Quaternary Geology, Stratigraphy and Applied Geomorphology in the Southern Nechako Plateau, Central British Columbia

by

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We accept this thesis as conforming
to the required standard

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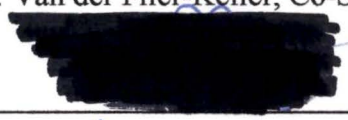

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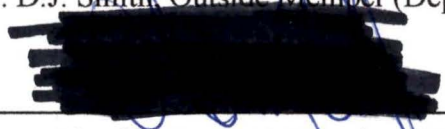

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## ABSTRACT

Erosion along the Nechako Reservoir and Skins Lake Spillway has resulted in unusually well exposed Quaternary and Holocene stratigraphy. Surficial sediments in the study area are mostly products of the Late Wisconsinan glaciation (Fraser). New evidence for pre-late Wisconsinan sedimentation has been found in a section along the shores of the Nechako Reservoir. Till of an older glaciation and organic-bearing, blue-grey, lacustrine sediments of probable Middle Wisconsinan age underlie younger sediments deposited during the Fraser Glaciation. Sediments deposited in front of the ice margin were overridden during ice advance and are locally preserved in the largest valleys.

Quaternary sediments cover most of the study area and large bedrock exposures are rare. The distribution of advance-phase glaciolacustrine sediments and associated deltaic deposits has shown that advance-phase lakes occurred at least up to several metres above the modern reservoir level (approximately 855 m). Till is the most common Pleistocene sediment covering approximately 80% of the area mainly as blankets greater than 1 metre thick. Retreat-phase glaciofluvial and glaciolacustrine deposits and fluvial sediments occur mainly along the Cheslatta River valley. Holocene bogs and swamps are common in low-lying areas between streamlined ridges.

Crag-and-tails, flutings, and drumlinoid ridges with a generally consistent northeast trend are the dominant landforms in the study area. Most stoss-ends of these forms consist of bedrock knobs, while ridges of till occur down-ice. Crescent and comma shaped erosional depressions wrap around these forms and are often filled with bogs or

standing water. They often combine to form large troughs oriented transverse to subglacial flow. It is concluded that these depressions are formed by subglacial meltwater floods. These floods have enhanced the preexisting subglacial topography and their progressive channelization is believed to have formed tunnel valleys within the region. These valleys are 1-2 km wide, flat-floored, steep sided and contain misfit streams and eskers in their bottoms.

Stratigraphic and geomorphic studies were conducted at several slope failures within the study area. Translational landslides are common along the shoreline of the Nechako Reservoir, in particular, Chelaslie Arm. They are approximately 15-50 m wide and usually extend 15-30 m up slope. Typically, these slides occur on southwest facing shorelines, consist of numerous small slump blocks and have main scarps less than a metre high. Slope movements in this area are smaller and have shallower rupture surfaces than those along the Cheslatta River.

Two active complex rotational-earthflow landslides were Investigated along a portion of the Cheslatta River that extends from a spillway at Ootsa Lake to Cheslatta Lake. Longitudinal profiles and detailed field observations were recorded at both slope movements. Slump 1 was approximately 34 m wide, 14 m high, has a 6 m high main scarp and one slump block. Slump 2 was approximately 230 m wide, 24 m high, had a 3 m high main scarp and three separate slump blocks. Both have amphitheatre shaped main scarps, some backward-tilted slump blocks, and earthflows and slickenside surfaces at their base. A small sag pond was also found at slump 2.

Several factors are responsible for translational slope movements. They include removal of lateral support by wave erosion at the base of shoreline slopes and shoreline

shaped erosional depressions wrap around these forms and are often filled with bogs or standing water. They often combine to form large troughs oriented transverse to subglacial flow. It is concluded that these depressions are formed by subglacial meltwater floods. These floods have enhanced the preexisting subglacial topography and their progressive channelization is believed to have formed tunnel valleys within the region. These valleys are 1-2 km wide, flat-floored, steep sided and contain misfit streams and eskers in their bottoms.

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# Dedication

In loving memory of Edward John Mate
who passed away on November 22, 1997.

# 1 INTRODUCTION

## 1.1 OVERVIEW

The purpose of this research is to describe and interpret the Quaternary geology and stratigraphy of a previously unstudied region of the Nechako Plateau. The study area focuses on the 1:50 000 scale Marilla map sheet (NTS 93 F/12) but also includes data from surrounding map areas, mainly the southern half of the Takysie Lake map sheet (NTS 93 F/13) (Fig. 1). Using surficial geology mapping (1:50 000 scale) and stratigraphic studies, this work provides an understanding of the distribution of Quaternary deposits and ice flow patterns and offers an interpretation for the glacial history of the study area. Unlike other regions in the Nechako Plateau, the Quaternary stratigraphy in this study area is exceptionally well exposed. The completion of the Nechako Reservoir (1952) is largely responsible for the abundance of large Quaternary sections. Geomorphic and stratigraphic data are also used to investigate the genesis of streamlined landforms within the study area and address slope stability issues along the banks of the Cheslatta River and shorelines of the Nechako Reservoir.

Besides providing information that increases geological understanding of Quaternary events in the region, this work is also beneficial for applied purposes. Data describing and interpreting the genesis of different tills in the area will help future prospectors locate suitable areas for drift exploration work and aid in the interpretation of till geochemical data. Stratigraphic and mapping information presented here is also useful for forestry terrain stability mapping within the Interior Plateau in general and provides relevant data relating to stability issues in specific locations such as the Skins Lake Spillway and Nechako Reservoir shoreline areas.

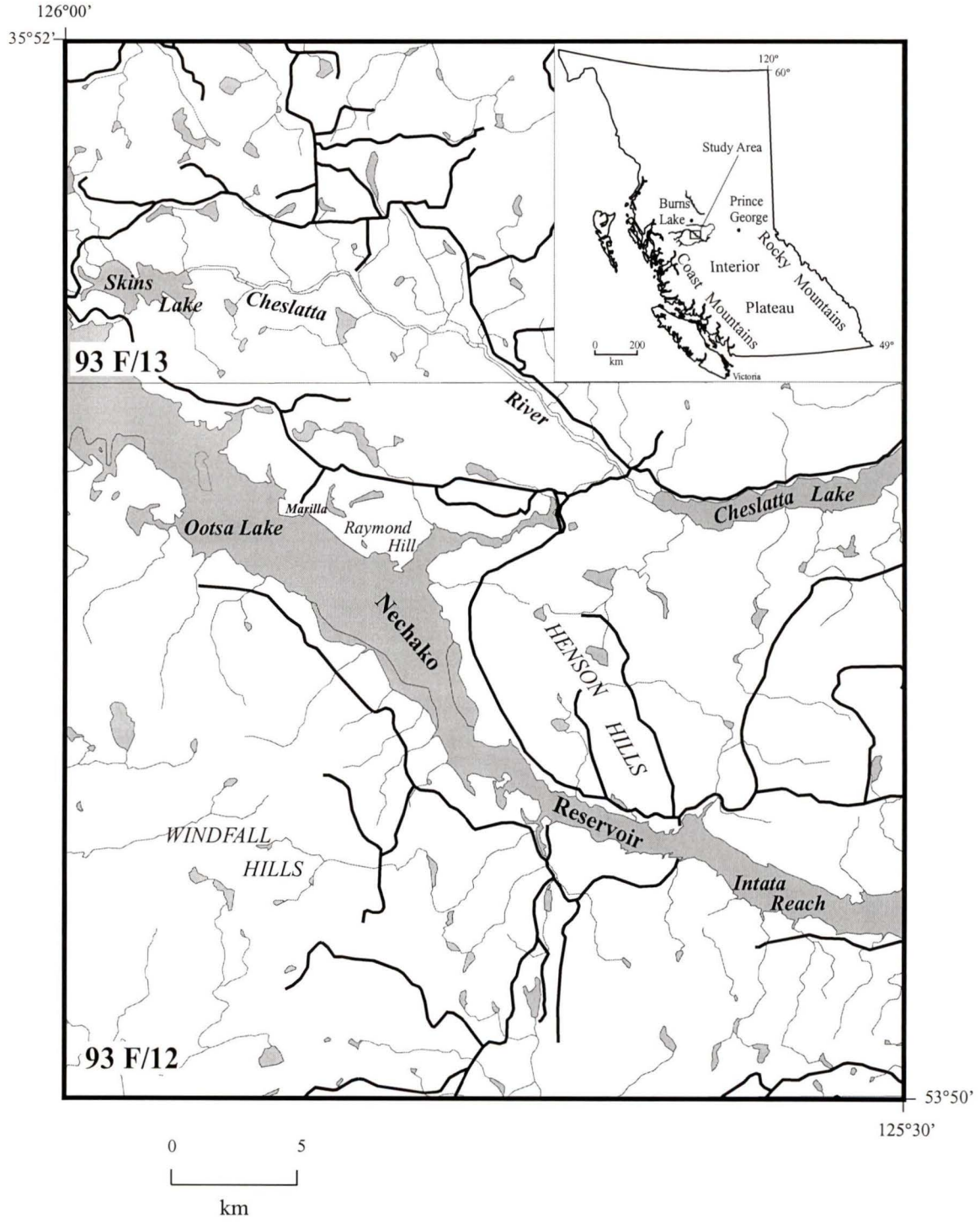



**Figure 1.** Location of study area, south of Burns Lake in the Nechako Plateau and straddling part of the Nechako Reservoir.

This research was conducted in conjunction with 1:50 000 scale till geochemistry studies (Levson et al. 1999) and is part of the Nechako National Mapping (NATMAP) program. The Nechako NATMAP program involves collaboration between the British Columbia Geological Survey and the Geological Survey of Canada. National Mapping Programs (NATMAP) were established by the Geological Survey of Canada in 1988 to address the dilemma of increasing demand for geoscientific information and decreasing government resources (Broome et al. 1993). These programs are multidisciplinary (Quaternary and bedrock geology mapping and stratigraphy, and till, stream, and lake sediment geochemistry, etc.) and involve collaboration between universities, the Geological Survey of Canada, provincial geological surveys, and industry.

## 1.2 DESCRIPTION AND PHYSIOGRAPHY OF STUDY AREA

The centre of the study area is located approximately 70 km south of Burns Lake in central British Columbia and lies just east of Tweedsmuir Provincial Park. Besides the Nechako Reservoir, which was built to generate power for aluminum refineries in Kitimat, other types of land use in the area are forestry and ranching. Access is good in most of the map area, and typically consists of logging roads and some well maintained secondary gravel roads. Areas without road access occur in the southwest corner of the study area and north of Cheslatta Lake. The north shore of Cheslatta Lake was accessed using an all-terrain vehicle. A private barge is needed to access forestry roads south of Ootsa Lake.

The study area lies entirely within the Nechako Plateau physiographic region (Holland 1976), an area of low relief with large surfaces of flat or gently rolling topography and elevations up to 1500 m (Fig. 2). Most of the ground surface is covered with thick glacial sediments and very little bedrock is exposed. Ootsa Lake and Intata Reach of the Nechako Reservoir form the main valley in the region and bisect the study area from the northwest to the southeast (see Fig. 1). Cheslatta River and Cheslatta Lake also trend east-west across the northern part of the study area. The Quanchus Range (including Mt. Wells, Tweedsmuir Peak and Michel Peak) lies immediately west of the map area in Tweedsmuir Provincial Park, while the Fawnie and Nechako ranges occur to the southeast. Highest elevations within the study area range from 1160 m – 1370 m a.s.l. and occur within the Windfall and Henson Hills (Fig. 1). The elevation of the Nechako Reservoir is approximately 850 m a.s.l. and the water level fluctuates a few metres annually.

**Figure 2.** Aerial view of Cheslatta Lake, from the northwest, showing general landscape characteristics of the study area. Cheslatta River can be seen entering Cheslatta Lake from the right of the picture.

## 1.3 PREVIOUS GEOLOGICAL WORK

Tipper (1963) pioneered some of the earliest mapping of Quaternary deposits in the Nechako Plateau when he provided preliminary observations and interpretations for glacial features within the Nechako River map area (NTS 93 F). Concentrating on bedrock mapping, he inferred that during the Fraser Glaciation the Nechako River map area (NTS 93F) was covered by glacial ice up to about 1500 m thick and that ice flow direction varied from northeast to east. He also interpreted the Ootsa Lake valley to be a large meltwater channel and identified a small region of crevasse fillings in the southwestern corner of the study area, concluding that both were formed during ice stagnation. The possibility that Ootsa Lake is a large meltwater channel implies that glacial meltwater flow through the area would have been immense as the Ootsa Lake valley is up to 3.5 km wide and approximately 135 m deep.

Tipper (1963) described crevasse fillings within the study area as straight ridges composed of coarse, unsorted, and unstratified material with uneven tops. He concluded that these features were formed as sediment was washed into crevasses in stagnating blocks of ice. He concluded that since crevasse fillings sometimes occur at right angles to each other they are not likely formed from moving ice. Tipper (1963) also mentions that the best developed drumlins occur in areas of thick glacial sediments that overlie flat-lying Miocene basalt, while crag and tails are best developed in areas of thin glacial cover underlain by Tertiary rhyolites and Mesozoic volcanic rock.

Tipper (1971), expanding on his Nechako River map area (93 F) work, mapped glacial features in several other 1:250 000 scale map sheets that cover a large part of the Interior Plateau. Ice flow indicators, meltwater channels, glaciolacustrine deposits, and

other selected geomorphic features were mapped in NTS 93 J (McLeod Lake), 93 G (Prince George), 93 C (Anahim Lake), 93 B (Quesnel), 92 N (Mount Waddington), 92 O (Taseko Lakes) and 92 P (Bonaparte Lake). During this mapping trough-like depressions (named by Tipper (1971) as glacial grooves) were observed to commonly occur within drumlinized areas of the Interior Plateau.

These features are described as shallow (depth unspecified), linear troughs (90-4800 m long) that are accentuated by vegetation and lie between drumlins and crag-and-tails. They also have the same orientation as the streamlined landforms. He also mentioned that the north and northeast portions of the Nechako River map area (with well defined streamlined landforms) underwent normal glacier retreat. Stagnation is believed to dominate in the south and southeast, where eskers and kettled topography are more common.

Terrain mapping by Howes (1977), identified large areas of ablation moraine, glaciofluvial landforms, randomly oriented meltwater channels and a lack of recessional moraines, south of the Nechako River map area (Map sheet 93 F/SW and parts of 93 C/NW and 93 E/SE). He interpreted these features to suggest that during deglaciation ice downwasted rapidly and stagnant ice conditions existed. Lacelle (1991) mapped the surficial geology and drainage of the eastern half of the Marilla map area (93 F/12).

Recent 1:100 000 scale mapping (Binta Lake map sheet, NTS 93 F/NW) in regions adjacent to the Marilla map area has been completed by Plouffe (1998*a*). Plouffe (1998b), also within the Nechako River map area (93 F), mapped the surficial geology of the Tahultzu Lake map sheet (NTS 93F/NE). Earlier surficial geology mapping in the Nechako Plateau (1:100 000 scale) was completed by Plouffe (1994) for the Chuchi Lake

(93 N/SE) and Tezzeron Lake (93 K/NE) map sheets. Plouffe (1996) mapped the surficial geology of a larger region of this plateau that included the Tsayta Lake (93 N/SW), Fraser Lake (93 K/SE), Cunningham Lake (93 K/NW), Burns Lake (93 K/SW), Manson Creek (93 N/NE) and Old Hogem (93 N/NW) map areas.

Surficial geology mapping at 1:50 000 scale was completed in the Fawnie Creek map area (93 F/3) by Levson and Giles (1994), in the Tsacha Lake map area (93 F/2) by Giles and Levson (1995) and the Chedakuz Creek map area (93 F/7) by Weary et al. (1995). As part of this research, the study area has been mapped at 1:50 000 scale by Mate and Levson (2000).

Previous Quaternary stratigraphy and ice flow studies in the Nechako River map area (93 F) have been provided by Giles and Levson (1994), Weary et al. (1995), Levson and Giles (1997), Plouffe (1998 *a, b*), Huscroft and Plouffe (1999), Levson et al. (1999), and Mate and Levson (1999a). Levson and Giles (1997) described the Quaternary stratigraphy along the Nechako Reservoir south and east of the study area. Lodgement and melt-out tills were identified as the most common sediments in this region. They are commonly overlain by glaciofluvial deposits and in places are underlain by advance-phase glaciofluvial, rare advance-phase glaciolacustrine, and rare lacustrine sediment. Massive to stratified sandy diamictons interpreted as glacigenic debris-flow deposits occur both above and below till in this region. The authors also mention that the first Late Wisconsinan glacier lobes advanced into the plateau along major valley systems, possibly damming tributary drainages and forming local proglacial lakes.

In the Nechako Plateau an easterly ice flow direction dominates. Around the Nechako Reservoir area ice flow direction is east to northeast (Tipper 1971; Levson and

Giles 1997). Evidence of an anomalous, westerly regional ice-flow direction within portions of the Nechako Plateau is discussed by Levson et al. (1998). This anomalous flow occurs in western and northwestern portions of the Nechako Plateau and extends over the Babine and Hazelton mountains. Glacial erratics, flutings and striae from the tops of Hudson Bay Mountain (2212 m), the southern Babine Mountains (2239 m) and Howson Range (2206 m) indicate that during the Late Wisconsinan glacial maximum, ice covered most peaks in those regions and moved west without being influenced by topography. It is noted that since westerly ice-flow indicators are also preserved in valley bottoms this anomalous flow is believed to have occurred during the Late Wisconsinan.

Prior to the Nechako NATMAP project, the best known Olympia Nonglacial Interval sediments within the Nechako Plateau occurred at the Bell copper mine (Harington et al. 1974) where radiocarbon ages from fossilized wood and mammoth bones underlying till were reported. Ages from pieces of spruce and fir were 42 900 ± 1860 yr BP (GSC-1657) and 43 800 ± 1830 yr BP (GSC-1687). An anterior mammoth rib fragment was dated at 34 000 ± 690 yr BP (GAC-1754). Paleoenvironmental data from these Olympia Nonglacial sediments show that during this period an environment similar to that existing at present day treeline occurred in the Babine Lake area.

However, during recent work in the Nechako Plateau new discoveries and interpretations of Olympia Nonglacial sites within the Nechako Plateau have been completed by Harington et al. (1996), Levson and Giles (1997), Plouffe and Jetté (1997), Levson (2001), Levson et al. (1998, 1999), Mate and Levson (1999*a*, 2001), and Plouffe and Levson (2001). In total, nine new stratigraphic sections with Olympia Nonglacial

sediments, some also with sediments from a glaciation older than the Fraser Glaciation, were discovered in the Nechako Plateau. These sites are summarized in table 1.

A radiocarbon age of 27 790 ± 200 BP (Beta-101017) from organics in nonglacial sediments occurring along Chelaslie arm of the Nechako Reservoir, about 10 km southwest of this study area was reported by Levson et al. (1998). At this section stratified and deformed, dense fine sands, silts and clay of lacustrine and advance-phase glaciolacustrine origin and glaciofluvial sediments underlie till of the Fraser Glaciation. Plouffe and Jetté (1997) found nonglacial organic-bearing fine to medium sand in Quaternary sections along the Necoslie and Nautley rivers in Central British Columbia. Wood in nonglacial sediments from a section along the Nautley River (approximately 90 km northeast of the study area) yielded AMS radiocarbon ages of 38 230 ± 410 BP (Beta-88557) and 42 460 ± 670 BP (Beta-88558). At both sites (Necoslie and Nautley rivers) pollen assemblages from organic-bearing sands are similar to tundra environments.

**Table 1.** Summary of 9 recently discovered and interpreted stratigraphic sections with sediments from the Olympia Nonglacial Interval or an earlier glaciation.

| Nonglacial Site Name | Site Location & NTS Mapsheet | Radiocarbon Dates | Pollen Assemblages | Simplified Site Stratigraphy (described from the bottom up) |
|---|---|---|---|---|
| Babine River (Levson 2001) | NTS 93M/10<br><br>UTM coord. (643691E, 6153716N) | No data | 66% herb, 34% tree and shrub pollen. Low pollen conc.; similar to tundra env.<br>*unit 1 sampled | Unit 1: Fluvial, parallel laminated silts and fine sands.<br>Unit 2: Advance-phase, rhythmically bedded, medium sands, silts, and very fine sands (glaciolacustrine).<br>Unit 3: Advance-phase, sand and gravel<br>Unit 4: Massive and dense till |
| Chuchi Lake (Harington et al. 1996) | NTS 93N/1<br><br>UTM coord. (412307E, 6116652N) | From bison bones:<br>30 740 ± 220 BP (TO-3653)<br>34 800 ± 420 BP (Beta-78573, CAMS 17566)<br>35 480 ± 1080 BP (Beta-78574)<br>*unit 1 sampled | 12% herb, 84% tree and shrub pollen. Similar to forest environments.<br>*unit 1 sampled | Unit 1: Horizontally laminated silt and clay. Rare organic debris<br>Unit 2: Massive and dense till<br>Unit 3: Massive, retreat-phase silt and clay with dropstones<br>Unit 4: Crudely bedded retreat-phase sand and gravel |
| Necoslie River (Plouffe and Jetté 1997) | NTS 93K/08<br><br>UTM coord. (429847E, 6022731N) | Concentration of organic matter in nonglacial sediments are too low for reliable dating. | 56% herb, 38% tree and shrub pollen. Low pollen conc.; similar to tundra env.<br>*unit 2 sampled | Unit 1: Till (pre-Late Wisconsinan)<br>Unit 2: Fluvial, organic-bearing, fine to medium sand.<br>Unit 3: Advance-phase, horizontally laminated silt and clay.<br>Unit 4: Till (Late Wisconsinan).<br>Unit 5: Retreat-phase horizontally laminated silt and clay.<br>Unit 6: Retreat-phase sand and gravel |
| Nautley River (Plouffe and Jetté 1997) | NTS 93K/02<br><br>UTM coord. (396023E, 5993725N) | 38 230 ± 410 BP (Beta-88557)<br>42 460 ± 670 BP (Beta-88558)<br>*unit 1 sampled | 56% herb, 34% tree and shrub pollen. Low pollen conc., similar to tundra env.<br>*unit 1 sampled | Unit 1: Fluvial, organic-bearing, fine to medium sand<br>Unit 2: Advance-phase sand and gravel<br>Unit 3: Till (Late Wisconsinan)<br>Unit 4 & 5: Retreat-phase sand and gravels |
| Corkscrew Creek (Plouffe and Levson 2001) | NTS 93F/16<br><br>UTM coord. (423350E, 5967550N) | 38 600 ± 520 BP (Beta-125677)<br>*unit 2 sampled | 1.7% herb, 97.4 tree and shrub pollen. Similar to forest environments.<br>*unit 2 sampled | Unit 1: Pebbly sand debris flow<br>Unit 2: Organic-bearing, pre-Late Wisconsinan, interbedded sand and silt and clay<br>Unit 3: Late Wisconsinan advance-phase sand and gravel<br>Unit 4: Till (Late Wisconsinan) |

**Table 1 (cont'd).** Summary of 9 recently discovered and interpreted stratigraphic sections with sediments from the Olympia Nonglacial Interval or an earlier glaciation.

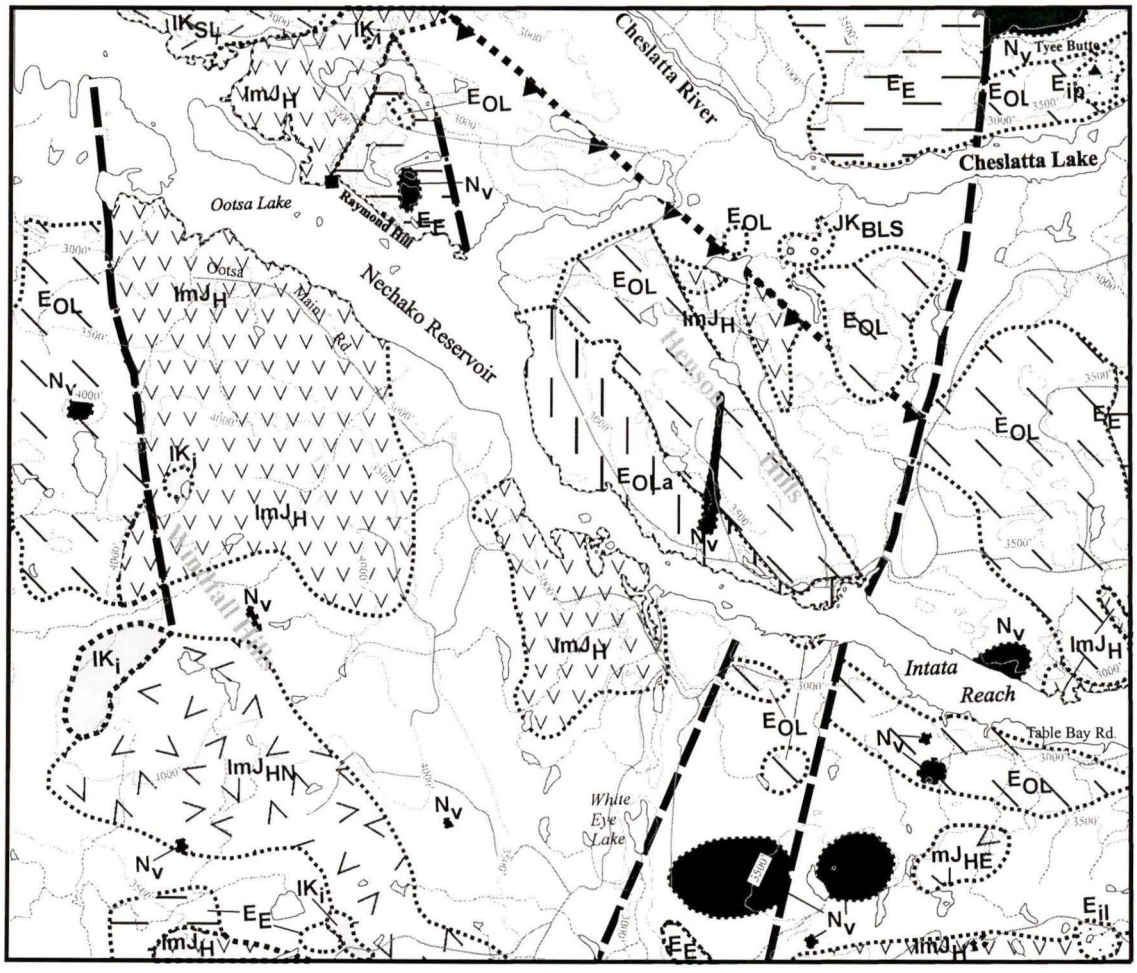
| Nonglacial Site Name | Site Location & NTS Mapsheet | Radiocarbon Dates | Pollen Assemblages | Simplified Site Stratigraphy (described from the bottom up) |
|---|---|---|---|---|
| Swanson Creek (Plouffe and Levson 2001) | NTS 93F/10<br><br>UTM coord. (387010E, 5954400N) | No data | No data | Unit 1: Pre-Late Wisconsinan pebble to cobble sand and gravel.<br>Unit 2: Pre-Late Wisconsinan till<br>Unit 3: Advance-phase, Late Wisconsinan sand and gravel<br>Unit 4: Late Wisconsinan till<br>Unit 5:Retreat phase gravel. |
| Knewstubb Lake (V. Levson, pers. Comm., 2000; (Plouffe and Levson 2001) | NTS 93F/10<br><br>UTM coord. (377300E, 5936100N) | 39 040 ± 530 BP (Beta 101016)<br>*Unit 1 sampled | 0.6% herb, 99.4% tree and shrub pollen. Similar to forest environments | Unit 1: Olympia Nonglacial, fluvial, fine sand and silt<br>Unit 2: Olympia Nonglacial, fluvial, sand and gravel. Possibly Late Wisconsinan advance-phase glaciofluvial.<br>Unit 3: Late Wisconsinan till |
| Chelaslie Arm (Levson et al. 1998) | NTS 93F/5<br><br>UTM coord. (324250E, 5928200N) | 27 790 ± 200 BP (Beta-101017)<br>*Unit 1 sampled | Pollen analysis in progress | Unit 1: Olympia Nonglacial fine sands<br>Unit 2: Late Wisconsinan advance-phase silts and clays.<br>Unit 3: Late Wisconsinan advance-phase sand and gravel<br>Unit 4: Late Wisconsinan till |
| Ootsa Lake (Mate and Levson 1999a, 2001) | NTS 93F/12<br><br>UTM coord. (328500E, 5938320N) | Concentration of organic matter in nonglacial sediments are too low for reliable dating. | Pollen analysis in progress | Unit 1: Pre-Late Wisconsinan till<br>Unit 2: Pre-Late Wisconsinan, nonglacial, lacustrine, organic-bearing, very fine sand and silt and clay<br>Unit 3: Late Wisconsinan advance-phase sand and gravel<br>Unit 4: Late Wisconsinan till |

## 1.4 BEDROCK GEOLOGY

The bedrock geology of the Nechako River map area (NTS 93 F) was first mapped at a scale of 1:250 000 by Tipper (1963). Recent 1:50 000 scale bedrock mapping of the Marilla map sheet was completed by Anderson et al. (2000*a*, 2000*b*). A summary of this bedrock geology mapping is provided in Fig. 3. Tertiary, Endako Group basalt and Ootsa Lake Group rhyolite are widespread in the study area and most common north of Ootsa Lake. Occasional Neogene volcanic centres and basalt flows are also present within the study area. Mesozoic, Hazelton Group rocks are more common south of Ootsa Lake. Sedimentary Bowser Lake Group and Late Cretaceous Skins Lake plutonic rocks are rare. Structurally the area is characterized by northeast to northwest trending Eocene block faults that crosscut an older northwest trending reverse fault north of Ootsa Lake.

Endako group rocks were deposited in the Eocene epoch. These rocks are commonly amygdaloidal basalts to basaltic andesite, while volcaniclastics and flow rocks are less common (Anderson et al. 2000*a*). These authors note that in places mafic volcaniclastic and flow rocks (correlating to Endako Group rocks) overlie Ootsa Lake Group rocks. They also mention that rubbly weathered, mafic to intermediate lapilli breccia and flow rocks occur north of Ootsa Lake in Raymond Hill and along the north shore of Cheslatta Lake (see Fig. 3).

Ootsa Lake Group rocks also are Eocene in age and consist of felsic and less common intermediate volcanic flow and volcaniclastic rocks (Grainger and Anderson 1999; Anderson et al. 2000*a*). The regional age range of Ootsa Lake Group volcanism within the Nechako River map area is from 54.0 to 47.6 Ma (Grainger and Anderson 1999). These authors mention that half of the Ootsa Lake Group rocks are flows with




## Legend

### Stratified Rocks

- Quaternary Sediments
- $N_V$ Neogene volcanics
- $E_E$ Eocene Endako Group

Eocene Ootsa Lake Group

- $E_{OL}$ Rhyolite
- $E_{OLa}$ Vesicular andesite
- $JK_{BLS}$ Jurassic or Cretaceous Bowser Lake or Skeena Group (?)

Lower to Middle Jurassic Hazelton Group

- $mJ_{HN}$ Naglico and Entiako formations
- $mJ_H$ Hazelton Group undivided

### Intrusive Rocks

Eocene Felsic Intrusions

- $E_i$ Porphyry (Eip) and miarolitic leucogranite (Eil)
- $lK_{SL}$ Late Cretaceous Skins Lake porphyry

### SYMBOLS

- Geological Contact (inferred)
- Block fault (approximate)
- Reverse fault (teeth on hanging wall; approximate - inferred)

**Figure 3.** Simplified bedrock geology of the Marilla (93F/12) map sheet. Modified from Anderson et al. (2000*a*, 2000*b*).

sub-equal amounts of tuff and breccia. As well, the most dominant Ootsa Lake Group rock type within the Nechako River map area is a red to white to grey, locally purple or green, flow-laminated rhyolite. It commonly occurs as flows and less frequently as domes. Some exposures of flow-laminated Ootsa Lake Group rocks have black, glassy, perlitic flow bases that suggest extrusion into a shallow water environment (Anderson et al. 2000*a*).

Some diagnostic field characteristics of Ootsa Lake Rhyolite are: minor, locally rotated rhyolite clasts; primary flow folding; rare vesicles and perlitic or spherulitic textures, and minor lithophysae. Texturally, Ootsa Lake Rhyolite may vary abruptly over short distances (a few metres), changing from flow-laminated rhyolite to rhyolite autobreccia (Grainger and Anderson 1999).

The best exposures of Ootsa Lake Group rocks within the study area occur in the Henson Hills (see Fig. 3). A succession of rhyolitic porphyry crystal tuff, pyroclastic breccia units, and flow-laminated rhyolite occur as you move east to west across this topographic feature (Grainger and Anderson 1999). Ootsa Lake Group rocks in this area share an eastern fault contact with lower to middle Jurassic Hazelton Group sedimentary rocks and potentially are unconformably overlain to the west by vesicular andesite, basalt breccia, and andesite flows.

Neogene volcanics occur as both lava flows and volcanic centres. They are distinguishable from Endako Group basalts because they are rarely amygdaloidal or vesicular and contain mantle, and less commonly, crustal xenoliths (Resnick et al. 1999). Lava flows are rare within the study area, occurring around Raymond Hill and north of Tyee Butte (see Fig. 3). North of Tyee Butte, flows are approximately 4 km long and are

columnar jointed (Resnick et al. 1999). Neogene volcanic centres within the study area are subdivided into two types, basaltic and diabasic. Both types occur as prominent topographic features consisting of rocks that typically have a dark grey to black colour, and weather rusty brown to dark grey (Resnick et al. 1999).

An example of a Neogene basaltic centre occurs on the west side of the map area, northwest of Windfall Hills (see Fig. 3). This centre is approximately 400 m x 300 m with well formed vertical columnar joints 30-75 cm wide (Resnick et al. 1999). These authors also note that at this location widespread mantle and rare crustal xenoliths make up approximately 5 % of the rock. Compared to diabase centres, basaltic centres have an aphanitic groundmass and thinner columnar joints (Resnick et al. 1999). Thinner columnar jointing in basaltic centres implies that they experienced a more rapid rate of cooling.

A good example of a diabasic centre within the study area occurs south of Table Bay Road in the southeastern corner of the Marilla map sheet. This circular centre is quite large (approximately 1 km in diameter), crosscuts Jurassic Hazelton Group volcanic rocks, contains no observable xenoliths, and has phenocrysts of plagioclase, pyroxene, and olivine (Resnick et al. 1999; Anderson et al. 2000*a*). These authors distinguish diabasic centres from basaltic ones because they lack xenoliths and have wider columnar jointing (1-3 m wide).

The oldest rocks in the study area are Mesozoic in age and include Hazelton and Bowser Lake Groups and the Late Cretaceous Skins Lake plutonic rocks. Of these, Lower to Middle Jurassic Hazelton Group rocks are the oldest and include both sedimentary and igneous rocks with maroon and green colours (Anderson et al. 2000*b*).

Pint et al. (2000) identified bedded, maroon to reddish-brown weathered Hazelton Group mudstone, greywacke, and conglomerate around Ootsa Lake. The mudstone has a clast content of 5-10 % and the greywacke occurs in 10-30 cm thick beds with a medium sand to pebble texture. The conglomerate is dominated by volcanic clasts, matrix supported, and occurs in lenticular beds that locally fine upwards and are interpreted as channel-fill deposits.

Hazelton Group rocks south of Ootsa Lake can be subdivided into Middle Jurassic Entiako and Naglico formations (Diakow et al. 1997; Quat and Struik 1999). Most of these rocks are comprised of interbedded rhyolitic tuffs, pebbly and silty sandstone and rare ash layers (Anderson et al. 2000*b*). Vesicular andesitic flows and pillow lavas overlying tuff and porphyritic andesites also occur within these formations.

Sedimentary rocks belonging to the Middle and Upper Jurassic Bowser Lake Group are extremely rare within the Marilla map area. It is possible that these sedimentary rocks correlate to the Lower Cretaceous Skeena Group. Anderson et al. (2000*b*) describes these rocks as unfossiliferous, coarse to medium siliciclastics. They are most common around Skins Lake and along a portion of the Cheslatta River just north of the Marilla map area. Along the Cheslatta River these rocks are poorly exposed and consist of reddish-brown shale, conglomerate, and greywacke. Part of the Skins Lake pluton occurs in the northwest corner of the Marilla map area. This pluton is comprised dominantly of porphyritic with some phaneritic mafic to felsic phases (Anderson et al. 2000). Other small, undivided plutons consisting of diorite, granite, and sometimes disseminated pyrite occur south of Ootsa Lake.

# 2 METHODS

## 2.1 QUATERNARY GEOLOGY MAPPING AND STRATIGRAPHY

Quaternary geology mapping in the study area included the description of surficial materials and glacial features at 198 field stations. Field station locations are shown on Fig. 4 (in pocket) and the field notes collected from each station are provided in Appendix A. Field checking was essential because heavy tree cover made identification of surficial sediments from air photographs difficult. Guidelines of the terrain classification system for British Columbia (Howes and Kenk 1997) were followed. Map production was completed using MapPlace, a World Wide Web based system created by the British Columbia Geological Survey (Kilby 1999). Topological and attribute data from air photographs and field notes were digitized directly over the internet using Autodesk MapGuide. This process involved "heads-up" digitizing on scanned, georeferenced, 1:20 000 scale map sheets. Map production by this process was the first of its kind at the British Columbia Geological Survey with the final end product produced in both paper and digital formats.

