phi	%	**hydrometry** Phi	%
<-2		<3.6	
-2 to -1		3.6-4.0	
-1 to 0		4.0-4.5	
0 - 1		4.5-5	
1 - 2		5.0-5.6	
2 - 3		5.6-6.2	
3 - 4		6.1-6.4	
>4		6.4-6.9	
		6.9-7.3	
		7.3-7.6	
		7.6-7.8	
		7.8-8.3	
		8.8-8.8	
		8.8-9.6	
		>9.6	

grain size	%
gravel	0
sand	0
silt	0
clay	0

gravel sand silt clay

clast roundness
other notes

fabric, n= n/a
mean azimuth
mean plunge
eigenvalue, S1
S2
S3

field notes near top, solid clay (estimated, sample not collected)
westernmost Powerline drumlin

sample # 83 | northing ? | easting ?
field ID a36 | collected 23/8/97 | elevation (masl) ?

sieved

Phi	%
<-2	0
-2 to -1	24
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

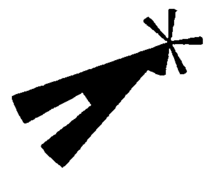
Phi	%
<3.6	19
3.6-4.0	7
4.0-4.5	4
4.5-5	7
5.0-5.6	4
5.6-6.2	6
6.1-6.4	4
6.4-6.9	4
6.9-7.3	6
7.3-7.6	1
7.6-7.8	4
7.8-8.3	2
8.8-8.8	3
8.8-9.6	3
>9.6	26

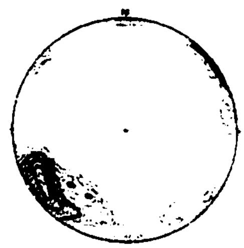
grain size	%
gravel	24
sand	20
silt	34
clay	22

clast roundness angular to subangular

other notes

fabric, n= 20
mean azimuth 229
mean plunge 13
eigenvalue, S 0.79
S2 0.19
S3 0.02





field notes 70% clay w/rounded gravels
near Stoner village

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sample # 84 | northing ? | easting ?
field ID july8a1 | collected 8/7/98 | elevation (masl) ?
lab ID 96

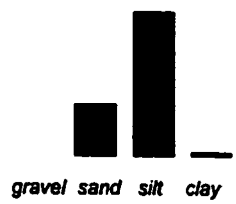
sieved

Phi	%
<-2	
-2 to -1	
-1 to 0	
0 - 1	
1 - 2	
2 - 3	
3 - 4	
>4	

hydrometry

Phi	%
<3.6	6
3.6-4.0	20
4.0-4.5	22
4.5-5	20
5.0-5.6	18
5.6-6.2	4
6.1-6.4	2
6.4-6.9	2
6.9-7.3	1
7.3-7.6	1
7.6-7.8	1
7.8-8.3	1
8.8-8.8	0
8.8-9.6	0
>9.6	2

grain size	%
gravel	0
sand	26
silt	72
clay	2



clast roundness

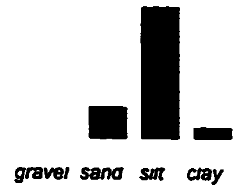
other notes

fabric, n= n/a
mean azimuth
mean plunge
eigenvalue, S1
S2
S3

field notes med. sand lens bench, 0.5 m thick, 25 m from top, visible from road
Nechako bluff

sample #	85	northing	?	easting	?
field ID	july8a2	collected	8/7/98	elevation (masl)	?
lab ID	97				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6	2	sand	18
-2 to -1		3.6-4.0	16	silt	76
-1 to 0		4.0-4.5	14	clay	6
0 - 1		4.5-5	16		
1 - 2		5.0-5.6	14	**clast roundness**	
2 - 3		5.6-6.2	12	**other notes**	
3 - 4		6.1-6.4	3		
>4		6.4-6.9	6	**fabric,** n=	n/a
		6.9-7.3	4	mean azimuth	
		7.3-7.6	2	mean plunge	
		7.6-7.8	2	eigenvalue, S1	
		7.8-8.3	1	S2	
		8.8-8.8	2	S3	
		8.8-9.6	2		
		>9.6	4		



field notes fine sand below med. sand bench, low angle x-bedding
Nechako bluff

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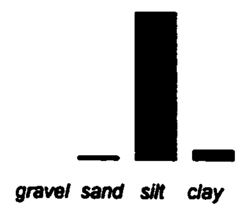
sample #	86	northing	?	easting	?
field ID	jul8a3	collected	8/7/98	elevation (masl)	?
lab ID	98				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6	0	sand	2
-2 to -1		3.6-4.0	2	silt	92
-1 to 0		4.0-4.5	8	clay	6
0 - 1		4.5-5	14		
1 - 2		5.0-5.6	20	**clast roundness**	
2 - 3		5.6-6.2	14	**other notes**	dark colour
3 - 4		6.1-6.4	9		
>4		6.4-6.9	10	**fabric,** n=	n/a
		6.9-7.3	5	mean azimuth	
		7.3-7.6	4	mean plunge	
		7.6-7.8	3	eigenvalue, S1	
		7.8-8.3	3	S2	
		8.8-8.8	2	S3	
		8.8-9.6	2		
		>9.6	4		



field notes 1.5 m fine sand above bench, climbing ripples to NE
eroded, disturbed silt/sand above
Nechako bluff

sample # 87 northing ? easting ?
field ID july8a4 collected 8/7/98 elevation (masl) ?
lab ID 99

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6	14	sand	30
-2 to -1		3.6-4.0	16	silt	67
-1 to 0		4.0-4.5	14	clay	3
0 - 1		4.5-5	20		
1 - 2		5.0-5.6	16	**clast roundness**	
2 - 3		5.6-6.2	6	**other notes**	
3 - 4		6.1-6.4	2		
>4		6.4-6.9	4	**fabric,** n=	n/a
		6.9-7.3	2	mean azimuth	
		7.3-7.6	1	mean plunge	
		7.6-7.8	1	eigenvalue, S1	
		7.8-8.3	1	S2	
		8.8-8.8	0	S3	
		8.8-9.6	0		
		>9.6	3		

field notes silt above disturbed silt/sand, alternating silt and sand beds above Strathnever drumlins

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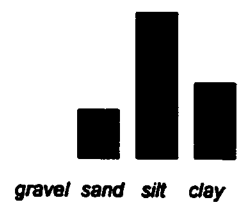
sample # 88 northing 5933839 easting 523891
field ID july12#1 collected 12/7/98 elevation (masl) 666
lab ID 105

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6	16	sand	18
-2 to -1		3.6-4.0	2	silt	54
-1 to 0		4.0-4.5	2	clay	28
0 - 1		4.5-5	2		
1 - 2		5.0-5.6	2	**clast roundness**	
2 - 3		5.6-6.2	4	**other notes**	light colour
3 - 4		6.1-6.4	5		
>4		6.4-6.9	3	**fabric,** n=	n/a
		6.9-7.3	7	mean azimuth	
		7.3-7.6	7	mean plunge	
		7.6-7.8	2	eigenvalue, S1	
		7.8-8.3	10	S2	
		8.8-8.8	10	S3	
		8.8-9.6	12		
		>9.6	16		



field notes silt, above contact with gravels below
Strathnever drumlins

sample #	89	northing	5933827	easting	523863
field ID	july12#2	collected	12/7/98	elevation (masl)	664
lab ID	106				

sieved		**hydrometry**		**grain size**	**%**
Phi	%	Phi	%	gravel	19
<-2	15	<3.6		sand	80
-2 to -1	4.2	3.6-4.0		silt	1
-1 to 0	9.8	4.0-4.5		clay	0
0 - 1	29	4.5-5			
1 - 2	32	5.0-5.6		**clast roundness**	subrounded to subangular
2 - 3	6	5.6-6.2		**other notes**	quartzite, siltstone
3 - 4	2.6	6.1-6.4			
>4	1.8	6.4-6.9		**fabric,** n=	n/a
		6.9-7.3		mean azimuth	
		7.3-7.6		mean plunge	
		7.6-7.8		eigenvalue, S1	
		7.8-8.3		S2	
		8.8-8.8		S3	
		8.8-9.6			
		>9.6			

field notes sand & gravel below contact
Strathnever drumlins

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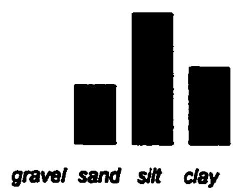
sample #	90	northing	5933860	easting	524112
field ID	july12#3	collected	12/7/98	elevation (masl)	694
lab ID	107				