Stratigraphic studies were conducted at all large Quaternary exposures within the region. Quaternary stratigraphic sections in this area are unusually abundant and well exposed due to the development of shoreline bluffs on the Nechako Reservoir and downcutting along the Cheslatta Spillway. The latter has provided an excellent cross-section through the Quaternary sequence in the area and has exposed some Holocene sediments, including sections through a number of drained Holocene lakes and deltas. At each section different lithologic units were described and data on unit thickness, texture, lower contacts, and sedimentary structures were collected. Till units were sampled for

geochemical analyses including instrumental neutron activation analysis (INA) and inductively coupled plasma atomic emission spectrometry analysis (ICP-AES).

## 2.2 LANDSLIDE STUDIES

Cross-section profiles were obtained at two landslides on the Cheslatta River in order to determine their surface topography and geomorphic features and to investigate mechanisms of failure. Detailed field observations were recorded at each slope failure. Landslide features like slump block orientations, dip and dip direction of slickensided shear surfaces at the base of landslides, and morphology and texture of mudflows were noted. Height of scarps and size and depth of sag ponds were also recorded. The effects that these slope movements had on local tree growth was also documented. Whether or not trees leaned back towards the main scarp and the direction they had fallen was recorded. Stratigraphic observations were made in exposed main and minor scarps at both failures and in surrounding river-cut exposures.

Guidelines established by Keaton and DeGraff (1996) were used when recording cross-section data. The cross-sections were compiled using a 50 m measuring tape, clinometer, compass, and a two person crew. Compass bearings were taken to maintain a constant line of direction while traversing over the slide. A clinometer was used as a sighting instrument to measure slope angles across the tops of the slides. The clinometer recorded slope angle in percent grade. During each traverse, distance along the ground was recorded between each break in slope. When drawing the profiles percent grade was converted to degrees (100% grade equaling 45°).

## 2.3 STREAMLINED LANDFORM STUDIES

Fluted and drumlinoid forms within the mapsheet were examined using 1:40 000 scale air photographs and low-level helicopter and float plane flights. Ground investigations were completed at eight separate streamlined forms scattered throughout the study area. At each site geomorphic characteristics of the forms and surrounding areas were described. A majority of the fluted and drumlinoid regions within the study area occur on the south side of Ootsa Lake, which is only accessible by forestry barge.

In places the surficial sediments occurring within the drumlins and adjacent areas were also examined. At three sites a total of 13 soil pits, approximately 1 m deep, were dug using a shovel and a dutch auger. Seventeen grain-size samples were collected at various depths in these pits to check for textural variations within the profiles. The grain-size distribution of these samples was analyzed by sieve analysis.

Samples were air dried in a lab for approximately 4 weeks. Dried samples were emptied into a preparation tray and any weathered pebbles or organic materials (rootlets) were removed. A mortar and pestle was used to disaggregate the matrix of each sample. Once disaggregated, a subsample of approximately 50 g was taken using a sample splitter. This subsample was sieved through a stack of sieves on a shaker for 15 minutes. Six sieves were used (2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.0625 mm) allowing gravel, very coarse sand, coarse sand, medium sand, fine sand, very fine sand and mud to be separated. After 15 minutes of shaking each sieve and the bottom pan (containing mud) were weighed and the proportion of each grain size fraction per sample was determined.

# 3 QUATERNARY STRATIGRAPHY AND HISTORY

## 3.1 INTRODUCTION

The purpose of this chapter is to describe and interpret the Quaternary geology and stratigraphy of a previously unstudied part of the Nechako Plateau. Before this work very little was known about the Quaternary geology of the study area. Previous research (Tipper 1963; 1971; Howes 1977) has been informative but is based mostly on the interpretation of air photographs. Very little ground data describing the various Pleistocene materials and information about the Quaternary stratigraphy and glacial history of the region have been compiled and interpreted. For this reason, emphasis was placed in this research on collecting stratigraphic information.

Stratigraphic information was collected from twenty large, well exposed Quaternary sections in the study area (Fig. 5). Section descriptions and stratigraphic columns for these sections are found in Appendix B. Thirteen sections occur along Cheslatta River (Fig. 5a). The seven remaining described sections are found along the shores of Ootsa Lake and Intata Reach of the Nechako Reservoir (Fig. 5b). Unlike many regions in the Nechako Plateau, the stratigraphy in this map area is exceptionally well exposed (Fig. 6). The completion of the Nechako Reservoir (in 1952) is largely responsible for this abundance of large Quaternary sections. Wave erosion along the shoreline of the Nechako Reservoir has produced numerous shoreline cliffs in Quaternary sediments. In addition, erosion along the Skins Lake Spillway has left large, well exposed Quaternary sections preserved along its banks (Fig 6).

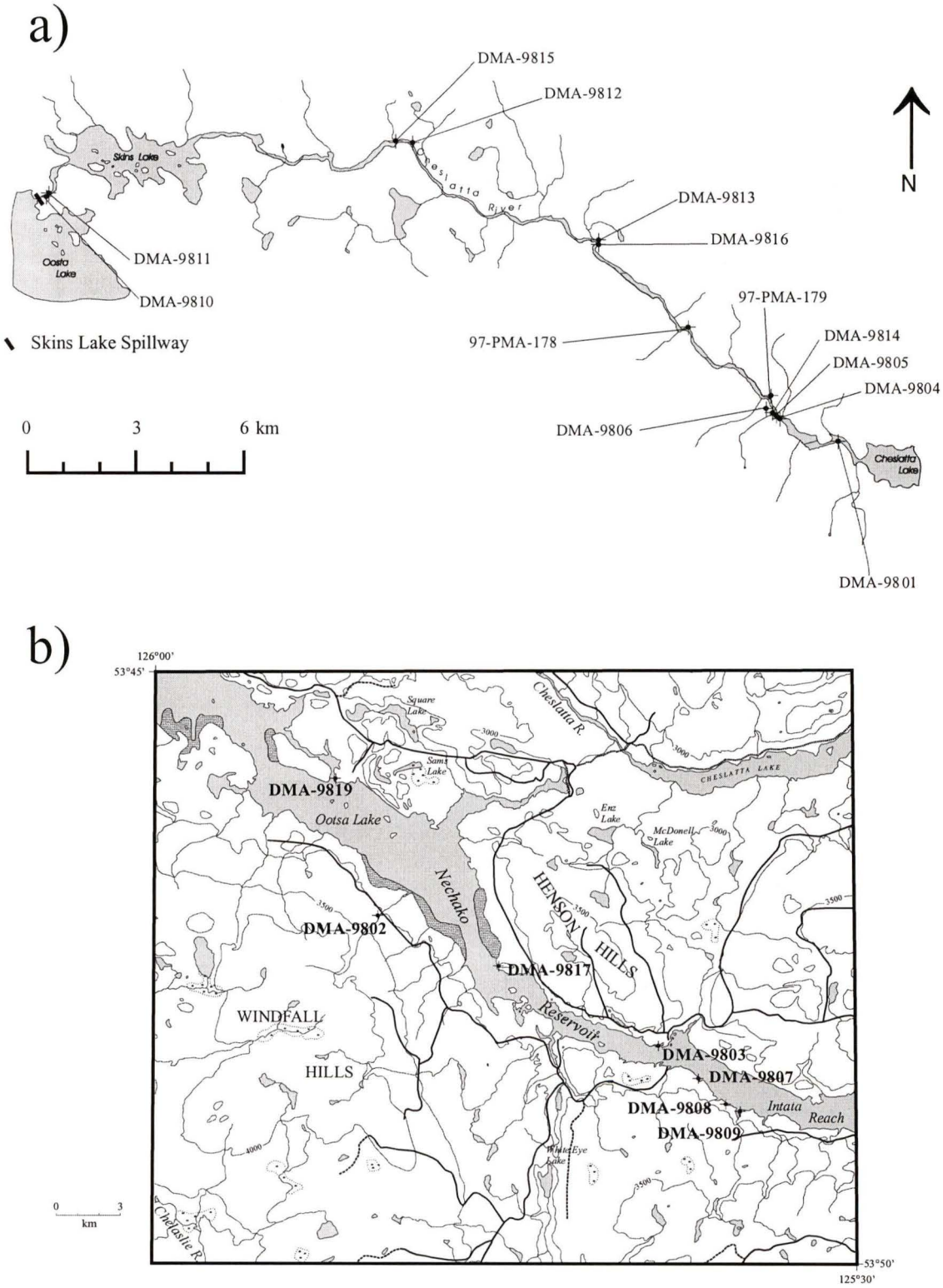



**Figure 5.** Location of stratigraphic sections that were investigated along a) the Cheslatta River and b) the shore and area surrounding the Nechako Reservoir.

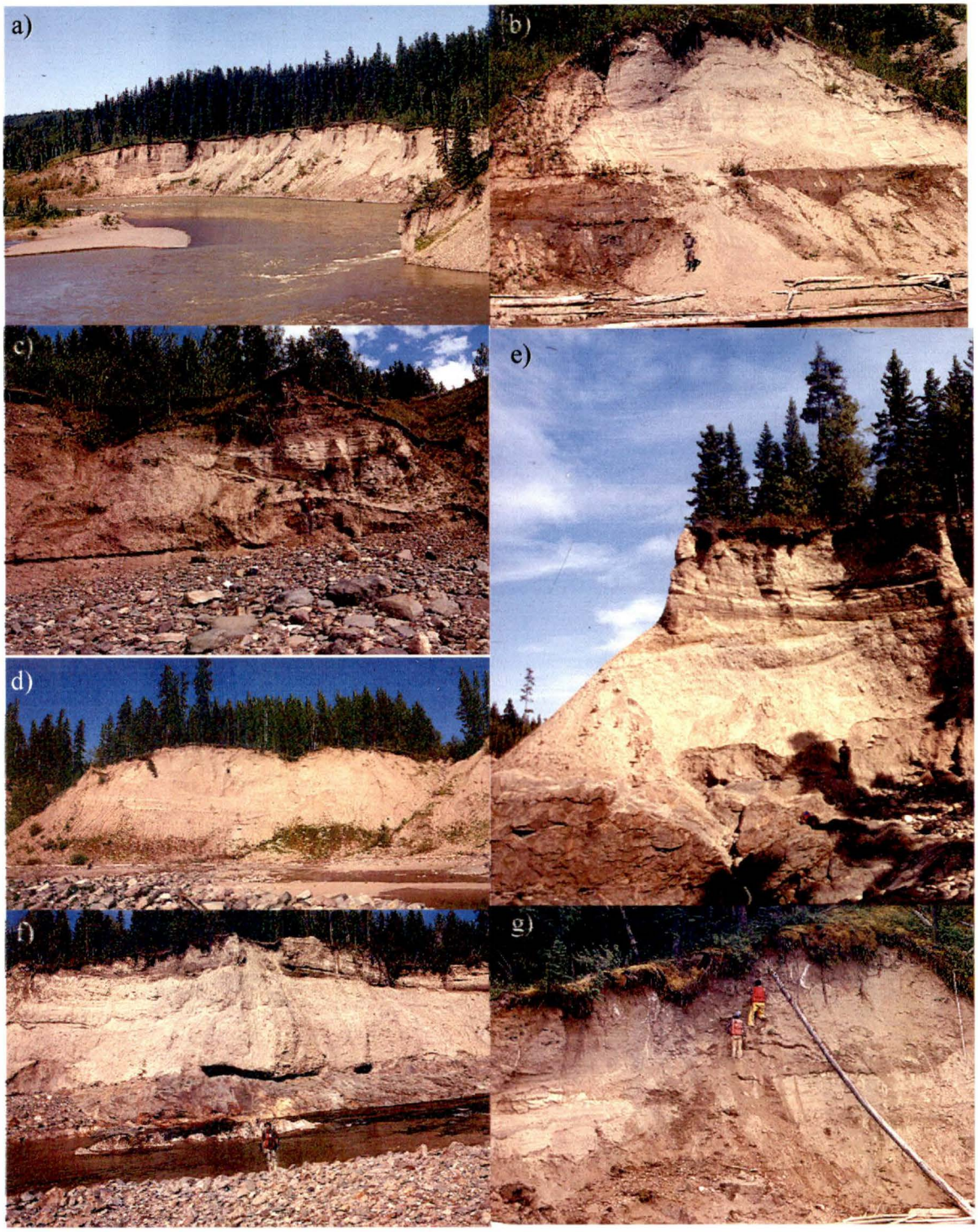



**Figure 6.** Examples of some large, well exposed Quaternary sections that commonly occur within the study area. a) Example of extent of well exposed Quaternary sections along the Cheslatta River. b) Large Quaternary sections exposed along the shoreline of the Nechako Reservoir (Note dark grey area is Olympia Nonglacial Interval sediment). c) Section DMA-9812 along Cheslatta River (note large sand lense above person). d) Section DMA-9813 along Cheslatta River. e) Section DMA-9810, Cheslatta River. f) Quaternary exposures close to section DMA-9811 (note, this section is on the opposite side of Cheslatta River from DMA-9810). g) Section DMA-9809, Nechako Reservoir.

## 3.2 SURFICIAL GEOLOGY AND GEOMORPHOLOGY

The distribution of surficial sediments in the study area is illustrated in Fig. 7 and in detail in the Quaternary geology map of the Marilla map area (in pocket). Surficial geological mapping has shown thick till cover to dominate over other material. Till accounts for approximately 80% of the ground cover in the map area and mantles the underlying topography either as a blanket (greater than 1 m thick) or veneer (less than 1 m thick). Till veneers usually drape bedrock controlled topography and are common at elevations above about 900 m where steeper slopes predominate. Till blankets occur at a range of elevations within the study area.

Till in the area generally is grey-brown, has clayey silt to silty sand texture, is poorly sorted, dense, well jointed with strong fissility, and contain numerous striated clasts. In places till is dark grey-red to purple-grey reflecting varied, local bedrock lithologies. Commonly maroon mudstones, belonging to the Bowser Lake Group, occur up-ice of areas with reddish till. For example, at section DMA-9812 along the Cheslatta River, greyish-red till can be attributed to Bowser Lake Group maroon mudstones that occur approximately 1 km up-ice. Morainal sediments at the surface are usually loose with low density due to weathering and colluviation.

The most common streamlined landforms within the study area are northeasterly oriented crag-and-tail ridges. Up-ice (stoss-ends) of these features are bedrock knobs, while down-ice (lee) portions are ridges of glacial diamicton (till). Flutings and drumlinoid ridges, dominantly composed of till, also occur. These forms are often nested and sometimes occur in *en echelon* arrangements. Streamlined landforms are

**Figure 7.** Simplified surficial geology and subglacial flow directions in the Marilla map area (modified from Mate and Levson 2000). Till is the dominant surficial sediment and bedrock outcrop is rare (approximately 5% of the ground cover). The dominant subglacial flow direction is to the northeast; evidence for westerly flow occurs only in the northwest corner of the map area.

approximately 100-500 m long and 40-100 m wide. In some areas they occur in clusters up to 1600 m long and 3000 m wide.

Well defined, depressions or grooves that are usually flat-bottomed, are consistently seen at the stoss-ends and wrapping around the sides of these landforms. These depressions are commonly bog filled and highlight the forms. Sometimes these depressions are eroded to bedrock. They resemble crescentic scours and lateral furrows described by Shaw and Sharpe (1987) and Shaw (1994*a*). Striae in the study area generally have the same orientation as these landforms, but rare valley parallel northwest trending striae also occur (see northwest corner of Fig. 7; see Quaternary History for discussion).

Unusual till ridges occur in the southwest portion of the map area. They are 100's of metres long, roughly 4-8 m high, steep sided, and locally have sharp bends. Relief along ridge tops is approximately 1-4 m. The till matrix in these forms is consistently finer grained, with a clayey silt texture, than tills elsewhere in the study area. Ridges are locally draped by poorly sorted gravel and massive silt and rarely, depressions occupied by small bogs occur along the ridge tops. These forms are interpreted as crevasse fillings and were first identified in the study area by Tipper (1963)

Glaciofluvial sediments in the study area are rare and account for about 5% of the surficial cover. Most deposits occur as blankets of pebble to cobble-sized gravel. These sediments are found in terraces and outwash plains along the Cheslatta River and in association with meltwater channels. Aggregate for local road construction is mined mainly from small, typically elongate eskers and glaciofluvial outwash deposits.

Localized glaciolacustrine sediments are rare within the study area and the surrounding regions mapped by Plouffe (1998*a*). Most areas of glaciolacustrine sediments were too small to be mapped separately. When present they are characteristically massive to laminated silts and clayey silts with thin fine-grained sand beds. They commonly occur adjacent to the Nechako Reservoir at elevations below 890 m.

The remaining ground cover (15%) is dominated by Holocene organic and fluvial deposits and minor areas of bedrock outcrop and colluvium, mainly north of Cheslatta Lake (Fig. 7). In the map area, colluvium is very localized usually occurring as a veneer over bedrock. Talus deposits composed of angular gravelly debris are rare and are found along slopes at the base of steep bedrock cliffs. Till covering steep bedrock hills often are reworked by gravity to form poorly sorted, sandy to gravelly diamicton.

Organic deposits in bogs are common in the study area. They occur in low-lying, poorly drained areas, especially depressions around streamlined landforms. Bogs contain black, organic rich peat and support sedge, sphagnum moss, and small willow vegetation. Fluvial sediments occur in the Cheslatta River valley and along streams in the map area. In larger river valleys these sediments are dominated by terrace and flood plain gravel and sand. Fluvial deposits in smaller streams are typically sand and fine gravel.

## 3.3 STRATIGRAPHY

Seven representative sections from the Cheslatta River and Nechako Reservoir areas that illustrate the Quaternary stratigraphy of the study area are provided in Fig. 8. From these sections, ten different stratigraphic units have been identified and grouped into five main stratigraphic packages: 1) pre-Late Wisconsinan sediments, 2) Late

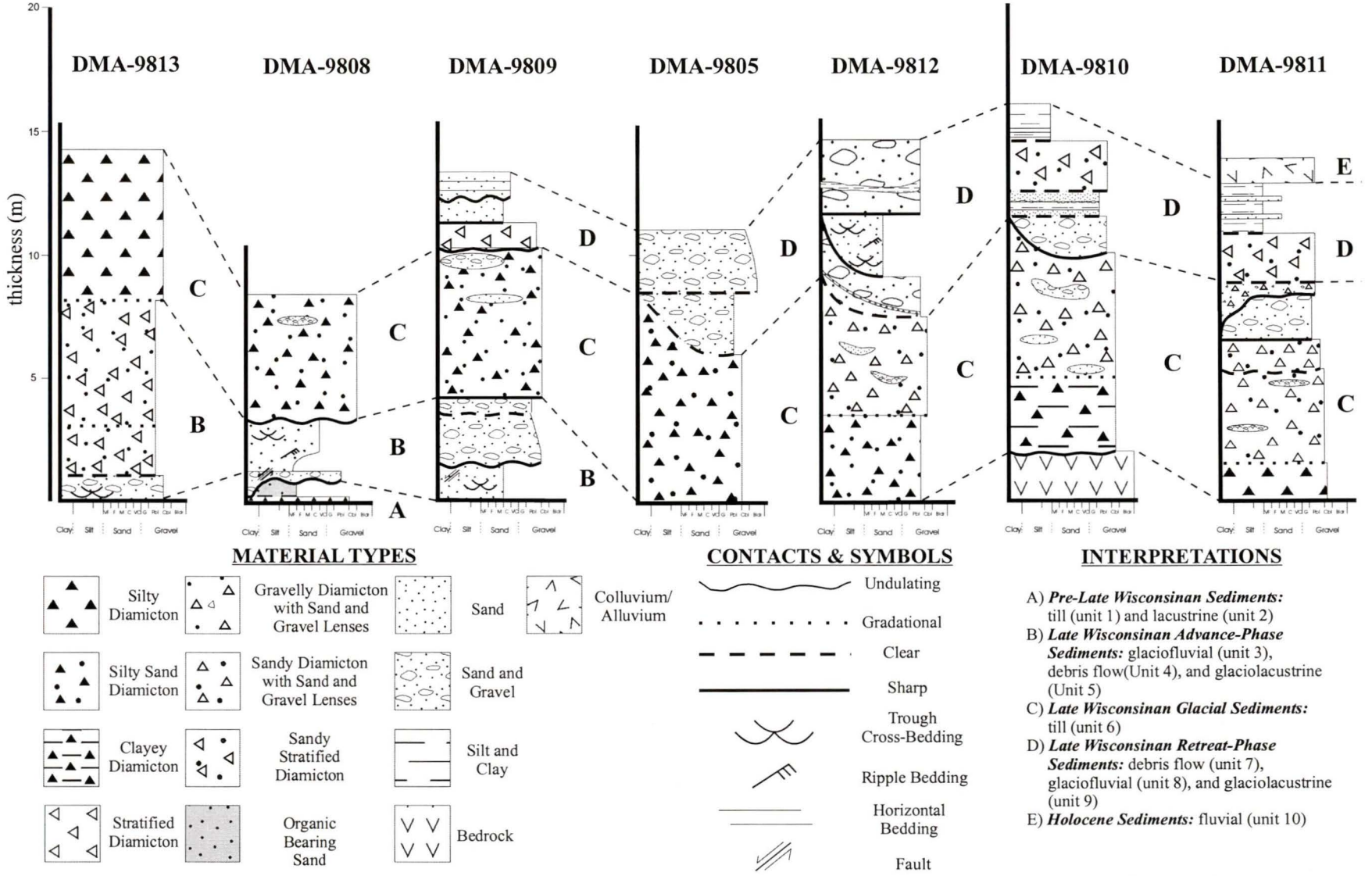



**Figure 8.** Representative sections illustrating the stratigraphy within the map area. Location of sections shown in Fig. 5.

Wisconsinan advance-phase sediments, 3) Late Wisconsinan glacial sediments, 4) Late Wisconsinan retreat-phase sediments, and finally 5) Holocene sediments.

### 3.3.1 Pre-Late Wisconsinan Sediments

3.3.1.1 Unit 1: Early Wisconsinan (?) Till

Pre-Late Wisconsinan sediments are represented by 2 units exposed in a single section (DMA-9808, Figs. 9 and 10). Unit 1 is the oldest Pleistocene sediment in the study area. It is a brown, slightly sandy, clayey silt diamicton, with moderate to high density, and is well jointed with oxidation along joints. Clasts within this unit are granule to cobble-sized; the modal size is medium to large pebbles. Clasts are subangular to subrounded and commonly striated.

Unit 1 is interpreted to be till deposited during an earlier glaciation. Till underlying organic-bearing sands (Unit 2) and Fraser Glaciation sediments are rarely seen in the Nechako Plateau. The only other reported occurrence of a till older than the Fraser Glaciation in the region occurs along the Necoslie River roughly 200 km northeast of section DMA-9808 (Plouffe and Jetté 1997; Table 1).

3.3.1.2 Unit 2: Lacustrine Sands and Silts

Unit 2 consists of dark, blue-grey, very fine sand, with silt and clay laminations and wavy and discontinuous lenses, laminae, and finely disseminated organics (Fig. 11). The unit is up to 65 cm thick at this site and occurs at an elevation of about 855 m, just a few metres above modern lake level. It is exposed for approximately 10 m, thinning southward and has a clear and undulating lower contact. Sand beds are 1-10 cm thick and contain silty clay rip-ups. Silt and clay laminae are up to 1 cm thick and have slickensides on subhorizontal surfaces showing a direction of movement into Intata

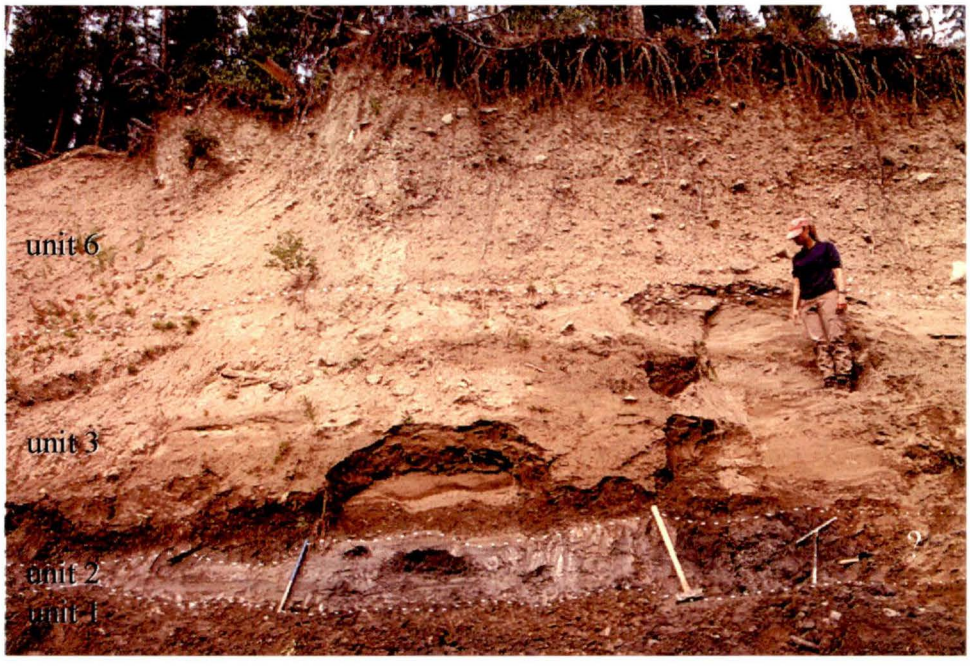



**Figure 9.** View of section DMA-9808 on Ootsa Lake. The lowest unit at this section (unit 1) is till, probably deposited during an older glaciation. This unit is overlain by organic-bearing, blue-grey lacustrine sands (unit 2), advance-phase glaciofluvial sediments (unit 3), and Late-Wisconsinan till (unit 6).

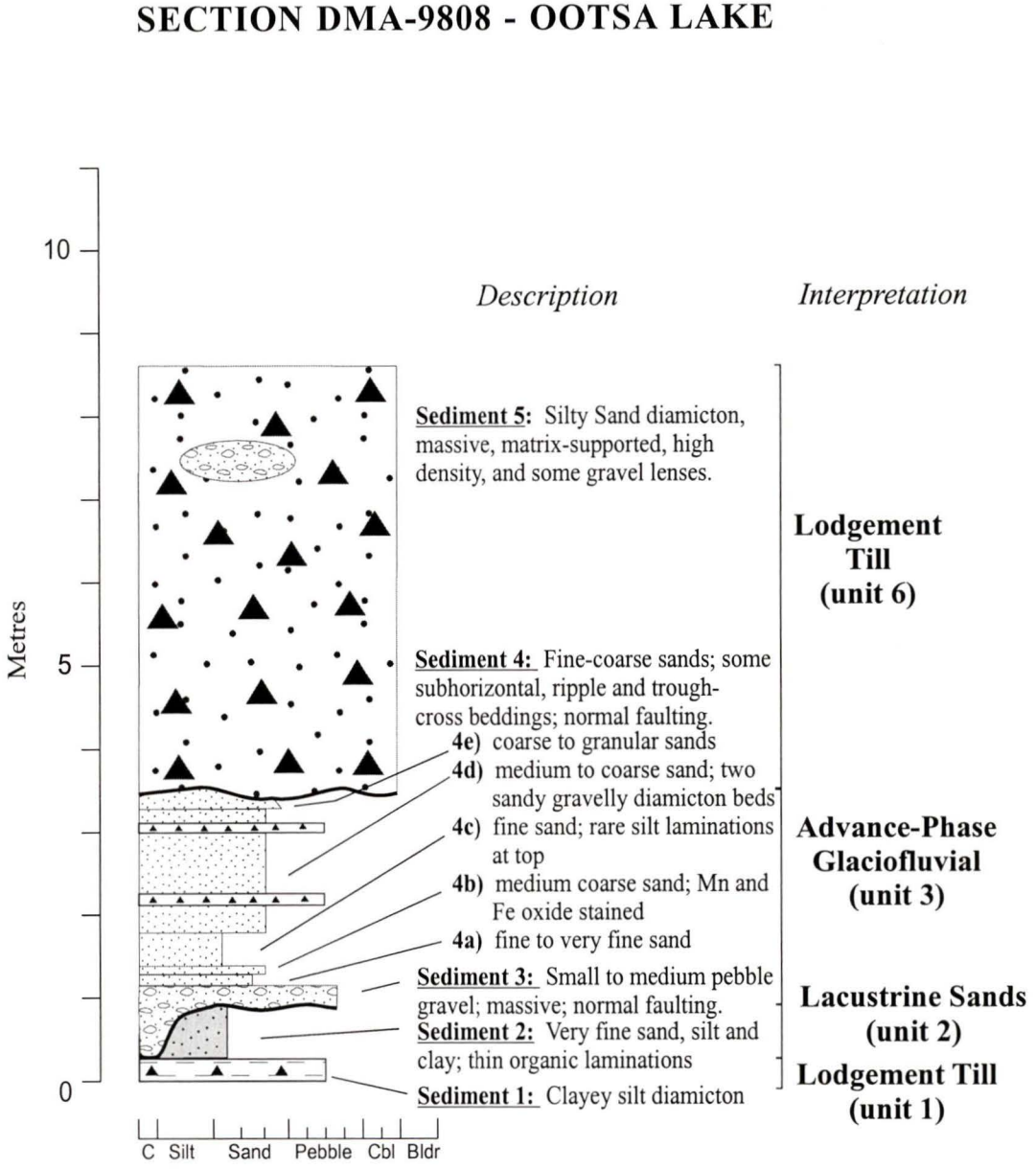



**Figure 10.** Detailed stratigraphy of section DMA-9808 from Ootsa Lake. Legend is the same as Fig. 8.

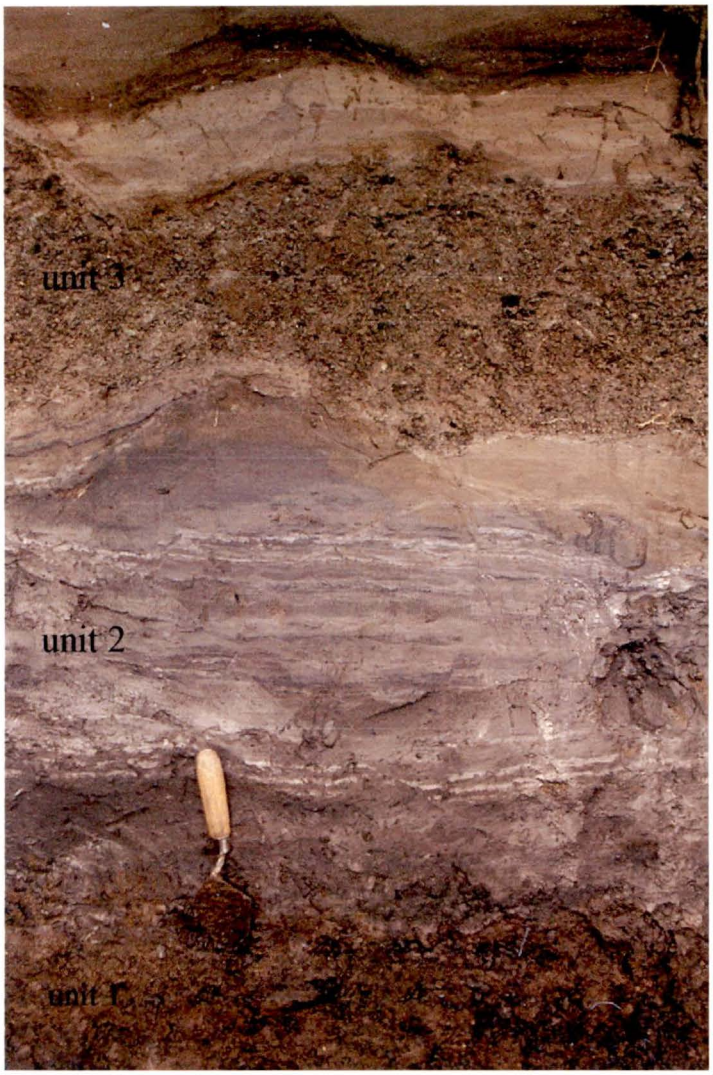



**Figure 11.** Close-up of nonglacial, very fine sand of unit 2 at section DMA-9808. Note lighter coloured silt and clay laminations. Advance-phase glaciofluvial sediments (unit 3) above have an undulating, erosive contact.

Reach of the Nechako Reservoir (048°-058°). Several small-scale normal faults have up to 5 cm of displacement.

This unit is interpreted to have a lacustrine origin. The fact that this unit contains organic material and pollen provides evidence that this sediment was probably deposited during a period when glacial ice was absent from the area. This unit also lacks rhythmic bedding and dropstones characteristic of glaciolacustrine environments. Due to this units position beneath Late Wisconsinan sediments (units 3 and 6, Fig. 10) it is believed to have been deposited during the Olympia Nonglacial Interval. Organic detritus was collected but was too disseminated for obtaining a radiocarbon date.

### 3.3.2 Late Wisconsinan Advance-Phase Sediments

3.3.2.1 Unit 3: Advance-Phase Glaciolacustrine

Late Wisconsinan advance-phase sediments are exposed below till at 9 different sections. Rare, poorly exposed silts and clays and interbedded very fine sands overlying tilted and sheared silty clay diamicton with clay laminations occur along portions of the Cheslatta River in the disturbed stratigraphy at the toe of slope movements (see locations of Slump 1 and Slump 2 in Fig. 17, Chapter 4). Some dropstones and rare silty clay diamicton beds were also observed within this unit. Bedding is commonly deformed, brecciated and sheared with polished slickenside surfaces (Fig. 12). Shear planes and slickenside surfaces are oriented in a variety of directions with some almost vertical. These surfaces usually dip into the riverbank at angles up to 20°. Intact blocks of bedded silts and clay, 1-2 m in thickness, are interpreted to be thrust blocks tilted up at steep angles at the toe of the slides. Thrust blocks are separated by slickensided shear surfaces.

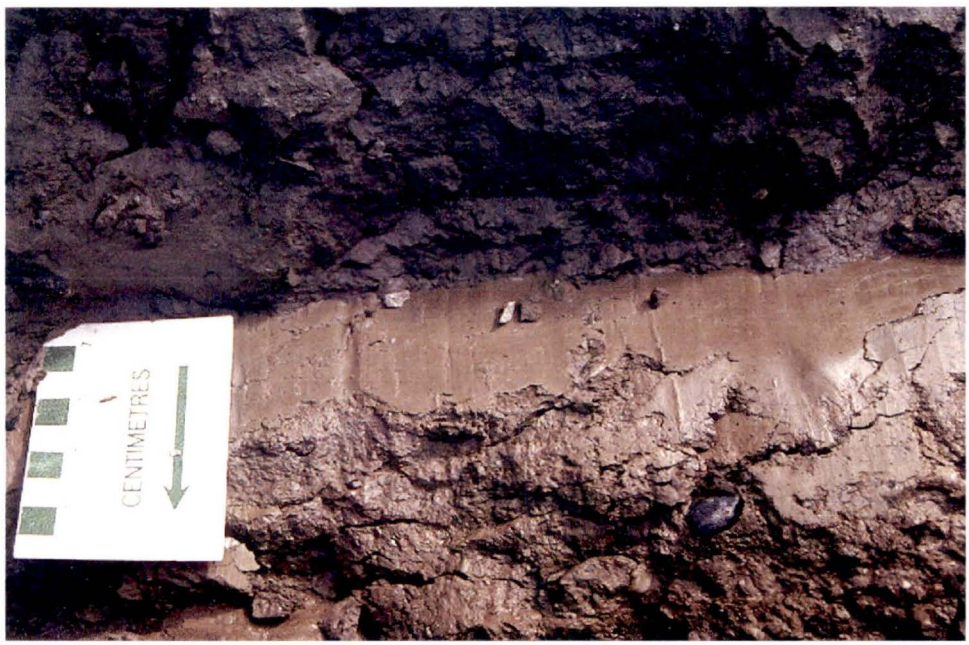



**Figure 12:** Polished and grooved slickenside surface in a thin bed of clay-rich, advance-phase glaciolacustrine sediment (unit 5) at the toe of a slump near section DMA-9814 along the Cheslatta River.

Unit 3 along the Cheslatta River is interpreted to be glaciolacustrine sediment deposited in advance-phase proglacial lakes. During the advance of the Fraser Glaciation several factors may have been responsible for proglacial lake formation in east flowing drainages like the Cheslatta River and pre-reservoir Ootsa Lake valleys. They are blockage of the Fraser River drainage east of the study area (Plouffe 2000) or more localized damming of the Cheslatta or Nechako Rivers, by ice or sediment, and/or isostatic depression.

Although not well exposed in the map area, advance-phase glaciolacustrine sediment has been identified at other locations in the region. Stratigraphic work by Levson and Giles (1997) on Knewstubb Lake of the Nechako Reservoir (approximately 65 km east of the study area) has identified the presence of advance-phase glaciolacustrine sediments there. These sediments are horizontally bedded sand, silt and clay and occur beneath a widespread massive till deposited during the Fraser Glaciation. Similar advance-phase glaciolacustrine sediments were also found under till in the Chelaslie Arm area (Levson et al. 1999) and thick sequences of advance-phase silt and clay rhythmites occur approximately 30 km to the south in sections along the north shore of Tetachuck Lake (map sheet NTS 93 F/5). The stratigraphic assignment of this unit to the advance-phase of the Fraser Glaciation is based on correlation with these other areas. However, the possibility exists that unit 3 represents a retreat phase glaciolacustrine unit of an earlier glaciation (possibly the one that deposited Unit 1).

This unit has a very significant geotechnical impact on slope stability in the region. For example, these sediments are largely responsible for triggering slope movements in

the region. Advance-phase clay-rich sediments were observed in the toe of two slope movements occurring along the banks of the Cheslatta River (Fig. 13). Brecciated and deformed bedding and slickenside surfaces are probably related to slide tectonics. When saturated with water these sediments lose their cohesion and shear strength providing a potential failure surface for overlying materials to move along (Cruden and Varnes 1996). Effects of advance-phase glaciolacustrine sediments on slope movements within and near the study area were discussed by Mate and Levson (1999b, 1999c) and the geotechnical properties of similar sediments in the northern Nechako Plateau were described by Stumpf et al. (1998).

3.3.2.2 Unit 4: Advance-Phase Glaciofluvial

Unit 4 sediments consist of fine to coarse sand and pebble to cobble-sized gravel. Sands are moderately to well sorted, show crude horizontal to subhorizontal bedding, and locally have small to medium scale, trough cross-bedding and poorly preserved ripple bedding. Gravel deposits are characterized by subrounded to rounded clasts, poor sorting, and crude medium to large-scale trough cross-bedding. Gravels are relatively dense and clast-supported, with a fine to coarse sand matrix. Sand and gravel sequences generally coarsen upward. Coarser deposits are generally poorly sorted gravel, and locally contain thin, silty sand, debris flow diamicton. Small-scale normal faults with various orientations and a few centimetres of displacement occur within unit 4. Sometimes displacement extends into underlying beds.

Unit 4 is interpreted to be advance-phase glaciofluvial sediment. At a few sites, such as section DMA-9808, unit 4 was probably deposited subaqueously as outwash infilled the lake basin in the Intata Reach valley. At one section (DMA-9817) dipping

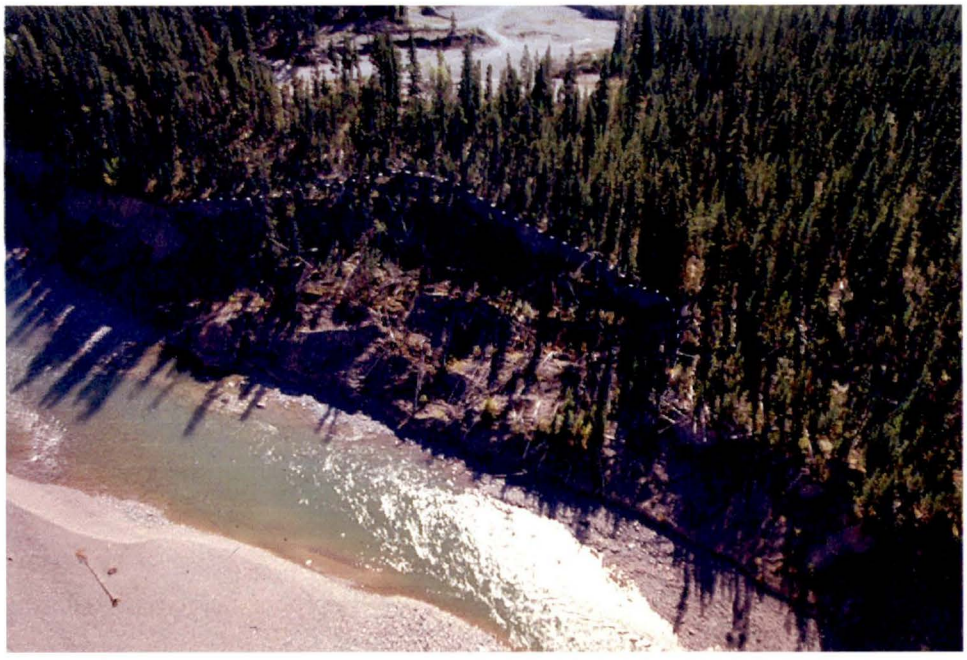


**Figure 13.** Rotational landslide along the Cheslatta River. Advance-phase glaciolacustrine sediments of unit 5 occur at the base of this landslide.

sand and gravel grades laterally into laminated sand, silt and clay representing an advance-phase delta. Steeply dipping gravel foreset beds and horizontal sand, silt and clay bottomset beds were preserved. The common upward-coarsening sequences and the presence of debris flow diamictons represent a shift from distal to ice-proximal sedimentation. Distal outwash deposits are more common and often have lens shapes which reflect channelized deposition in outwash plains. Lower contacts are generally clear to sharp and subhorizontal to undulatory.

#### 3.3.2.3 Unit 5: Advance-Phase Debris Flow

Unit 5 is a stratified silty to silty sand diamicton that generally has a high clast content (up to 50%) and is interbedded with silt, sand and gravel. They are thickest and best exposed at section DMA-9813 (Figs. 6 and 8). This diamicton generally has a high density, moderate to strong fissility, and is poorly jointed. Clasts are subrounded and striated and have a modal size of small to large pebble. Commonly, this diamicton is interbedded with silt, sand and gravel. Occasional, thinly bedded, sand lenses occur. These beds generally are 5-20 cm thick, typically extend laterally for several metres and contain scattered clasts.

This unit is interpreted to be an advance-phase glacigenic debris flow deposit. Lawson (1979) used similar characteristics to identify glacigenic debris flow deposits at the Matanuska Glacier in Alaska. An increase in thickness of diamicton beds, in places, toward the top of the unit possibly reflects the advance of glaciers into the study area. Sand and silt beds contain some scattered clasts that were probably deposited by icebergs in ice-contact lakes. Lower contacts are subhorizontal to undulatory, and clear to gradational.

### 3.3.3 Late Wisconsinan Glacial Sediments

3.3.3.1 Unit 6: Till

Sediments belonging to this unit are widespread within the study area and preserved at 14 Quaternary exposures. This unit includes two facies. The first is a clayey to silty, massive, diamicton. It has moderate to high density, high fissility, and is moderate to well jointed with weak oxidation along joints. Clasts are commonly angular to subrounded, striated and have varied lithologies. Clasts in this facies are generally small pebble to small cobble with the largest clasts up to 50 cm. Clast percentage varies from 10-20% and lower contacts can be gradational but are usually clear to sharp and undulating. Where this unit overlies bedrock, striae are common with generally northeast orientations. Gravel and fine to coarse sand lenses locally occur within this facies (see sections DMA-9808 and DMA-9809, Fig. 8). Sand lenses are crudely stratified and most lenses are horizontal but some dip steeply up to 45°.

This facies is interpreted to be basal till, possibly lodgement. Barnett (1992) notes that sand lenses can be formed in lodgement tills by periodic draining of subglacial meltwater in channels scoured into till. Determining a precise origin of these diamicts is difficult, but in some locations sedimentologic data assists interpretation. For example, deformation till, with irregular shaped lenses and beds enriched with local bedrock lithologies and inclusions of local brecciated bedrock (Fig. 14), occur within this facies.

The second facies is a massive to very crudely bedded, gravelly to sandy diamicton. It has a high density, strong fissility, and is well jointed. Clasts are mainly pebble-sized with the largest up to 15 cm in diameter. Clast content in this diamicton is usually 20-30%. In places, this diamicton is gravelly (rarely up to 50% gravel) and may appear crudely bedded.

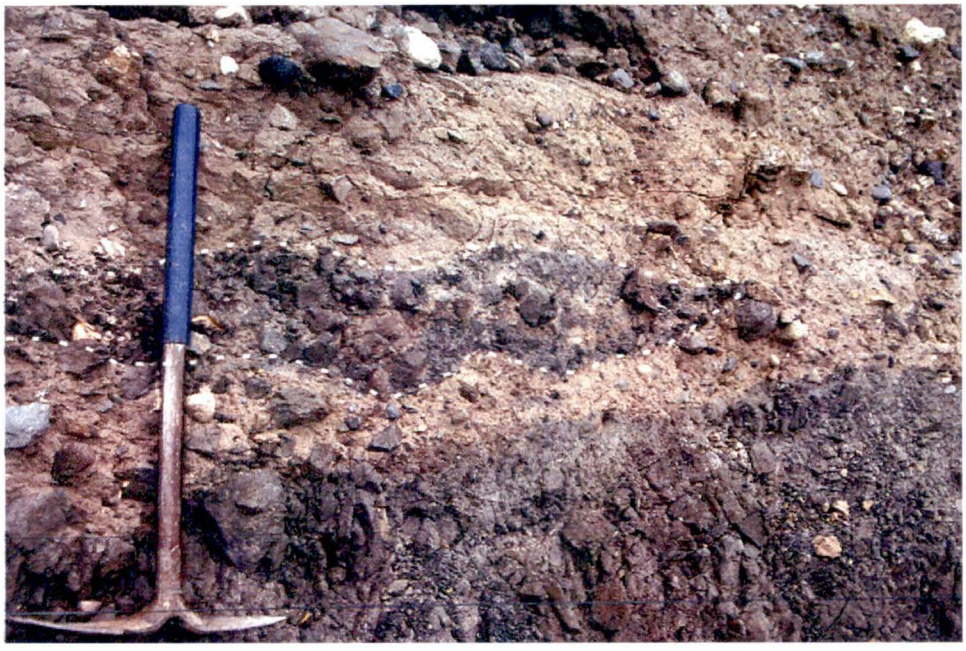


**Figure 14.** Deformation till at the contact between bedrock and till (unit 6) along a portion of the Cheslatta River. In the study area, deformation till may contain large lenses of gravelly diamicton and inclusions of local, brecciated bedrock (dotted line).

Thin, wavy and discontinuous, sand and gravel lenses, approximately 10-20 cm thick and up to 8 m wide are common in this facies. In general, lenses become more abundant, larger, and oxidized towards the top of the unit. Some lenses are horizontal while others dip up to 30° in a northwesterly (345°) direction. Locally, gravel lens and diamicton contacts are loaded showing signs of soft sediment deformation. A large lens of interbedded sand and gravel occurs at section DMA-9811 (see Fig. 8). This lens was approximately 15 m long with a sharp horizontal lower contact and a concave upper surface. These sediments were heavily faulted (thrust faults) with some overturned chevron folds and intrastratal folds and faults. Lenses with concave upper surfaces suggest deposition by subglacial meltwater in a tunnel carved into overlying ice (Levson and Rutter 1988).

This second facies is interpreted to be melt-out till. Melt-out till in this area can be distinguished from lodgement till because they have a lower density, contain significantly more sand and gravel lenses, some of which have convex upper surfaces, and usually have a coarser texture. Fine material in melt-out till may be removed by escaping porewater resulting in a generally coarser matrix than lodgement till (Lawson 1971). Furthermore, gradational lower contacts over lodgement till, commonly observed in this facies, suggest that it may have been deposited during downwasting of stagnant ice, at the end of the Fraser Glaciation.

### 3.3.4 Late Wisconsinan Retreat-Phase Sediments

#### 3.3.4.1 Unit 7: Retreat-Phase Debris Flow

Late Wisconsinan retreat-phase sediments are exposed above till at 14 sections. Unit 7 consists of diamicton interstratified with sand, gravel, and silt beds; sand and gravel

lenses also occur. Sand and silt beds sometimes contain rare clasts. Lower contacts of this unit are sharp to clear and gently undulating. The diamicton is commonly sandy and has lithologic characteristics similar to unit 5. Diamicton beds generally thin towards the top, possibly reflecting the retreat of glacier ice from the study area. Sediments belonging to this unit are interpreted to be retreat-phase glacigenic debris flows.

3.3.4.2 Unit 8: Retreat-Phase Glaciofluvial

This unit consists of sand and gravel. Sand units have a variety of textures and are commonly interbedded. Sedimentary structures include horizontal bedding, trough cross-bedding, ripple bedding and rhythmic laminations. Occasionally, sand units occur as lenses up to 50 m wide and 2.5 m thick (see section DMA-9812 Figs. 3c and 8). Gravel deposits are pebble to boulder-sized, usually clast-supported and matrix-filled, have rare interbeds of sand and silt and show trough, planar, and cross-bedding. Gravels occur above and below sands as lens-shaped units at least 5 m wide and up to 2.5 m thick. Some gravels contain silty sand diamicton beds while others are strongly oxidized. Lower contacts of unit 8 are gradational to sharp with horizontal, undulatory, and trough shapes.

Unit 8 sediment is interpreted to be retreat-phase glaciofluvial outwash. This unit was deposited as glacier ice retreated from the study area. This sediment has relatively lower densities than advance-phase glaciofluvial sediments possibly because glacier ice did not override them. The common lens shape of beds suggests deposition as channelized outwash deposits. Sands were probably deposited in more distal outwash environments where lower energy regimes occur. Gravel outwash was probably deposited in a higher energy environment closer to the glacier margin. Debris flow

diamicton within gravels provide further evidence of deposition in a proximal environment.

3.3.4.3 Unit 9: Retreat-Phase Glaciolacustrine

Sediments in this unit are dominated by silt and locally by interbedded silt and clay with occasional dropstones. Silts are horizontally bedded to massive (top of section DMA-9810, Fig. 8) and are occasionally interbedded with sand (see top of section DMA-9811 Fig. 8). Silt beds are 10-50 cm thick with crude internal bedding and laminations. Sand lenses were also observed and were typically 10 cm thick and 2 m wide.

The best exposure of interbedded silt and clay occur at section DMA-9819 on Ootsa Lake (Fig. 15). Silt is generally white in colour and clay is light brown. Silt and clay couplets generally fine upwards with silt in sharp contact with overlying clay. The thickness of silt beds ranges from 2-15 cm and averages 5 cm while clay bed thickness generally averages 1 cm. Both silt and clay show internal laminations and clay beds locally have shear surfaces with north-south oriented slickensides. Medium to coarse sand beds, approximately 0.5-1 cm thick, occur in the lower part of this unit. Silt and clay beds show local soft sediment deformation structures (small-scale load structures and overturned folds) that appear to be syndepositional.

Topography around this section is hummocky, with individual hummocks 20-50 m wide and having 3-4 m of relief. Some overturned folds in silt and clay may relate to collapse or movement towards hollows between hummocks. Silt and clay couplets in one hummock dip steeply towards the northwest and are anticlinally folded in another with their axial plane near the centre of the hummock. In the latter example, beds on the north side of the hummock dip 60° while on the south side they are mainly horizontal and

**Figure 15.** Deformed glaciolacustrine silts and clays exposed in hummocky topography at section DMA-9819 on Ootsa Lake.

gently folded (see Fig. 15). Steep normal faults and near vertical faults juxtapose steeply dipping and subhorizontal beds.

Unit 9 is interpreted to be retreat-phase glaciolacustrine sediment deposited in localized glacial lakes. The presence of dropstones (ice-rafted debris) indicate that at least a portion of these lakes were probably in contact with the retreating glacier. Retreat-phase glaciolacustrine sediments commonly occur at elevations below 890 m. Sediments dominated by silt and interbedded silt and clay were most likely deposited away from glaciofluvial streams where suspension settling and density currents dominate. Silts interbedded with sands (section DMA-9811) were probably deposited in closer proximity to the glacier margin and experienced fluctuating flow velocities. Presence of rare dropstones in silt beds suggests iceberg activity and the presence of ice-contact glacial lakes.

Glaciolacustrine sedimentation on buried blocks of stagnant ice is likely responsible for the deformed bedding of silt and clay and the hummocky topography at section DMA-9819. Deposition of retreat-phase glaciolacustrine sediments on stagnant ice blocks within the Nechako River Map Area (93 F) has also been noted around Fraser Lake and Burns Lake by Plouffe (1997) and Knewstubb Lake and Big Bend Creek by Huscroft and Plouffe (1999).

### 3.3.5 Holocene Sediments

#### 3.3.5.1 Unit 10: Fluvial Sediments

Holocene sand and gravel overlies all other units described and are exposed at 2 sections in the study area. Gravel is usually clast-supported and open work or matrix-filled. Clasts are angular to well rounded and sometimes heavily oxidized. Gravel can

also be imbricated and generally have sharp and undulatory to trough-shaped, lower contacts. Sand generally has fine to medium grain-sizes, occasionally coarsens upwards, and sometimes contains numerous buried organic horizons. Lower contacts are gradational to sharp and horizontal to undulatory.

These sediments are fluvial deposits formed after Fraser Glaciation ice left the area. Sands with organic horizons are interpreted to be overbank sediments. An unusual Holocene sequence occurs at section DMA-9815 along the Cheslatta River (Fig. 16). At this section small to large pebble gravel is interbedded with peat. Geomorphic evidence shows that interbedded gravel and peat at this section were deposited in a small delta above the Cheslatta River level. The delta was probably formed by a small tributary flowing into Cheslatta River when water levels were much higher, prior to the construction of the spillway.

Gravel units probably represent active distributary channel deposition along the delta front. As these channels shift, quiet water conditions follow allowing for the development of organic material and formation of peat. As distributary channels shift back, peat deposits are overlain by outwash gravels. If this interpretation is correct then channels shifted several times at this section.

In places, the peat beds are horizontal to undulatory and 5-20 cm thick. Most peat units are dominated by woody material that is often flattened. Other beds are charcoal rich and contain reed and shell fragments. Imbrication in the lowest gravel bed has an approximate paleoflow direction of 120°. Locally, massive silty diamictons containing organics occur at the top of some sections (e.g. DMA-9811, Fig. 8). These sediments are probably colluvial debris flow deposits or alluvium.

a)

b)

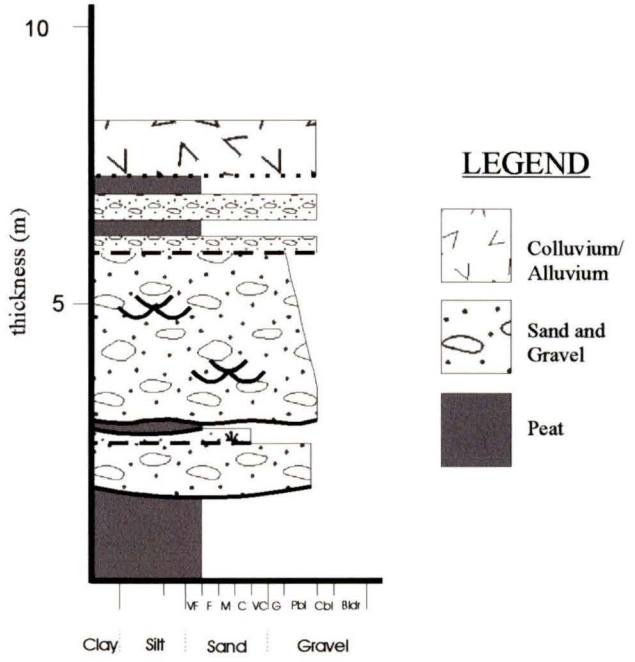



**Figure 16.** a) Interbedded gravel and peat in exposed Holocene delta sediments at section DMA-9815 along the Cheslatta River. b) Stratigraphic column of section DMA-9815. Refer to Fig. 5 for a more complete legend.

### 3.3.6 Discussion

At section DMA-9808 (Fig. 10) this till has similar characteristics of the main till unit above it which is assigned to the Fraser Glaciation. Therefore, pebble counts and till geochemistry were two techniques used to determine if these tills had any diagnostic characteristics (Tables 2a and 2b). The dominant pebble lithologies of unit 1 till are rhyolite, greywacke, basalt, and andesite while in the overlying till (unit 6) the most common pebbles are andesite, basalt, and volcanic breccia (Table 2a). Geochemical data for unit 1 and unit 6 tills from section DMA-9808 are found in Table 2b. Element concentrations between these units are very similar with some (e.g. cobalt (ICP) and molybdenum (INA) being identical. However, slightly higher concentrations of most elements occur in unit 1.

At section DMA-9808 there is enough variation in pebble lithologies between the two tills (see Table 2a and Fig. 10) to possibly indicate different source areas. A large area of Ootsa Lake Group rhyolite occurs in the vicinity of this section (Anderson 2000*a*). A local derivation for the lower till clasts explains the high rhyolite pebble content in the lower till. The source of the abundant greywacke in the lower till is unknown but is most likely from Hazelton Group rocks that occur to the south. Potential source areas for the numerous breccia clasts in the upper till include Upper Cretaceous rocks to the west, Endako Group rocks to the southwest and Ootsa Lake andesitic breccia to the northwest. All of these sources are a few to several km away from the site. Therefore, clast lithologies indicate differential transport distance although different transport directions cannot be ruled out. However, even though pebble lithologies between the two till units at section DMA-9808 vary, geochemically they are quite

**Table 2.** a) Pebble counts from lower (unit 1) and upper (unit 6) tills at section DMA-9808 and b) Selected results of geochemical analysis of two tills (unit 1 and unit 6) at section DMA-9808 using INA and ICP. **Note:** DL stands for detection limit.

a)

| | # Pebbles | % Present | # Pebbles | % Present |
|---|---|---|---|---|
| **Rock Type** | **Unit 1** | **Unit 1** | **Unit 6** | **Unit 6** |
| Green Andesite Tuff | 2 | 4 | 2 | 4 |
| Red Rhyodacite | 2 | 4 | 8 | 14 |
| Volcanic Breccia | 1 | 2 | 10 | 18 |
| Basalt | 9 | 17 | 11 | 20 |
| Andesite | 8 | 15 | 14 | 25 |
| Greywacke (volcanic and Chert) | 11 | 21 | 3 | 5 |
| Dacite | 1 | 2 | 0 | 0 |
| Rhyolite | 13 | 25 | 5 | 9 |
| Intrusive | 2 | 4 | 1 | 2 |
| Diorite | 1 | 2 | 1 | 2 |
| Chert Conglomerate | 2 | 4 | 1 | 2 |
| Quartzite | 0 | 0 | 1 | 2 |
| **Total** | 52 | | 56 | |

b)

| | ICP | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Cu ppm** | **Pb ppm** | **Zn Ppm** | **Ni ppm** | **Co ppm** | **Mn ppm** | **Sr ppm** | **V ppm** | **Cr ppm** | **Ba ppm** |
| **DL** | **1** | **3** | **1** | **1** | **1** | **2** | **1** | **1** | **1** | **1** |
| Unit 1 | 26 | 8 | 63 | 20 | 12 | 753 | 77 | 60 | 28 | 139 |
| Unit 6 | 22 | 4 | 60 | 17 | 12 | 639 | 67 | 56 | 21 | 135 |

| | INA | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **As ppm** | **Ba ppm** | **Co Ppm** | **Cr ppm** | **Fe %** | **Mo ppm** | **Sc ppm** | **Th ppm** | **La ppm** | **Ce ppm** |
| **DL** | **0.5** | **50** | **1** | **5** | **0.01** | **1** | **0.1** | **0.2** | **0.5** | **3** |
| Unit 1 | 12 | 1000 | 14 | 73 | 4.5 | 7 | 14 | 6.4 | 26 | 51 |
| Unit 6 | 13 | 940 | 13 | 63 | 4.1 | 7 | 13 | 6.5 | 27 | 53 |

similar. This suggests that the matrix is locally derived while the clast content reflects more distal sources. Thus both tills have the same general transport directions.

Unit 1 could also be interpreted as basal till deposited during the Fraser Glaciation with the overlying till (unit 6) representing a re-advance. Although possible, the presence of organic-bearing sands between these two units (see Fig. 9) suggests deposition during a warmer period that is unlikely to have occurred in a minor re-advance scenario. Postglacial slumping or glaciotectonic faulting at section DMA-9808 could also explain the presence of the two till units (e.g. if the upper till and underlying sediments were thrust over unit 1 resulting in a stratigraphic repetition). However, only small-scale ( less than 5 cm) normal faulting was identified at this section and is believed to represent only minor slumping. In addition, observations on the ground and from air photographs showed that banks around section DMA-9808 were generally stable. Finally, the distinct pebble lithologies of units 1 and 6 suggest that they are not the same unit repeated by faulting.

Unit 2 is interpreted to be lacustrine in origin. The fact that this unit contains organic material, provides evidence that this sediment may have been deposited during a period when glacial ice was absent from the area. It also lacks rhythmic bedding common in glaciolacustrine environments. Due to its position beneath Late Wisconsinan sediments (units 3 and 6, Figs. 9 and 10), unit 2 is believed to have been deposited during the Olympia Nonglacial Interval.

Unit 2 at section DMA-9808 on Ootsa Lake has similar characteristics to fluvial, organic-bearing, nonglacial sediments found along the Necoslie River (200 km northeast, Plouffe and Jetté 1997) and Chelaslie Arm of the Nechako Reservoir (10 km southwest,

Levson et al. 1998, 1999). At all three sites, fine sands containing finely disseminated organics within stratified silt and clay, underlie advance-phase glaciofluvial sediments and till deposited during the Fraser Glaciation. Nonglacial sediments at the Necoslie River section overlie a second till unit and organic material within them was too dispersed for radiocarbon dating. A radiocarbon date of organic material taken from lacustrine sediments in a section along Cheslaslie Arm yielded a date of 27 790 ± 200 BP (Beta-101017) (Levson et al. 1998). The proximity of section DMA-9808 to the Chelaslie Arm section and the similar stratigraphy at both sites, suggests that unit 2 is correlative with the dated nonglacial sediments at Chelaslie Arm.

The lacustrine sediments at Chelaslie Arm (e.g., Fig. 6b) are 3-4 m thick and are exposed over a distance of approximately 15 km. Lake sediments at DMA-9808 on Intata Reach are at the same elevation as the Chelaslie Arm lake sediments suggesting that an extensive lake or lake system occurred in the region. The cause of high lake levels in the region at this time is unknown. It reflects a higher regional base level probably due to thick sediment accumulation in the valley with little stream incision.

Until recently the discovery of Olympia Nonglacial sediments within the Interior Plateau of British Columbia has been limited to very few sites (Plouffe and Jetté 1997; Levson et al. 1998, 1999; Mate and Levson 1999*a*; and Plouffe and Levson 2001). One reason for this, is that most nonglacial sediments were eroded during the Fraser Glaciation and only occur as erosional remnants in specific areas. In addition, nonglacial sediments may be concealed by Fraser Glaciation deposits. Limited access within the Interior Plateau has probably also made the discovery of Olympia age sediments difficult.

### 3.3.7 Summary

The Quaternary stratigraphy within this portion of the Nechako Plateau is dominated by ten surficial units. Unit 1 (till) is the oldest Pleistocene sediment in the area and was probably deposited during a pre-Fraser Glaciation. This unit is a massive, well jointed, clayey silt diamicton with moderate to high density and striated clasts. It is overlain by organic-bearing, blue-grey, very fine sand with silt and clay laminations (unit 2). This sediment is interpreted to be lacustrine and probably correlates to the Olympia Nonglacial Interval.

Advance-phase glaciolacustrine sediments (unit 3) are poorly exposed and consist of silts and clays and interbedded very fine sands. These sediments are brecciated and observed only at the base of slope movements along the Cheslatta River. Advance-phase glaciofluvial fine to coarse sands and pebble to cobble-sized gravels (unit 4) overlie unit 2 and occur below debris flow diamicton (unit 5) and till (unit 6) deposited during the Fraser Glaciation. Generally, advance-phase sediments have a higher density and contain more faults than retreat-phase sediments.

Table 3 summarizes some of the main physical characteristics of till and debris flow sequences within the study area. Advance (unit 5) and retreat-phase (unit 7) glacigenic debris flow sequences are often interstratified with silt, sand, and gravel. Till deposited during the Fraser Glaciation (unit 6) is the most common sediment type found in exposures in the study area. Two facies are recognized within this unit: 1) lodgement till and 2) melt-out till. Lodgement tills usually have a high density, strong fissility, and are massive. Rare deformed inclusions of local, brecciated bedrock occur within this facies. Melt-out till is slightly less dense than lodgement till and commonly has a coarser

**Table 3.** Summary of some of the typical physical characteristics of tills and debris flow sequences within the study area.

| Genetic Interpretation | Bedding | Matrix | Clast Content | Density | Jointing | Fissility | Lenses | Other features |
|---|---|---|---|---|---|---|---|---|
| Advance-Phase Debris Flow Sequence | Interbedded with sand, gravel, and silt. Rarely massive | Silty to Silty Sand | 10-50% clasts, modal size is small to large pebble, largest clasts are usually 5-15 cm. | Moderate to High | Poor, rarely well developed | Moderate | Thinly bedded sand lenses | Sand and silt beds contain dropstones, diamict beds 5cm-1m thick, lower contact gradational, subrounded and some striated clasts. |
| Retreat-Phase Debris Flow Sequence | Interbedded with sand, gravel, and silt | Sandy | Modal size medium to large pebble. | Moderate | Moderate | Moderate | Sand and gravel lenses common | Sand and silt beds contain dropstones, lower contact is usually clear and subhorizontal or with gentle undulations. |
| Lodgement Till | Massive | Clayey, Silty, to Silty Sand | 10-20% clasts, modal size is medium to large pebble, largest clasts usually about 15-30 cm, varied lithologies. | High | Moderate to Well | High, Rarely Low to Moderate | Some gravel and sand lenses. Gravels usually matrix filled and sometimes openworked | Striated clasts, subhorizontal fabric with similar direction to local striations and streamlined landforms, occasionally colour reflects local bedrock, angular to subrounded clasts, approximately 60% matrix, lower contact sharp and planar or undulatory. |
| Meltout Till | Massive to crudely bedded | Usually silty to sandy, often with higher gravel and sand content than lodgement till. | 20-50% clasts, modal size is small to large pebble. | Moderate to High | Moderate to Well | Moderate to Strong | Wavy, discontinuous sand and gravel lenses. Gravel lenses may be openworked, some trough shaped. | Lenses increase towards top of unit, soft sediment deformation along lense/diamict contact, gradational to clear lower contact that is sharp and undulatory, occasionally lower contact will be sharp and have convex upward surfaces. |
| Deformation Till | Massive; some brecciated bedrock inclusions and sheared clay beds | Sandy Silt | 15-40% clasts, locally 90-100%. | High | Poor to Moderate | | Enriched with local bedrock lithologies and brecciated bedrock. | Inclusions of brecciated bedrock, fractures in underlying bedrock are filled with diamict. |

texture. Sand and gravel lenses with convex upper surfaces are also common in this facies.

Retreat-phase glaciofluvial, glaciolacustrine and Holocene sediments (units 8, 9 and 10) occur above Fraser Glaciation till (unit 6) and retreat-phase debris flow (unit 7) sediments. Retreat-phase glaciolacustrine sediments are dominated by silt and locally by interbedded silts and clays. Finally, Holocene sand and gravel (unit 10) interpreted to be fluvial deposits overlie all other units. Often these sand and gravel contain organic material or are interbedded with peat.

## 3.4 QUATERNARY HISTORY

Pre-Late Wisconsinan, till (unit 1) and organic-bearing lacustrine sediments, occur within the Ootsa Lake valley. This valley is transverse to the regional ice flow direction (see Fig. 7) allowing for their preservation. Till underlying organic-bearing sediments along Ootsa Lake suggests there was glacial activity in this area before the Late Wisconsinan and Olympia Nonglacial Interval.

Late Wisconsinan glacial ice advancing into the study area most likely originated in the Coast Mountains (Tipper 1971). During early, and probably late phases of glaciation, ice was topographically controlled and moved through valleys like the Ootsa Lake and Cheslatta River valleys. Rare striation directions along the shoreline of Ootsa Lake are valley parallel (125° to 150°; Fig. 7) supporting this interpretation. Evidence of topographically controlled, valley parallel, ice movement in other regions of the Nechako Plateau has been identified by Levson and Giles (1997). Representative orientations of streamlined landforms and striae within the study area (see Fig. 7) have strong northeasterly trends.

At the onset and at the end of the Fraser Glaciation ice was confined in the lowest areas like the Ootsa Lake valley. Ice confined in this major valley would have dammed local tributaries, depositing advance and retreat-phase glaciofluvial, glaciolacustrine and glacigenic debris flow sediments. Advance-phase glaciolacustrine sediments were formed in local ice-contact lakes or glacier-fed lakes. Aggradation by more proximal glaciofluvial outwash soon followed. Glacigenic debris flows interbedded with and overlying outwash originated from the ice margin indicating more proximal deposition.

As ice continued to advance from the Coast Mountains it coalesced and thickened in the study area and the influence of topography on its movement diminished. This resulted in the dominant northeasterly ice flow direction, which is supported by striation and streamlined landform orientations. Striation measurements from bedrock outcrops have an average orientation of 75° and range from 60-94°. Streamlined landforms have an average orientation of 70° and range from 60-80°. During this phase, thick lodgement tills were deposited over extensive portions of the study area. The ice either eroded advance-phase or older sediments or overrode them.

Although easterly ice flow indicators dominate in the study area, westerly flow indicators are preserved on a roche-moutonneé in the northwest corner of the Marilla map sheet (see Fig. 7). On the steep easterly exposed lee side of this form there are weak, west-trending rat-tails and striations approximately oriented 300°. Striations on the stoss side (facing west) are oriented in a northeasterly direction (070°). Evidence of anomalous westward flow has been identified in adjacent areas of the Nechako Plateau and interpreted to be a late glacial event (Levson et al. 1998, 1999). It is believed that this anomalous flow reflects an eastward shift in an ice divide originally positioned over

the Coast Mountains to the west (Clague 1989). Westward paleoflow indicators found in this area record the most southerly known evidence of this shifting ice divide.

During deglaciation ice stagnation occurred in parts of the study area. Crevasse filling landforms, present in the southwest corner of the Marilla map area, provide evidence for stagnant ice. Areas of poorly sorted pebble and cobble gravel commonly occur as thin veneers throughout the study area. These deposits probably reflect winnowing of fine material as surface materials are washed by glacial meltwater. Retreat-phase glaciolacustrine sediments locally formed in proglacial lakes dammed by stagnating ice blocks. These sediments are thin and shorelines are not seen suggesting that the lakes were probably short lived. Eskers, outwash, and other glaciofluvial deposits potentially associated with stagnating ice are poorly represented in the area. Most of these deposits occur around the Cheslatta River valley.

Holocene sand and gravel occur as modern fluvial sediment or in terrace deposits. Terrace deposits are commonly found at the top of Quaternary sections along the banks of the Cheslatta River. Recent, fluvial incision, caused by the Skins Lake Spillway, is responsible for exposing this sediment.

Peat and marl accumulated in poorly drained areas throughout the study area. Often peat deposits occur adjacent to some lakes and at the stoss-end and along the sides of streamlined landforms. Both peat and marl are well exposed in sections, up to 4m high, along the Cheslatta River. Such excellent exposure of these sediments is extremely rare in British Columbia and should provide abundant information about climate and vegetation patterns during the Holocene.

Finally, anthropogenic flooding has had a significant influence on the geomorphology of the study area. Higher lake levels in Ootsa Lake, following the completion of the Nechako Reservoir, has rapidly increased shoreline and riverbank erosion. This erosion has lead to the development of numerous slope movements (see Chapter 4) and the exposure of large Quaternary sections and shoreline bluffs (see Fig. 6). Also, higher lake levels have covered most of the Ootsa Lake valley hiding Quaternary deposits and landforms that occur there.

# 4 LANDSLIDES IN PLEISTOCENE SEDIMENTS: EXAMPLES FROM THE INTERIOR PLATEAU, BRITISH COLUMBIA

## 4.1 INTRODUCTION

A variety of natural hazards are common in the Canadian Cordillera due largely to tectonic activity and the mountainous topography. Clague and Evans (1998) provide a recent summary of the types of natural hazards occurring within the province of British Columbia. One hazard type, slope movements, are becoming more frequent due to increasing development in mountainous terrain in the form of mining, ski resorts, forestry and urban development.

A landslide is defined as the movement of a mass of rock, debris, or earth down a slope (Cruden 1991, p. 28). Slope movement, mass wasting, and mass movement are synonymous with landslides. These terms do not imply an interpretation and are used to encompass all movements involving a downward motion of rock, debris or earth. In this chapter, the term landslide will only be used for describing slope movements that involve material slipping over one or more surfaces of rupture (Working Party on World Landslide Inventory 1990; Trenhaile 1998). Other types of slope movements such as topples, falls, lateral spreads and flows (Appendix C) are not included in this discussion.

In British Columbia slope movement hazards are commonly observed in mountainous regions, but damaging and problematic failures also occur in areas of low relief such as the Interior Plateau. The main objective of this chapter is to describe characteristics of slope movements in the Interior Plateau and discuss some of the factors responsible for their initiation. Specific reference will be made to slope movements

occurring along the Cheslatta River and the shores of Chelaslie Arm of the Nechako Reservoir (Fig. 17).

## 4.2 LITERATURE REVIEW

### Historical Studies

Most geotechnical and geological research on slope movements did not begin until the late 1700's and early 1800's. Some reasons for this were low economic incentives and poorly developed scientific knowledge for such research. Turner and Jayaprakash (1996) focus on historical aspects of landslide studies and their development. Four early examples of landslide studies in Europe; the Rossberg landslide of 1806, the Bindon Landslide of 1839, the Elm landslide of 1881, and slope stability studies along French canals are concisely summarized. The Rossberg, Bindon and Elm landslides all occur in bedrock.

Weakening of geological materials by water saturation was partly responsible for slope movements at Rossberg, Bindon, and along the French canal. Extraction of slate from the base of a steep mountain slope (undermining at the toe) was one of the main factors responsible for triggering the Elm landslide. Both of these causes are relevant for slope movements discussed in this chapter and throughout the Interior Plateau.

Turner and Jayaprakash (1996) also provide a short summary about Alexandre Collins work on clay slopes along French canals (Collin 1846). This French engineer was one of the first to recognize rotational slides and use soil mechanics (shear tests conducted on clay) to explain them. It is noted that Alexandre Collin attributed failure in clay slopes to low shear strength caused by progressive softening of clay by water saturation.