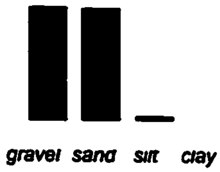
sieved		**hydrometry**		**grain size**	**%**
Phi	%	Phi	%	gravel	0
<-2		<3.6	20	sand	22
-2 to -1		3.6-4.0	2	silt	49
-1 to 0		4.0-4.5	1	clay	29
0 - 1		4.5-5	1		
1 - 2		5.0-5.6	4	**clast roundness**	
2 - 3		5.6-6.2	2	**other notes**	
3 - 4		6.1-6.4	2		
>4		6.4-6.9	3	**fabric,** n=	n/a
		6.9-7.3	4	mean azimuth	
		7.3-7.6	6	mean plunge	
		7.6-7.8	4	eigenvalue, S1	
		7.8-8.3	13	S2	
		8.8-8.8	9	S3	
		8.8-9.6	16		
		>9.6	13		



field notes nose of drumlin, hard, distorted, compacted silt
Strathnever drumlins, centre drumlin

sample #	91	northing	5933868	easting	524389
field ID	r071221a	collected	12/7/98	elevation (masl)	661
lab ID	159				

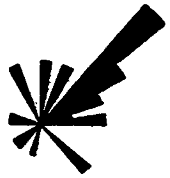
sieved Phi	%	**hydrometry** Phi	%	**grain size**	%
<-2	46	<3.6		gravel	49
-2 to -1	3.7	3.6-4.0		sand	49
-1 to 0	5.6	4.0-4.5		silt	2
0 - 1	28	4.5-5		clay	0
1 - 2	8.8	5.0-5.6			
2 - 3	3.2	5.6-6.2			
3 - 4	1.9	6.1-6.4			
>4	3.4	6.4-6.9			
		6.9-7.3			
		7.3-7.6			
		7.6-7.8			
		7.8-8.3			
		8.8-8.8			
		8.8-9.6			
		>9.6			

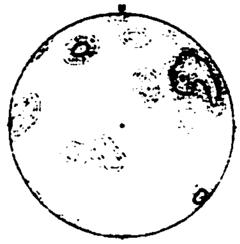


clast roundness subrounded

other notes quartzite, siltstone

fabric, n= 25
mean azimuth 56
mean plunge 23
eigenvalue, S 0.58
S2 0.25
S3 0.16





field notes behind barn, sand & gravel
Strathnever drumlins

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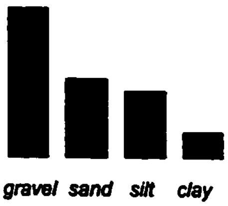
sample #	92	northing	5934015	easting	524550
field ID	r071222a	collected	12/7/98	elevation (masl)	665
lab ID	167				

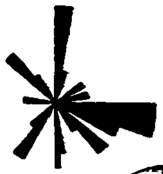
sieved Phi	%	**hydrometry** Phi	%	**grain size**	%
<-2	43	<3.6	42	gravel	47
-2 to -1	4.1	3.6-4.0	4	sand	25
-1 to 0		4.0-4.5	3	silt	21
0 - 1		4.5-5	4	clay	8
1 - 2		5.0-5.6	5		
2 - 3		5.6-6.2	6		
3 - 4		6.1-6.4	4		
>4		6.4-6.9	4		
		6.9-7.3	3		
		7.3-7.6	2		
		7.6-7.8	2		
		7.8-8.3	3		
		8.8-8.8	3		
		8.8-9.6	4		
		>9.6	11		

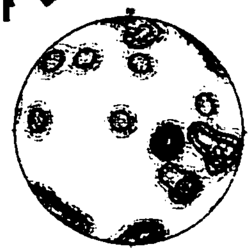


clast roundness subangular

other notes largest are rounded quartzite, light colour, yellow

fabric, n= 25
mean azimuth 105
mean plunge 32
eigenvalue, S 0.48
S2 0.35
S3 0.17





field notes sand & gravel NE of house
Strathnever drumlins

sample # 93 northing ? easting ?
field ID july14 hill collected 14/7/98 elevation (masl) ?
lab ID 108

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	40
<-2	38	<3.6	38	sand	25
-2 to -1	1.6	3.6-4.0	4	silt	26
-1 to 0		4.0-4.5	4	clay	9
0 - 1		4.5-5	4		
1 - 2		5.0-5.6	4	**clast roundness**	subrounded to subangular
2 - 3		5.6-6.2	2	**other notes**	quartzite, siltstone clasts
3 - 4		6.1-6.4	3		large rounded clasts
>4		6.4-6.9	4	**fabric,** n=	n/a
		6.9-7.3	6	mean azimuth	
		7.3-7.6	4	mean plunge	
		7.6-7.8	2	eigenvalue, S1	
		7.8-8.3	6	S2	
		8.8-8.8	4	S3	
		8.8-9.6	6		
		>9.6	9		

field notes gravel on drumlin stoss end
easternmost Strathnever drumlin

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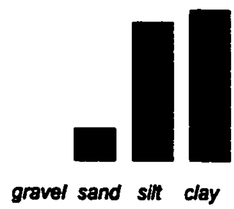
sample # 94 northing ? easting ?
field ID july14 fiel collected 14/7/98 elevation (masl) ?
lab ID 109

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6	6	sand	10
-2 to -1		3.6-4.0	4	silt	43
-1 to 0		4.0-4.5	2	clay	47
0 - 1		4.5-5	2		
1 - 2		5.0-5.6	2	**clast roundness**	
2 - 3		5.6-6.2	2	**other notes**	
3 - 4		6.1-6.4	2		
>4		6.4-6.9	4	**fabric,** n=	n/a
		6.9-7.3	6	mean azimuth	
		7.3-7.6	4	mean plunge	
		7.6-7.8	3	eigenvalue, S1	
		7.8-8.3	8	S2	
		8.8-8.8	8	S3	
		8.8-9.6	10		
		>9.6	37		



field notes silt from fields
south Strathnever drumlin

sample #	95	northing	?	easting	?
field ID	18 of Jul	collected	18/7/98	elevation (masl)	?
lab ID	110				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	22
<-2	19	<3.6	42	sand	42
-2 to -1	2.8	3.6-4.0	12	silt	31
-1 to 0		4.0-4.5	10	clay	5
0 - 1		4.5-5	6		
1 - 2		5.0-5.6	5	**clast roundness**	
2 - 3		5.6-6.2	2	**other notes**	light colour
3 - 4		6.1-6.4	2		
>4		6.4-6.9	3	**fabric,** n=	n/a
		6.9-7.3	3	mean azimuth	
		7.3-7.6	1	mean plunge	
		7.6-7.8	1	eigenvalue, S1	
		7.8-8.3	3	S2	
		8.8-8.8	4	S3	
		8.8-9.6	3		
		>9.6	3		

field notes silt from top of Vanderhoof drumlin

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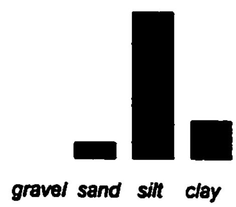
sample #	96	northing	?	easting	?
field ID	july18 N	collected	18/7/98	elevation (masl)	?
lab ID	111				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6	4	sand	8
-2 to -1		3.6-4.0	4	silt	73
-1 to 0		4.0-4.5	0	clay	19
0 - 1		4.5-5	1		
1 - 2		5.0-5.6	3	**clast roundness**	
2 - 3		5.6-6.2	5	**other notes**	dark colour, red
3 - 4		6.1-6.4	7		
>4		6.4-6.9	10	**fabric,** n=	n/a
		6.9-7.3	16	mean azimuth	
		7.3-7.6	8	mean plunge	
		7.6-7.8	6	eigenvalue, S1	
		7.8-8.3	8	S2	
		8.8-8.8	9	S3	
		8.8-9.6	7		
		>9.6	12		



field notes silt NW of drumlin stoss end
Vanderhoof drumlin

sample #	97	northing	?	easting	?
field ID	lee sand	collected	18/7/98	elevation (masl)	?
lab ID	113				

sieved		**hydrometry**		**grain size**	**%**
Phi	%	Phi	%	gravel	0
<-2	0	<3.6		sand	86
-2 to -1	0	3.6-4.0		silt	14
-1 to 0	0.5	4.0-4.5		clay	0
0 - 1	1	4.5-5			
1 - 2	6.6	5.0-5.6		**clast roundness**	
2 - 3	42	5.6-6.2		**other notes**	
3 - 4	36	6.1-6.4			
>4	14	6.4-6.9		**fabric,** n=	n/a
		6.9-7.3		mean azimuth	
		7.3-7.6		mean plunge	
		7.6-7.8		eigenvalue, S1	
		7.8-8.3		S2	
		8.8-8.8		S3	
		8.8-9.6			
		>9.6			

field notes lee end of Vanderhoof drumlin, sand, underlying silt beds

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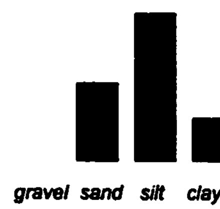
sample #	98	northing	?	easting	?
field ID	lee silt	collected	18/7/98	elevation (masl)	?
lab ID	114				