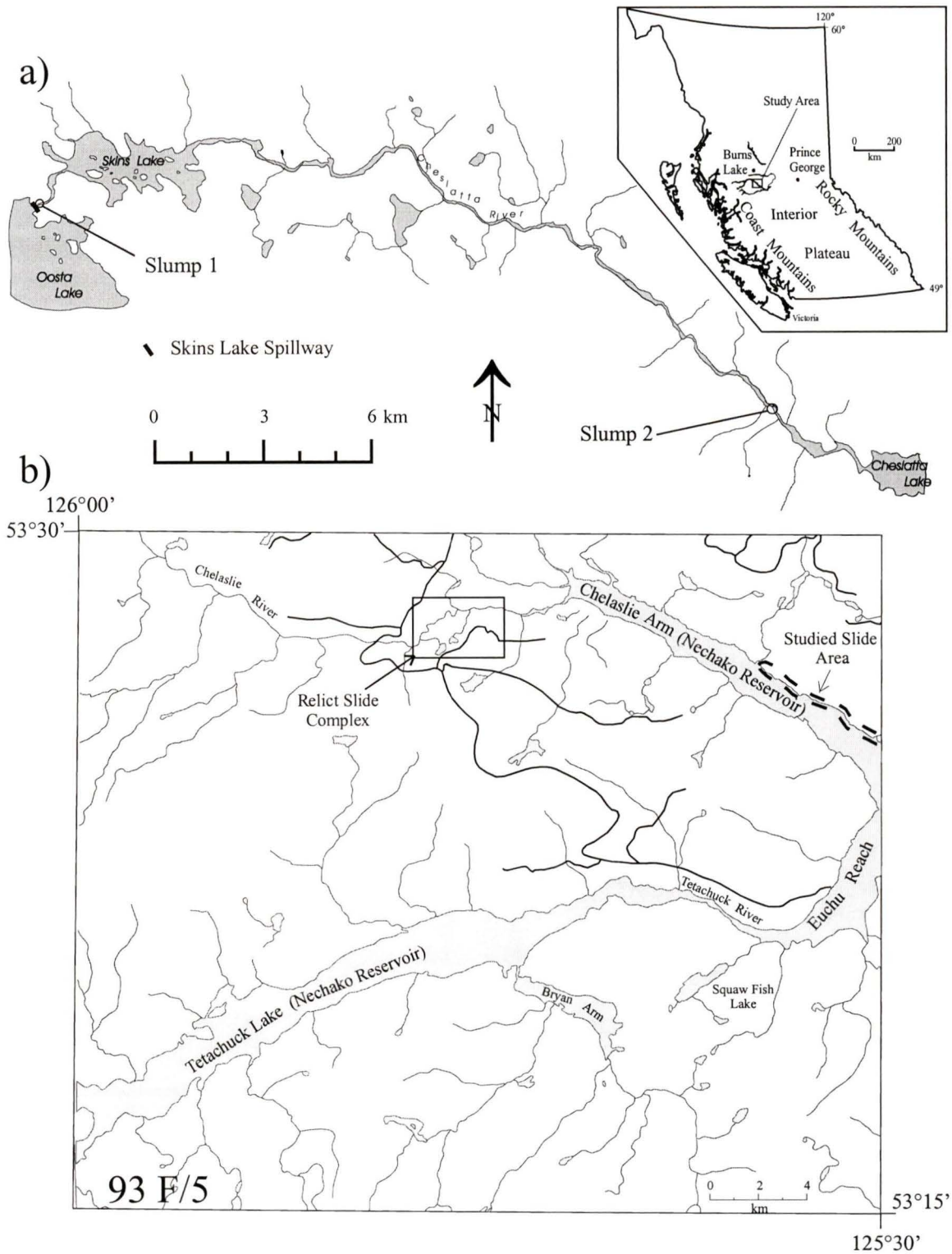



**Figure 17.** Location of the slope movements a) that were identified and investigated along the Cheslatta River. Slump 1 occurs on the south side of the river below the spillway. Slump 2 is found on the southwest side of the river approximately 28 km downstream from the spillway close to Cheslatta Lake. b) Slide area along a southwest facing portion of Chelaslie Arm (Nechako Reservoir) and the location of a large relict slide (Fig. 29a) along Chelaslie River.

## Classification Systems and Nomenclature

One of the first comprehensive summaries and descriptions of various slope movement types and processes was provided by Varnes (1978). The slope movement classification system created by this author is widely accepted and used to classify failures discussed in this chapter. Cruden and Varnes (1996), focusing on new developments made since 1978, expand upon the work done by Varnes (1978) and provide additional explanations of landslide nomenclature and activity. For example, they comment on the formation of sag ponds above backward-tilted rotational slump blocks and note these ponds, representing a disruption in drainage, keep displaced material wet and perpetuate future slope movements.

The landslide classification system created by Varnes (1978) and a summary of types of slope movements (Cruden and Varnes 1996) are found in Appendix C. Schematic diagrams are also included to help explain these slope movement types. A comprehensive checklist, compiled by Cruden and Varnes (1996), of possible landslide causes and factors responsible for both rotational and translational failures can be found in Appendix D.

Nomenclature proposed by the International Association of Engineering Geology (IAEG) Commission on Landslides (1990) is used in this chapter to identify the various features of slope movements. This commission divides landslide nomenclature into two groups: those that define identifiable features and those that define dimensions of identifiable features. Definition of the terms used in these two groups, and cross-section and plan view diagrams to illustrate them, are found in Appendix E.

Terms proposed by the United Nations Educational, Scientific and Cultural Organization (UNESCO) Working Party on World Landslide Inventory (1993) are used to describe the activity of landslides. This working party has divided landslide activity into three separate groups. The first group is state of activity which describes the timing of slope movements. The second group, distribution of activity, describes where the landslide is moving. Finally, style of activity tries to explain how different movements within failures contribute to the overall slope movement. Definitions of the type of activity belonging to each group, as well as diagrams explaining landslide distribution and style of activity are found in Appendix F.

**Landslide Causes and Triggers**

A comprehensive discussion of causes of slope instability is provided by Crozier (1986). This author states that stresses within every slope act to promote or resist movement. These stresses are shear stress (promote movement) and shear strength (resist movement). Crozier (1986) helps explain factors controlling slope instability by introducing the concept of stability states. In total there are three different stability states: preparatory, triggering and controlling. Preparatory factors are those that make slopes unstable but do not initiate movement. The presence of weak, geologic materials within a slope is an example of a preparatory factor. Triggering factors initiate movement, turning marginally-stable slopes into active ones. Removal of lateral support and undercutting of banks by fluvial processes are examples of triggering mechanisms. Controlling factors determine how a failure perpetuates; they control the form, rate and duration of movement. Some controlling factors on slope movements could be the size and distribution of sag ponds and the location of fluvial erosion along the toe. Sag ponds on

rotational failures can increase pore water pressures in the displaced mass, decreasing its stability. This also helps perpetuate future failures. Multiple failures sometimes occur in slumps along erosive cut banks of rivers where stabilizing material from their toe is constantly removed and replaced with material from above.

Wieczorek (1996) provides a recent summary of landslide triggering mechanisms and attempts to distinguish between causes and triggers of landslides. He mentions that landslides may have many causes (Appendix D) but only one trigger. He defines a trigger (e.g. intense rainfall) as an external stimulus that initiates an almost immediate slope movement response. External causes can either increase stress or decrease strength of slope materials. Landslide triggers discussed include intense rainfall, rapid snowmelt, water-level change, volcanic eruptions and earthquake shaking. Of these the most relevant in this study area are believed to be intense rainfall and water-level change. Wieczorek (1996) explains that high water levels saturate shoreline slopes increasing pore pressure within the sediments. A sudden lowering of water level against a slope removes lateral support and exposes weak saturated sediment.

Other specific studies on causes and triggers of slope movements have been conducted by Fukuoka (1979) and Alexander (1992). Fukuoka (1979) studied factors responsible for initiating mass wasting in the Izu Peninsula, Japan. Earthquakes, heavy rains and increased pore water pressures were investigated. It was found that percolating water from heavy rainfall increases the pore water pressure of soil lowering its shear resistance. This author also notes that mudflows are common in water saturated, loosely consolidated soils that texturally are composed of sands and finer materials. It was also

noted that road construction (steepening slopes along roadways) influences mass movements.

Alexander (1992) examines the causes, both natural and human, of three different landslides. Examples were from Cuyocuyo in the Peruvian Cordillera and in Calciano and Valle dell'Orco in southern Italy. Short lists describing types of external and internal causes that act on slope movements are provided. Some external causes are steepening or heightening of slopes and removal of lateral or underlying support (from road building or stream erosion). One internal cause listed is the presence (or absence) of plant roots.

A summary of the type of slope movements occurring along reservoir shorelines has been provided by Schuster (1979). Slope movements from the shore of Franklin D. Roosevelt Lake (Grand Coulee Dam Reservoir, in the State of Washington) are used in this paper as an analogue for landslides on the Nechako Reservoir. Extreme water level fluctuations is the main factor used to explain the initiation of failures along Roosevelt Lake. The author mentions that reservoir related rockslides are more destructive than reservoir related failures in surficial sediments. Common reservoir related slope movements in coarser debris materials are slides, flows and avalanches, while slumps, slides, spreads and flows occur in finer-grained (earth) materials.

**British Columbia Landslide Studies**

Research by the Geological Survey of Canada (Eisbacher and Clague 1984), based on 137 landslide case studies from the Alps has been influential in guiding development in mountainous terrain of the Canadian Cordillera. Their research focused mostly on destructive mass movements in British Columbia, notably mountain torrents and failures of steep bedrock slopes. A section on debris flows in surficial deposits notes that high-

intensity downpours, sustained regional rainstorms and rainstorms combined with rapid snowmelt are three major debris-generating meteorological events.

Evans (1982) provides a review of slope movements in surficial deposits occurring in urban areas of British Columbia. Types of surficial material that are commonly prone to failure are the focus of this paper. Therefore, glaciomarine sediments, glaciolacustrine deposits and till that mantles steep mountain slopes were the material types investigated. Geotechnical differences between glaciolacustrine deposits in the northern and southern Interior Plateau are also discussed. Varves are classified as type B (clay thickness greater than silt thickness) in the northern interior and type A (silt thickness greater than clay) in the Southern Interior. Other publications that deal with slope movements in British Columbia are Eisbacher (1979) and Evans and Gardner (1989).

Slope stability research in the Bulkley Valley around Smithers, approximately 165 km northwest of the study area (Stumpf et al. 1998), has addressed slope stability and the characteristics of glaciolacustrine deposits in this region of central British Columbia. These authors briefly explain that glaciolacustrine sedimentation occurred in the Interior Plateau when large bodies of water flooded low-lying areas and valleys during advance and retreat of glaciers. Advance-phase glaciolacustrine sediments, found within the Bulkley, Pine Creek and Morice River valleys are overlain by a sequence of till and/or debris flow deposits and glaciofluvial sediments. Varves of glaciolacustrine sediments studied in the Smithers-Houston area have variable texture and thickness. For example, type A and B varves (type A are susceptible to retrogressive failure) were both found to occur within the Bulkley River Valley. A fieldwork paper by Huscroft and Plouffe (1999) briefly discusses slope movements occurring in retreat-phase glaciolacustrine

sediments of glacial Lake Knewstubb, roughly 62 km east of the study area. They inferred that increased pore pressures can develop within interbedded fine sand, silt and clay packages due to dissimilar permeability's between layers.

## 4.3 OBSERVATIONS

### 4.3.1 Cheslatta River Slope Movements

#### 4.3.1.1 Location

Two slope movements were identified and investigated along a section of the Cheslatta River during this research. This part of the river flows southeast from Ootsa Lake into Cheslatta Lake and is controlled by a spillway that separates it from the Nechako Reservoir (Ootsa Lake). The Skins Lake spillway, built by ALCAN is the reservoir outlet to Cheslatta River. Both failures are significant because they potentially pose local safety hazards and increase river siltation, possibly degrading the aquatic environment. Slump 1 (Fig. 18a) the smallest of the two slope movements, is on the south side of the river just below the Skins Lake spillway, while slump 2 (Fig. 18b) occurs on the southwest side of the river approximately 28 km downstream from the spillway and 3.5 km northwest of Cheslatta Lake (see Fig. 17).

#### 4.3.1.2 Geological Features

Stratigraphic information was collected from thirteen large, well exposed Quaternary sections along the Cheslatta River (see Chapter 3 for a more detailed description of stratigraphic information). The most common stratigraphic unit along this portion of the Cheslatta River is a massive diamicton that is interpreted to be till deposited during the Fraser Glaciation. This diamicton is poorly sorted and well jointed with striated and faceted clasts, strong fissility and high density. Till is stratigraphically underlain by well

a)

b)

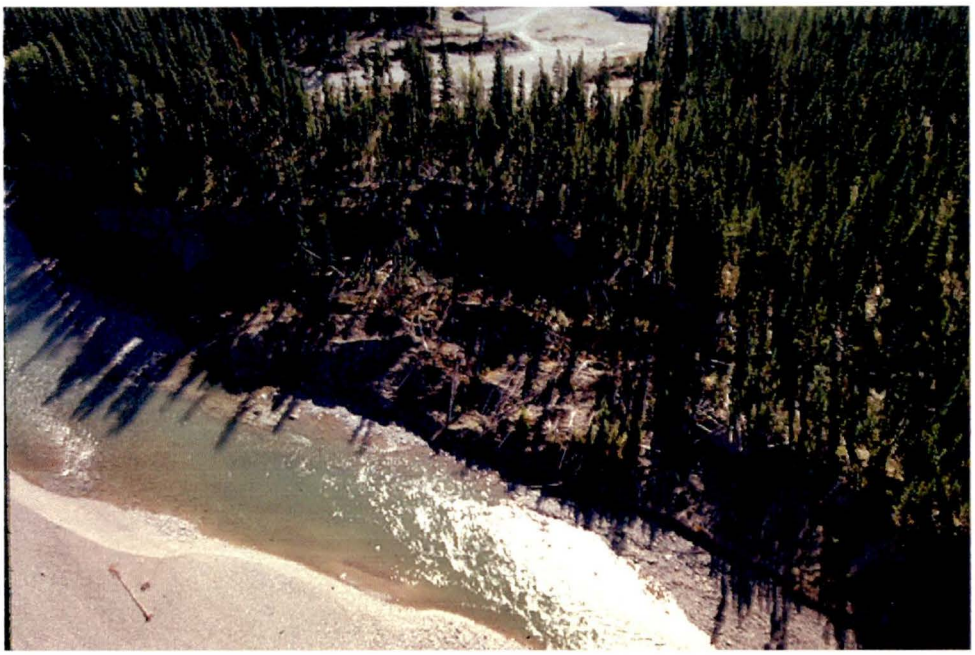


**Figure 18.** a) Slump 1 found below the Skins Lake Spillway. This failure is the smallest of the two slope movements measuring 34 m wide along its toe and the crown is approximately 14 m above river level. During high water levels, cobble and boulder lag areas in front of slump 1 are inundated by turbulent river water. b) Aerial view of slump 2. Slump 2 is larger than Slump 1, measuring 230 m across its toe and its crown is approximately 24 m above river level. Numerous spalled and fallen trees litter the displaced mass of this failure. During high water levels turbulent river water flowing close to the toe of this slump is over 3 m higher than shown.

to crudely stratified advance-phase glaciofluvial and glaciolacustrine deposits. Advance-phase glaciofluvial sediments are moderately to well sorted, sand and pebble to cobble-sized gravel. Clasts are typically rounded to well rounded. Advance-phase glaciolacustrine sediments consist of interbedded very fine sand, silt and clay. Advance-phase glaciolacustrine sediment is found within the disturbed stratigraphy of slope movement toes. There is widespread evidence for glaciolacustrine sediments under Fraser Glaciation till in other parts of central British Columbia (e.g. Eyles and Clague 1991). Locally, sand and gravel overlie till and are interpreted to be retreat-phase glaciofluvial and fluvial deposits.

Diamictons, originating as glacigenic debris flows are also common in river bluffs. These diamictons possess a low to moderate density and are commonly interbedded with, and contain, lenses of silt, sand and gravel. Texturally, subaerial debris flow diamictons are usually more sandy than basal till. Debris flow deposits occur in both advance and retreat-phase deposits. They can also be deposited subaerially in glaciofluvial environments or as subaqueous flows in glaciolacustrine environments.

Interbedded very fine sand, silt and clay overlying tilted and sheared silty clay diamicton with clay laminations occurs in the toe of slump 1. Bedding in this unit is commonly folded, locally brecciated and dips towards the main scarp (Fig. 19). Much of this deformation is probably related to slide tectonics.

Undisturbed stratigraphy close to slump 1 shows late-Wisconsinan lodgement till overlain by retreat-phase debris flow, glaciofluvial and glaciolacustrine sequences (Fig. 20). Dense, silty sand diamicton containing small gravel pods and sand lenses was exposed in the main scarp (approximately 6 metres high) of this slump. It is overlain by

**Figure 19.** Brecciated and sheared, interbedded very fine sands, silts and clays exposed in flat-lying area at base of slump 1 (foreground of Fig. 18a). Beds dip into the slope at angles up to 54°. Note, pebbles and cobbles are laying on the surface and are not part of the deposit.

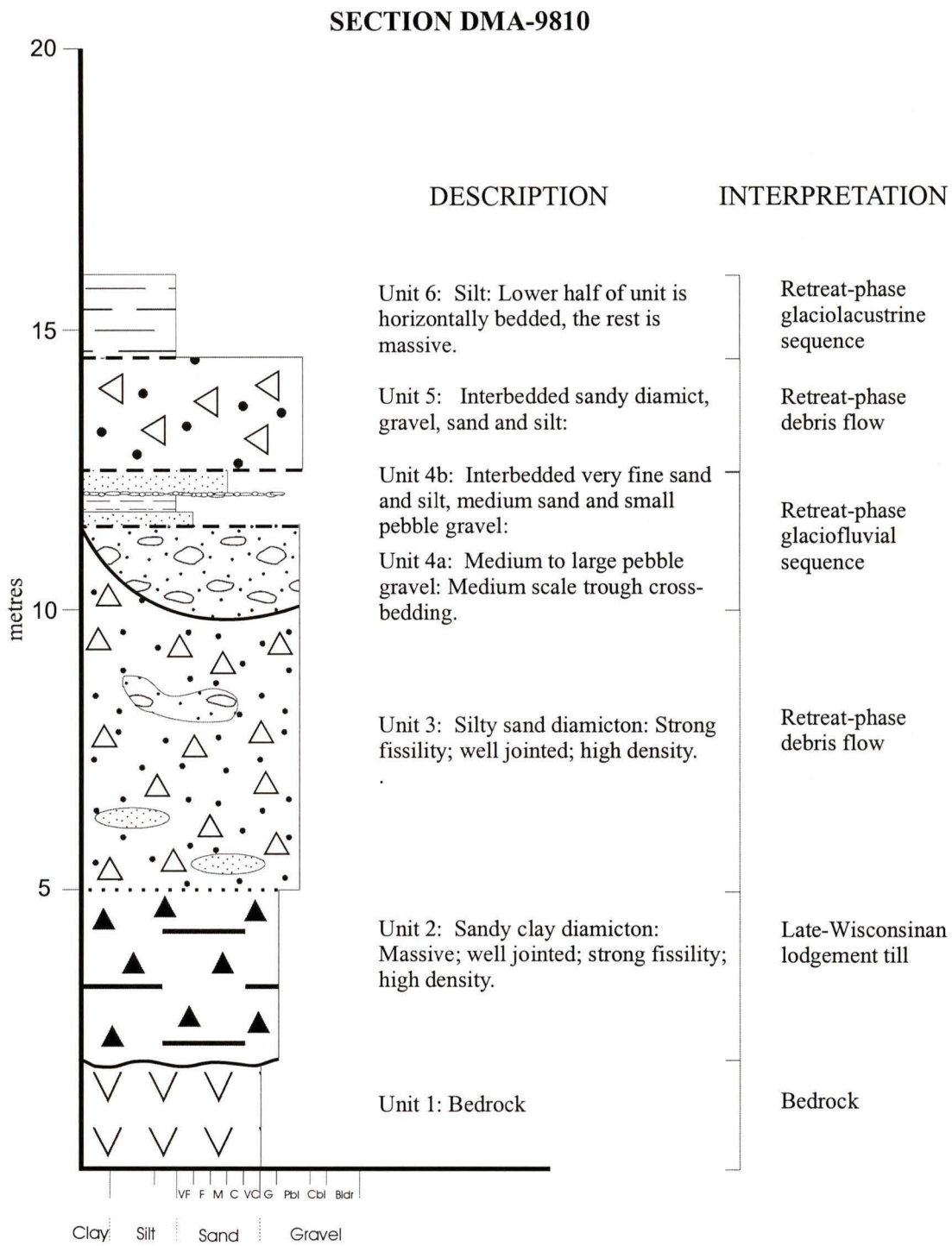



**Figure 2**. Undisturbed stratigraphy approximately 150 m downstream of slump 1. Late-Wisconsinan lodgement til is overlain by retreat-phase debris flow, glaciofluvial and glaciolacustrine sediments. Materials observed in the main scarp of slump 1 possibly correspond to retreat-phase glaciolacustrine (unit 6) and retreat-phase debris flow sequences (unit 3) in the above column.

massive, well jointed, fissile silt that contain some granules and small pebbles. The diamict possibly corresponds to unit 3 in Fig. 20, which is interpreted as a Fraser Glaciation meltout till. The massive silt unit likely corresponds to unit 6 in Fig. 20, which is interpreted as retreat-phase glaciolacustrine sediments.

At slump 2 a brecciated and deformed clayey silt unit was identified. This semi-continuous silt unit is overlain by massive, poorly sorted, dense, diamict. The contact between these two units is sharp and undulatory with roughly a metre of relief. Undisturbed stratigraphy beside slump 2 shows late-Wisconsinan lodgement till underlain by advance-phase glaciofluvial and debris flow sediments and overlain by retreat phase glaciofluvial gravels (Fig. 21). Sandy to clayey diamicton overlain by a metre and a half of sand and gravel was exposed in the main scarp (3 metres high) of slump 2. The diamicton has a high density, is well jointed and has moderate to strong fissility. This diamict is interpreted as late-Wisconsinan lodgement till and probably corresponds to unit 3 in Fig. 21. Overlying glaciofluvial deposits are probably retreat-phase glaciofluvial gravels that correspond to unit 4 in Fig. 21.

#### 4.3.1.3 Geomorphic Features

Slump 1 is approximately 34 m wide with a 6 m high main scarp and its crown occurs 14 m above river level (Figs. 18a and 22). For a complete list of the dimensions of Slump 1 refer to Table 4. This failure presently shows a single style of activity and is active (see Appendix F for definitions of these terms). It could possibly retrogress further into the bank and become a multiple slope movement.

Slump 2 is approximately 230 m wide with a 3 m high main scarp, and contains up to four separate slump blocks. Its crown is 24 m above river level (Figs. 18b and 23).

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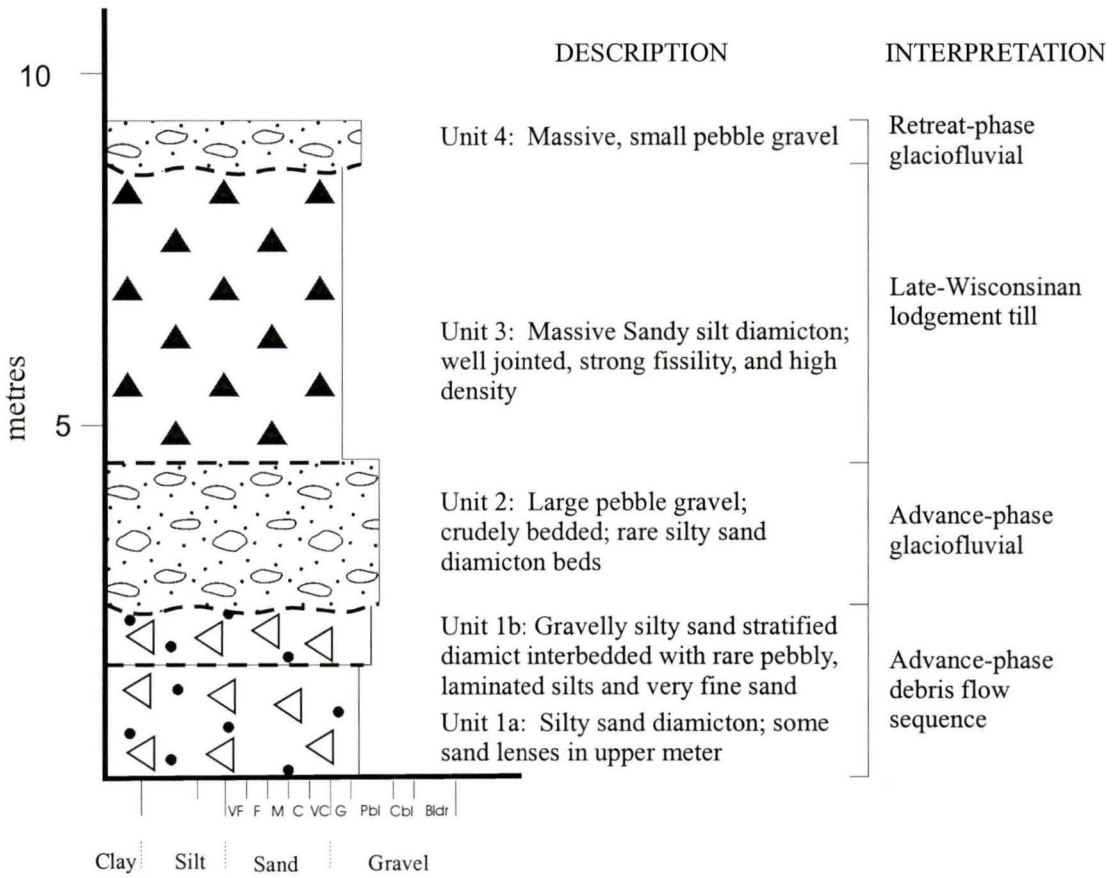



**Figure 21.** Undisturbed stratigraphy directly downstream (southeast) of slump 2. Late-Wisconsinan lodgement till is underlain by advance-phase debris flow and glaciofluvial sediments and overlain by retreat-phase glaciofluvial gravels. Sediments exposed in the main scarp of Slump 2 possibly correspond to retreat-phase glaciofluvial sediments (unit 4) and lodgement till (unit 3) in the above stratigraphic column.

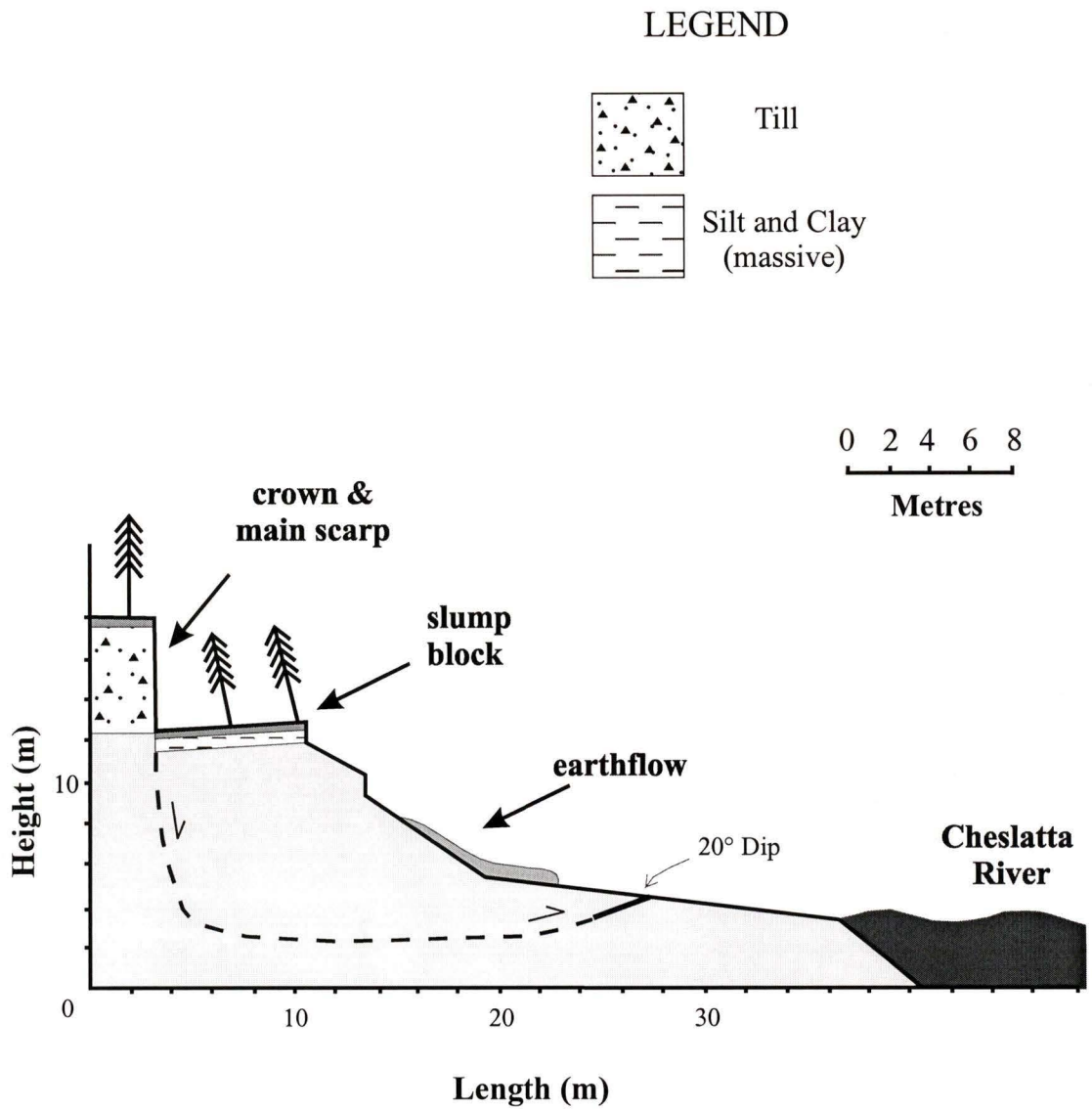
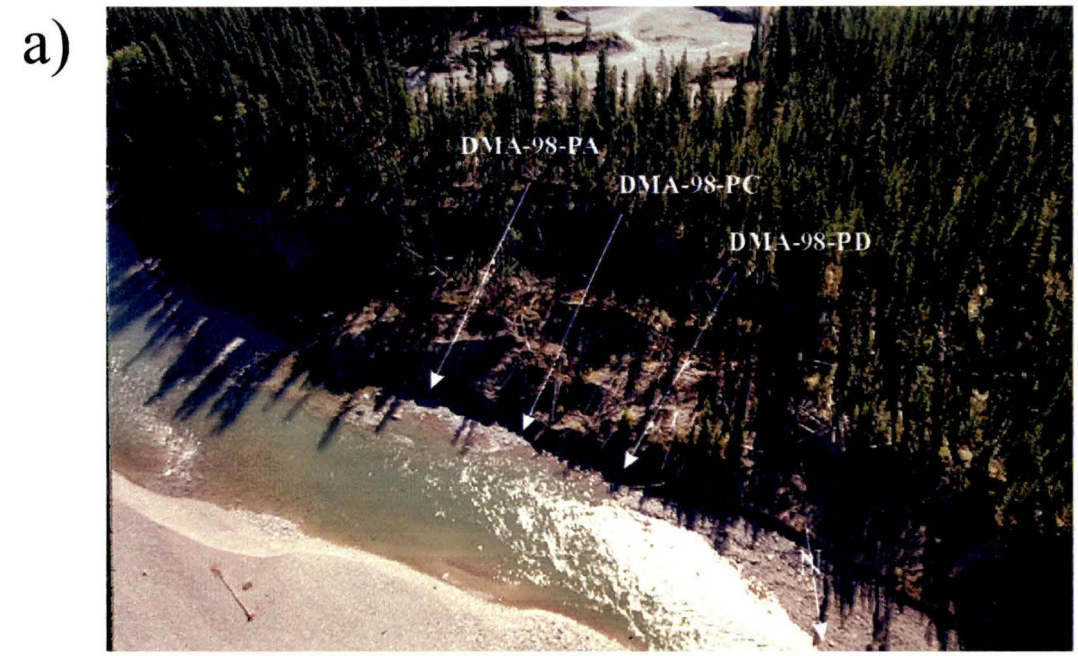



**Figure 22.** Surface profile DMA-98-PD from Slump 1 along the Cheslatta River. Field data for this profile is found in Appendix G. This slump is 34 m wide with a 6 m high main scarp, has one slump block and its crown occurs approximately 14 m above river level. Materials exposed in main and minor scarps are indicated on profile.

**Table 4.** List of the dimensions of Slump 1 and Slump 2 located along the Cheslatta River. Landslide dimensions used in this table follow those set by the IAEG Commission on Landslides (1990). For an explanation of these different dimensions refer to Appendix E.

| Landslide Dimensions | Slump 1 | Slump 2 |
|---|---|---|
| **Length of Rupture Surface (Lr)** | 26 m | 60 m |
| **Length of Displaced Mass (Ld)** | 22 m | 60 m |
| **Total Length (L)** | 26 m | 60 m |
| **Width of Rupture Surface (Wr)** | 34 m | 230 m |
| **Width of Displaced Mass (Wd)** | 34 m | 230 m |
| **Depth of Rupture Surface (Dr)** | 16 m | 27.5 m |
| **Maximum Depth of Displaced Mass (Dd)** | 11 m | 22.5 m |
| **Volume** | 4300 $m^3$ | 160 000 $m^3$ |



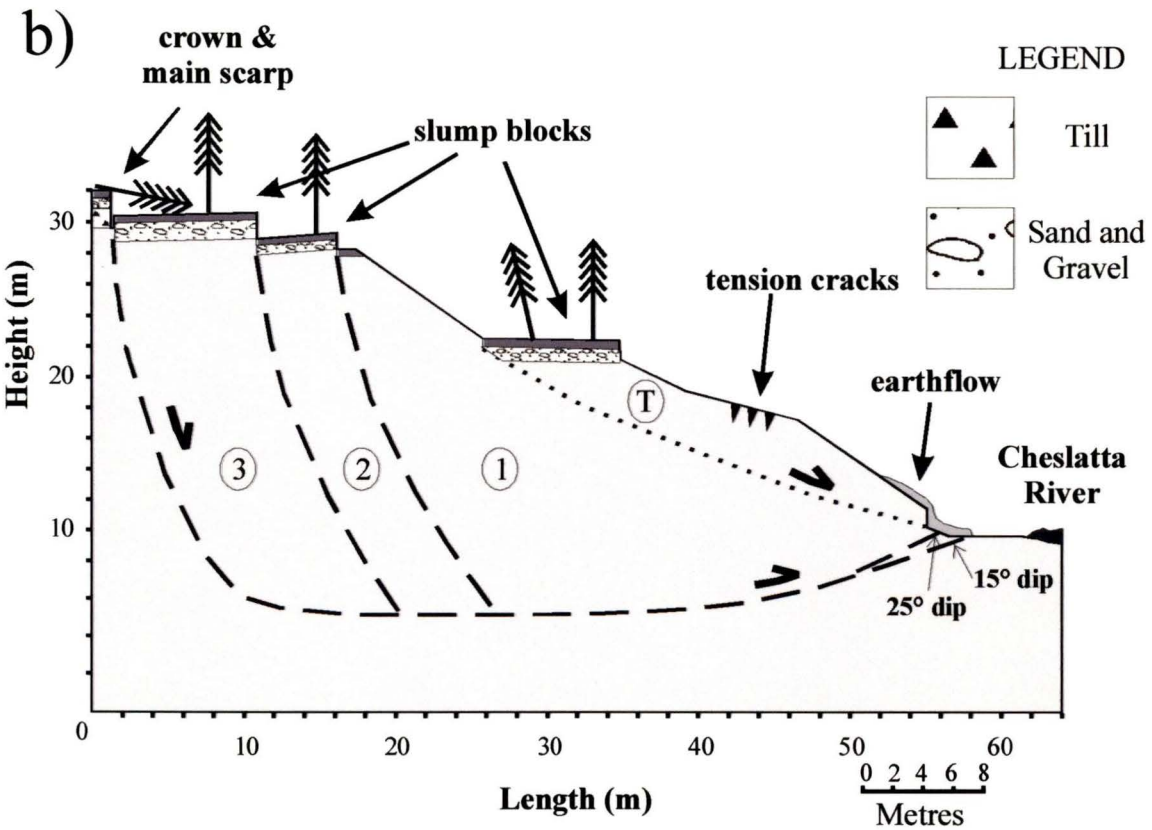




**Figure 23.** a) Location of topographic profiles conducted at Slump 2 b) Surface profile DMA-98-PA from Slump 2 along the Cheslatta River. Rotational slumping (1,2, and 3) was probably the initial movement, followed by earthflows (labelled), translational failures (T) and creep (not shown). This slump is 230 m wide with a 3 m high main scarp, has up to 4 slump blocks and its crown occurs 24 m above river level. Field data for this profile can be found in Appendix G.

Additional dimensions of this landslide are found in Table 4. Similar to slump 1, this slide is assumed to be active and retrogressing into the river bank with a multiple style of activity.

The volume of these two slope movements was calculated using a formula that assumes their displaced mass is half an ellipsoid (World Party on World Landslide Inventory 1990):

$$V = \frac{\pi \times Wd \times Ld \times Dd}{6}$$

Where Wd is the width of the displaced mass (measured perpendicular to Ld), Ld the length of the displaced mass (measured from tip to top) and Dd is the maximum depth of the displaced mass (measured perpendicular to the surface of displaced material). Therefore, using this formula the volume of the displaced mass of Slump 1 was 4300 $m^3$ and 160 000 $m^3$ for Slump 2.

#### 4.3.1.4 Failure Surfaces

Slickenside surfaces on clay-rich sediments were found at the toe of both slides. At slump 1 most of the basal slide movement seems to occur on a laminated silty clay shear zone that is up to 1 cm thick. Well developed slickenside surfaces in this shear zone dip 16° – 20° towards 152° - 160° (Fig. 24) and the slide faces northwest. Movements may also occur along clayey silt diamicton units and silty clay laminations found below this main shear plane although slickenside surfaces were rarely seen in these units. Interbedded very fine sand, silt and clay beds (see Fig. 19) above the main basal shear plane, locally dip 37° - 54° towards a direction of 175°. Some slickenside surfaces were observed in these overlying sediments.

**Figure 24.** Polished and grooved slickenside surface found in clay-rich sediments at the toe of slump 1. Measurements of these surfaces show that they dip towards the main scarp suggesting that slide material rose at the toe. Multiple slickenside surfaces were observed at the toe of both slides.

At slump 2 slickenside surfaces were observed in a clayey silt unit at the toe of the slide (profile C, Appendix G). At this location the slump surface has a northeasterly aspect. Dip and dip direction measurements recorded from the main slickenside surfaces were 72°/245°, 9°/240°, and 15°/220°. Additional slickenside surfaces with a variety of orientations were also identified. Some of these surfaces were almost vertical, while others were observed to be steeply dipping in a direction of about 245°. The clayey silt unit at slump 2 is highly brecciated and sheared. It is poorly exposed along the toe of the slide.

4.3.1.5 Other Features

Photos showing the crown, main scarp and slump blocks from Slump 2 are found in Fig. 25a and 25b. At each slump the crown and main scarps have an arcuate or amphitheatre shape. Along these morphological features numerous coniferous trees have fallen onto the slumped masses (see Fig. 25a). Some fallen trees have needles that are still green, indicating that they have only been uprooted recently. Other trees have brown needles and others have no needles and no bark indicating that they have been dead for a much longer time. Tops of slump blocks observed in the field are commonly tilted back toward the main scarp (see Figs. 22 and 23). Occasionally some slump blocks are rotated forward instead of back towards the main scarp. Some of these rotated forward slump blocks could be broken pieces from slump blocks above that have slid down the slump surface. Original forest floor, containing soil, moss, shrubs, and trees are preserved on the tops of all slump blocks (see Fig. 25b).

At both slides some trees on top of slump blocks lean towards the main scarp. At slump 1 trees growing on the single slump block lean up to approximately 20° towards

a)

b)

**Figure 25.** a) Crown and main scarp of slump 2. This scarp is steep and has an arcuate or amphitheatre shape. Numerous trees along this crown have fallen onto the displaced mass. Two dark upright trees (foreground) below the main scarp lean towards the crown. Note man for scale (top, centre). b) View looking up the middle of slump 2 from its base. Two slump blocks with preserved forest floor can be seen just left of centre. Tops of these slump blocks are tilted back towards the main scarp which is just visible in the background.

the crown. Trees growing on the tops of slump blocks at slump 2 lean up to 12° towards the crown. Commonly, vertical growing trees on slump blocks are young with ages less than about 14 years old. This suggests a minimum age of approximately 1986 for both slumps 1 and 2. An elongate sag pond, approximately 1 m deep, 1 to 1.5 m wide, and 3 to 4 m long was also identified above a backward-tilted slump block at slump 2 (Fig. 26a; profile DMA-98-C Appendix G). A 1 m buffer of damp ground surrounds this feature.

Small mudflows occurring along the toes of both slumps (Fig. 26b) are characterized by elongate tracks (approximately 1 – 2 m wide and 4 – 5 m long) and lobate accumulation zones (approximately 4 - 5 m wide and 2 m long). They are composed of very fine sand and clayey silt that is wet and viscous. Material in the mudflows is probably derived from the displaced mass of the slump.

New crown cracks, 10 – 15 m above the main scarp were identified at slump 2. Vertical displacement at one of these cracks, extending laterally for 15 – 25 m, was approximately 1 – 2 m. Small coniferous trees with curved trunks, concave up slope, were identified in the foot area at slump 2.

### 4.3.2 Nechako Reservoir Slope Movements

#### 4.3.2.1 Location

Slope movements were also observed along portions of Chelaslie Arm found on NTS mapsheet 93 F/5, directly south of the study area (Fig. 17). Chelaslie Arm is oriented in a southeasterly direction and has been significantly modified by the rising water levels of the reservoir. Chelaslie River flows into the arm at its northwestern end. Slope movements along Chelaslie Arm mainly occur along sections of the southwest-facing

a)

b)

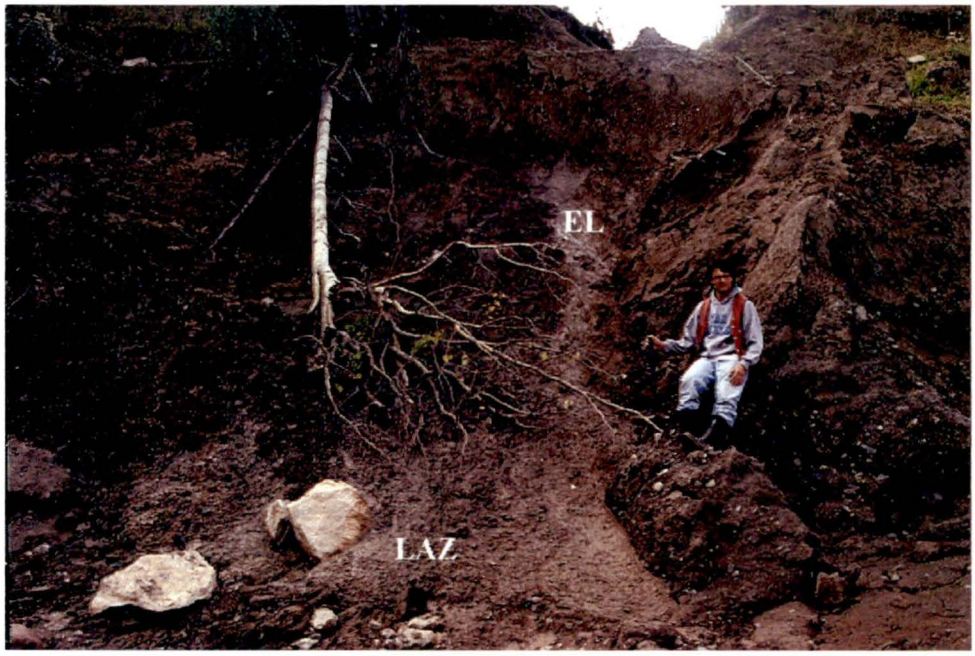



**Figure 26.** a) Small sag pond found at slump 2. Pond is approximately 1 m deep, 3 - 4 m long and 1 - 1.5 m wide. These ponds are formed as surface water becomes trapped above back-tilted tops of slump blocks. They represent a disruption in drainage caused by the hummocky surface of the slumps displaced mass. Stephen Mate for scale. b) Mudflow occurring at the toe of slump 1. Mudflows at both slumps are characterized by elongate tracks (EL) approximately 1 - 2 m wide and 4 - 5 m long and lobate accumulation zones (LAZ) approximately 2 m long and 4 - 5 m wide. Elongate tracks occur on slopes with a higher angle than lobate toes which are usually found on the flat-lying shoreline. Mudflows have a very fine sand and clayey silt texture and are wet. Stephen Mate for scale.

shoreline. Failures in this area increase sediment input into the arm and limit development along its shoreline.

4.3.2.2 Geological Features

The Quaternary stratigraphy of the Nechako Reservoir area has been described by Levson and Giles (1997) and Mate and Levson (1999a, 2001.). More specific stratigraphic work focusing on the shoreline of Chelaslie Arm was completed by Levson *et al.* (1998,1999). Stratigraphic sections in this area are large and well exposed (refer to Chapter 3 for more detailed stratigraphic information).

Nonglacial lacustrine sediment occurs below sediments deposited during the Fraser Glaciation. This sediment is horizontally laminated silt with minor clay and sand that coarsens upwards and becomes more deformed near its top. Advance-phase glaciofluvial sediment and till are common along the Chelaslie Arm shoreline while advance-phase glaciolacustrine sediment is rare. Sandy debris-flow diamict occurs both above and below till. Retreat-phase glaciofluvial sediment overlies till and debris-flow diamict. Generally, slope movements along the shoreline of Chelaslie Arm occur in areas where sediments are clay-rich or clay-rich sediments underlie Fraser Glaciation sediments.

4.3.2.3 Geomorphic Features

Slope movements in this area are smaller than those along the Cheslatta River. They are approximately 15 – 50 m wide, consist of numerous small slide blocks and have main scarps less than a metre high. Tops of slide blocks are oriented in the same direction as the original slope surface. Natural vegetation, containing soil, moss, shrubs and grasses are preserved on the tops of these blocks. These failures usually extend 15 – 30 m upslope from the reservoir level and are widest at their base, which occurs at shoreline

level (Fig. 27). Failure surfaces for these slope movements are much shallower than those along the Cheslatta River.

## 4.4 INTERPRETATIONS

### 4.4.1 Slope Movement Types

The dominant types of slope movement observed along the Cheslatta River and Nechako Reservoir were rotational and translational landslides (Appendix C). Landslides are movements of material along one or more surfaces of rupture (Working Party on World Landslide Inventory 1990). Rotational movements fail along curved surfaces, while translational movements fail along planar or undulatory surfaces (Cruden and Varnes 1996). Slump failure surfaces can also occur at greater depths, are slower moving, and their rotational movement restores stability to the sliding mass.

#### 4.4.1.1 Cheslatta River Slope Movements

Slope movements along the banks of the Cheslatta River are classified as complex rotational slumps and earthflows. The initial movement at these slumps was rotational slumping. The presence of slump blocks with back-tilted tops and trees that lean towards the crown suggest that these failures are rotational. Rotational movement of a slump block involves lowering of its head and rising at its toe. Lowering of the head of the slump block is what exposes the steep main scarps at both slides. Rising at the toe is indicated by slickenside surfaces that dip into the displaced mass. These surfaces are effectively small-scale thrust faults with upward movement of slide material across underlying sediments. Secondary slope movements, such as translational failures, earthflows and creep, occur closer to the toe of this slump (see Fig. 23).

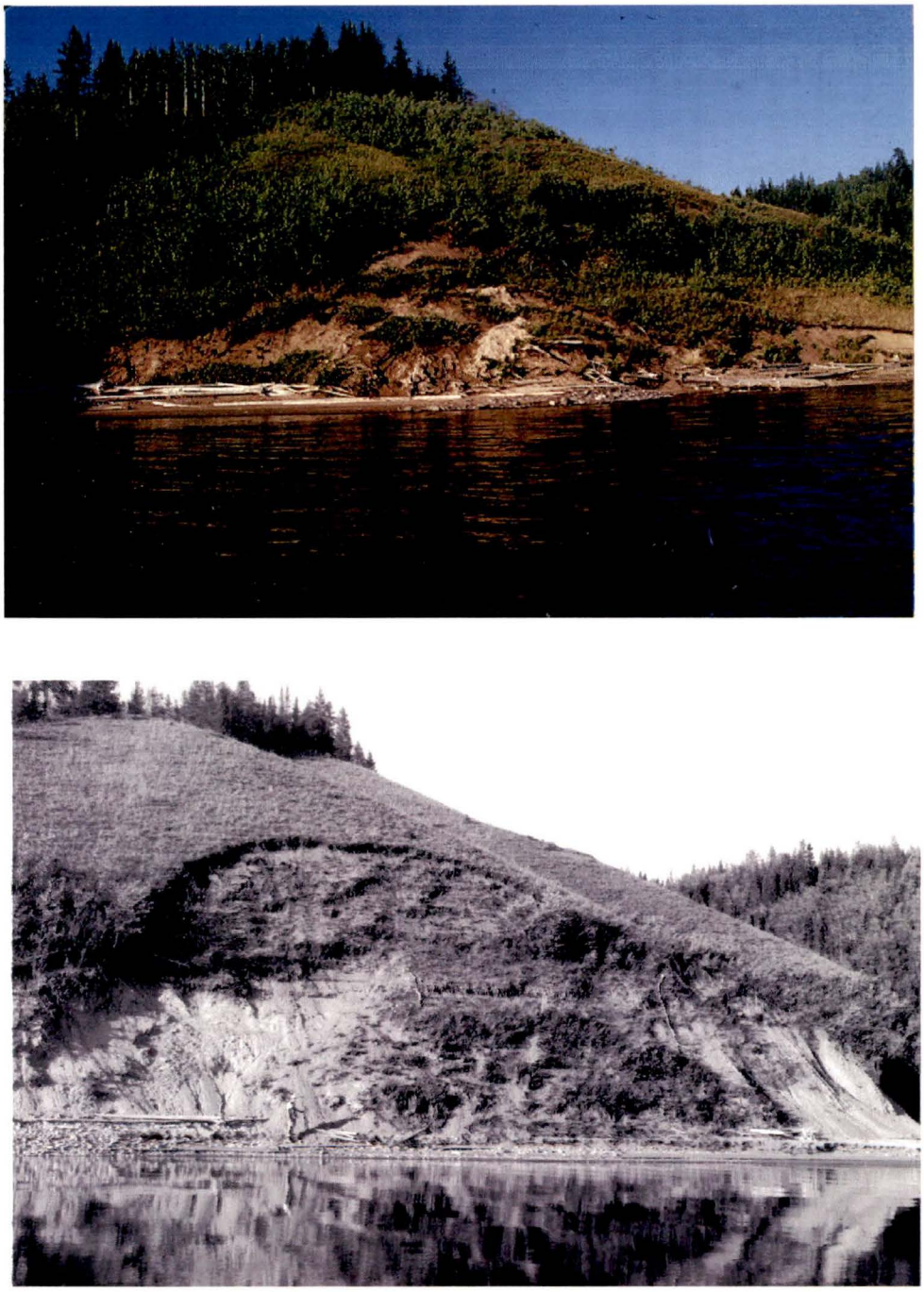


**Figure 27.** Examples of translational slope movements occurring along the southwest facing shoreline of Chelaslie Arm (NTS 93 F/5) on the Nechako Reservoir. See Fig. 17b for location. Slope movements in this area are approximately 15 - 50 m wide, consist of numerous, small slump blocks, and have main scarps less than a meter high. The base of these failures occur at the shoreline and their surfaces of rupture are more shallow compared to slumps along the Cheslatta River.

The displaced masses of slump 1 and slump 2 occur mostly in silty sand to silty clay till and glaciofluvial sediment. Since these sediments contain a large proportion of grain sizes above 2 mm they are classified as debris slumps. Cruden and Varnes (1996) define debris as material consisting of 20 – 80% particles larger than 2 mm. Earth material, on the other hand, has a grain size that is dominated (at least 80%) by particles smaller than 2 mm in size.

Slickensides are formed as one surface moves across another (Park 1989). The polishing and rubbing action caused by this movement can create shiny, striated surfaces. Tilting of slickenside surfaces and brecciated fine grained units found within the toe at both slumps are most likely related to slide tectonics.

The presence of at least one sag pond on slump 2 is further evidence for rotational movement. Sag ponds form as surface water is trapped above the back-tilted top of slump blocks. These features represent a disruption of drainage which is commonly caused by back-tilted slump block surfaces. Sag ponds are significant because they keep the displaced material wet, increasing instability and perpetuating future slope movements.

Steep and unvegetated landslide features (main scarp and main body of the displaced mass) provided some evidence to support that both rotational landslides are active (Fig. 28). Trees present along the toe of slump 2, that have trunks concave upslope, also indicate surface creep and downslope tilting. Mudflows at the base of rotational slumps along the Cheslatta River have a very fine sand and clayey silt texture and are classified as earthflows. These flows initiate in areas where moisture levels within the displaced material are high. Earthflows at the toe of slumps 1 and 2 extend below the high water

**Figure 28.** Steep and unvegetated main scarp at slump 1. Pronounced landslide features like these indicate the failure is fairly recent and potentially still active. Stephen Mate for scale.

mark and are likely eroded when water levels are high. Input of eroded sediment from earthflows into the Cheslatta River will increase siltation.

#### 4.4.1.2 Nechako Reservoir Slope Movements

Translational slides were the most common type of slope movement along the shore of the Nechako Reservoir (see Fig. 27). These failures tend to occur in areas where the surficial sediment is clay-rich or where clay-rich sediments underlie Pleistocene deposits. The latter situation occurs along parts of Chelaslie Arm (Nechako Reservoir, NTS 93F/5) where Olympia Nonglacial sediments (interbedded very fine sand, silt, and clay) underlie younger sediments of the Fraser Glaciation. Because these sediments are dominated by grain sizes less than 2 mm in diameter, slope movements in this area are classified as earth slides (Appendix C). However, it is possible that in some areas these slides occur in more poorly sorted diamict and glaciofluvial sediments. In this case translational slope movements would be classified as debris slides (Appendix C).

#### 4.4.1.3 Other Slope Movements

A large relict slide complex occurs along Chelaslie River close to the northwestern tip of Chelaslie Arm on NTS mapsheet 93 F/5 (see Fig. 17 for location and Fig. 29a). This complex was not identified on early terrain maps of the area probably due to the heavy forest cover. Relatively minor slope movements occurred in this area after clear-cutting and road construction (Fig. 29b).

## 4.5 FACTORS RESPONSIBLE FOR SLOPE MOVEMENTS

Now that the characteristics of slope movements in the study area have been discussed, the factors contributing to slope movement will be addressed. Distinguishing between the triggers and causes of slides or the identification of one main factor

a)

b)

**Figure 29.** (a) large relict slide complex along Chelaslie River close to the Northwestern tip of Chelaslie Arm (NTS 93 F/5). Road for scale. (b) Minor slope movements have become reactivated in this area following clear cutting and road construction.

responsible for initiating a slope movement can be difficult. This is explained by the quote below:

*In most cases a number of causes exist simultaneously and so attempting to decide which one finally produced failure is not only difficult but also incorrect. Often the final factor is nothing more than a trigger that set in motion an earth mass that was already on the verge of failure. Calling the final factor the cause is like calling the match that lit the fuse, that detonated the dynamite, that destroyed the building the cause of the disaster (Varnes 1978).*

Numerous factors responsible for initiating slope movements are summarized in a comprehensive table in Appendix D. Factors that make a slope susceptible to failure can either be internal or external. A common internal factor is the presence of weak geological materials and examples of external factors are erosion (fluvial) of the slope toe or prolonged rainfall.

### 4.5.1 Cheslatta River

Historical air photographs (Fig. 30 and 31) of the Skins Lake Spillway and Cheslatta River indicate that substantial down-cutting and the subsequent exposure of steep riverbanks occurred within this system after the completion of the Nechako Reservoir in 1952. Numerous small lakes, that had formed in the Cheslatta River valley prior to 1952, were drained after the spillway was created. The increased water flow to Cheslatta River has resulted in stream incision accompanied by the lowering of lake outlets, and eventual draining of the lakes. After this time the morphology of the Cheslatta River changed from meandering to straight and water level fluctuation in the river is over 3 m.

Therefore, it is believed that most slope movement problems in this region occurred after this time. Removal of material from the base of the slope and associated steepening of the lower part of the slope increases the susceptibility of the slope materials to failure.

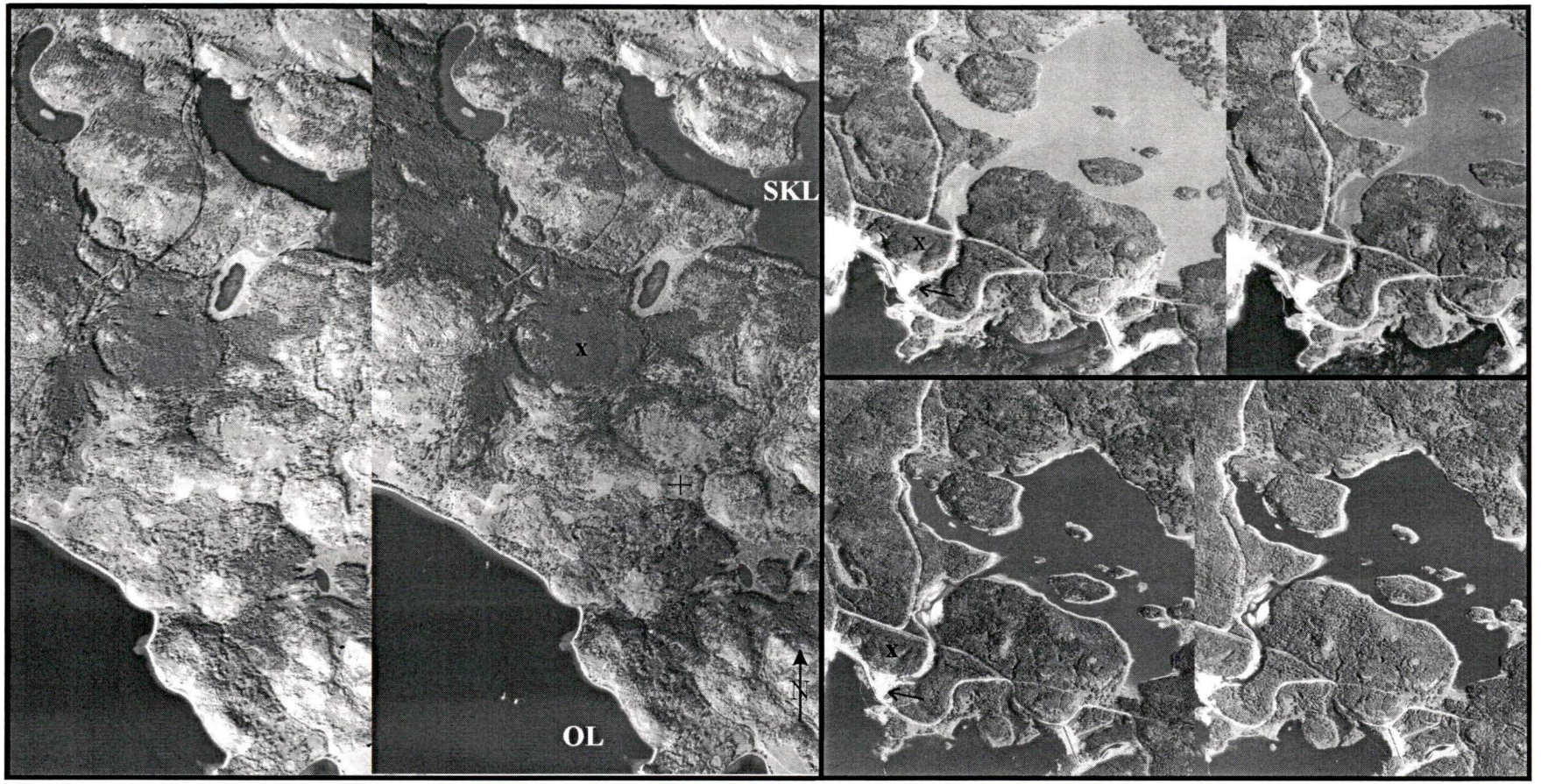



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**Figure 30.** Historical evidence of fluvial downcutting and exposure of steep slopes through Quaternary sediments at the Skins Lake Spillway. The "x" in all photos illustrates how the shoreline has changed in Ootsa Lake since the completion of the Nechako Reservoir (1952). Black arrows indicate the location of Slump 1. Approximately 50 000 ha of land was flooded by the reservoir (BC Research Inc. 1998). Skins Lake (SKL), Ootsa Lake (OL).

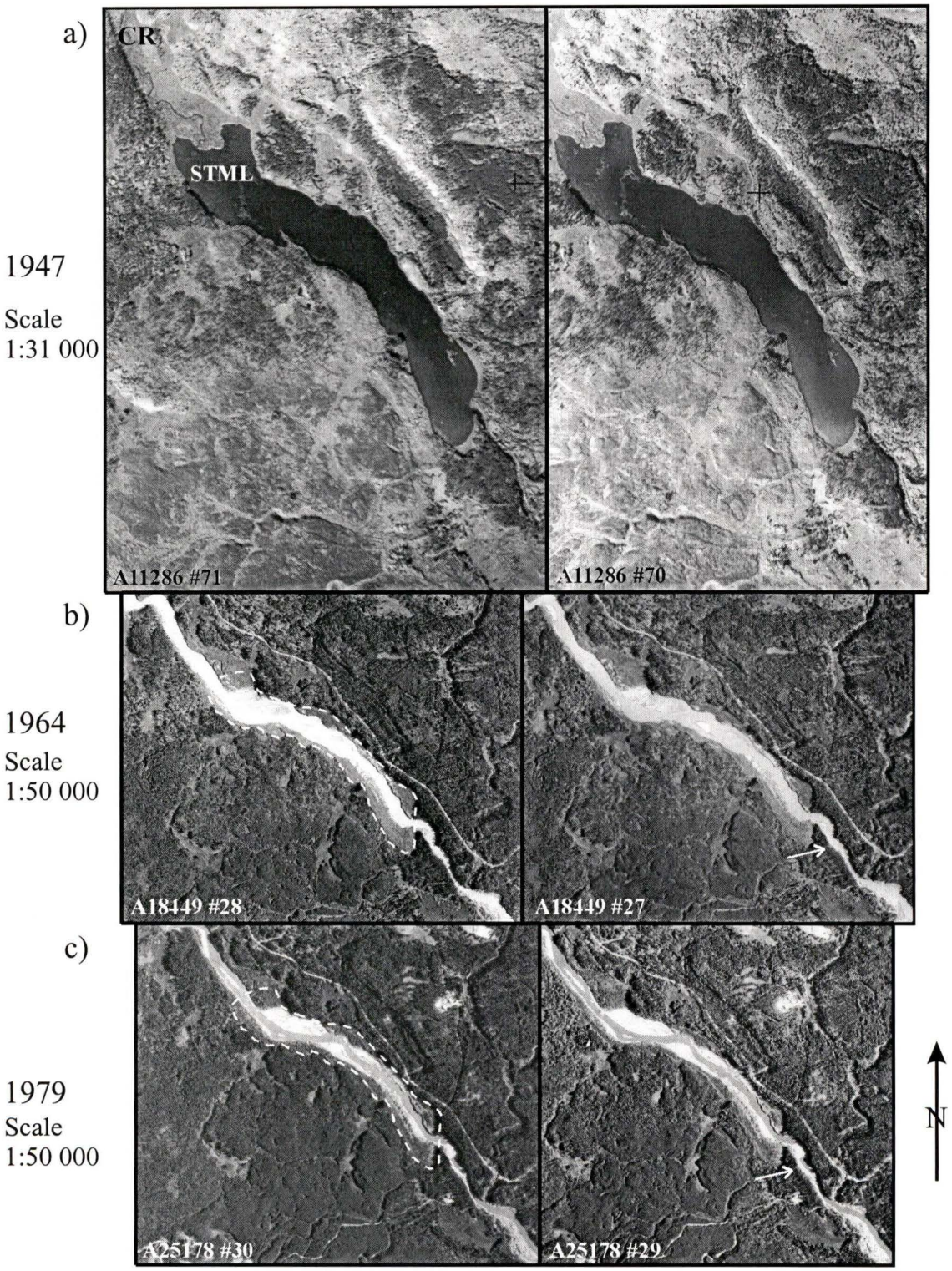



**Figure 31.** Historical evidence of fluvial downcutting and the exposure of steep slopes through Quaternary sediments along the Cheslatta River (CR). White arrows mark the location of Slump 2, occurring just downstream of the former St. Mary's Lake (STML). a) Air photographs showing the areal extent of St. Mary's Lake. Cheslatta River (meandering and narrow) enters into the northwest portion of the lake, forming a small delta. b) 12 years after the completion of the spillway St. Mary's Lake (outlined in white) has drained. Cheslatta River (much larger and straighter than in a) has begun to incise the lake bottom. c) 27 years after the completion of the spillway, fluvial downcutting in this area is probably complete.

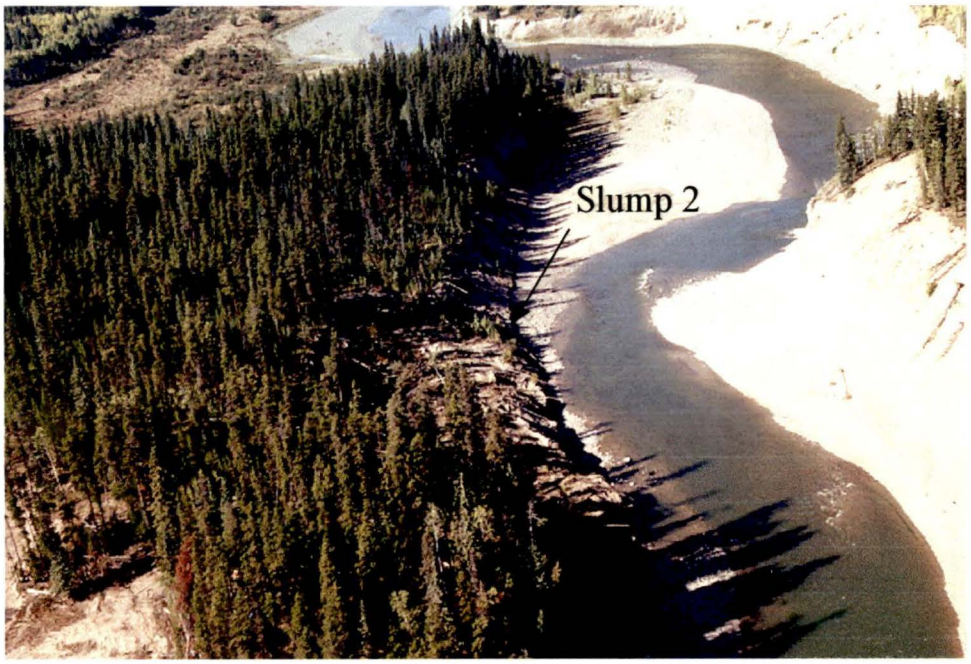
If steepening of a slope face occurs in banks composed of weaker geological materials their probability of failure is much greater.

As noted earlier, rotational movement (lowering at the head and rising at the toe) of a slump block eventually equilibrates the slope. This equilibrium is a very delicate one and is often maintained by the presence of lateral support. Crozier (1986) defines lateral support as material in contact with the slope or part of the slope itself. It increases a slopes resistance to shear stress (movement). It can consist of the original slope sediment as well as water, ice and/or artificial materials. Removal of this support from the toe of a slump (or base of a slope) also increases the angle of its slope face and therefore the weight on its shear plane.

Removal of lateral support by fluvial processes is evident along the toe of Slump 2, located on an erosive cut-bank of the Cheslatta River (Fig. 32a). Extreme water level fluctuations, due to the spillway control at Ootsa Lake, are a unique characteristic of this river (Fig. 32b). When water levels are high, it is likely that erosion of material along the toe of slumps will be substantial. During fieldwork in the summer of 1998, water level fluctuations exceeded 3 metres.

The presence of subsurface clay-rich sediments within the stratigraphic sequence along this river is another significant factor because it provides a slip surface for the slides to move along. When saturated with water, clay-rich sediments tend to lose their cohesion and shear strength. Cohesion, defined as the tendency of clay particles to stick together, is maintained by the attraction of these particles to water molecules between them (Brady 1990). Brady also notes that hydrogen bonding between clay and water molecules and water molecules themselves are also important for cohesion. Varnes

a)

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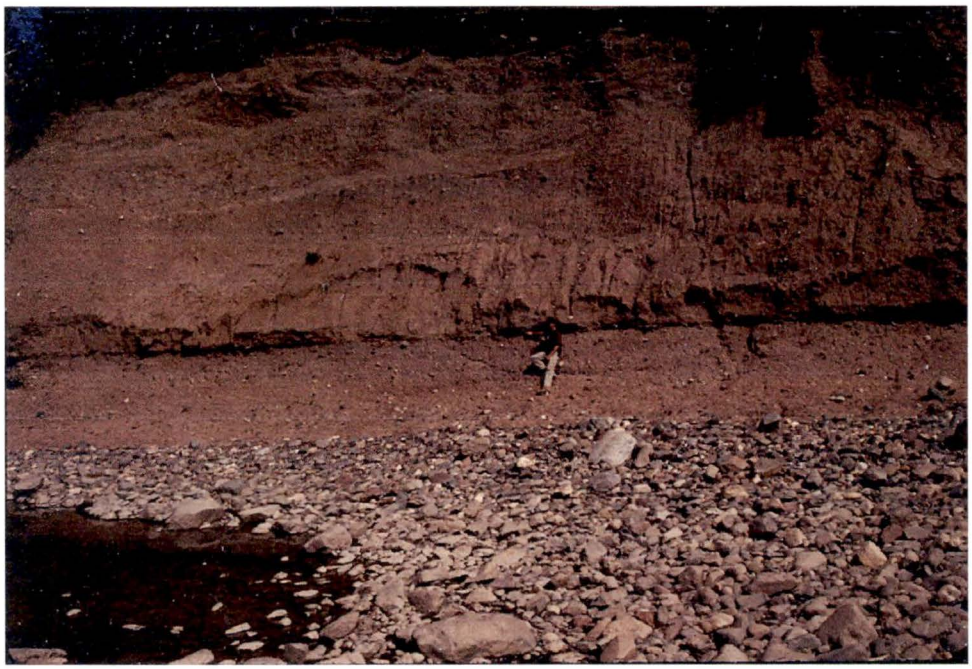


**Figure 32.** a) Slump 2 and its location at an erosive section of the Cheslatta River. During periods of high water levels, river erosion occurs along the toe of the slump, possibly increasing the likliehood of failure. b) Evidence of high water level along Cheslatta River (dark line close to base of section) roughly 3 metres above present river level. Fluctuating water levels are a unique characteristic of this river which is spillway controlled. Stephen Mate for scale.

(1978) mentions that water saturation decreases the effective intergranular pressure (capillary tension) and friction of a soil. Highly sheared and slickenside surfaces provide evidence that movement occurred within and along these clay-rich units.

Although not described in any detail here, external climatic factors on slope movement cannot be ignored. Factors such as intense rainfall, rapid snowmelt and prolonged exceptional precipitation could all influence slope movements in the area (appendix D). Extreme water level fluctuation (over 3 metres in some cases) within the Cheslatta River could also be significant. During periods of high water level riverbank sediments become inundated and saturated. This weakens the sediments by increasing their porewater pressure. As water levels in the river drop, the lateral support it provides is removed from around the weakened sediments increasing the likelihood of failure.

### 4.5.2 Nechako Reservoir

Several factors may be responsible for triggering slope movements along the shoreline of Chelaslie Arm. The most dominant factor is undercutting at the base of shoreline slopes by wave erosion. This process reduces the ability of the slope to resist the weight of the overlying material (Crozier 1986). Removal of underlying support by wave erosion is enhanced in this area due to increased water levels in the Nechako Reservoir. Terrain stability work along other shorelines of the Nechako Reservoir, Ootsa Lake just north of the study area, and Tahtsa Reach, approximately 75 km northwest of the study area, also identified wave erosion as being a major factor for triggering slope movements (BC Research Inc. 1998).

Aspect of the reservoir shoreline is also an important factor controlling slope movements. For example, most slumping observed along Chelaslie Arm occurs on

southwest-facing shorelines where vegetation cover on slopes is sparse, dominated mostly by grasses and small bushes (see slope in Fig. 27). In contrast, forest cover on northeast-facing shorelines is more dense and evidence for slope movements in this area is less common.

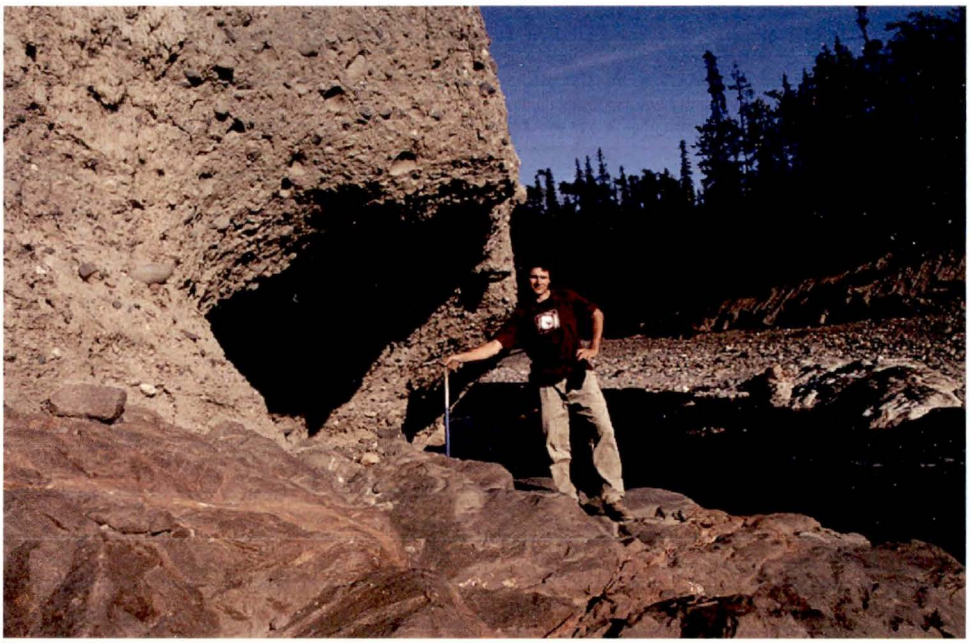
The effect that vegetation has on slope stability is summarized by Evans (1982). Limited vegetation cover on slopes reduces evapotranspiration rates. This reduction increases groundwater penetration and pore pressures in underlying sediments. Secondly, root systems are usually not as well developed in areas of sparse vegetation. Root systems help increase the shear strength of underlying material increasing slope stability.