sieved		**hydrometry**		**grain size**	**%**
Phi	%	Phi	%	gravel	0
<-2		<3.6	26	sand	29
-2 to -1		3.6-4.0	3	silt	55
-1 to 0		4.0-4.5	1	clay	16
0 - 1		4.5-5	0		
1 - 2		5.0-5.6	1	**clast roundness**	
2 - 3		5.6-6.2	2	**other notes**	
3 - 4		6.1-6.4	3		
>4		6.4-6.9	8	**fabric,** n=	n/a
		6.9-7.3	14	mean azimuth	
		7.3-7.6	8	mean plunge	
		7.6-7.8	4	eigenvalue, S1	
		7.8-8.3	6	S2	
		8.8-8.8	8	S3	
		8.8-9.6	6		
		>9.6	10		



field notes silt, overlying sand
Vanderhoof drumlin, lee end

sample # 99 | northing ? | easting ?
field ID ssw west | collected 21/7/98 | elevation (masl) ?
lab ID 115

sieved		hydrometry		grain size	%
Phi	%	Phi	%	gravel	63
<-2	56	<3.6	42	sand	19
-2 to -1	6.9	3.6-4.0	8	silt	16
-1 to 0		4.0-4.5	4	clay	3
0 - 1		4.5-5	4		
1 - 2		5.0-5.6	10	**clast roundness**	angular
2 - 3		5.6-6.2	6	**other notes**	some shale
3 - 4		6.1-6.4	2		very dark colour
>4		6.4-6.9	6	**fabric,** n= n/a	
		6.9-7.3	4	mean azimuth	
		7.3-7.6	1	mean plunge	
		7.6-7.8	1	eigenvalue, S1	
		7.8-8.3	2	S2	
		8.8-8.8	2	S3	
		8.8-9.6	2		
		>9.6	6		

field notes shale drumlin, sand pocket

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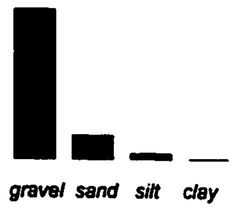
sample # 100 | northing ? | easting ?
field ID slope gr | collected 18/8/98 | elevation (masl) ?
lab ID 157

sieved		hydrometry		grain size	%
Phi	%	Phi	%	gravel	84
<-2	82	<3.6	76	sand	13
-2 to -1	1.9	3.6-4.0	4	silt	3
-1 to 0		4.0-4.5	6	clay	0
0 - 1		4.5-5	3		
1 - 2		5.0-5.6	3	**clast roundness**	subangular
2 - 3		5.6-6.2	3	**other notes**	igneous
3 - 4		6.1-6.4	0		dark colour
>4		6.4-6.9	1	**fabric,** n= n/a	
		6.9-7.3	0	mean azimuth	
		7.3-7.6	1	mean plunge	
		7.6-7.8	1	eigenvalue, S1	
		7.8-8.3	0	S2	
		8.8-8.8	1	S3	
		8.8-9.6	0		
		>9.6	1		



field notes Vanderhoof diamict, southwest slope

sample # 101 | northing ? | easting ?
field ID aug18a | collected 18/8/98 | elevation (masl) ?
lab ID 120

sieved Phi	%	**hydrometry** Phi	%
<-2	47	<3.6	52
-2 to -1	9.9	3.6-4.0	6
-1 to 0		4.0-4.5	2
0 - 1		4.5-5	4
1 - 2		5.0-5.6	4
2 - 3		5.6-6.2	2
3 - 4		6.1-6.4	4
>4		6.4-6.9	3
		6.9-7.3	4
		7.3-7.6	2
		7.6-7.8	2
		7.8-8.3	1
		8.8-8.8	2
		8.8-9.6	3
		>9.6	9

grain size	%
gravel	57
sand	25
silt	13
clay	5

clast roundness angular to subangular
other notes angular schist, rounded quartzite, dark colour

fabric, n= n/a
mean azimuth
mean plunge
eigenvalue, S1
S2
S3

field notes red coarse sand
survey between two middle Stone Creek drumlins

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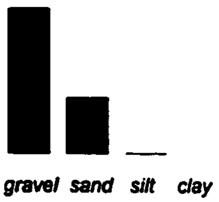
sample # 102 | northing ? | easting ?
field ID aug18b | collected 18/8/98 | elevation (masl) ?
lab ID 121

sieved Phi	%	**hydrometry** Phi	%
<-2	66	<3.6	
-2 to -1	6.2	3.6-4.0	
-1 to 0	8.3	4.0-4.5	
0 - 1	8.8	4.5-5	
1 - 2	6.8	5.0-5.6	
2 - 3	2.5	5.6-6.2	
3 - 4	0.9	6.1-6.4	
>4	0.5	6.4-6.9	
		6.9-7.3	
		7.3-7.6	
		7.6-7.8	
		7.8-8.3	
		8.8-8.8	
		8.8-9.6	
		>9.6	

grain size	%
gravel	72
sand	28
silt	0
clay	0



clast roundness subangular
other notes schist, quartzite, siltstone

fabric, n= n/a
mean azimuth
mean plunge
eigenvalue, S1
S2
S3

field notes large cobbles
survey between two middle Stone Creek drumlins

sample #	103	northing	?	easting	?
field ID	aug18c	collected	18/8/98	elevation (masl)	?
lab ID	122				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	41
<-2	35	<3.6	46	sand	33
-2 to -1	5.6	3.6-4.0	10	silt	21
-1 to 0		4.0-4.5	4	clay	5
0 - 1		4.5-5	4		
1 - 2		5.0-5.6	6	**clast roundness**	
2 - 3		5.6-6.2	5	**other notes**	
3 - 4		6.1-6.4	1		
>4		6.4-6.9	4	**fabric,** n=	n/a
		6.9-7.3	4	mean azimuth	
		7.3-7.6	2	mean plunge	
		7.6-7.8	1	eigenvalue, S1	
		7.8-8.3	3	S2	
		8.8-8.8	2	S3	
		8.8-9.6	3		
		>9.6	5		

field notes survey between two middle Stone Creek drumlins

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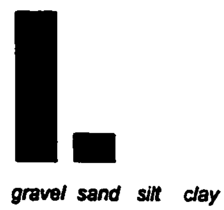
sample #	104	northing	?	easting	?
field ID	aug18d	collected	18/8/98	elevation (masl)	?
lab ID	123				

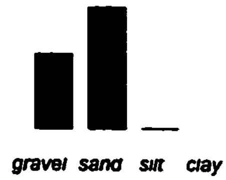
sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	84
<-2	74	<3.6		sand	16
-2 to -1	10	3.6-4.0		silt	0
-1 to 0	8.1	4.0-4.5		clay	0
0 - 1	3.9	4.5-5			
1 - 2	1.8	5.0-5.6		**clast roundness**	subangular
2 - 3	1	5.6-6.2		**other notes**	
3 - 4	0.6	6.1-6.4			
>4	0.4	6.4-6.9		**fabric,** n=	n/a
		6.9-7.3		mean azimuth	
		7.3-7.6		mean plunge	
		7.6-7.8		eigenvalue, S1	
		7.8-8.3		S2	
		8.8-8.8		S3	
		8.8-9.6			
		>9.6			



field notes survey between two middle Stone Creek drumlins

sample # 105 | northing ? | easting ?
field ID aug18e | collected 18/8/98 | elevation (masl) ?
lab ID 124

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	38
<-2	27	<3.6		sand	62
-2 to -1	11	3.6-4.0		silt	0
-1 to 0	19	4.0-4.5		clay	0
0 - 1	21	4.5-5			
1 - 2	17	5.0-5.6		**clast roundness**	subangular to subrounded
2 - 3	3.8	5.6-6.2		**other notes**	coal present
3 - 4	1	6.1-6.4			
>4	0.5	6.4-6.9		**fabric,** n=	n/a
		6.9-7.3		mean azimuth	
		7.3-7.6		mean plunge	
		7.6-7.8		eigenvalue, S1	
		7.8-8.3		S2	
		8.8-8.8		S3	
		8.8-9.6			
		>9.6			



field notes red sand, gravel poor
survey between two middle Stone Creek drumlins

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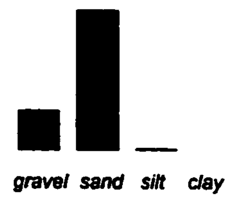
sample # 106 | northing ? | easting ?
field ID aug18f | collected 18/8/98 | elevation (masl) ?
lab ID 125

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	22
<-2	12	<3.6		sand	77
-2 to -1	10	3.6-4.0		silt	1
-1 to 0	21	4.0-4.5		clay	0
0 - 1	31	4.5-5			
1 - 2	21	5.0-5.6		**clast roundness**	angular
2 - 3	2.8	5.6-6.2		**other notes**	quartzite, siltstone clasts
3 - 4	1	6.1-6.4			
>4	0.9	6.4-6.9		**fabric,** n=	n/a
		6.9-7.3		mean azimuth	
		7.3-7.6		mean plunge	
		7.6-7.8		eigenvalue, S1	
		7.8-8.3		S2	
		8.8-8.8		S3	
		8.8-9.6			
		>9.6			



field notes well sorted sand
survey between two middle Stone Creek drumlins

sample #	107	northing	?	easting	?
field ID	aug18g	collected	18/8/98	elevation (masl)	?
lab ID	126				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	49
<-2	45	<3.6	59	sand	35
-2 to -1	3.8	3.6-4.0	10	silt	13
-1 to 0		4.0-4.5	4	clay	3
0 - 1		4.5-5	4		
1 - 2		5.0-5.6	6	**clast roundness**	subangular
2 - 3		5.6-6.2	2	**other notes**	1 large cobble
3 - 4		6.1-6.4	2		
>4		6.4-6.9	2	**fabric,** n=	n/a
		6.9-7.3	2	mean azimuth	
		7.3-7.6	1	mean plunge	
		7.6-7.8	1	eigenvalue, S1	
		7.8-8.3	1	S2	
		8.8-8.8	1	S3	
		8.8-9.6	1		
		>9.6	4		

field notes grey sand, 30% gravel & cobbles
survey between two middle Stone Creek drumlins

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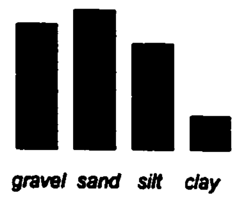
sample #	108	northing	?	easting	?
field ID	aug18h	collected	18/8/98	elevation (masl)	?
lab ID	127				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	31
<-2	26	<3.6	44	sand	35
-2 to -1	5	3.6-4.0	6	silt	26
-1 to 0		4.0-4.5	4	clay	8
0 - 1		4.5-5	6		
1 - 2		5.0-5.6	7	**clast roundness**	subangular
2 - 3		5.6-6.2	5	**other notes**	largest clast subrounded
3 - 4		6.1-6.4	1		
>4		6.4-6.9	3	**fabric,** n=	n/a
		6.9-7.3	3	mean azimuth	
		7.3-7.6	2	mean plunge	
		7.6-7.8	2	eigenvalue, S1	
		7.8-8.3	2	S2	
		8.8-8.8	3	S3	
		8.8-9.6	4		
		>9.6	8		



field notes 10% gravel
survey between two middle Stone Creek drumlins

sample # 109 northing ? easting ?
field ID aug18i collected 18/8/98 elevation (masl) ?
lab ID 128

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	33
<-2	29	<3.6	45	sand	34
-2 to -1	4.8	3.6-4.0	6	silt	26
-1 to 0		4.0-4.5	8	clay	7
0 - 1		4.5-5	6		
1 - 2		5.0-5.6	6	**clast roundness**	subangular
2 - 3		5.6-6.2	4	**other notes**	
3 - 4		6.1-6.4	4		
>4		6.4-6.9	2	**fabric,** n= n/a	
		6.9-7.3	1	mean azimuth	
		7.3-7.6	3	mean plunge	
		7.6-7.8	1	eigenvalue, S1	
		7.8-8.3	2	S2	
		8.8-8.8	2	S3	
		8.8-9.6	2		
		>9.6	8		

field notes poorly sorted, more fines than sample 108
survey between two middle Stone Creek drumlins

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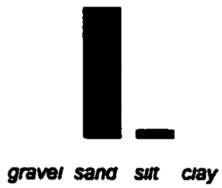
sample # 110 northing ? easting ?
field ID aug18j collected 18/8/98 elevation (masl) ?
lab ID 129

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	49
<-2	41	<3.6	47	sand	28
-2 to -1	8.1	3.6-4.0	8	silt	19
-1 to 0		4.0-4.5	4	clay	4
0 - 1		4.5-5	6		
1 - 2		5.0-5.6	6	**clast roundness**	subangular
2 - 3		5.6-6.2	4	**other notes**	
3 - 4		6.1-6.4	2		
>4		6.4-6.9	3	**fabric,** n= n/a	
		6.9-7.3	3	mean azimuth	
		7.3-7.6	3	mean plunge	
		7.6-7.8	1	eigenvalue, S1	
		7.8-8.3	3	S2	
		8.8-8.8	2	S3	
		8.8-9.6	2		
		>9.6	6		

field notes similar to sample 109
survey between two middle Stone Creek drumlins

sample #	111	northing	?	easting	?
field ID	aug18k	collected	18/8/98	elevation (masl)	?
lab ID	130				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2	0	<3.6		sand	94
-2 to -1	0	3.6-4.0		silt	6
-1 to 0	0.8	4.0-4.5		clay	0
0 - 1	0.7	4.5-5			
1 - 2	19	5.0-5.6		**clast roundness**	
2 - 3	54	5.6-6.2		**other notes**	
3 - 4	19	6.1-6.4			
>4	5.7	6.4-6.9		**fabric,** n=	n/a
		6.9-7.3		mean azimuth	
		7.3-7.6		mean plunge	
		7.6-7.8		eigenvalue, S1	
		7.8-8.3		S2	
		8.8-8.8		S3	
		8.8-9.6			
		>9.6			



field notes well-sorted medium sand
survey between two middle Stone Creek drumlins

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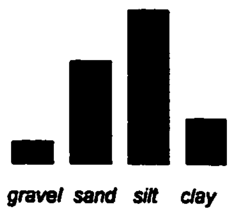
sample #	112	northing	?	easting	?
field ID	aug18l	collected	18/8/98	elevation (masl)	?
lab ID	131				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	7
<-2	4.5	<3.6	28	sand	32
-2 to -1	2.4	3.6-4.0	6	silt	47
-1 to 0		4.0-4.5	6	clay	14
0 - 1		4.5-5	8		
1 - 2		5.0-5.6	10	**clast roundness**	angular
2 - 3		5.6-6.2	4	**other notes**	light color
3 - 4		6.1-6.4	6		
>4		6.4-6.9	6	**fabric,** n=	n/a
		6.9-7.3	4	mean azimuth	
		7.3-7.6	2	mean plunge	
		7.6-7.8	2	eigenvalue, S1	
		7.8-8.3	2	S2	
		8.8-8.8	1	S3	
		8.8-9.6	3		
		>9.6	12		



field notes similar to sample 111
survey between two middle Stone Creek drumlins

sample # 113 northing ? easting ?
field ID aug18m collected 18/8/98 elevation (masl) ?
lab ID 132

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	36
<-2	31	<3.6	52	sand	37
-2 to -1	5	3.6-4.0	6	silt	22
-1 to 0		4.0-4.5	6	clay	5
0 - 1		4.5-5	4		
1 - 2		5.0-5.6	2	**clast roundness**	subangular
2 - 3		5.6-6.2	6	**other notes**	dark red colour, 1 50g cobble
3 - 4		6.1-6.4	2		
>4		6.4-6.9	4	**fabric,** n=	n/a
		6.9-7.3	4	mean azimuth	
		7.3-7.6	1	mean plunge	
		7.6-7.8	2	eigenvalue, S1	
		7.8-8.3	2	S2	
		8.8-8.8	1	S3	
		8.8-9.6	2		
		>9.6	6		

field notes poorly sorted
survey between two middle Stone Creek drumlins

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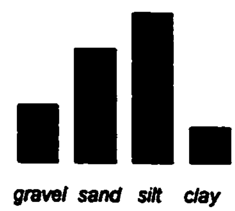
sample # 114 northing ? easting ?
field ID aug18n collected 18/8/98 elevation (masl) ?
lab ID 133

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	16
<-2	11	<3.6	32	sand	32
-2 to -1	5.3	3.6-4.0	6	silt	42
-1 to 0		4.0-4.5	6	clay	10
0 - 1		4.5-5	9		
1 - 2		5.0-5.6	9	**clast roundness**	subangular
2 - 3		5.6-6.2	6	**other notes**	
3 - 4		6.1-6.4	4		
>4		6.4-6.9	4	**fabric,** n=	n/a
		6.9-7.3	4	mean azimuth	
		7.3-7.6	2	mean plunge	
		7.6-7.8	1	eigenvalue, S1	
		7.8-8.3	2	S2	
		8.8-8.8	3	S3	
		8.8-9.6	2		
		>9.6	10		



field notes sand, cobbles, boulders
survey between two middle Stone Creek drumlins

sample # 115 northing ? easting ?
field ID aug18o collected 18/8/98 elevation (masl) ?
lab ID 134

sieved Phi	%	**hydrometry** Phi	%	**grain size**	%
<-2	19	<3.6	48	gravel	23
-2 to -1	3.5	3.6-4.0	8	sand	43
-1 to 0		4.0-4.5	6	silt	27
0 - 1		4.5-5	4	clay	7
1 - 2		5.0-5.6	2	**clast roundness**	
2 - 3		5.6-6.2	6	**other notes**	dark colour
3 - 4		6.1-6.4	3		
>4		6.4-6.9	4	**fabric,** n=	n/a
		6.9-7.3	3	mean azimuth	
		7.3-7.6	3	mean plunge	
		7.6-7.8	1	eigenvalue, S1	
		7.8-8.3	1	S2	
		8.8-8.8	2	S3	
		8.8-9.6	3		
		>9.6	6		