Southwest oriented shorelines also face into the dominant wind direction (westerly) and are more likely to receive powerful, erosive, wave action compared to shorelines that face other directions. Fluctuating water levels in the reservoir could also be another factor influencing slope movements in the area. Weaker, saturated, clay-rich glaciolacustrine sediments and till occurring in the drawdown zone along the reservoir shoreline could be prone to failure during prolonged periods of low water levels. However, water levels did not fluctuate drastically during fieldwork in the summer 1998 and it is believed that this factor is less significant than other factors discussed above.

## 4.6 GEOLOGICAL CONTROLS ON SLOPE MOVEMENT

Occurrence of slope movements in the study area seem to be related to certain geologic conditions. In places along Cheslatta River, deep and pronounced scours formed by river undercutting during periods of high, turbulent water levels occur in stable river banks. One well developed scour was observed along a till bedrock interface below the Skins Lake Spillway (Fig. 33a). Looking at the same scour from the other side of the

a)



b)

**Figure 33.** (a) Evidence of undercutting along the banks of the Cheslatta River. This deep scour was formed during periods of maximum water level and occurs just above the till-bedrock interface. This particular scour is found below the Cheslatta River Spillway. (b) Panoramic view of the same scour that occurs for some length along the river bank. Stephen Mate for scale.

river (Fig. 33b) shows that it is quite prominent and occurs for some distance along the bank.

Stable river banks comprised dominantly of diamicton have been observed at other erosive, sections along the Cheslatta River. For example, Fig. 34a shows two steep cut-banks at the upper Cheslatta Falls. Reconnaissance stratigraphy work shows that till is the dominant material type in this area. Advance-phase glaciolacustrine sediments, like those found in the toe of Slumps 1 and 2 appear to be absent or occur in minor quantities. Most of the Nechako Reservoir shoreline is also quite stable. Where the dominant sediment type is till, wave undercutting creates more stable shore bluffs (Fig. 34b).

Observed unstable areas seem to be associated, at least partly, with clay-rich material that underlies till. Similar conclusions were made along tributaries to the Peace River by Cruden et al. (1993,1997) (Saddle and Montagneuse Rivers respectively) in the western Peace River Lowland. They found that areas prone to slope movements occurred where tributaries eroded through till and into underlying clay-rich lacustrine sediments.

It is more difficult for river undercutting to trigger a slump if there is no internal cause. For the large part, banks of Cheslatta River are composed of very dense and massive diamicton interpreted to be lodgement and meltout till. This material possesses a high inherent shear strength allowing it to form competent riverbanks. Holtz and Kovacs (1981) note that high density (low void ratio), presence of angular clasts, and poor sorting, all characteristics of lodgement and meltout till, are some of the main factors responsible for increasing the shear strength in a soil or sediment. Therefore, along the banks of the Cheslatta River and shoreline of the Nechako Reservoir the most stable areas

a)

b)

**Figure 34.** a) Steep but stable river banks at upper Cheslatta Falls. These banks occur along erosive sections of the Cheslatta River. Reconnaissance stratigraphic work in this area revealed that till was the dominant material type and advance-phase glaciolacustrine sediments are rare. b) Stable shore bluffs in till along the Nechako Reservoir. When banks and bluffs are composed of till, removal of slope material by wave erosion creates competent shore bluffs. Man for scale.

occur where till is thick or where it overlies another unit with high shear strength (e.g. bedrock).

# 5 STREAMLINED EROSIONAL LANDFORMS IN THE INTERIOR PLATEAU: EXAMPLES FROM THE MARILLA MAP SHEET (NTS 93 F/12)

## 5.1 INTRODUCTION

Drumlins, crag-and-tails and flutings are common and easy to recognize Quaternary landforms. Drumlins were first recognized in 1867 by M.H. Close, and named after the Gaelic word *druim*, meaning hill (Menzies 1979). Upham (1892) while working in New Hampshire, was the first person to map drumlins in North America. He identified nearly 700 drumlins in the southern part of this state as well as a total of 130 in northeast Massachusetts and southwest Maine. An important observation made by Upham during mapping was that drumlins occur mainly in belts and are separated by broad areas where drumlins are scarce.

Drumlins are oval hills composed of till or stratified sediment (Barnett 1992). Trenhaile (1998) notes the term 'drumlinoid' can be used to describe long and narrow drumlin-like ridges, while crag-and-tails can be considered types of drumlins, with tails composed of glacial sediment extending behind an obstruction (usually a bedrock knob). Since a variety of processes may form drumlins it is critical that any definition of this form not include a genetic interpretation. Drumlins are made of a variety of materials including till, bedrock and/or stratified sediments (commonly glaciofluvial deposits). One of the most diagnostic characteristics of drumlins is that their long-axis is oriented parallel to ice flow.

Generally, stoss-ends of drumlins (facing up-ice directions) in the Nechako Plateau are blunt and steep, while lee-sides gently slope down-ice and eventually merge with the surrounding ground surface (Fig. 35). Typically, drumlins are 1-2 km long, have widths

**Figure 35.** Aerial view of characteristic streamlined landforms within the Nechako Plateau.

of 400 to 600 m and are 5 to 50 m high (Ritter 1982). However, Tipper (1963) notes that in the Nechako River map area (93F) drumlins and other streamlined landforms are roughly 1.6 km long, up to 400 m wide and 15-60 m high. In the study area these forms are 100-1600 m long, 40-650 m wide and commonly occur in groups or fields (Fig. 36). This suggests that a large-scale process was responsible for their formation.

Crag-and-tail and drumlinoid ridges are the most common landforms within the Marilla map area and surrounding region. These forms are easily recognized on air photographs and in the field especially where forest cover has been removed by logging companies. The objective of this chapter is to describe these geomorphic features and provide a possible hypothesis for their formation. Data was collected from field investigations at 8 separate streamlined landforms located in the Marilla (93 F/12) and Tetachuck Lake (93 F/5) map areas and from air photograph interpretation and high resolution DEM's (Fig. 37).

## 5.2 CONTROVERSY SURROUNDING DRUMLIN FORMATION

There are numerous theories that explain the formation for crag-and-tail and drumlinoid ridge landforms (Table 5a). Unfortunately, most of these theories are based on assumptions in the absence of direct observations (Shaw 1983). Smalley and Unwin (1968) also mention that most theories on drumlin formation are simply suggestions for "conditions within which certain unspecified processes operate". Even if hard data on streamlined landform genesis could be collected, it is quite possible that more than one mechanism of formation exists. In order for one theory to be able to explain the formation of all streamlined landforms numerous conditions have to be accounted for

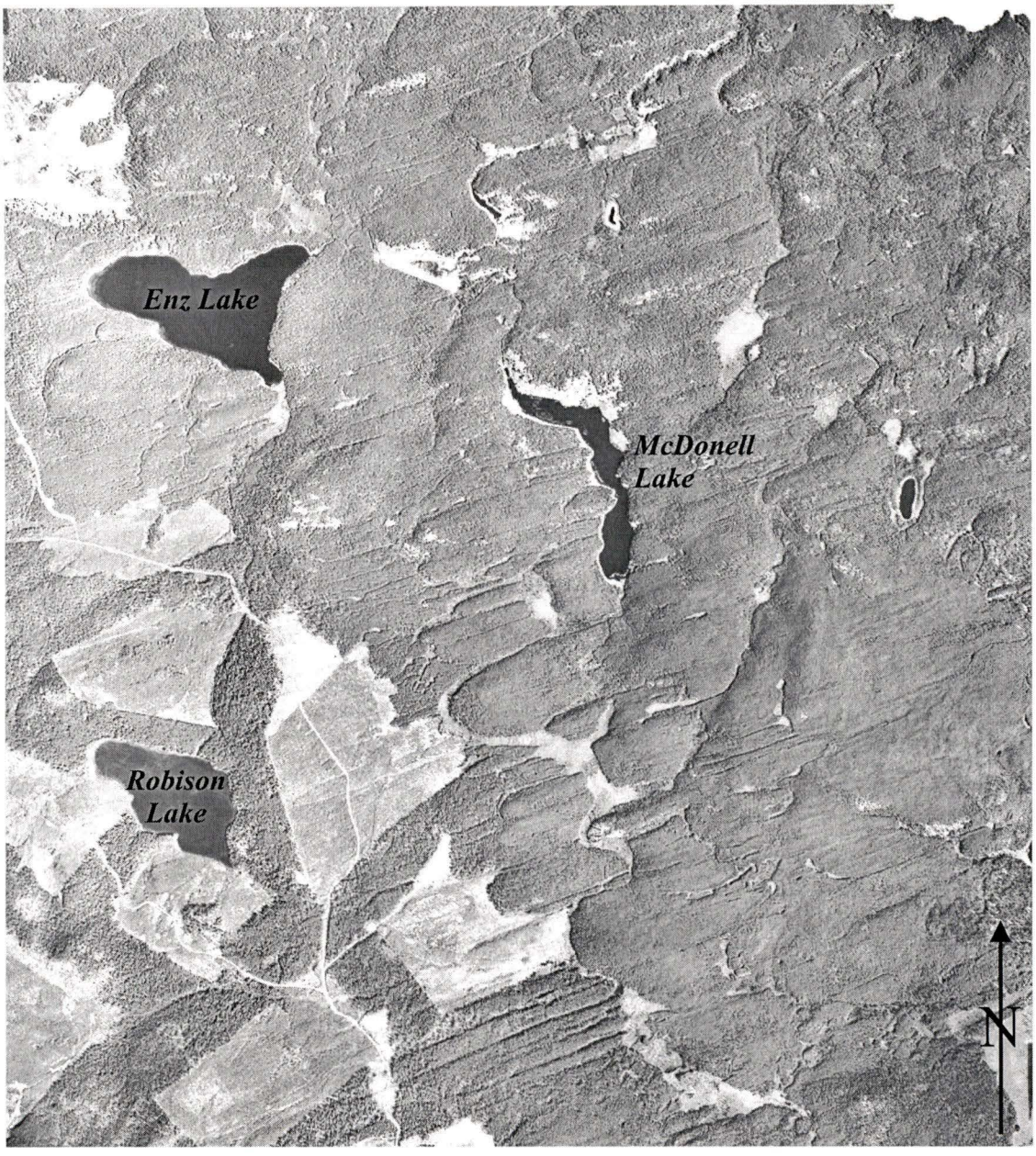



**Figure 36.** Large scale view of ridged and rolling, streamlined landforms south of Cheslatta Lake (aerial photo 15BCB96004 no. 70, scale 1:40 000). Streamlined landforms are commonly grouped in fields and are rarely found individually. Often these landforms are accentuated by horseshoe shaped, bog filled, depressions (e.g. see large streamlined landform south of McDonell Lake). Ice flow is to the northeast.

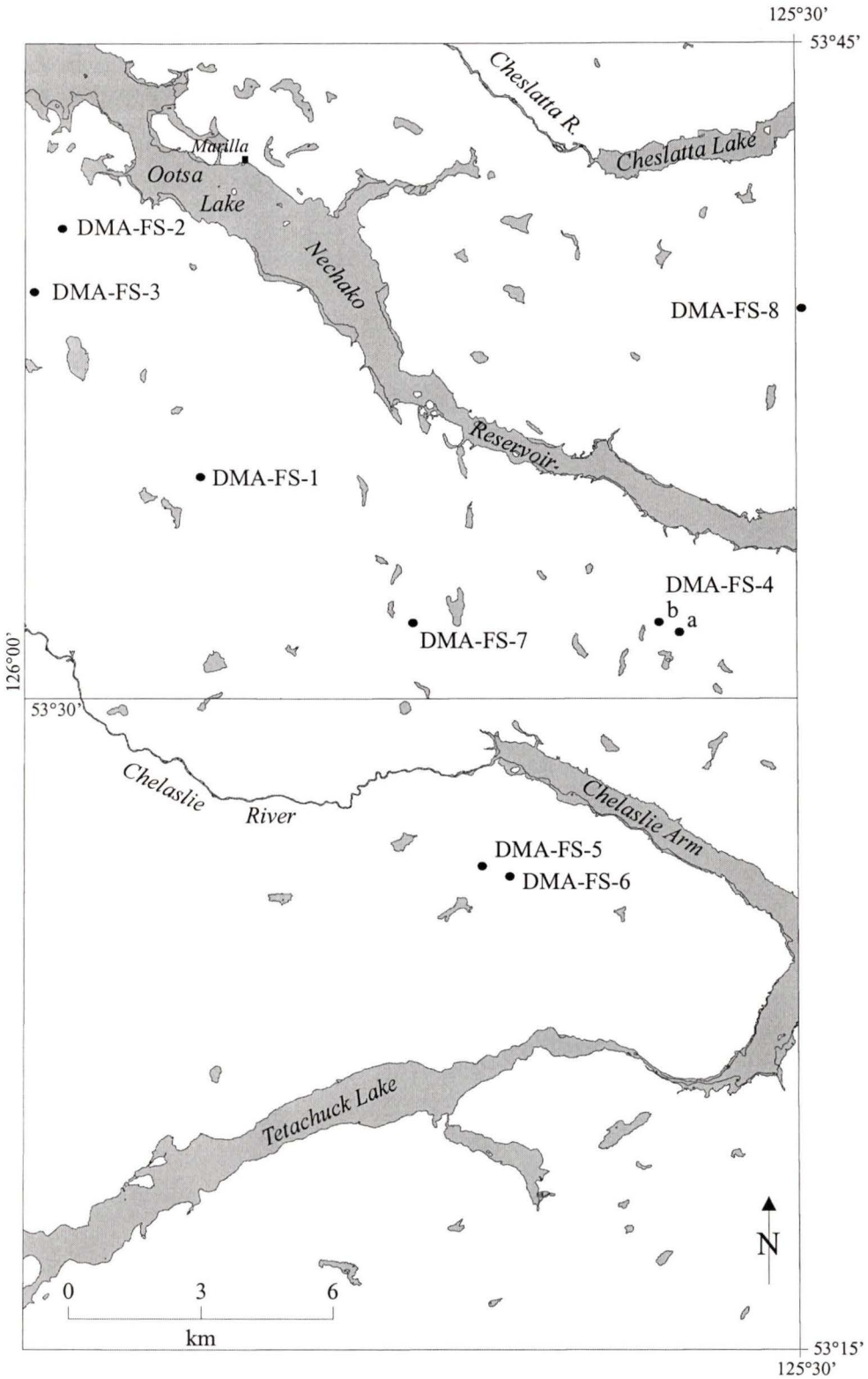



**Figure 37.** Location of streamlined landform field investigation sites. Sedimentological data from depressions around streamlined forms was collected at sites DMA-FS-1, DMA-FS-5 and DMA-FS-8. Site DMA-FS-8 occurs just east of the study area in NTS map sheet 93F/11(scale 1:50 000).

**Table 5.** a) Major drumlin forming models as summarized by Menzies (1979), Barnett (1992) and Menzies and Shilts (1996). b) List of some of the conditions that need to be met in order for one theory to explain the formation of all streamlined landforms (after Gravenor 1953).

a)

| **Hypotheses** | **Authors** |
|---|---|
| 1. Accretion Theory (Accretion of till around obstacles) | Boulton (1970, 1971) |
| 2. Till Squeeze Theory | Dyson (1952); Stalker (1960) |
| 3. Changes in geotechnical properties of subglacial debris due to pressure variations (dilatancy theory) | Smalley and Unwin (1968); Crozier (1975); Menzies (1989) |
| 4. Frost Heave Theory | Baranowski (1969) |
| 5. Glacial Kinematic Fluting Theory | Shaw and Freschauf (1973) |
| 6. Pressure differences at base of glacier | Evenson (1971) |
| 7. Cavity fill hypothesis | Shaw (1983) |
| 8. Subglacial meltwater erosion model | Shaw and Sharpe (1987) |
| 9. Formation by moulding previously deposited material within the subglacial environment where a limited amount of subglacial meltwater activity occurs | Whittecar and Mickelson (1979) |

b)

| **Conditions** |
|---|
| 1) Drumlins consist of a variety of materials |
| 2) They contain lenses or layers of stratified materials that can be folded and faulted |
| 3) Rock drumlins can be found beside drumlins of other materials |
| 4) Most glaciated areas do not have drumlins |
| 5) Drumlins exist in fields wider than most end moraines and rarely occur as isolated forms |
| 6) Drumlins have a streamlined shape with the stoss end pointing up-ice |
| 7) Some drumlins have cores (e.g. bedrock), while others do not |
| 8) Drumlins are found behind terminal moraines that mark the outer limit of ice advance |
| 9) Drumlin long axes are parallel to ice movement |

(table 5b).

Two major theories are presently being used to explain drumlin formation. They are: 1) glacial processes (subglacial deformation and accretion of lodgement till) and 2) powerful catastrophic subglacial meltwater floods. The effects of glacial processes on streamlined landform formation were first suggested in the late 1800's and are still widely accepted (Upham 1892; Tarr 1894). The idea that streamlined landforms could be formed by subglacial meltwater floods was introduced in the early 80's (Shaw 1983). Drumlin forming hypotheses can be further subdivided into two other categories; those that are **erosional** and those that are **depositional.** Erosional models explain drumlin formation by the removal of pre-existing drift from around the form. Depositional categories explain landform genesis by deposition and moulding of till, on or around obstacles to ice flow, at the base of a glacier.

## 5.3 LITERATURE REVIEW

As mentioned above, there are many different models that try to explain drumlin formation. Only the more prevalent models from Table 5a will be discussed here.

### 5.3.1 Dilatancy Theory

The dilatancy theory was first proposed by Smalley (1966) and later expanded on by Smalley and Unwin (1968). Dilatancy theory was the first model to acknowledge geotechnical properties of till and effects they might have on drumlin formation. This theory states that drumlins (streamlined landforms) are formed by the dilatancy of the material that composes them. Dilatancy, a property of granular masses, is an increase in volume during deformation, caused by a change from a close-packed structure, accompanied by an increase in the pore volume (Dictionary of Geological Terms 1984).

Simply, dilatancy occurs when a mass of particles under certain pressure levels actually increases in volume (dilates) instead of decreasing in volume. Smalley and Unwin (1968) speculate that dilatancy occurs, under certain, unspecified stress limits, along the till-glacier interface.

Dilatancy applies only to granular masses and fine-grained sediments like silt or fine-grained tills do not dilate under critical stress levels. Smalley and Unwin (1968) note that tills must contain a minimum concentration of boulders to become dilatant. Smalley (1981) made a similar statement while reviewing the dilatancy theory fourteen years after its creation. It was reiterated that dense, stony till within areas of certain stress levels (exact stress level is unspecified) are key for streamlined landform formation.

For this model to work, it is assumed that pressure levels required for the dilatancy of subglacial material are produced from the ice sheet. Smalley and Unwin (1968) suggest that stress conditions required for dilatancy are related to the thickness of the ice mass lying on top of the till. Three broad pressure zones occurring within a glacier were proposed (Fig. 38). In stress zone A thick glacial ice exerts pressures too high to allow for dilatancy. In zone B, ice is too thin (ablation zone), exerting pressures that are too low to initiate dilatancy. However, in zone C suitable pressure levels for dilatancy are thought to occur. In this zone subglacial material is allowed to expand (dilate) forming obstructions to ice flow. These obstructions are then shaped by flowing ice into a form that provides the least resistance to flow. This shape is the streamlined shape of the drumlin.

This theory does have limitations and cannot be used to explain the genesis of all streamlined landforms. It only applies to drumlins formed exclusively of till and cannot

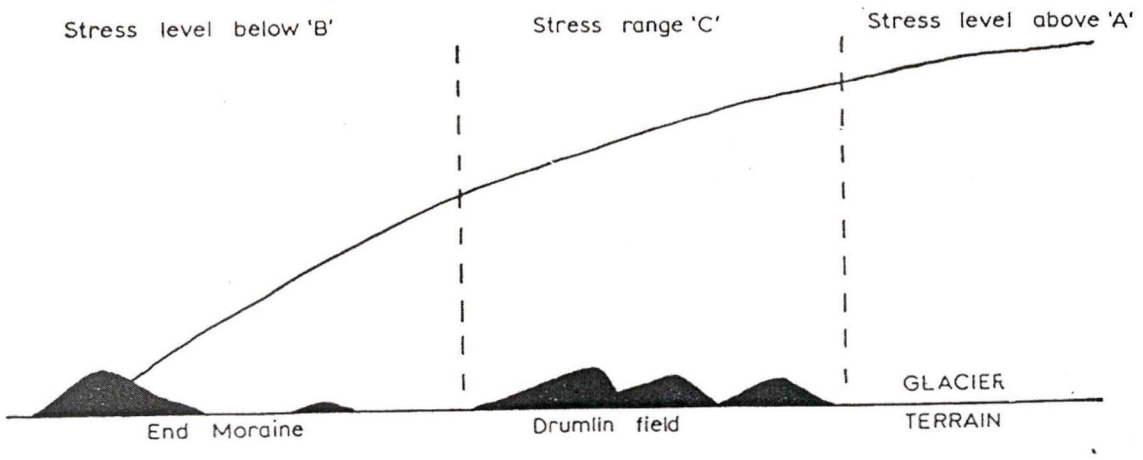



**Figure 38.** Three broad pressure (stess) ranges within an ice sheet as proposed by Smalley and Unwin (1968). The zone that contains critical stress levels for drumlin formation occurs in range C. In stress level 'A' thick glacial ice exerts pressures that are high enough to prevent dilatancy. In stress level 'B', thinner glacial ice is unable to exert pressures that are high enough to initiate dilatancy. However, in stress level 'C', pressure levels are suitable for dilatancy and local dilatant areas are streamlined by advancing ice, creating flutes.

be used to explain stratified sediments in streamlined landforms. Secondly, the dilatancy theory is unable to account for the presence of crescentic scours and lateral furrows (see Subglacial Meltwater Erosion Model (section 5.3.6)) around drumlins. Finally, since dilatancy applies only to granular masses, therefore another process must explain the formation of crag-and-tails which have bedrock stoss-ends.

### 5.3.2 Accretion of Till Around Obstacles

An accretionary theory for drumlin formation was proposed by Boulton (1970, 1971). This model explained drumlin formation by pressure melting at the glacier sole as active ice encounters bedrock obstructions. Field observations from a site where till was seen accumulating on both sides (stoss and lee) of a bedrock obstacle helped develop this theory. Two different till deposition mechanisms, one for the stoss and one for the lee, were used to explain this phenomena. Deposition of material from basal, debris-rich, stagnant ice, trapped against an obstruction beneath clean, active glacier ice was used to explain till deposition at the stoss end and along the flanks of streamlined landforms (Boulton 1970, 1971). This occurs because basal debris-rich ice is less plastic than clean ice when moving at high velocities. Clean ice is able to flow around the obstruction while debris-rich ice can't and remains trapped in front. The stagnant ice mass deposits till around the front of the obstruction through a melt-out process.

Till is deposited on the lee-side by pressure melting of the glacier sole as it passes over the obstruction (Boulton 1971). Pressure melting in a subglacial environment occurs when high pressures, generated on the upstream sides of obstructions to ice flow cause glacier ice to melt and the subsequent meltwater flows to the lee side.

Also, as active ice loses contact with the obstacle it overrides, till along the ice/bedrock contact is deposited by slumping and sliding into the new space (Fig. 39). Both, slow melting of till from stagnant debris-rich ice in front of an obstacle and the deposition of till by pressure melting as glacier ice passes around an obstruction can be used to explain the formation of rock cored drumlins
and streamlined landforms. Boulton (1976) also notes that flutes can be formed by "squeezing-up" of subglacial sediment into low pressure cavities found in the lee of obstructions to ice flow.

However, since not all streamlined landforms have bedrock stoss-ends (or are rock-cored), it is unlikely that this theory explains the formation of all streamlined landforms in a drumlin field. Like dilatancy, this theory also cannot explain the presence of crescentic scours and lateral furrows around, and stratified sediments within streamlined landforms. A much larger process, possibly working in conjunction with smaller processes, must be involved.

### 5.3.3 Pressure Differences at Base of Glacier

Evenson (1971) developed a model explaining drumlin formation as a result of differential pressures at the base of a glacier. The hypothesis was that till, at the base of a glacier, would move from zones of high pressure into zones of low pressure. These pressure zones may possibly be formed by an undulating ice surface, however what is believed to have caused these different pressure zones is not clearly defined by the author. Drumlin crests occur in low pressure zones (less overlying ice) and low areas between crests occur in high pressure zones (more overlying ice compared to drumlin

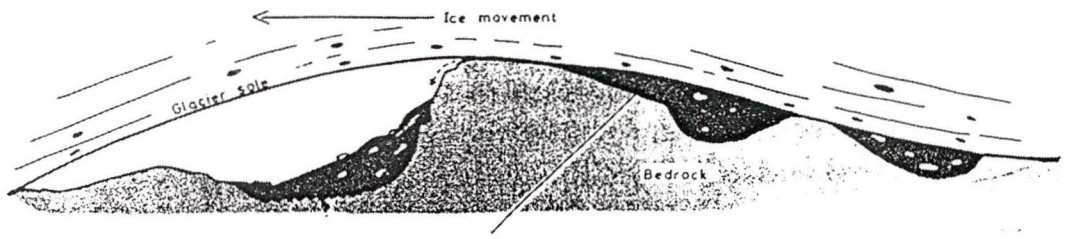



**Figure 39.** Diagram showing stagnant, debris-rich ice trapped on the up-glacier side of a bedrock obstacle and till deposition (by pressure melting) in lee-side cavities (diagram taken from Boulton (1971)). Both mechanisms occur simultaneously, forming a rock cored drumlin.

crests) (Fig. 40). Data used to support this theory was collected from imbricated clasts (till fabric analysis) found in drumlins of Jefferson County, Wisconsin.

Till fabric analysis is a technique used in Quaternary geology to study stress conditions within till and to aid in interpreting ice flow direction. Till fabrics are obtained by measuring the orientation and plunge direction of long axes of elongate pebbles within the till. Elongate pebbles generally align themselves parallel to ice flow and have a preferred plunge in an up-glacier direction (Harrison 1957). It is also suggested by Harrison (1957) that this plunge results as particles are transported in upward rising shear planes (dipping up-glacier) within the ice. The same shearing can occur in till as it is transported from high to low-pressure zones beneath a glacier. Therefore, evidence for the migration of till from high to low pressure zones (drumlins) should be reflected by the plunge of its clasts.

Evenson (1971) used a till-shear theory to explain up-glacier plunge of clasts within drumlins. This theory assumes that tills behave as viscous liquids flowing and shearing in response to stress. Hoppe (1952) notes that the weight of overlying ice will transport till outward and upward from its place of deposition. Till transported in this fashion is packed into crevasses in basal ice. During transport, pebbles within till become reoriented by flow shear with their long axes plunging toward the block of ice that displaced them. Therefore, clasts can show an up-glacier imbrication (following shape of shear zone) and become oriented almost parallel to flow as materials move from high to low pressure zones.

The most obvious limitation of this model is that the cause of the pressure difference responsible for forming streamlined ridges is not identified. How such a

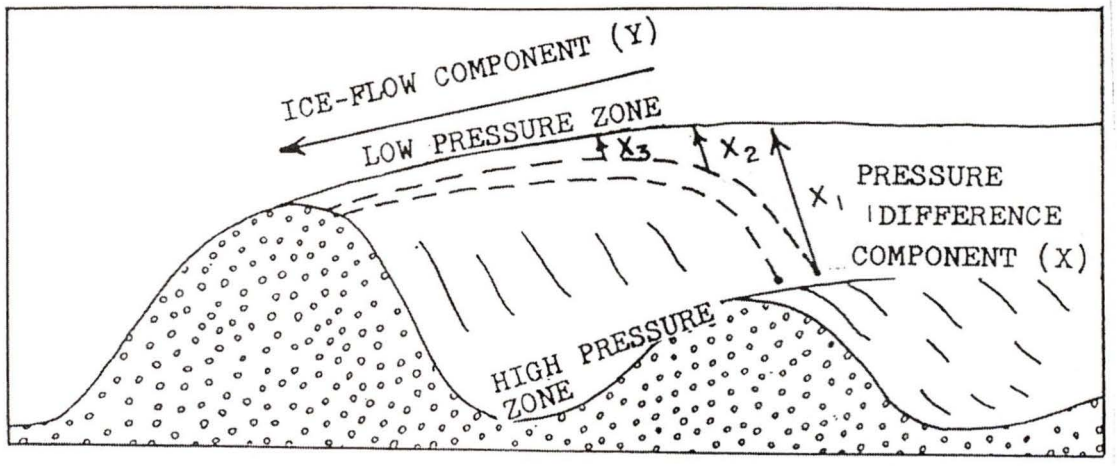



**Figure 40.** Diagram showing theoretical high pressure trough zones and low pressure drumlin ridges developing at the base of a glacier (diagram from Evenson 1971). Evenson (1971) hypothesized that till at the base of a glacier will move from zones of high pressure into zones of low pressure. Ice flow (Y) is constant, while pressure (x) is variable. Pressures on materials are highest at $x_1$ and lowest at $x_3$. Drumlin crests occur in low pressure zones (less overlying ice).

difference could be generated between drumlins in fields is difficult to explain. Even if this model is valid it would not be able to explain drumlins that have rock cores or are composed of stratified drift. It also offers no explanation for crescentic scours and lateral furrows (section 5.3.6).

### 5.3.4 Kinematic Flow Model

Shaw and Freschauf (1973) used helical flow patterns created by kinematic waves within glacial ice to explain drumlin formation. A kinematic wave in glacial ice is a solitary wave of increased, constant discharge, moving at greater velocities and having a greater thickness than surrounding ice (Sharp 1991). It was stated that helical flow causes horizontal debris-rich zones at the base of a glacier to become focused into thick linear belts (Fig. 41a). It is assumed that rotating helical flow cells occur such that bands of relatively clean ice alternate with bands of debris laden ice. This allows deposition to form ridges that are separated by grooves or areas of erosion.

Till fabric data was collected in the field from individual flutings to try and prove this theory (Fig. 41b). Fabric data formed a "herring-bone" shape, with fabrics on the west side of ridges (C and D) oriented in a counterclockwise direction, and fabrics on the east side of the ridge (E and F) oriented clockwise. Therefore, fabrics on each side of the ridge were inferred to represent two different helical flow cells, acting simultaneously to form the ridge.

Formation of helical flow patterns within glacial ice is difficult to conceptualize. Benn and Evans (1998) mention that modern research has determined that this model is physically impossible. Even if it were possible, the kinematic flow model would have the

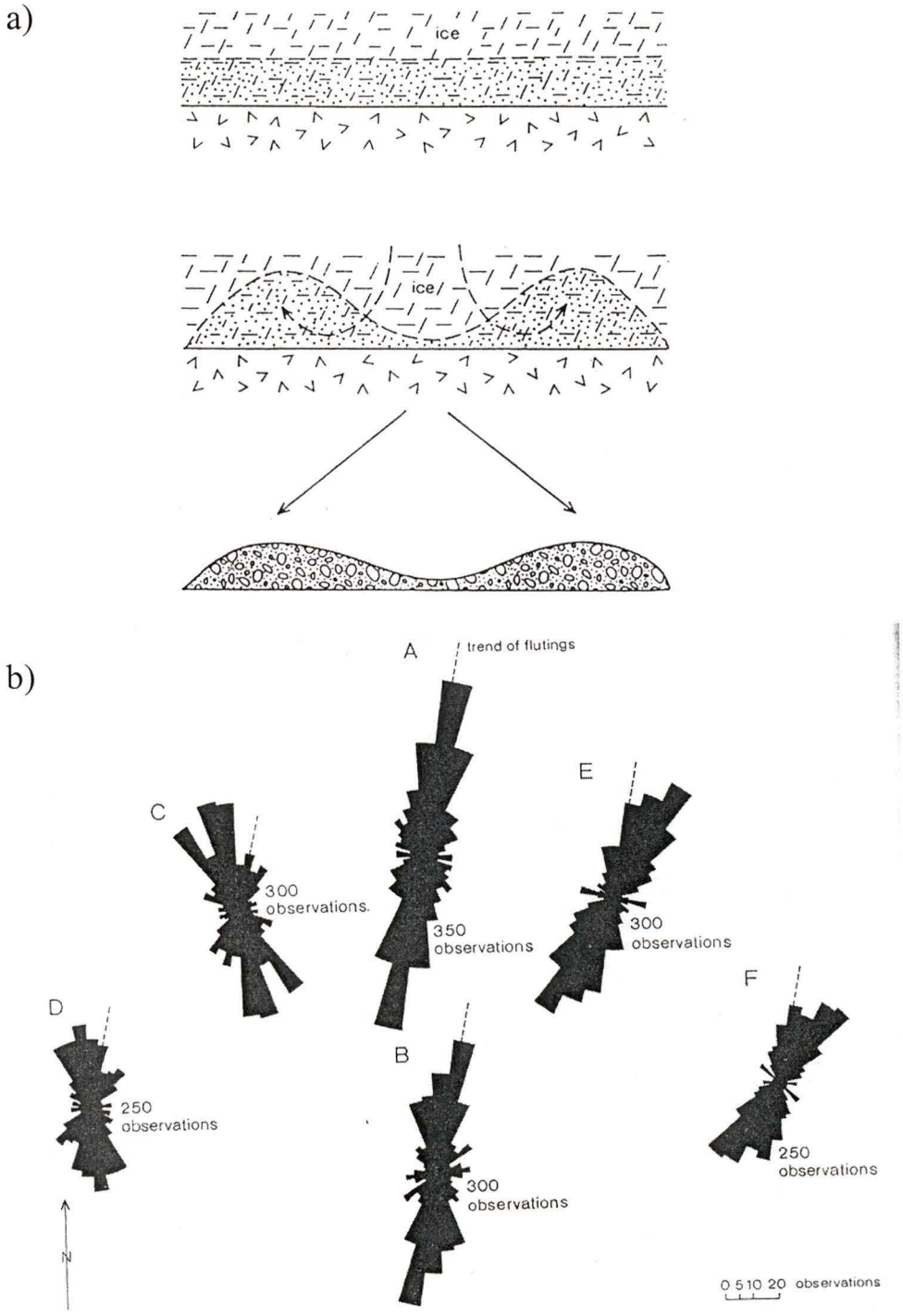



**Figure 41.** a) Effects of secondary helical flow in ice on horizontal debris-rich zones. Helical flow causes horizontal debris-rich zones at the base of a glacier to accumulate into thick, linear belts (diagram from Shaw and Freschauf 1973). b) Various positions of till fabric data from a fluting near the town of Athabasca in central Alberta. Fabrics C and D are tilted counterclockwise while fabrics E and F are tilted clockwise, forming a "herring-bone" shape (Shaw and Freschauf 1973). This fabric data was used to provide evidence of two separate helical flows occurring on each side of the fluting (diagram from Shaw and Freschauf 1973).

same limitations as the above models (does not explain drumlins with rock cores, stratified sediment and crescentic scours and lateral furrows).

### 5.3.5 Subglacial Meltwater Depositional Model (Cavity-Fill Hypothesis)

Shaw (1983) developed this theory based on a form analogy between drumlins and moulds of erosional marks associated with turbidites. The only difference between the two is the order of magnitude of formation. It was hypothesized that large subglacial meltwater discharges carve cavities, similar in shape to flute marks, into the base of a glacier. These cavities become infilled with stratified sediment as floodwaters begin to loose velocity.

This theory was developed in the Livingston Lake drumlin field in northern Saskatchewan. It was noted that the drumlins in this field have a much different form than those proposed by Menzies (1979). Instead of having the characteristic blunt, up-ice stoss-end and gently sloping lee-sides (see Fig. 35) these drumlins were spindle, parabolic and transverse asymmetrical in shape (Fig. 42). Form similarities between turbidite erosional marks and drumlins from northern Saskatchewan are striking. It is also interesting to note that both erosional marks and drumlins occur in groups. Therefore, a cavity fill hypothesis helps to explain why drumlins form in large fields or swarms.

This theory requires a high magnitude flood to lift areas of the overlying glacier above the glacier/terrain interface. In order for subglacial water to erode cavities at the base of the ice it must be turbulent. As flood water depth increased, erosional marks would be sculptured in both the substrate and overlying ice sheet. When flood water depth declined and the ice settled back towards the sliding surface, water levels between

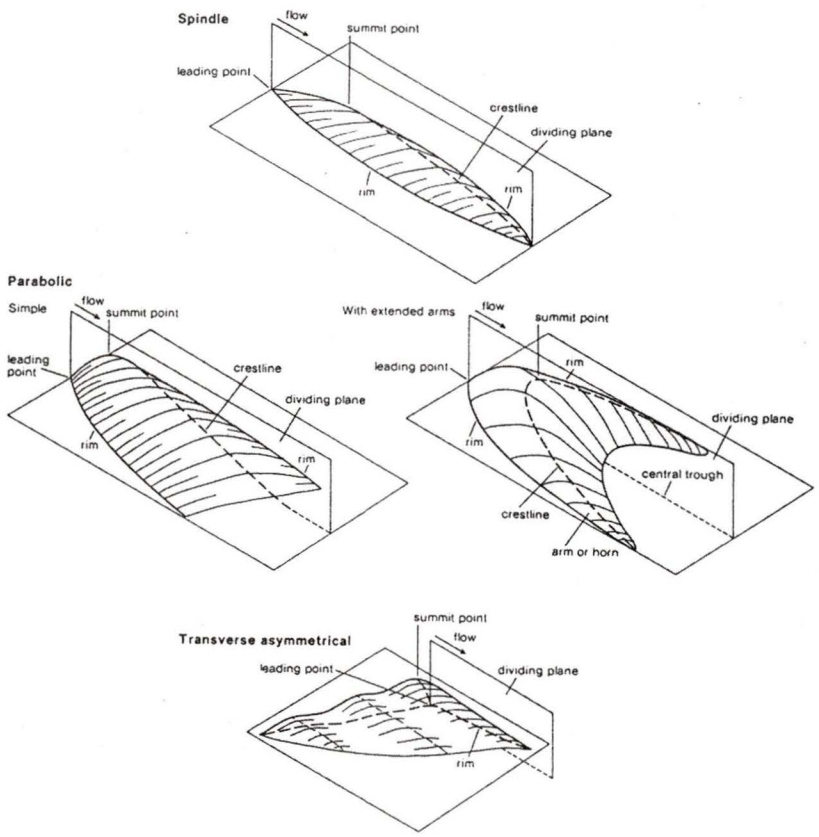



**Figure 42.** Diagrammatic representations of the various shapes of drumlins in the Livingstone Lake drumlin field. Drumlins in this field do not have blunt, up-ice stoss-ends and gently sloping lee-sides. Instead, they have spindle, parabolic and transverse asymmetrical shapes. The shapes of these drumlins are similar to turbidite erosional marks (diagram from Shaw 1983).

cavities becomes confined into shallow sheets containing extremely high velocities. Sediment swept into cavities would eventually settle out as the hydraulic pressure of the water decreased and the sediment content increased, creating a subglacial meltwater deformational drumlin (Shaw and Kvill 1984).