field notes sand, gravel
survey between two middle Stone Creek drumlins

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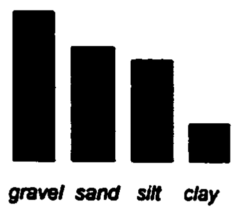
sample # 116 northing ? easting ?
field ID aug18p collected 18/8/98 elevation (masl) ?
lab ID 135

sieved Phi	%	**hydrometry** Phi	%	**grain size**	%
<-2	31	<3.6	37	gravel	37
-2 to -1	6	3.6-4.0	8	sand	28
-1 to 0		4.0-4.5	4	silt	25
0 - 1		4.5-5	4	clay	9
1 - 2		5.0-5.6	6	**clast roundness**	subangular
2 - 3		5.6-6.2	4	**other notes**	
3 - 4		6.1-6.4	4		
>4		6.4-6.9	4	**fabric,** n=	n/a
		6.9-7.3	4	mean azimuth	
		7.3-7.6	2	mean plunge	
		7.6-7.8	2	eigenvalue, S1	
		7.8-8.3	3	S2	
		8.8-8.8	3	S3	
		8.8-9.6	3		
		>9.6	12		



field notes survey between two middle Stone Creek drumlins

sample #	117	northing	?	easting	?
field ID	aug18q	collected	18/8/98	elevation (masl)	?
lab ID	136				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%		
<-2	20	<3.6		gravel	26
-2 to -1	5.7	3.6-4.0		sand	73
-1 to 0	11	4.0-4.5		silt	1
0 - 1	13	4.5-5		clay	0
1 - 2	15	5.0-5.6		**clast roundness**	subangular
2 - 3	19	5.6-6.2		**other notes**	
3 - 4	14	6.1-6.4			
>4	1.9	6.4-6.9		**fabric,** n=	n/a
		6.9-7.3		mean azimuth	
		7.3-7.6		mean plunge	
		7.6-7.8		eigenvalue, S1	
		7.8-8.3		S2	
		8.8-8.8		S3	
		8.8-9.6			
		>9.6			

field notes survey between two middle Stone Creek drumlins

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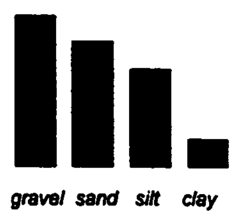
sample #	118	northing	?	easting	?
field ID	aug18r	collected	19/8/99	elevation (masl)	?
lab ID	137				

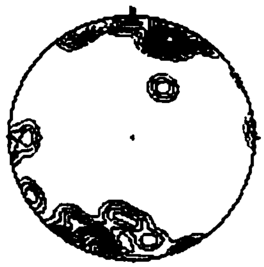
sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%		
<-2	31	<3.6	42	gravel	38
-2 to -1	6.4	3.6-4.0	8	sand	31
-1 to 0		4.0-4.5	6	silt	24
0 - 1		4.5-5	2	clay	7
1 - 2		5.0-5.6	8	**clast roundness**	angular to subangular
2 - 3		5.6-6.2	7	**other notes**	some schist, light colour
3 - 4		6.1-6.4	2		angular large clasts
>4		6.4-6.9	4	**fabric,** n=	n/a
		6.9-7.3	3	mean azimuth	
		7.3-7.6	2	mean plunge	
		7.6-7.8	2	eigenvalue, S1	
		7.8-8.3	1	S2	
		8.8-8.8	2	S3	
		8.8-9.6	3		
		>9.6	8		



field notes sandy diamict
survey between two middle Stone Creek drumlins

sample #	119	northing	?		easting	?
field ID	98h	collected	19/08/98		elevation (masl)	?
lab ID	138					
sieved		**hydrometry**		**grain size**		%
Phi	%	Phi	%	gravel		0
<-2		<3.6		sand		0
-2 to -1		3.6-4.0		silt		0
-1 to 0		4.0-4.5		clay		0
0 - 1		4.5-5				
1 - 2		5.0-5.6		**clast roundness**		
2 - 3		5.6-6.2		**other notes**		
3 - 4		6.1-6.4				
>4		6.4-6.9		**fabric,** n=	25	
		6.9-7.3		mean azimuth	198	
		7.3-7.6		mean plunge	0	
		7.6-7.8		eigenvalue, S	0.76	
		7.8-8.3		S2	0.16	
		8.8-8.8		S3	0.08	
		8.8-9.6				
		>9.6				

gravel sand silt clay



field notes quartzite and basalt clasts
subangular to subrounded
near small lake NW of Summit Lake crag and tail

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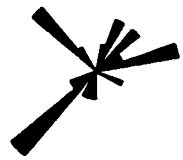
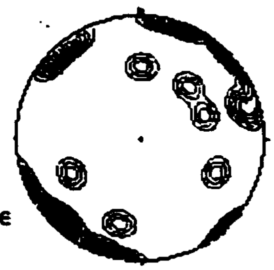
sample #	120	northing	?		easting	?
field ID	98i	collected	19/08/98		elevation (masl)	?
lab ID	139					
sieved		**hydrometry**		**grain size**		%
Phi	%	Phi	%	gravel		0
<-2		<3.6		sand		0
-2 to -1		3.6-4.0		silt		0
-1 to 0		4.0-4.5		clay		0
0 - 1		4.5-5				
1 - 2		5.0-5.6		**clast roundness**		
2 - 3		5.6-6.2		**other notes**		
3 - 4		6.1-6.4				
>4		6.4-6.9		**fabric,** n=	25	
		6.9-7.3		mean azimuth	40	
		7.3-7.6		mean plunge	2	
		7.6-7.8		eigenvalue, S	0.63	
		7.8-8.3		S2	0.27	
		8.8-8.8		S3	0.10	
		8.8-9.6				
		>9.6				

gravel sand silt clay

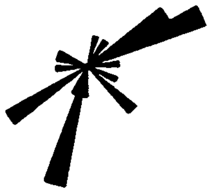


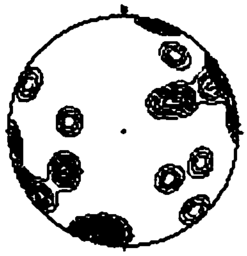


field notes Cale Creek Forestry Road, 1 km south of small lake

sample #	121	northing	?	easting	?
field ID	98g	collected	20/8/98	elevation (masl)	?
lab ID	140				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	69
<-2	66	<3.6	35	sand	14
-2 to -1	3.1	3.6-4.0	8	silt	12
-1 to 0		4.0-4.5	4	clay	6
0 - 1		4.5-5	4		
1 - 2		5.0-5.6	6	**clast roundness**	subangular
2 - 3		5.6-6.2	4	**other notes**	largest clasts subrounded
3 - 4		6.1-6.4	4		
>4		6.4-6.9	2	**fabric,** n=	25
		6.9-7.3	3	mean azimuth	46
		7.3-7.6	3	mean plunge	0
		7.6-7.8	2	eigenvalue, S	0.58
		7.8-8.3	3	S2	0.27
		8.8-8.8	3	S3	0.15
		8.8-9.6	4		
		>9.6	15		





field notes sand/gravel, rounded clasts
south of Macleod Lake

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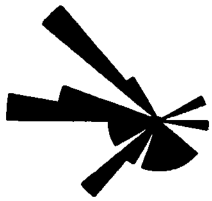
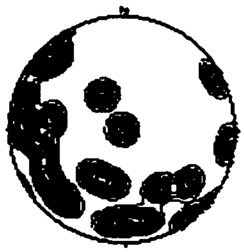
sample #	122	northing	?	easting	?
field ID	aug20b	collected	20/9/98	elevation (masl)	?
lab ID	141				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6		sand	0
-2 to -1		3.6-4.0		silt	0
-1 to 0		4.0-4.5		clay	0
0 - 1		4.5-5			
1 - 2		5.0-5.6		**clast roundness**	
2 - 3		5.6-6.2		**other notes**	
3 - 4		6.1-6.4			
>4		6.4-6.9		**fabric,** n=	24
		6.9-7.3		mean azimuth	275
		7.3-7.6		mean plunge	19
		7.6-7.8		eigenvalue, S	0.50
		7.8-8.3		S2	0.38
		8.8-8.8		S3	0.12
		8.8-9.6			
		>9.6			

gravel sand silt clay



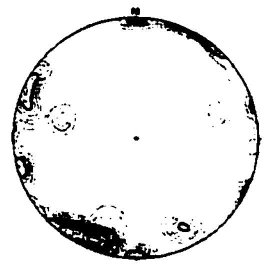


field notes diamict underlies 5 alternating beds of silt/clay
beds draped or tilted south west
64 km north of Mackenzie, on highway, may be disturbed

sample # 123 | northing ? | easting ?
field ID 98r | collected 21/8/98 | elevation (masl) ?
lab ID 142

sieved		**hydrometry**		**grain size**	**%**
Phi	%	Phi	%	gravel	0
<-2		<3.6		sand	0
-2 to -1		3.6-4.0		silt	0
-1 to 0		4.0-4.5		clay	0
0 - 1		4.5-5			
1 - 2		5.0-5.6		**clast roundness**	
2 - 3		5.6-6.2		**other notes**	
3 - 4		6.1-6.4			
>4		6.4-6.9		**fabric,** n=	25
		6.9-7.3		mean azimuth	212
		7.3-7.6		mean plunge	8
		7.6-7.8		eigenvalue, S	0.61
		7.8-8.3		S2	0.35
		8.8-8.8		S3	0.05
		8.8-9.6			
		>9.6			

gravel sand silt clay



field notes central Williston Lake area

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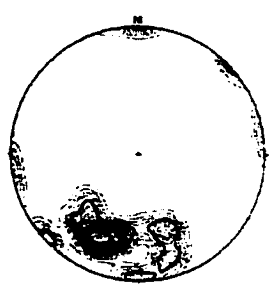
sample # 124 | northing ? | easting ?
field ID 98j | collected 21/8/98 | elevation (masl) ?
lab ID 143

sieved		**hydrometry**		**grain size**	**%**
Phi	%	Phi	%	gravel	0
<-2		<3.6		sand	0
-2 to -1		3.6-4.0		silt	0
-1 to 0		4.0-4.5		clay	0
0 - 1		4.5-5			
1 - 2		5.0-5.6		**clast roundness**	
2 - 3		5.6-6.2		**other notes**	
3 - 4		6.1-6.4			
>4		6.4-6.9		**fabric,** n=	25
		6.9-7.3		mean azimuth	199
		7.3-7.6		mean plunge	29
		7.6-7.8		eigenvalue, S	0.78
		7.8-8.3		S2	0.17
		8.8-8.8		S3	0.05
		8.8-9.6			
		>9.6			

gravel sand silt clay

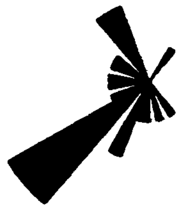


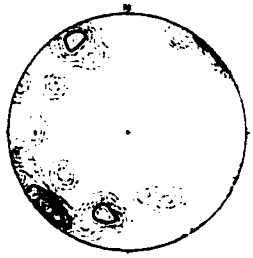
field notes 10 km north of MacKenzie turnoff
subangular to subrounded,
includes well-rounded quartzite pebbles

sample # 125 | northing ? | easting ?
field ID 98k | collected 22/8/98 | elevation (masl) ?
lab ID 144

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6		sand	0
-2 to -1		3.6-4.0		silt	0
-1 to 0		4.0-4.5		clay	0
0 - 1		4.5-5			
1 - 2		5.0-5.6		**clast roundness**	
2 - 3		5.6-6.2		**other notes**	
3 - 4		6.1-6.4			
>4		6.4-6.9		**fabric,** n=	24
		6.9-7.3		mean azimuth	218
		7.3-7.6		mean plunge	15
		7.6-7.8		eigenvalue, S	0.59
		7.8-8.3		S2	0.32
		8.8-8.8		S3	0.08
		8.8-9.6			
		>9.6			

gravel sand silt clay





field notes Moberly Lake diamict
subangular clasts

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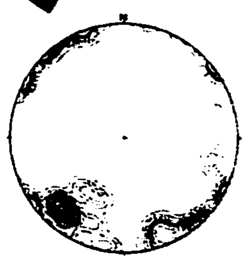
sample # 126 | northing ? | easting ?
field ID 98m | collected 22/8/98 | elevation (masl) ?
lab ID 145

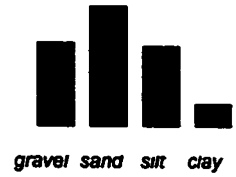
sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	9
<-2	5.5	<3.6	10	sand	12
-2 to -1	3	3.6-4.0	3	silt	59
-1 to 0		4.0-4.5	3	clay	20
0 - 1		4.5-5	5		
1 - 2		5.0-5.6	9	**clast roundness**	
2 - 3		5.6-6.2	7	**other notes**	
3 - 4		6.1-6.4	4		
>4		6.4-6.9	8	**fabric,** n=	25
		6.9-7.3	11	mean azimuth	186
		7.3-7.6	4	mean plunge	14
		7.6-7.8	2	eigenvalue, S	0.59
		7.8-8.3	5	S2	0.37
		8.8-8.8	7	S3	0.04
		8.8-9.6	6		
		>9.6	16		



field notes Finlay FSR, km 20
clast-poor till
metamorphic, incl. rounded quartzites

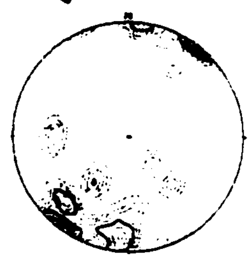
sample # 127 | northing ? | easting ?
field ID 98n | collected 22/8/98 | elevation (masl) ?
lab ID 146

sieved Phi	%	**hydrometry** Phi	%	**grain size**	%
<-2	22	<3.6	46	gravel	27
-2 to -1	5.1	3.6-4.0	8	sand	39
-1 to 0		4.0-4.5	4	silt	26
0 - 1		4.5-5	4	clay	7
1 - 2		5.0-5.6	8		
2 - 3		5.6-6.2	4		
3 - 4		6.1-6.4	4		
>4		6.4-6.9	2		
		6.9-7.3	3		
		7.3-7.6	2		
		7.6-7.8	1		
		7.8-8.3	2		
		8.8-8.8	2		
		8.8-9.6	2		
		>9.6	8		



clast roundness angular
other notes schist and quartzite
light colour, yellow

fabric, n= 26
mean azimuth 203
mean plunge 16
eigenvalue, S 0.72
S2 0.14
S3 0.14



field notes mostly igneous clasts, (granite, quartz)
Finlay FSR, km 106

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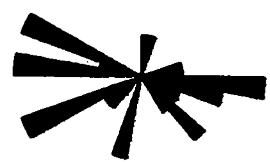
sample # 128 | northing ? | easting ?
field ID 98o | collected 22/8/98 | elevation (masl) ?
lab ID 147

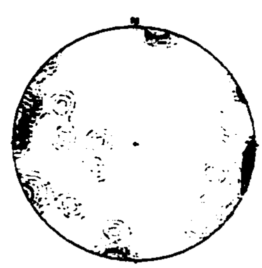
sieved Phi	%	**hydrometry** Phi	%	**grain size**	%
<-2		<3.6		gravel	0
-2 to -1		3.6-4.0		sand	0
-1 to 0		4.0-4.5		silt	0
0 - 1		4.5-5		clay	0
1 - 2		5.0-5.6			
2 - 3		5.6-6.2			
3 - 4		6.1-6.4			
>4		6.4-6.9			
		6.9-7.3			
		7.3-7.6			
		7.6-7.8			
		7.8-8.3			
		8.8-8.8			
		8.8-9.6			
		>9.6			

gravel sand silt clay

clast roundness
other notes

fabric, n= 28
mean azimuth 279
mean plunge 2
eigenvalue, S 0.61
S2 0.27
S3 0.12





field notes Finlay FSR, km 122
metamorphic (Schist), igneous, basalt, quartz

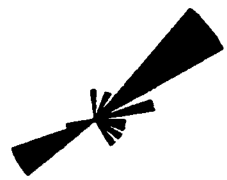
sample # 129 | northing ? | easting ?
field ID 98p | collected 23/8/98 | elevation (masl) ?
lab ID 148

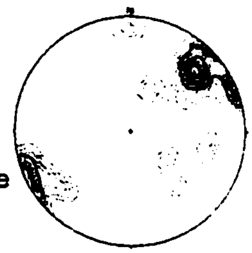
sieved Phi	%	**hydrometry** Phi	%
<-2	52	<3.6	25
-2 to -1	3.7	3.6-4.0	4
-1 to 0		4.0-4.5	2
0 - 1		4.5-5	4
1 - 2		5.0-5.6	4
2 - 3		5.6-6.2	6
3 - 4		6.1-6.4	6
>4		6.4-6.9	4
		6.9-7.3	6
		7.3-7.6	6
		7.6-7.8	6
		7.8-8.3	4
		8.8-8.8	4
		8.8-9.6	5
		>9.6	14

grain size	%
gravel	56
sand	13
silt	23
clay	8

clast roundness subangular to subrounded
other notes

fabric, n= 25
mean azimuth 58
mean plunge 15
eigenvalue, S 0.75
S2 0.15
S3 0.10





field notes schist, basalt,conglomerate, lots of quartz and jade

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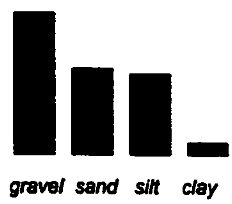
sample # 130 | northing ? | easting ?
field ID 98q | collected 23/8/98 | elevation (masl) ?
lab ID 149