Discharges required to erode cavities large enough to form drumlins must be catastrophic. Such flows could either result from the sudden drainage of large sub or englacial lakes or from the channeling of basal meltwater from a large catchment area (Shaw 1983). The influence of large amounts of subglacial meltwater and basal cavities within the ice help explain the presence of sorted and stratified materials within drumlins.

### 5.3.6 Subglacial Meltwater Erosion Model

A subglacial meltwater erosion model for drumlin formation was first proposed by Shaw and Sharpe (1987). This model was a modification of the cavity fill hypothesis mentioned above. Both hypotheses are similar in that they base the formation of drumlins on sheets of subglacial meltwater (Shaw et al. 1989). However, this theory proposes drumlins are remnant ridges of preexisting material left after the surrounding substrate has been eroded by subglacial sheet floods.

Drumlins are thought to form behind obstructions (bedrock knobs and potentially stony till) which deflect subglacial sheet flood water. Deflection or flow-separation of meltwater around an obstruction creates turbulent, unidirectional flow (Shaw and Sharpe, 1987) (Fig. 43). These flows are very erosive, preferentially eroding material upstream of the obstacle and on both sides of the developing remnant ridge. Shaw and Sharpe (1987) describe erosional marks upstream of an obstacle as crescentic scours while those along each side of the ridge are referred to as lateral furrows.

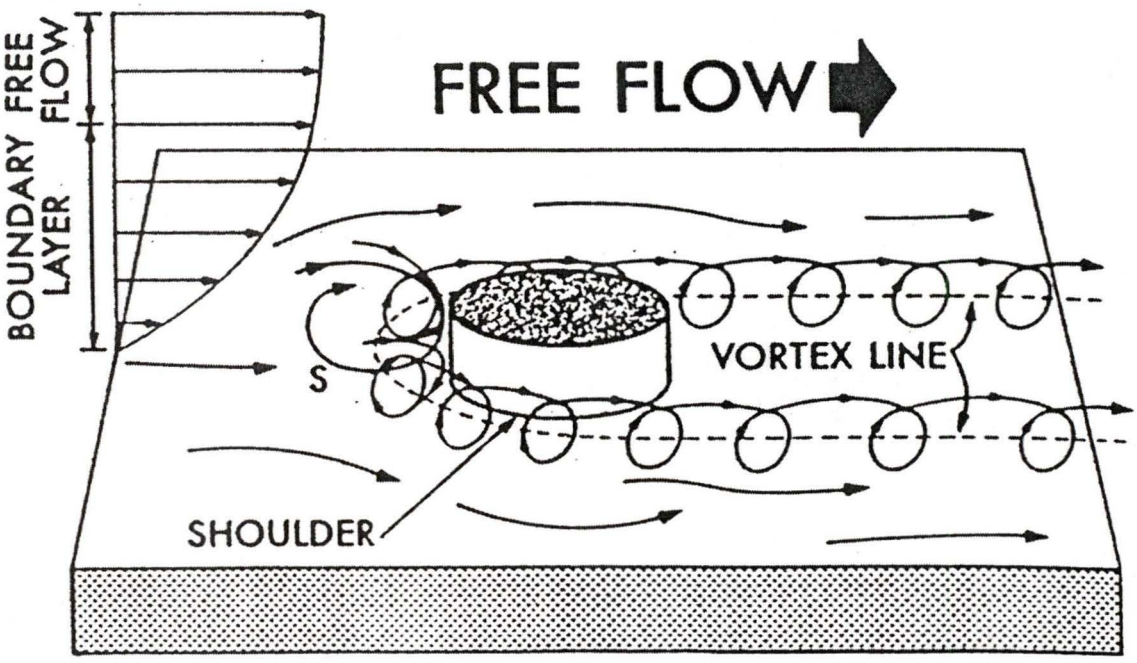


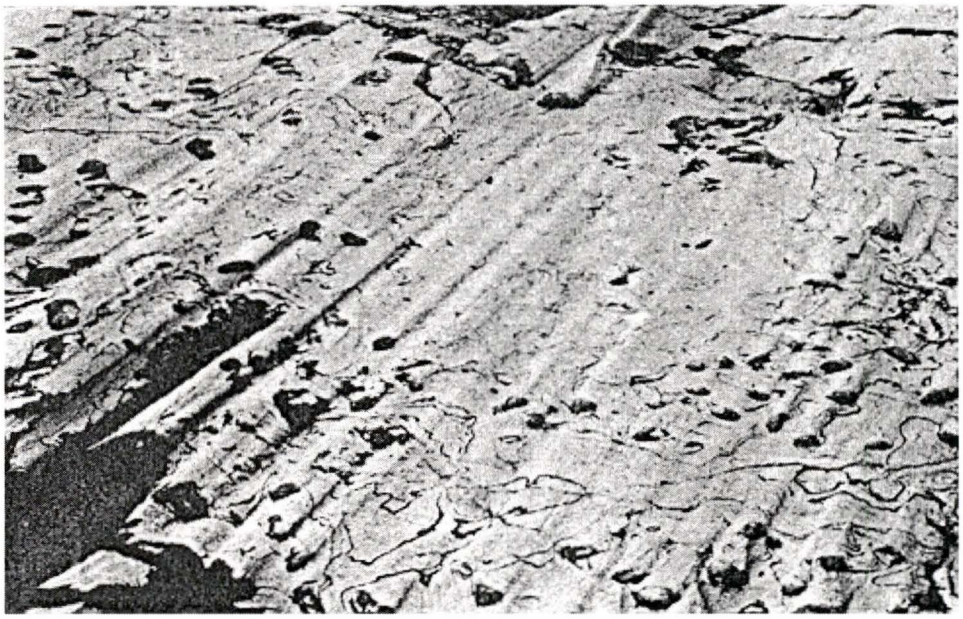

**Figure 43.** Simple diagram showing how laminar flow in a subglacial meltwater flood becomes deflected and experiences flow separation around an obstacle. Flow separation generates horseshoe vortices that are believed to be very erosive and responsible for producing crescentic scours and lateral furrows (defined by Shaw and Sharpe 1987). Diagram taken from Shaw (1994*a*).

Shaw (1994*a*) explains that velocity of subglacial meltwater flows increases away from the ground surface. When this higher velocity flow impinges on an obstacle it generates high pressure in the fluid, causing it to plunge towards the bed. This plunging of the fluid towards the bed results in separated flow (Daraghi 1990) and the creation of a horseshoe vortex forming crescentic scours and lateral furrows.

Crescentic scours can be explained by flow separation. In places they can be occupied by lakes (crescent-shaped lakes). They form at the stoss-end of obstacles and extend down-ice as a set of lateral furrows. These furrows are often paired (e.g. one on each side of the obstacle), becoming broader and more shallow with distance downstream. With distance these furrows blend with the original ground surface. Remnant drumlin ridges have a similar form analogy with intermediate and small-scale erosional ridges that occur on bedrock outcrops (Dahl 1965, Shaw 1988; Kor et al. 1991; Shaw 1994b; Kor and Cowell 1998). These authors infer that these features are formed by subglacial meltwater flows.

Rat-tails are small-scale erosional ridges, oriented in the direction of ice flow. They are found on bedrock outcrops, and were first named by Prest (1983). Rat-tails may be only a few millimetres wide and occur in the lee of obstructions of similar width. Obstructions usually are knobs of harder rock (e.g. concretions) set within softer rock (e.g. dolomite) (Fig. 44a). Prest (1983) found evidence of well defined crescentic scours and lateral furrows around rat-tails on outcrops along the Niagara Escarpment (Fig. 44b). Scours and furrows are often smooth or lightly striated while the surrounding outcrop surface is heavily striated. The smooth and lightly striated nature of the scours and furrows discounts ice as the erosive agent. Shaw and Sharpe (1987) mention that such

a)



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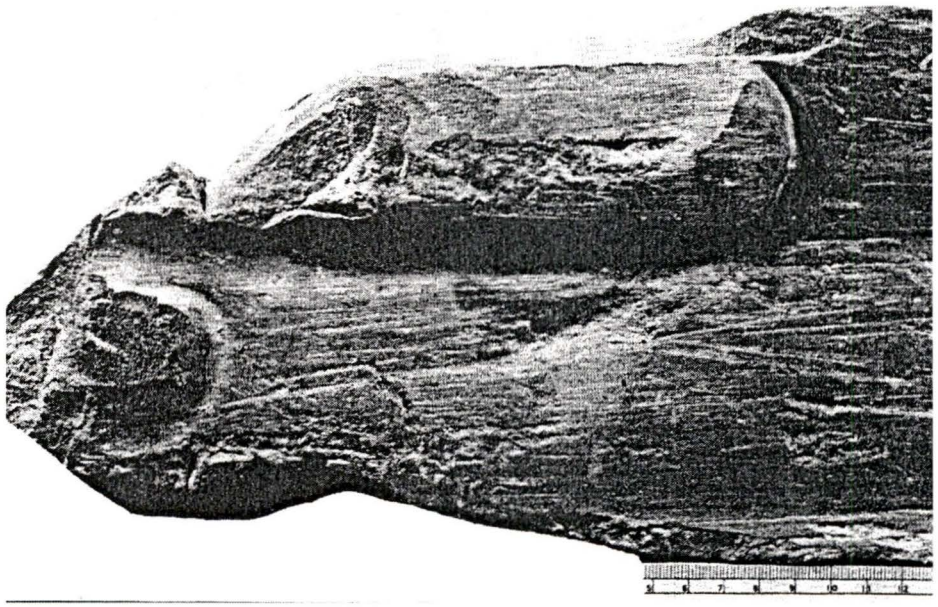


**Figure 44.** Rat-tails, found on bedrock outcrops, are small-scale meltwater erosional ridges that are parallel to ice flow. These features are formed in the lee of obstructions. a) Photo showing dolomite remnant ridges (rat-tails) formed behind more resistant chert nodules. Ice flow is from lower left to upper right (photo taken from Prest (1983)). b) Rat-tail from the Niagara Escarpment showing well developed crescentic scour and lateral furrow (photo taken from Prest (1983)). Rat tail morphology is similar to that of streamlined landforms in the study area.

smooth scours and furrows are caused by a fluid of low viscosity that forms turbulent, unidirectional flow around obstacles. Since large and small-scale remnant ridges have very similar forms it is possible that they were both formed by the same process (subglacial meltwater). The only difference would be that the process occurred at a different scale.

An erosional subglacial meltwater hypothesis can explain the internal composition of all drumlins. Furthermore, the subglacial meltwater erosion hypothesis easily accounts for the presence of crescentic scours and lateral furrows. However, these models do have shortcomings. Firstly, the water reservoir needed to create such features is immense. How such reservoirs form and where they occurred is still uncertain or unknown. Secondly, widespread coarse gravel lag deposits are rarely found on drumlin surfaces and surrounding areas. If such large scale, regional erosion of the land surface took place some type of evidence (lag deposit?) should remain. Thirdly, the model cannot explain the different orientations of till fabrics within a single drumlin as observed for example, by Shaw and Freschauf (1973).

## 5.4 CHARACTERISTICS OF STREAMLINED LANDFORMS IN THE STUDY AREA

### 5.4.1 Geomorphology

The most common streamlined landforms within the study area are crag-and-tail ridges. Up-ice (stoss-ends) of these features are bedrock knobs, while down-ice (lee) portions are ridges of glacial diamicton (till). Flutings and drumlinoid ridges, dominantly composed of till, also occur. These forms are often nested and sometimes occur locally in *en echelon* arrangements. Shaw (1996) defines *en echelon* arrangements as those that are offset in a flow-parallel direction.

Collectively, crag-and-tails, flutings and drumlinoid ridges within the study area have an average orientation of 70° (n = 164), a variance of 21° and range from 58°-79°. Striation measurements from bedrock outcrops in the study area have an average orientation of 75° (n = 16), a variance of 34° and range from 60°-94°. Since striae are widely recognized to be good indicators of ice flow, the similar orientations of striae and streamlined forms suggests that both can be used to determine ice flow direction in the Nechako Plateau.

Well defined, depressions or grooves that are usually flat-bottomed, are consistently seen at the stoss-ends and wrapping around the sides of these streamlined landforms (Figs. 45 and 46). These depressions are commonly bog filled and highlight these forms. They resemble the crescentic scours and lateral furrows described by Shaw and Sharpe (1987) and Shaw (1994*a*). Sometimes these depressions are eroded to bedrock.

Depressions along the side (lateral depressions) of streamlined ridges have moderately to steeply sloping sides and are usually deeper than the surrounding ground surface. They are commonly 5 – 50 m wide, 2 – 5 m deep (Fig. 47) and, widen and become more shallow with distance down-ice. Often lateral depressions are better developed on one side of the streamlined landform. Stoss-end depressions are crescent-shaped and are often deeper than lateral depressions. Lateral depressions merge with but never cross-cut crescent-shaped depressions occurring down-flow.

Areas of maximum erosion occur at the stoss-end of streamlined forms creating troughs that are deeper than the surrounding surface and oriented transverse to ice flow direction (consistent northwest-southeast trend). The morphology of macro-landforms in

a)

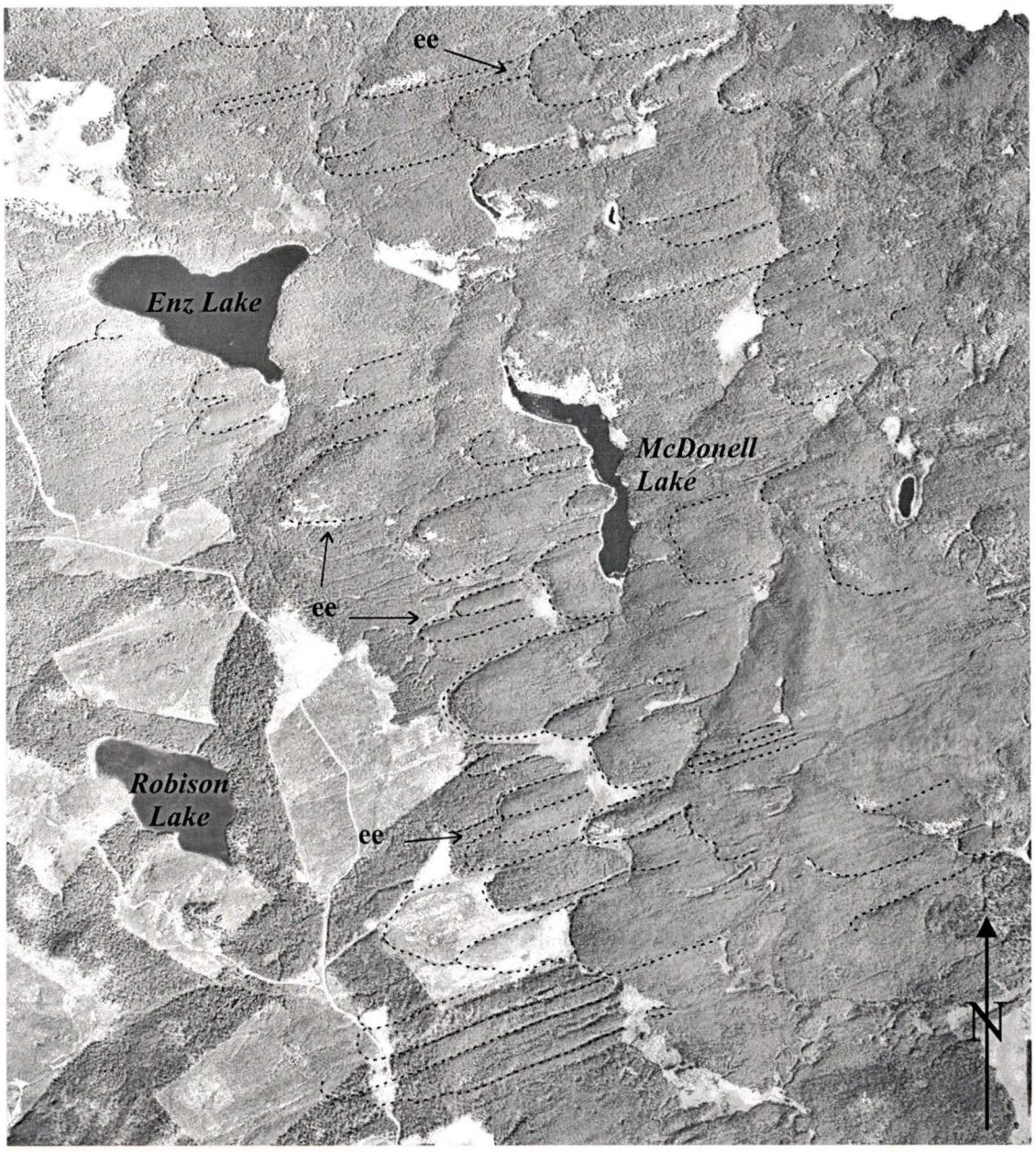



**Figure 45.** a) Traced, flat-bottomed (horseshoe and comma-shaped) depressions helps accentuate streamlined landforms within the study area. Note how some of the streamlined forms in this figure are arranged in an *en echelon* (ee on photo), step-like pattern. Ice flow is to the northeast. Refer to Fig. 36 to see the same air photograph unmarked. Aerial photograph 15BCB96004 no. 70, scale 1:40 000.

**Figure 46.** a) Traced, flat-bottomed depressions (horseshoe and comma-shaped) immediately south of Ootsa Lake (aerial photograph 15BCB96003 no. 81). Composite forms (c on photo) have smaller forms superimposed on them. Ice flow is to the northeast.

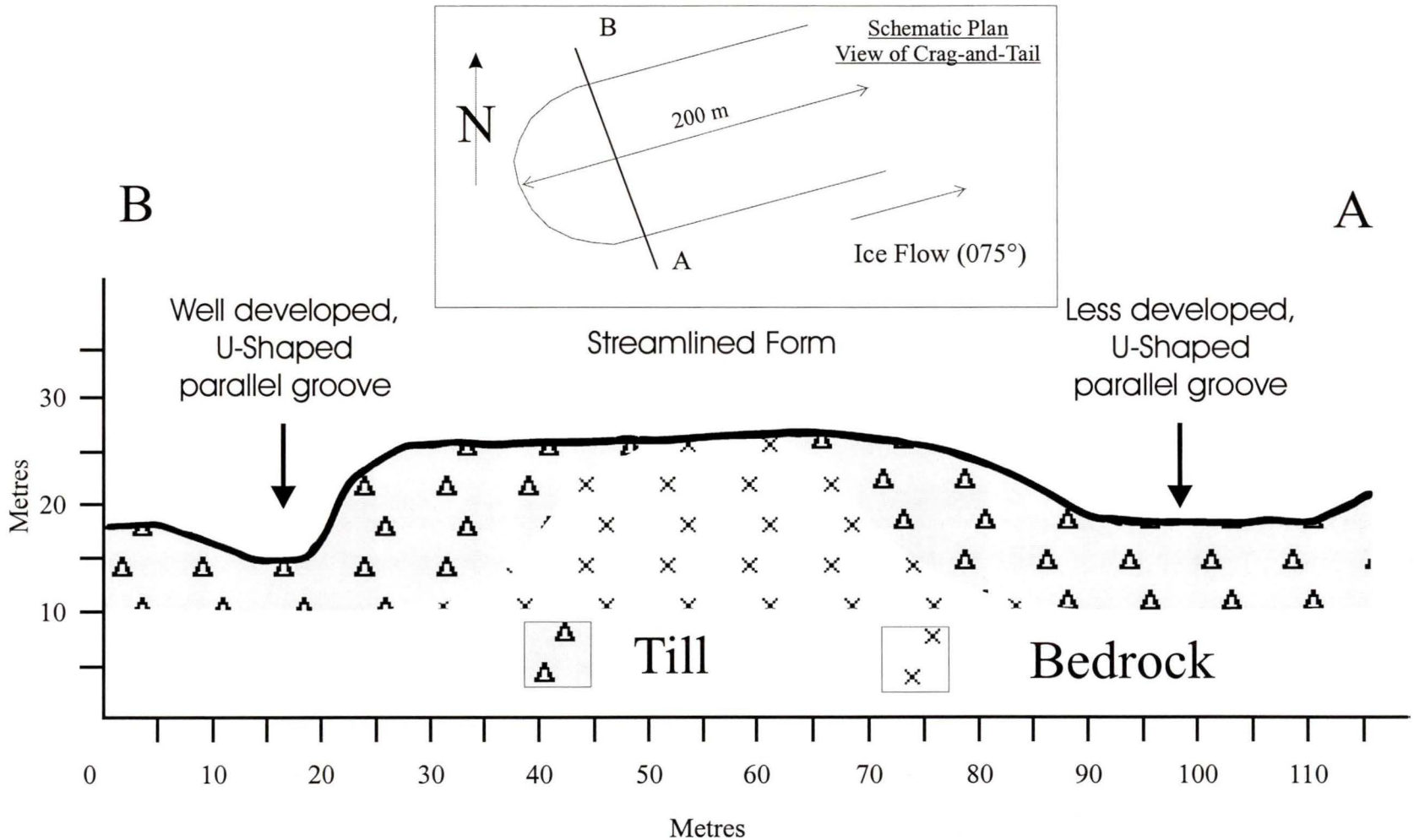



**Figure 45.** Measured transverse profile across crag-and-tail ridge (at site DMA-FS-2, Fig. 37), close to stoss-end. Lateral depressions along sides of ridge are approximately 3 m below the surrounding till plain and 7-12 m below the ridge crest. The lateral depressions are 5-20 m wide at the base and 20-50 m wide at their crests.

the study area is dominated by these troughs (Fig. 48). These troughs extend up to 3 km before they bend and form lateral depressions up to 1.6 km long. Combined, these depressions have a C-shaped appearance (see Fig. 48). Groups or clusters of streamlined landforms often form a large composite landform defined by a single (or a series of joined) crescentic scour at the up ice end (illustrated on Fig. 46).

Holocene drainage systems (streams and creeks) often do not occupy these depressions. However, at one field site (DMA-FS-7, see Fig. 37) postglacial drainage from a small lake flows through one of these depressions. This drainage has incised the groove further and deposited a small fan, at the end of the form, where the stream enters a small lake.

Numerous small lakes and bogs occur in stoss-end crescent-shaped troughs and lateral depressions. This is illustrated just north of Ootsa Lake near the small hamlet of Marilla (see Fig. 37). In this location, Sams Lake has formed along one side of a large bedrock escarpment in a well developed lateral depression (Fig. 49). This lake has a comma-shaped morphology. Just west of Sams Lake is another body of water that has formed in a stoss-end depression and has a very well defined crescent shape.

A west to east topographic profile (A-A' Fig. 49) in this area shows that up-ice sides of bedrock escarpments are quite steep while down-ice portions tend to taper more gradually into the surrounding ground surface. A north-south profile (B-B' Fig. 49) in the same area shows very undulating topography with lateral depressions around bedrock escarpments. Sams Lake occurs in a depression to the north of the bedrock escarpment that is approximately 20 m lower than a similar depression to the south.

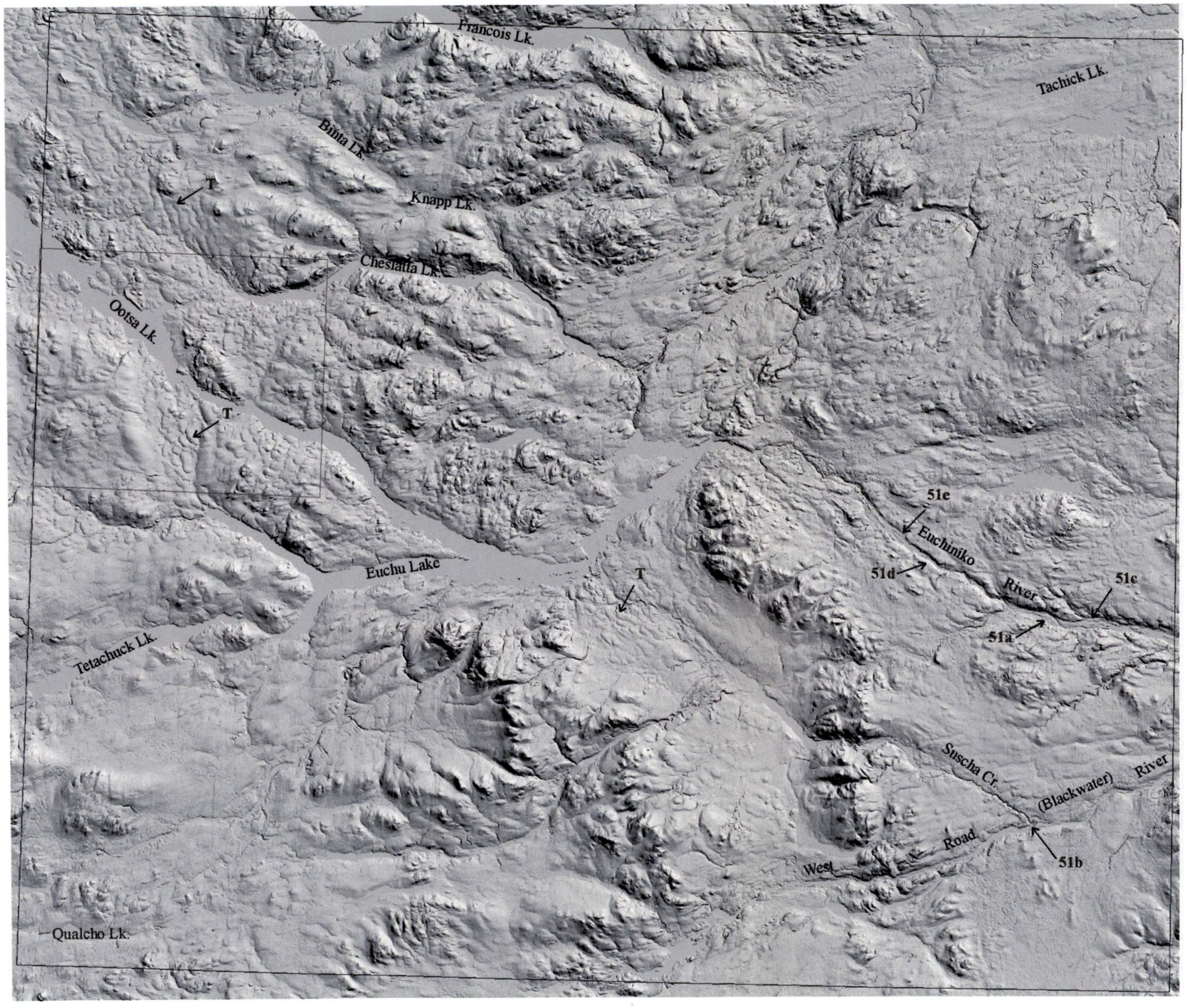



**Figure 48.** Digital elevation model for the Nechako River (93F) map area (Lowe and Kung 2000). The black box highlights the map sheet that comprised most of the study area (Marilla map sheet, 93 F/12). Southwest trending troughs (T), transverse to ice flow are common in the study area and surrounding regions. This DEM was from 1:20 000 Terrain Resource Information Management (TRIM) digital elevation model data. The DEM is projected using a UTM coordinate system and its datum is NAD 83. Locations of the aerial photographs used in Fig. 51 are identified (e.g., 51a, 51b, etc.).

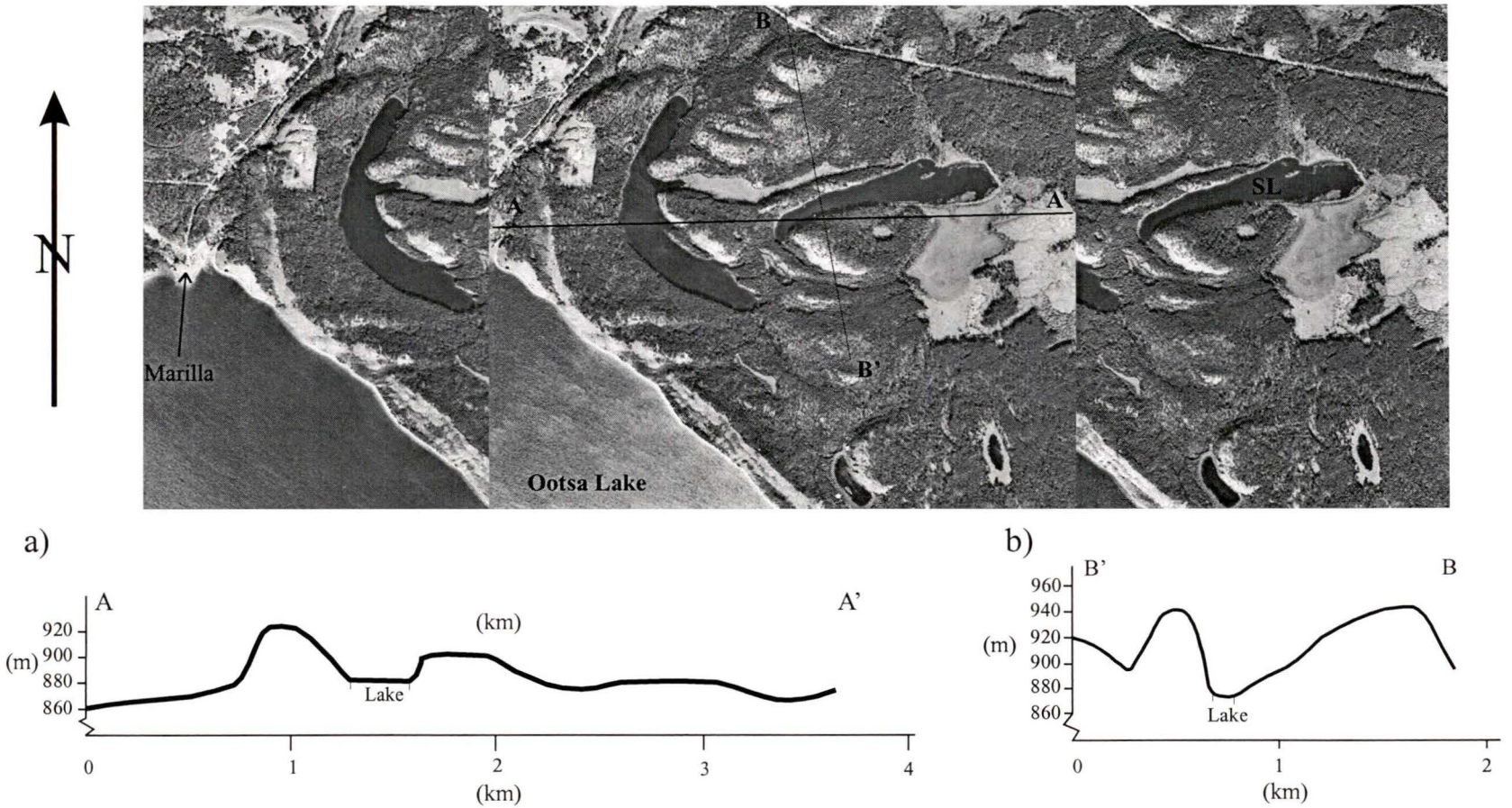



**Figure 49.** Aerial photograph showing crescent and comma-shaped lakes occupying stoss-end and lateral depressions in the Marilla hamlet area (cleared areas on far left photo). a) A west-east topographic profile, constructed from TRIM topographic data, shows that steep surfaces occur on up-ice sides of bedrock escarpments while down-ice sides taper more gradually towards the surrounding ground surface. b) A north-south profile shows undulating topography with depressions around large bedrock knobs. Ice flow direction is northeast and SL stands for Sams Lake. Refer to Fig. 4 (back pocket) to see complete profile transect. Aerial photographs 15BCB96105 no. 60, no. 59 and no. 58, scale 1:40 000.

Nested flutes at a variety of scales are another significant feature illustrated in Fig. 49. A large (approximately 1.75 km long), crescent-shaped depression occurs just east of Marilla. This depression (part of which is obscured by Ootsa Lake) highlights a prominent bedrock ridge, roughly 65 m above lake level. Smaller crescent-shaped scours occur east of this large bedrock ridge in front of bedrock controlled topography. These scours also occur at a variety of elevations (see Fig. 49, northeast of crescent-shaped lake). Some scours are too small to see on air photographs and can only be observed on the ground.

A good example of the effects of bedrock control on subglacial flow occurs in the southeast corner of the Marilla map area, NTS 93 F/12 (see Fig. 37). The most dominant topographic feature in this area is a large Neogene diabasic centre that has a diameter of approximately 1 km and is roughly 80 m above the ground surface (see bedrock geology section in chapter 1 for more details). Directly up-ice from this feature is a small, crudely crescent-shaped, lake (Fig. 50). Smaller, crescent-shaped scours occur along the sides and to the south of this feature. A prominent tail of till occurs on the down-ice side of this volcanic centre.

A topographic profile parallel to ice flow across this Neogene centre (see Fig. 50) shows that the lake occurs in a large stoss-end depression that is transverse to the regional ice-flow direction. The same profile also shows that the up-ice side of the Neogene centre is quite steep, while the lee has a tail that slopes towards the adjacent ground surface much more gradually. A lateral depression also occurs on the south side of this large bedrock knob. Bog filled depressions on top of this volcanic centre are visible on air photographs and topographic profiles in Fig. 50.

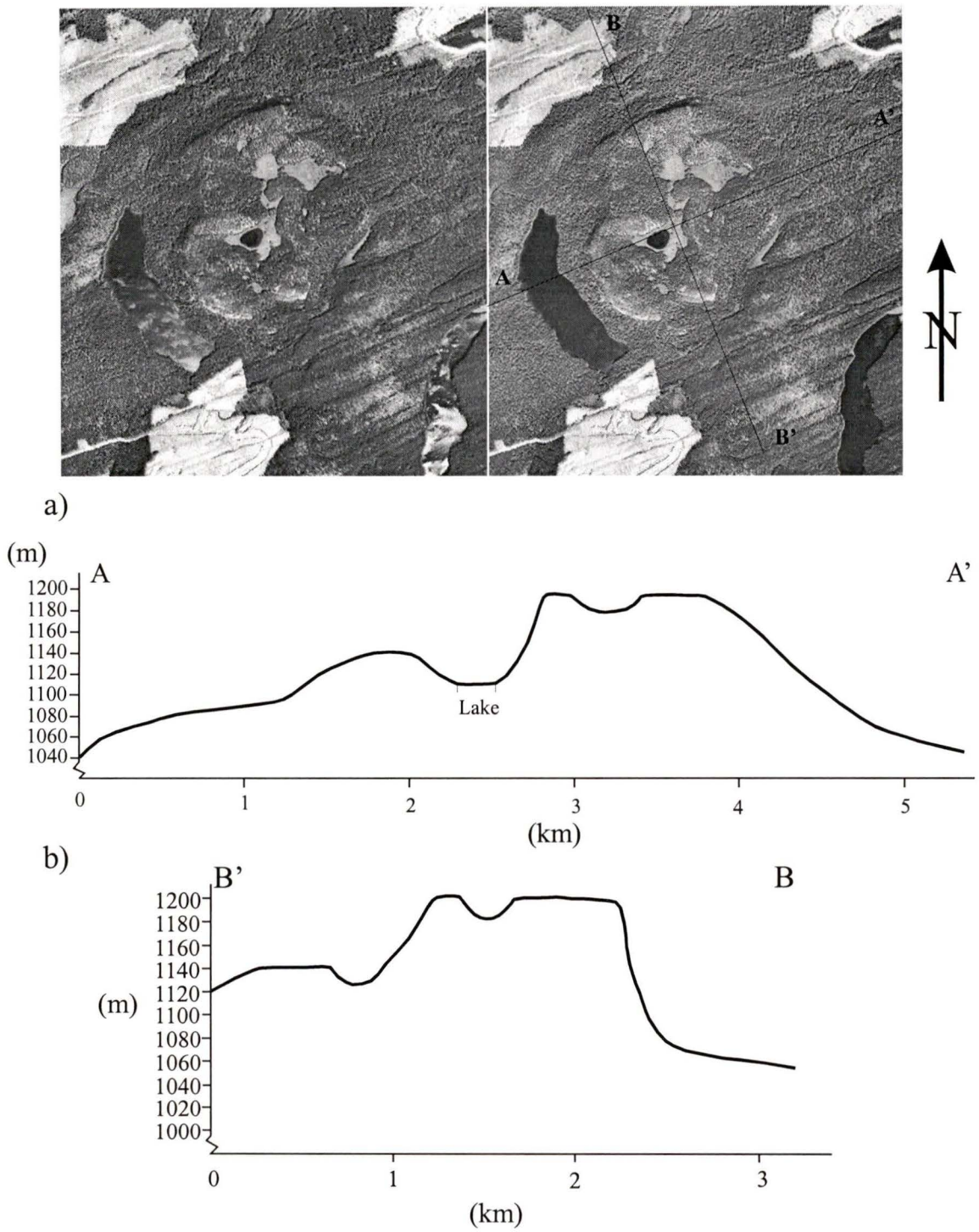



**Figure 50.** Aerial photograph showing a small, crescent-shaped lake occupying a stoss-end depression in front of a large Neogene diabasic centre in the southwest corner of the map sheet (aerial photographs 15BCB96103 no. 198 and 199, scale 1:40 000). a) A southwest-northeast (A-A') topographic profile shows that up-ice facing sides of the Neogene centre are steep while down-ice facing sides slope more gradually towards the ground surface. b) Profile B-B' shows evidence of a lateral depression on the south side of the bedrock knob. Ice flow direction is northeast. Refer to Fig. 4 (back pocket) to see complete profile transect.