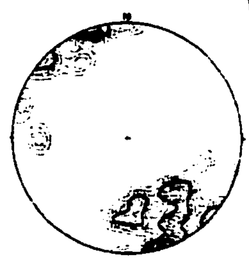
sieved Phi	%	**hydrometry** Phi	%
<-2	38	<3.6	38
-2 to -1	6.4	3.6-4.0	10
-1 to 0		4.0-4.5	6
0 - 1		4.5-5	7
1 - 2		5.0-5.6	7
2 - 3		5.6-6.2	8
3 - 4		6.1-6.4	2
>4		6.4-6.9	6
		6.9-7.3	3
		7.3-7.6	2
		7.6-7.8	1
		7.8-8.3	2
		8.8-8.8	1
		8.8-9.6	2
		>9.6	5

grain size	%
gravel	44
sand	27
silt	25
clay	4



clast roundness subangular
other notes schist and siltstone
light colour

fabric, n= 25
mean azimuth 150
mean plunge 17
eigenvalue, S 0.77
S2 0.14
S3 0.09



field notes metamorphic (schist), basalt, quartz

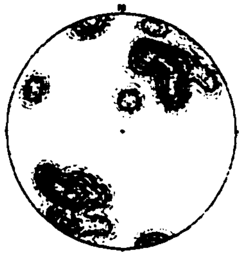
sample # 131 | northing ? | easting ?
field ID 98d | collected 24/8/98 | elevation (masl) ?
lab ID 150

sieved Phi	%	**hydrometry** Phi	%
<-2		<3.6	
-2 to -1		3.6-4.0	
-1 to 0		4.0-4.5	
0 - 1		4.5-5	
1 - 2		5.0-5.6	
2 - 3		5.6-6.2	
3 - 4		6.1-6.4	
>4		6.4-6.9	
		6.9-7.3	
		7.3-7.6	
		7.6-7.8	
		7.8-8.3	
		8.8-8.8	
		8.8-9.6	
		>9.6	

grain size	%
gravel	0
sand	0
silt	0
clay	0

clast roundness
other notes

fabric, n= 25
mean azimuth 32
mean plunge 5.6
eigenvalue, S 0.65
S2 0.23
S3 0.12



field notes
basalt, quartz, jade, conglomerate
west of Prince George,
diamict underlies 4 silt rhythmites

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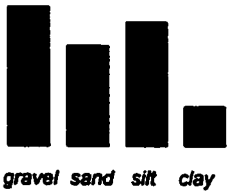
sample # 132 | northing ? | easting ?
field ID 98a | collected 24/8/98 | elevation (masl) ?
lab ID 151

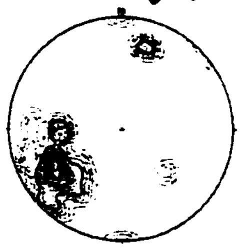
sieved Phi	%	**hydrometry** Phi	%
<-2	31	<3.6	32
-2 to -1	3.9	3.6-4.0	6
-1 to 0		4.0-4.5	5
0 - 1		4.5-5	3
1 - 2		5.0-5.6	6
2 - 3		5.6-6.2	5
3 - 4		6.1-6.4	4
>4		6.4-6.9	4
		6.9-7.3	7
		7.3-7.6	3
		7.6-7.8	2
		7.8-8.3	7
		8.8-8.8	1
		8.8-9.6	5
		>9.6	10

grain size	%
gravel	35
sand	25
silt	31
clay	10



clast roundness angular to subangular
other notes shale, siltstone, schist
large angular clasts

fabric, n= 25
mean azimuth 238
mean plunge 29
eigenvalue, S 0.8
S2 0.12
S3 0.08



field notes
basalt, quartz, jade, conglomerate
Tabor road, below lookout

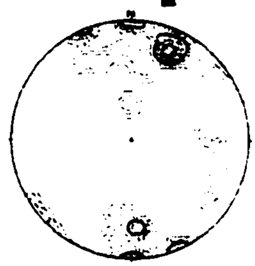
sample # 133 northing ? easting ?
field ID 98b collected 24/8/98 elevation (masl) ?
lab ID 152

sieved Phi	%	**hydrometry** Phi	%
<-2	49	<3.6	28
-2 to -1	5.5	3.6-4.0	10
-1 to 0		4.0-4.5	4
0 - 1		4.5-5	3
1 - 2		5.0-5.6	7
2 - 3		5.6-6.2	4
3 - 4		6.1-6.4	3
>4		6.4-6.9	3
		6.9-7.3	6
		7.3-7.6	2
		7.6-7.8	2
		7.8-8.3	3
		8.8-8.8	4
		8.8-9.6	5
		>9.6	16

grain size	%
gravel	54
sand	17
silt	19
clay	10

clast roundness angular
other notes shale, siltstone, schist
light colour

fabric, n= 26
mean azimuth 9
mean plunge 9
eigenvalue, S 0.63
S2 0.25
S3 0.11



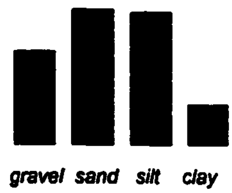
field notes schist, basalt, lots of quartz
angular to subrounded
18 km west of Giscome

---

sample # 134 northing ? easting ?
field ID 98c collected 24/8/98 elevation (masl) ?
lab ID 153

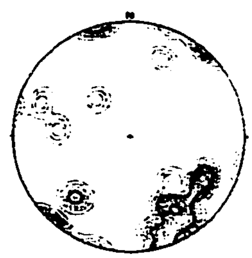
sieved Phi	%	**hydrometry** Phi	%
<-2	17	<3.6	36
-2 to -1	6.6	3.6-4.0	8
-1 to 0		4.0-4.5	6
0 - 1		4.5-5	5
1 - 2		5.0-5.6	7
2 - 3		5.6-6.2	6
3 - 4		6.1-6.4	4
>4		6.4-6.9	3
		6.9-7.3	3
		7.3-7.6	3
		7.6-7.8	1
		7.8-8.3	2
		8.8-8.8	3
		8.8-9.6	3
		>9.6	10

grain size	%
gravel	23
sand	34
silt	33
clay	10



clast roundness subangular
other notes

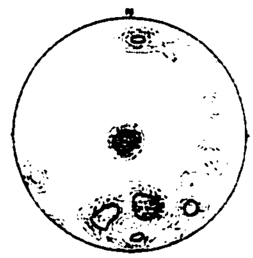
fabric, n= 25
mean azimuth 152
mean plunge 18
eigenvalue, S 0.61
S2 0.26
S3 0.13



field notes igneous and metamorphic clasts
sandy diamict
east of Giscome, 6 km west of Hwy 16

sample #	135	northing	?		easting	?	
field ID	98e	collected	24/8/98		elevation (masl)	?	
lab ID	154						
sieved		**hydrometry**			**grain size**		%
Phi	%	Phi	%		gravel		0
<-2		<3.6			sand		0
-2 to -1		3.6-4.0			silt		0
-1 to 0		4.0-4.5			clay		0
0 - 1		4.5-5					
1 - 2		5.0-5.6			**clast roundness**		
2 - 3		5.6-6.2			**other notes**		
3 - 4		6.1-6.4					
>4		6.4-6.9			**fabric,**	n=	25
		6.9-7.3			mean azimuth		173
		7.3-7.6			mean plunge		29
		7.6-7.8			eigenvalue, S		0.6
		7.8-8.3				S2	0.26
		8.8-8.8				S3	0.14
		8.8-9.6					
		>9.6					

gravel sand silt clay



field notes 6 km north of Summit Lake

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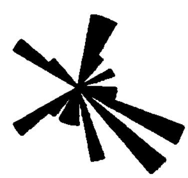
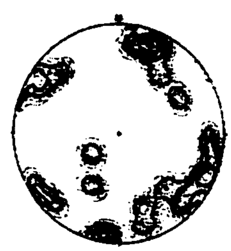
sample #	136	northing			easting		
field ID	98f	collected	24/8/98		elevation (masl)		
lab ID	155						
sieved		**hydrometry**			**grain size**		%
Phi	%	Phi	%		gravel		0
<-2		<3.6			sand		0
-2 to -1		3.6-4.0			silt		0
-1 to 0		4.0-4.5			clay		0
0 - 1		4.5-5					
1 - 2		5.0-5.6			**clast roundness**		
2 - 3		5.6-6.2			**other notes**		
3 - 4		6.1-6.4					
>4		6.4-6.9			**fabric,**	n=	25
		6.9-7.3			mean azimuth		187
		7.3-7.6			mean plunge		8.4
		7.6-7.8			eigenvalue, S		0.49
		7.8-8.3				S2	0.33
		8.8-8.8				S3	0.18
		8.8-9.6					
		>9.6					

gravel sand silt clay





field notes 5 km north of Summit Lake

sample # 137 northing ? easting ?
field ID aug23lt collected 23/8/98 elevation (masl) ?
lab ID 158

sieved		**hydrometry**		**grain size**	**%**
Phi	%	Phi	%	gravel	5
<-2	4	<3.6	28	sand	34
-2 to -1	1.4	3.6-4.0	8	silt	40
-1 to 0		4.0-4.5	4	clay	21
0 - 1		4.5-5	4		
1 - 2		5.0-5.6	3	**clast roundness**	
2 - 3		5.6-6.2	2	**other notes**	subrounded large clasts, dark red colour
3 - 4		6.1-6.4	3		
>4		6.4-6.9	3	**fabric,** n=	n/a
		6.9-7.3	5	mean azimuth	
		7.3-7.6	3	mean plunge	
		7.6-7.8	4	eigenvalue, S1	
		7.8-8.3	5	S2	
		8.8-8.8	6	S3	
		8.8-9.6	8		
		>9.6	14		

field notes silt west of Prince George (light)

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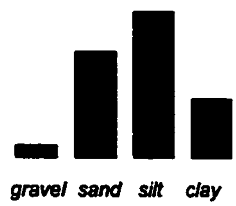
sample # 138 northing ? easting ?
field ID aug23dk collected 23/8/98 elevation (masl) ?
lab ID 166

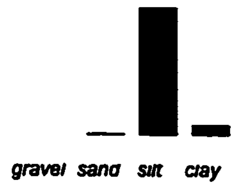
sieved		**hydrometry**		**grain size**	**%**
Phi	%	Phi	%	gravel	4
<-2	3.2	<3.6	28	sand	33
-2 to -1	0.6	3.6-4.0	6	silt	45
-1 to 0		4.0-4.5	4	clay	18
0 - 1		4.5-5	4		
1 - 2		5.0-5.6	6	**clast roundness**	angular
2 - 3		5.6-6.2	4	**other notes**	large clasts rounded, dark red colour
3 - 4		6.1-6.4	4		
>4		6.4-6.9	2	**fabric,** n=	n/a
		6.9-7.3	6	mean azimuth	
		7.3-7.6	3	mean plunge	
		7.6-7.8	3	eigenvalue, S1	
		7.8-8.3	5	S2	
		8.8-8.8	6	S3	
		8.8-9.6	7		
		>9.6	12		



field notes silt west of Prince George (dark)

sample # 139 northing ? easting ?
field ID Bluffs silt collected ? elevation (masl) ?
lab ID 161

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6	0	sand	1
-2 to -1		3.6-4.0	1	silt	92
-1 to 0		4.0-4.5	7	clay	7
0 - 1		4.5-5	11		
1 - 2		5.0-5.6	21	**clast roundness**	
2 - 3		5.6-6.2	13	**other notes**	
3 - 4		6.1-6.4	13		
>4		6.4-6.9	9	**fabric,** n=	n/a
		6.9-7.3	7	mean azimuth	
		7.3-7.6	4	mean plunge	
		7.6-7.8	2	eigenvalue, S1	
		7.8-8.3	4	S2	
		8.8-8.8	1	S3	
		8.8-9.6	2		
		>9.6	5		



field notes hako bluffs silt

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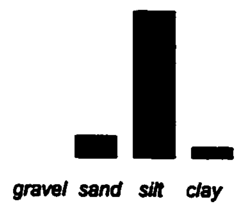
sample # 140 northing ? easting ?
field ID Bluffsand collected ? elevation (masl) ?
lab ID 162

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6	2	sand	12
-2 to -1		3.6-4.0	10	silt	82
-1 to 0		4.0-4.5	12	clay	6
0 - 1		4.5-5	18		
1 - 2		5.0-5.6	21	**clast roundness**	
2 - 3		5.6-6.2	10	**other notes**	
3 - 4		6.1-6.4	3		
>4		6.4-6.9	7	**fabric,** n=	n/a
		6.9-7.3	4	mean azimuth	
		7.3-7.6	3	mean plunge	
		7.6-7.8	2	eigenvalue, S1	
		7.8-8.3	2	S2	
		8.8-8.8	0	S3	
		8.8-9.6	1		
		>9.6	5		



field notes ako bluffs sand

sample #	141	northing	?	easting	?
field ID	Chubb	collected	21/7/98	elevation (masl)	?
lab ID	163				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6	8	sand	8
-2 to -1		3.6-4.0	0	silt	43
-1 to 0		4.0-4.5	0	clay	49
0 - 1		4.5-5	1		
1 - 2		5.0-5.6	0	**clast roundness**	
2 - 3		5.6-6.2	0	**other notes**	only 43.5 g sediment used
3 - 4		6.1-6.4	0		
>4		6.4-6.9	1	**fabric,** n= n/a	
		6.9-7.3	3	mean azimuth	
		7.3-7.6	5	mean plunge	
		7.6-7.8	2	eigenvalue, S1	
		7.8-8.3	18	S2	
		8.8-8.8	13	S3	
		8.8-9.6	23		
		>9.6	26		

field notes red/black clay
Chubb Lake road red/black clay

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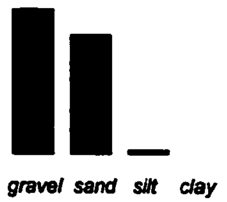
sample #	142	northing	?	easting	?
field ID	jun20up	collected	20/6/98	elevation (masl)	?
lab ID	160				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	54
<-2	47	<3.6		sand	44
-2 to -1	7.2	3.6-4.0		silt	2
-1 to 0	17	4.0-4.5		clay	0
0 - 1	9	4.5-5			
1 - 2	8.1	5.0-5.6		**clast roundness**	subrounded to subangular
2 - 3	5.3	5.6-6.2		**other notes**	schist, quartzite, siltstone
3 - 4	3.4	6.1-6.4			
>4	3.6	6.4-6.9		**fabric,** n= n/a	
		6.9-7.3		mean azimuth	
		7.3-7.6		mean plunge	
		7.6-7.8		eigenvalue, S1	
		7.8-8.3		S2	
		8.8-8.8		S3	
		8.8-9.6			
		>9.6			



field notes upper diamict, Hixon highway
mostly sand/gravel, overlain by cobble lag

sample # 143 northing ? easting ?
field ID jun20low collected 20/6/98 elevation (masl) ?
lab ID 164

sieved Phi	%	**hydrometry** Phi	%	**grain size**	%
<-2	28	<3.6	34	gravel	33
-2 to -1	4.3	3.6-4.0	6	sand	27
-1 to 0		4.0-4.5	4	silt	29
0 - 1		4.5-5	5	clay	11
1 - 2		5.0-5.6	5		
2 - 3		5.6-6.2	6		
3 - 4		6.1-6.4	4		
>4		6.4-6.9	4		
		6.9-7.3	4		
		7.3-7.6	3		
		7.6-7.8	2		
		7.8-8.3	5		
		8.8-8.8	1		
		8.8-9.6	5		
		>9.6	12		

clast roundness angular
other notes angular quartz, large subrounded quartzite

fabric, n= n/a
mean azimuth
mean plunge
eigenvalue, S1
S2
S3

field notes lower diamict, Hixon highway

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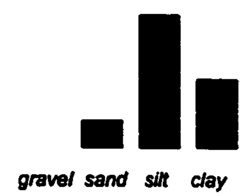
sample # 144 northing ? easting ?
field ID jul13top collected 13/7/98 elevation (masl) ?
lab ID 165

sieved Phi	%	**hydrometry** Phi	%	**grain size**	%
<-2		<3.6	10	gravel	0
-2 to -1		3.6-4.0	2	sand	12
-1 to 0		4.0-4.5	2	silt	58
0 - 1		4.5-5	0	clay	30
1 - 2		5.0-5.6	0		
2 - 3		5.6-6.2	2		
3 - 4		6.1-6.4	1		
>4		6.4-6.9	5		
		6.9-7.3	10		
		7.3-7.6	6		
		7.6-7.8	11		
		7.8-8.3	13		
		8.8-8.8	8		
		8.8-9.6	11		
		>9.6	19		



clast roundness angular
other notes

fabric, n= n/a
mean azimuth
mean plunge
eigenvalue, S1
S2
S3

field notes Vanderhoof silts (top)

sample #	145	northing		easting	
field ID		collected		elevation (masl)	
lab ID	156				

sieved		**hydrometry**		**grain size**	%
Phi	%	Phi	%	gravel	0
<-2		<3.6	22	sand	50
-2 to -1		3.6-4.0	28	silt	48
-1 to 0		4.0-4.5	22	clay	2
0 - 1		4.5-5	14		
1 - 2		5.0-5.6	8	**clast roundness**	
2 - 3		5.6-6.2	2	**other notes**	
3 - 4		6.1-6.4	1		
>4		6.4-6.9	1	**fabric,** n=	n/a
		6.9-7.3	0	mean azimuth	
		7.3-7.6	0	mean plunge	
		7.6-7.8	0	eigenvalue, S	
		7.8-8.3	0	S2	
		8.8-8.8	0	S3	
		8.8-9.6	0		
		>9.6	2		

field notes Macmillan bluffs sand