### 5.4.2 Composition of Different Forms

To investigate the origin of the crescentic scours and lateral furrows, sedimentary materials within flat bottomed depressions were described. Several small soil pits up to 1.3 m deep were dug in the depressions and on the flutings at three different sites (DMA-FS-1, DMA-FS-5 and DMA-FS-8 in Fig. 37) to identify what material types were present in these features. Sedimentologic data from soil pits and streamlined ridges is found in Appendix H and summarized in Table 6. At every site a thin pebble to cobble-sized lag with some boulders overlies silty to sandy diamicton.

In flat bottomed depressions along the side of streamlined forms, large pebble to large cobble-sized lags up to 80 cm thick are overlain by 5-50 cm of peaty, forest soil. Typically, the pebble-cobble unit is 1-3 clasts thick and contains clasts that are subangular to rounded with some striations. Overall the unit is clast-supported. In crescent-shaped depressions forest soil with scattered cobbles and boulders overlies sandy, small to large pebbly gravel and pebbly sand. Sometimes, in both crescent-shaped (stoss-end) and lateral depressions, scattered cobbles and boulders occur at the surface. Pebble to cobble lags on adjacent streamlined forms are poorly preserved or absent in most places.

At each site, this pebble to cobble unit abruptly overlies a massive, poorly sorted, sandy diamicton (Table 6). The diamicton is dense, has moderate to high fissility and contains pebble-sized clasts, some of which are striated. It is interpreted as Fraser Glaciation till. Occasionally this diamicton is orange mottled.

**Table 6.** Summary of the sedimentary characteristics of materials within soil pits from lateral and crescent-shaped depressions and streamlined ridges. For a complete summary of sedimentologic data from all pits refer to Appendix H.

| Location | Material (Top Down) | Avg. Thickness (cm) | Max. Thickness (cm) | Number of Sites | Number of Samples | Avg. (wt%) | |
|---|---|---|---|---|---|---|---|
| | | | | | | Sand | Mud |
| **Lateral Depression** | Soil | 20 | 50 | 7 | - | - | - |
| | Surface Gravels (cobbles) and Sand | 25 | 80 | 7 | - | - | - |
| | Diamicton | 39 | 75 | 6 | 9 | 76 | 24 |
| **Crescent-Shaped Depression** | Soil | - | 25 | 1 | - | - | - |
| | Surface Gravels (sm.-lg. pebble) | - | 10 | 1 | - | - | - |
| | Pebbly, fine to coarse sand | - | 35 | 1 | 1 | 84 | 16 |
| | Clay | - | 10 | 1 | - | - | - |
| | Diamicton | - | 25 | 1 | 2 | 80 | 20 |
| **Streamlined Ridge** | Soil | 7.5 | 10 | 2 | - | - | - |
| | Diamicton | 102 | 150 | 3 | 5 | 74 | 26 |

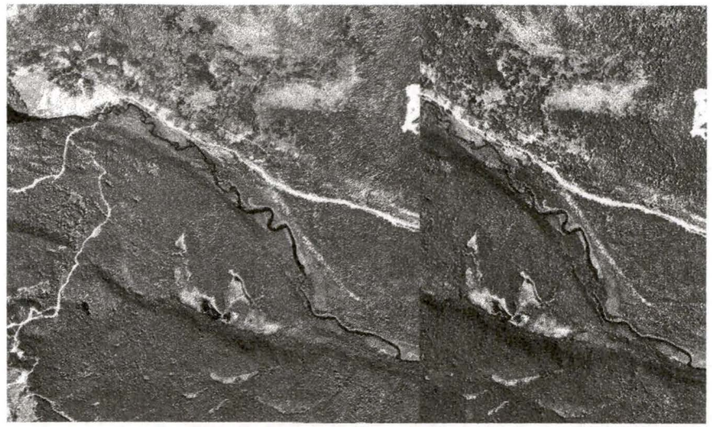
### 5.4.3 Other Features

Another morphological feature common in the Nechako River map area (93 F) are large valleys. Some of the more prominent valleys are the Ootsa Lake valley, Big Bend Creek/Euchiniko River valley (east of the study area), West Road (Blackwater) River valley (southeast of the study area) and the Binta Lake, Knapp Lake and Knapp Creek valley (immediately north of the study area; see DEM in Fig. 48 for more details). Generally, these valleys have a variety of orientations, however the largest ones are oriented northwest to southeast (Euchiniko River and Knapp Lake valleys) and southwest to northeast (West Road River valley).

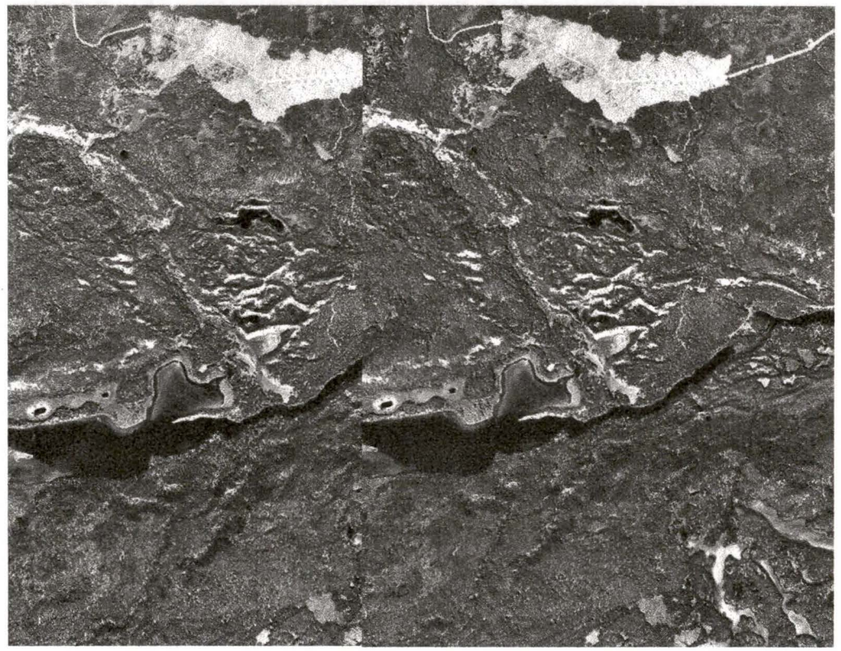
These larger valleys are flat-floored, have steep sides, contain misfit streams and are commonly 1-2 km wide (Fig. 51a). Geomorphic evidence suggests that subglacial, fluvial landforms, commonly eskers, may occur along the floors of some of these valleys (Fig. 51b, c, d, e). Subglacial landforms occurring in valley bottoms suggests that the valleys were formed before the last glaciation or in a subglacial environment prior to esker formation. At one location, one of these valleys crosscut streamlined landforms (Fig. 51e) indicating that the valley formed after these features.

Immediately northeast of the study area (in NTS map sheet 93 E/16) a sonar survey of Ootsa Lake (BC Research Inc. 1998) shows that this water body covers a valley with similar morphological characteristics. The contour map (10 m contour interval) of post-flood Ootsa Lake, generated from this sonar survey, shows that a large, approximately 1 km wide, flat-bottomed valley occurs in the middle of the lake (Fig. 52). In places the walls of this valley are quite steep. It is probable that this valley continues, southeast along the bottom of Ootsa Lake, into the study area.

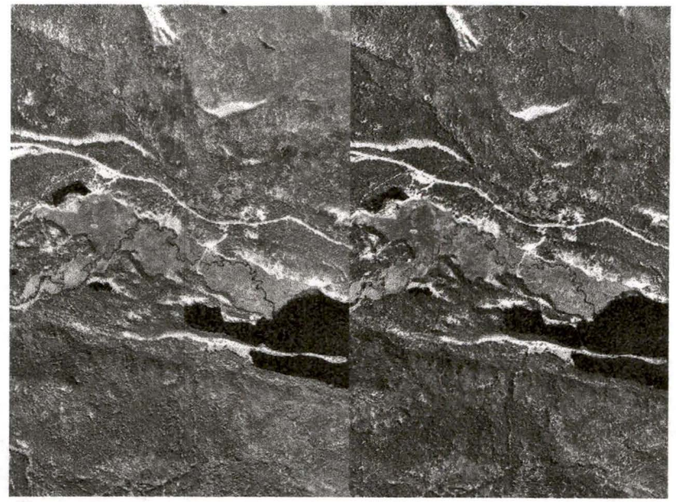
a)



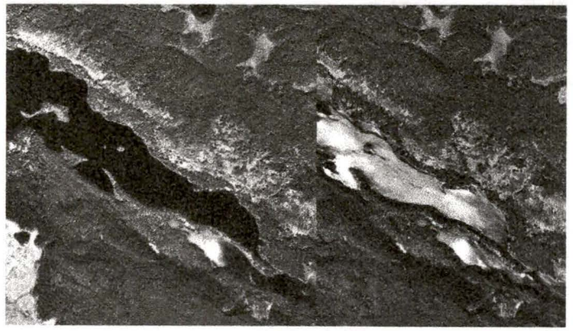
b)



c)



d)



e)

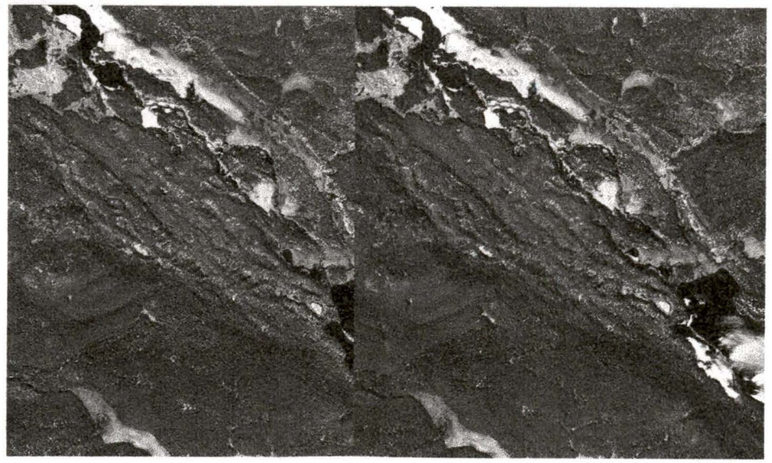


**Figure 51.** 1:40 000 scale aerial photographs from the Nechako River map sheet (NTS 93F, scale 1:250 000) that highlight morphological characteristics of some of the large valleys in the region. a) Larger valleys, approximately 1-2 km wide, are commonly flat-floored, have steep sides and contain misfit streams. Example from the Euchiniko River valley, southeast of Klunchatistli Lake (aerial photographs 15BCB96005 no. 138 and 15BCB96005 no. 139). Geomorphic evidence shows that eskers (subglacial landforms) commonly occur in the bottoms of these valleys (b, c, d, e). b) Esker complex occurring both in the valley bottom and upland area at the northeast end of Euchiniko Lakes in the west Road (Blackwater) River valley. Southwest flowing Suscha Creek has eroded through parts of this esker complex (aerial photographs 15BCB96009 no. 196 and 15BCB96009 no. 197). c) and d) Eskers and glaciofluvial sediments in the Euchiniko River valley. c) occurs at the west end of Comstock Lake (aerial photographs 15BCB96005 no. 140 and 15BCB96005 no. 141). d) Aerial photographs 15 BCB96005 no. 29 and 15BCB96005 no. 30. e) Large esker complex in the Euchiniko River valley that crosscuts streamlined landforms to the south (aerial photographs 15BCB96005 no. 29 and 15BCB96005 no. 30).

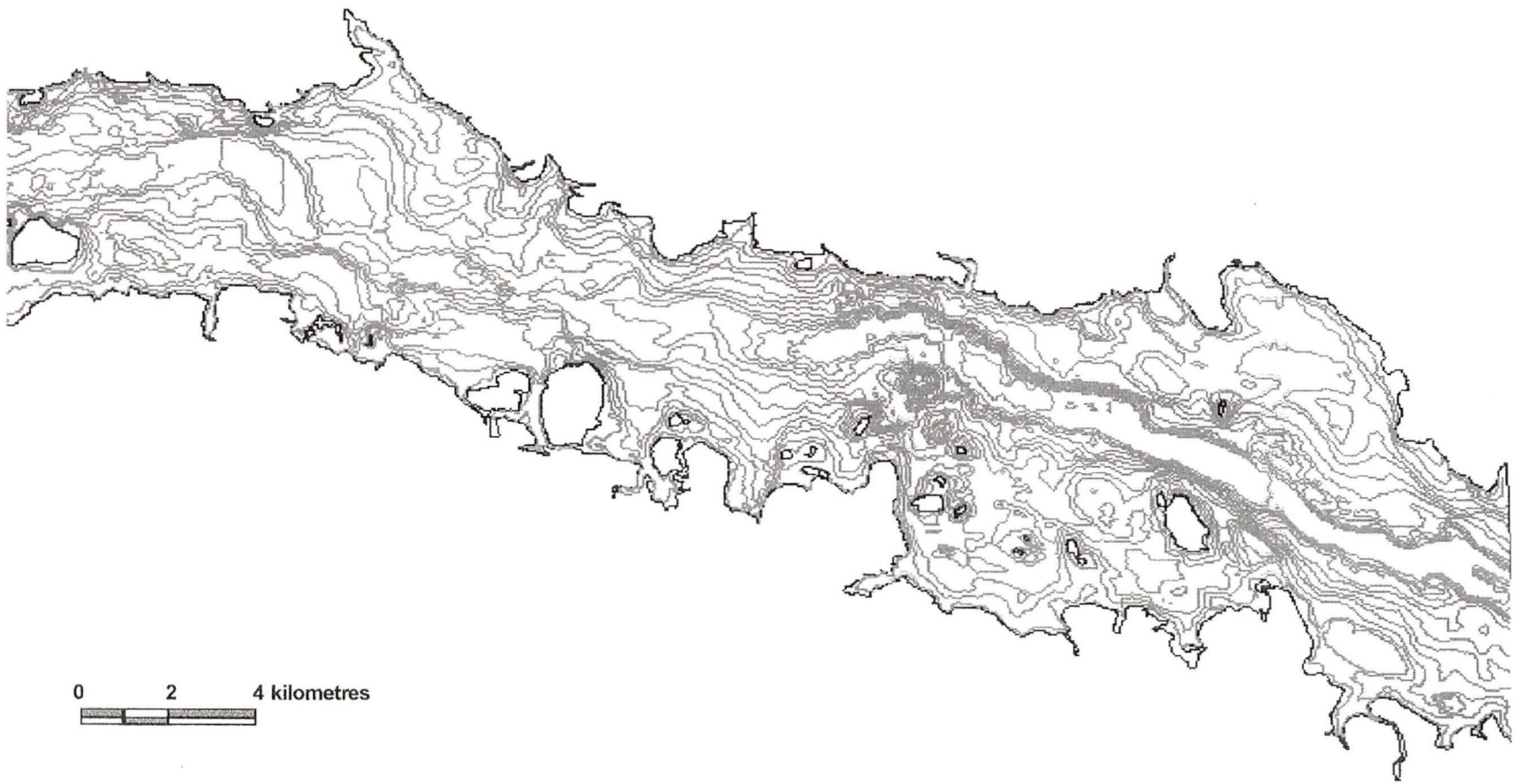



**Figure 52.** Lake bottom contour map of post-flood Ootsa Lake, northeast of the study area (NTS 93 E/16). Contour interval is 10 m and the map was produced from a sonar survey (675 kHz with 150 m line spacing, locally 40 m line spacing) conducted in 1997 by BC Research Inc. (1998). Note the large (approximately 1 km wide), flat-bottomed, steep walled valley running down the middle of the lake. This valley has a morphology that is similar to the Euchiniko and West Road river valleys.

## 5.5 DISCUSSION

Several subglacial processes are likely responsible for creating streamlined landforms in the study area. The formation of crag-and-tails, with bedrock stoss-ends, can be explained by Boulton (1970, 1971; see section 5.3.2) and soft sediment deformation of saturated till into the lee-side of bedrock obstructions (Eklund and Hart 1996). The formation of drumlins, flutes and large-scale features comprised dominantly of till can be explained by subglacial erosion and deposition of deformable beds (Boulton 1987). Erosion of a subglacial deforming bed occurs when water saturated sediment is detached from a rigid bed and is set in motion by shear stress (Hart 1995; Boulton 1996). Static or slowly deforming resistant cores within this layer eventually become streamlined landforms. Other models discussed in the literature review (Smalley and Unwin 1968, Shaw and Freschauf 1973; and Evenson 1971) of this chapter are now considered to be unlikely mechanisms for the formation of drumlins (Benn and Evans 1998).

However, these processes do not explain the genesis of the crescent-shaped scours and lateral depressions that wrap around streamlined landforms in the study area. It is also not easy to explain the formation of these erosive depressions by glacial ice erosion. Glacial ice commonly erodes in the subglacial environment by abrasion and plucking (Iverson 1996). Both processes are most effective on bedrock surfaces and at small scales and do not readily explain the formation of these depressions.

Glacial abrasion scratches (striates) and polishes subglacial bedrock. It is also accepted that under sustained abrasion, bed irregularities would disappear (Hallet 1979, Iverson 1996, Benn and Evans 1998). Therefore, over time glacial abrasion would tend

to flatten streamlined forms. Also, since abrading rock fragments, frozen to the glacier bed and dragged by glacial ice, move parallel to ice flow, the formation of crescentic scours transverse to ice flow seems unlikely. Plucking, the fracture and entrainment of bedrock, caused by temporary stress concentrations, has probably little effect on the formation of crescent-shaped and lateral depressions.

Mechanisms that transfer ice past obstacles, regelation and enhanced creep, also do not explain the formation of depressions around streamlined landforms in the study area. Regelation is a process where glacial ice melts on the upglacier side of obstacles (high pressure zone) and refreezes downglacier (low pressure zone) of the obstacle (Weertman 1964; Hubbard and Sharp 1993). For enhanced creep, stress concentrations around upstream sides of bumps increase strain rates in ice causing it to accelerate around (and over) the obstacle (Benn and Evans 1998). These authors also note that regelation is most effective on a small-scale (less than 5 cm), while enhanced creep occurs around larger-scale obstacles (greater than 50 cm). It is unclear if these processes can form erosive, horseshoe-shaped depressions around streamlined landforms.

The meltwater erosion model (Shaw and Sharpe 1987; see section 5.3.6) does explain the formation of these geomorphic features as well as the associated streamlined ridges. Horseshoe vortices, generated when water from a subglacial flood comes in contact with an obstacle, effectively explains the formation of crescentic scours and lateral furrows (see section 5.3.6 for more details). Gilbert and Shaw (1994) note that obstructions to subglacial meltwater flood discharge confine the flow, substantially increasing its velocity, erosive power, and turbulence. Resultant vortices wrap around the obstruction and flow downstream forming characteristic lateral furrows. Vortices are

able to wrap around obstructions in a down flow direction because they are sheared by the surrounding (and overlying) faster flow that is not affected by local obstacles. This shearing redirects vortices and keeps them straight (Shaw 1994*a*). Ultimately, flow expansion downstream of the obstruction reduces the vortices erosive power and eventually scouring stops.

In order for a fluid to form horseshoe vortices it must be turbulent and have the ability to produce high Reynolds numbers. A Reynolds number uses four factors to determine whether fluid flow will be laminar or turbulent (Streeter 1962):

$$R = \frac{\rho v d}{\mu}$$

Where R is the Reynolds number (dimensionless), $\rho$ is fluid density, $v$ is discharge velocity, d is the diameter of the passageway which the fluid moves through and $\mu$ is viscosity. In order for these vortices to erode bedrock or surficial sediment and transport material effectively, flows need to have Reynolds numbers greater than $10^3$ (Richardson 1968; Allen 1982). Reynolds numbers for realistic flows of water and ice around an obstacle 100 m in diameter was calculated by Shaw (1994*a*). The Reynolds number of water was $2.8 \times 10^8$ and $2.0 \times 10^{-16}$ for ice. Therefore, ice is clearly not capable of producing Reynolds numbers high enough to generate erosive horseshoe vortices. Water, occurring as catastrophic, sheet floods, from large subglacial lakes could produce horseshoe vortices around large obstacles creating crescentic scours and lateral furrows.

Evidence for large, subglacial lake outburst floods has been identified in other regions of Canada (Shaw and Gilbert 1990; Rains *et al.* 1993). These flows are believed to have been as wide as drumlin fields and deep enough to submerge even the largest streamlined landforms. Considering the size of Pleistocene ice sheets, catastrophic

subglacial floods of this magnitude would be mere streams (Shaw and Sharpe 1987). The possible influence of subglacial meltwater erosion on streamlined landforms in the Nechako Plateau has been observed by Levson *et al.* (1997) and Mate and Levson (1999*a*).

Some of the most recent mechanisms used to explain the formation of large subglacial lakes are subglacial ponding (Shoemaker 1991), supraglacier meltwater (Shoemaker 1992) and reversed subglacial drainage from proglacial lakes (Shoemaker 1992). Basal melting at stoss-ends of obstacles (high pressure) under thick ice is responsible for initiating subglacial ponding. This meltwater will first collect in bed depressions and slowly pool and advance into regions beneath thinner ice forming a subglacial lake. However, Shoemaker (1992) notes that if the Livingstone Lake drumlin field was produced by a catastrophic outburst flood with a volume of 84 000 $km^3$ (Shaw *et al.* 1989), subglacial ponding alone is insufficient to form such large water bodies.

Therefore, to form large subglacial lakes, subglacial ponding needs to be enhanced by other processes. The input of supraglacial meltwater into the subglacial environment through a moulin-crevasse system is one process. Shoemaker (1995) notes that if only 6% of the estimated 14 000 $km^3$/yr of supraglacier meltwater produced during deglaciation of the Laurentide ice sheet (Fairbanks 1989) is input into a large subglacial lake, only 100 years is needed to store 84 000 $km^3$ of water.

However, Shoemaker (1995) later refutes the presence of a moulin-crevasse system, stating that crevasses in glacier ice directly above a subglacial lake only form after an outburst flood. Shaw (1996) on the other hand, at least partly attributes the formation of large subglacial floods to the connecting of a supraglacial lake to the

subglacial bed. Alternatively, large water bodies may be trapped under advancing glacial ice forming subglacial lakes. Therefore, the process of how, if any, supraglacial water can enter into a subglacial lake is debatable.

Reverse drainage from a proglacial lake into a subglacial lake has also been suggested. Reverse drainage into a subglacial lake (or under glacial ice) is likely to occur if the water has a higher hydraulic head or is situated on higher ground than the glacial ice supporting it (Shoemaker 1992). Hydraulic head is the total sum of the elevation head, pressure head and velocity head at a given point (Fetter 1994). Modern ice-dammed outburst floods in the Canadian Cordillera commonly occur as glacial ice progressively thins and retreats until it can no longer support the proglacial water behind it (Evans and Clague 1994). For example, Hazard Lake in the St. Elias Mountains, Yukon, drained catastrophically as the hydrostatic pressure of the water exceeded that of the downwasting ice-dam (Clarke 1982; Liverman 1987). Outburst floods may also occur as proglacial lakes connect to glacial drainage systems.

Meltwater inputs by any of these processes may have been responsible for pooling large amounts of subglacial water in the Nechako Plateau and surrounding regions. During Late Wisconsinan deglaciation in the Canadian Cordillera, ice retreated from alpine accumulation areas first, leaving large stagnant ice masses in the low-lying Interior Plateau (Fulton 1991). Therefore, during deglaciation it is possible that large amounts of meltwater were focused towards and accumulated under ice in the Interior Plateau. Proglacial or supraglacial lakes also formed along the margins of glacial ice retreating into the plateau. Early in deglaciation these lakes would occur at high elevations and may have had sufficient hydraulic head to cause reverse drainage into a subglacial lake

environment. At this point, these ideas are speculative and more research into the processes of subglacial lake formation in the Interior Plateau has to be conducted.

Some large, flat-bottomed valleys in the Nechako River map area (93 F, scale 1:250 000), e.g. Ootsa Lake and Euchiniko River valleys, are interpreted to be tunnel valleys. Recent identification and research into tunnel valleys in other parts of Canada has been conducted on Victoria Island (Brennand and Sharpe 1993), in south-central Ontario (Brennand and Shaw 1994) and around the Oak Ridges Moraine (Barnett *et al.* 1998). Many of the geomorphic features of tunnel valleys in these areas are similar to those in the Nechako Plateau.

Firstly, the presence of eskers (subglacial landforms) in the bottom of tunnel valleys in the Nechako Plateau indicates that they existed beneath glacial ice. As noted by Brennand and Shaw (1994), the preservation of eskers and presence of misfit streams, suggests postglacial drainage has had little influence on these valleys. The varied orientation of these valleys, most of which are not parallel to ice flow, and their somewhat sinuous morphology make direct glacial erosion unlikely. Erosion from progressive channelization of a subglacial outburst flood is a more reasonable explanation for the formation of these valleys.

Secondly, geomorphic evidence shows that tunnel valleys in the Nechako Plateau truncate streamlined landforms. Therefore, streamlined forms were created before tunnel valley incision. Initially, broad, catastrophic sheet floods accentuate or form streamlined landforms by creating crescentic scours and lateral furrows. As the outburst flood wanes and flow paths become channelized by topography, tunnel valleys form. Once flood

water is exhausted, glacial ice sets back down on the subglacial bed. Tunnel valleys become the focus of seasonal subglacial drainage and esker development occurs.

Thin pebble and cobble lags found in the bottoms of crescentic scours and lateral furrows suggest deposition at the end of a waning outburst flood. Similar lag deposits are absent away from these erosional depressions and a regional gravel lag does not occur within the study area. This implies that a majority of the subglacial meltwater erosion was restricted to these depressions.

Subglacial topography was most likely irregular and undulating during the Fraser Glaciation. The formation of streamlined landforms by soft sediment deformation and erosion and deposition of deformable beds as well as the presence of large-scale bedrock controlled topography is responsible for creating this irregular topography. During a catastrophic meltwater flood event, horseshoe vortices would initiate around subglacial topographic highs (obstacles to flow) and erode characteristic scours and furrows. In areas away from irregular subglacial topography, erosive vortices would not be generated. Erosion is believed to be minimal in these areas suggesting that much of the landscape within this study area existed prior to catastrophic subglacial flood erosion.

Therefore, a two-step process was involved in the formation of streamlined landforms and their surrounding erosional depressions within the study area. First, streamlined landforms were partly or totally formed by subglacial processes (e.g. erosion and deposition of deformable beds and deposition of saturated till in the lee-side of bedrock obstructions). Secondly, during a catastrophic subglacial flood, crescentic scours and lateral furrows were eroded around streamlined landforms formed both in till

and in the lee of bedrock highs (obstacles to flow). In essence, meltwater flood erosion enhanced and accentuated pre-existing subglacial topography.

# 6 CONCLUSION

A new site with mid-Wisconsinan nonglacial sediments and two till units, extremely rare in the Nechako Plateau, was discovered along the shore of Ootsa Lake. Pebble lithologies and texture suggest that some differences exist between the two till units; however, geochemically they are very similar. These two tills are separated by nonglacial, organic-bearing sands suggesting that they formed during different glaciations.

Late Wisconsinan ice moved through the area in a northeasterly direction. Advance-phase glaciolacustrine, glaciofluvial, and glacigenic debris-flow sediments were deposited in front of the ice margin and overridden. Locally, these sediments are preserved in major valleys such as Ootsa Lake and Cheslatta River valleys.

Although rare, advance-phase glaciolacustrine sediments are one of the most significant stratigraphic units in the area from a slope stability perspective. Landslides identified along the Cheslatta River occur only where advance-phase glaciolacustrine sediments were identified. In contrast, where only till occurs, river banks are more stable, although locally very steep. Advance-phase glaciolacustrine sediments generally occur up to several metres above the modern reservoir level suggesting that the lakes were either slightly more extensive in the region than the modern reservoir or ponded at higher elevations against the ice margin. This stratigraphic information is useful for forestry terrain stability mapping within the Interior Plateau in general and also provides relevant data relating to stability issues in specific locations such as along the Skins Lake Spillway and Nechako Reservoir shoreline areas as discussed below.

Massive, poorly sorted diamicton with strong fissility, jointing, and a high density, interpreted as basal till deposited during the Fraser Glaciation, is the most common Pleistocene sediment within the study area. Flutes, drumlinoid ridges, and the lee sides of crag-and-tails are commonly composed of this sediment. Till typically has a lodgement or melt-out genesis and occurs as thick blankets that totally obscure the bedrock or thin (less than 1 metre) veneers which mantle bedrock-controlled topography. Lodgement till was deposited during the active phases of glaciation, whereas melt-out till was probably deposited during later phases of glaciation.

Local, retreat-phase glaciolacustrine, glaciofluvial and glacigenic debris flow sediment was deposited during deglaciation. Glaciolacustrine silt and clay formed when small glacial lakes were dammed by stagnating blocks of ice. Glaciofluvial sand and gravel was deposited in outwash streams in front of the glacier margin. During the Holocene peat-rich bogs and marshes formed in low, poorly drained areas. These deposits are commonly associated with fluted and drumlinized terrain. Holocene sand and gravel, preserved in incised deltas and terraces, are best exposed along the Cheslatta River.

Two types of slope movement were recognized during fieldwork along the shores of the Nechako Reservoir and banks of the Cheslatta River. Rotational slides occur along the Cheslatta River and are characterized by backward-tilted slump blocks, sag ponds, basal slickenside surfaces and steep head scarps. Translational slides occur along the shore of the Nechako Reservoir and consist of numerous, small failure blocks oriented parallel to the slope.

A major factor inferred to be responsible for slope movements in the area is the presence of clay-rich sediments at or near the base of Quaternary sequences. River and lakeshore erosion of toe material are inferred to be the main external factors influencing slope movements in the area. Since there is an association between subsurface clay-rich sediments and mass movements, detailed mapping of their distribution may aid in future identification of potentially unstable areas in the region and possibly in other parts of the Interior Plateau.

Crag-and-tails, flutings and drumlinoid ridges (streamlined landforms) are the most common glacial landforms in the study area. These forms are dominantly composed of till and have rounded, up-ice ends and down-ice tails that taper and eventually merge with the surrounding ground surface. Streamlined landforms within the study area generally have the same orientation as striations and sometimes these landforms are nested at a variety of scales.

Often well defined, flat bottomed, bog or lake filled depressions occur around these forms. Stoss-end, crescent-shaped depressions are oriented transverse to ice flow direction and can extend up to 3 km before they bend, forming lateral depressions. The sedimentology within these depressions shows that a pebble to cobble-sized lag up to 80 cm thick, with some boulders abruptly overlies till. This lag is on average 30 cm thick and clast-supported. Similar lag deposits are absent on adjacent streamlined landforms.

A two step process is suggested for the formation of streamlined landforms and their stoss-end crescentic and lateral depressions. Firstly, the streamlined landforms were formed by subglacial erosion and deposition, possibly by deformable beds. Secondly, the crescentic and lateral depressions were eroded by subglacial meltwater. Therefore,

subglacial topography and streamlined landforms (obstacles to meltwater flow) were enhanced and accentuated by meltwater erosion. In areas between obstacles to flow, meltwater erosion is believed to have been minimal. Meltwater erosion is also thought to be responsible for the formation of tunnel valleys.

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Appendix A - Mapping Station Locations. Coordinates 305131E 5954615N are NAD27 and *304980E 5954820N* are NAD83

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-1 | 307110 | 5959215 | 3 plus meters of till. Mb |
| | *307000* | *5959400* | |
| DMA-98-2 | 307850 | 5958760 | Fairly steep, topographically controlled slope, approximately 15°. Mv |
| | *307750* | *5958950* | |
| DMA-98-3 | 310270 | 5958605 | 3 plus meters of till. Mb |
| | *310200* | *5958805* | |
| DMA-98-4 | 310490 | 5958510 | Low, narrow depression. Spruce bog. Ov over Mb |
| | *310450* | *5958730* | |
| DMA-98-5 | 310150 | 5958500 | Small rock outcrops on steep north faces. Mvb//R |
| | *310140* | *5958300* | |
| DMA-98-6 | 318200 | 5957300 | Approximately 2 m of till. Mbu |
| | *318190* | *5957450* | |
| DMA-98-7 | 316600 | 5956725 | Rock is lithic conglomerate and red to brown mudstone. On top edge of little valley. Valley bottom |
| | *316500* | *5956900* | is bog filled. Mv over R |
| DMA-98-8 | 316205 | 5956300 | In clearcut. Rock ridge with Mv was visible as well as two crag and tail features, rock is rhyolite. |
| | *316100* | *5956510* | Mv over R |
| DMA-98-9 | 315050 | 5955375 | Small esker ridge |
| | *315050* | *5955550* | |
| DMA-98-10 | 314530 | 5955450 | Abundant angular rock fragments in till, on hilltop area and in low-lying areas |
| | *314400* | *5955650* | |
| DMA-98-11 | 312200 | 5955800 | Small crag and tail in mainly an Mb area. Crag and tails are oriented east northeast. Mb |
| | *311290* | *5956600* | |
| DMA-98-12 | 311563 | 5958661 | Some crag and tails with Mv over R or rarely R at the stoss end. Mb |
| | *311490* | *5958810* | |
| DMA-98-13 | 333955 | 5955200 | Narrow, gravelly terrace. FGt |
| | *333850* | *5955400* | |
| DMA-98-14 | 331180 | 5954590 | Pebble to cobble gravel. FG |
| | *331080* | *5954810* | |
| DMA-98-15 | 330900 | 5954575 | Low swampy area, protected bay behind spit. Lv over FG |
| | *330790* | *5954770* | |

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-16 | 321785 | 5954160 | 3-5 m of washed sandy till in road cut. On steep slope (15°). zsMb |
| | *321690* | *5954410* | |
| DMA-98-17 | 321250 | 5952450 | Silty lacustrine veneer over till. |
| | *321200* | *5952640* | |
| DMA-98-18 | 323940 | 5955100 | Gravel pit. Ripple bedded sands and silts. |
| | *323860* | *5955270* | |
| DMA-98-19 | 322550 | 5954800 | Silty, sandy gravel (almost diamict). Mb/FG |
| | *322750* | *5955030* | |
| DMA-98-20 | 322000 | 5953705 | Silty sand diamicton with good fissility |
| | *321890* | *5953920* | |
| DMA-98-21 | 315710 | 5955180 | sandy silt <10 cm. |
| | *315650* | *5955400* | |
| DMA-98-22 | 334622 | 5942265 | Wet, flat marsh area. Shrubs and willows growing. Ob |
| | *334500* | *5942430* | |
| DMA-98-23 | 334000 | 5942200 | Wet, flat marsh area. Shrub grass and willows growing. Ob |
| | *333860* | *5942400* | |
| DMA-98-24 | 334501 | 5947344 | Till in area is over 1 m thick, however some rock outcrops are visible. Contact between Mb and Mv |
| | *334390* | *5947500* | lies further to west. Mb//Mv |
| DMA-98-25 | 334205 | *5947950* | Small rock outcrop within Mb polygon. Unit probably is not to extensive. Mv/R |
| | *334200* | *5948150* | |
| DMA-98-26 | 333580 | 5947300 | Small rock outcrop within Mb polygon. Unit is probably not to extensive. Mv/R |
| | *333500* | *5947505* | |
| DMA-98-27 | 332080 | 5946370 | Bedrock outcrop. Striae 76°-81°. |
| | *331980* | *5946550* | |
| DMA-98-28 | 333400 | 5944900 | Low lying swamp area. Ob |
| | *333290* | *5945115* | |
| DMA-98-29 | 334175 | 5950905 | In valley bottom close to creek. 50 cm pebble, small cobble gravel with medium sand to coarse sand |
| | *334150* | *5951220* | matrix over 1.5 m of massive, medium to coarse sand with some pebbles. Most of this unit was covered. Mb/FG |
| DMA-98-30 | 332710 | 5950750 | Small but mappable pocket of glaciolacustrine blanket over till. LGb over M |
| | *332710* | *5950920* | |

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-31 | 331805 | 5950850 | Very large crag and tail. Rock knob at stoss end of feature is covered in Mv. |
| | *331800* | *5951000* | |
| DMA-98-32 | 332719 | 5949951 | In small sand and gravel pit in old clearcut area. Pit face was covered. Material is very coarse sand, |
| | 332550 | *5950120* | pebble gravel matrix to clast supported. FG |
| DMA-98-33 | 330490 | 5949350 | Large crag and tail with large exposed bedrock knob. Looking east into clearcut from road. |
| | *330320* | *5949490* | |
| DMA-98-34 | 329580 | 5947835 | Large rock outcrop. Bedrock is exposed in roadcut but I think it is covered on top by a thin till |
| | *329370* | *5947900* | veneer. Mv/R |
| DMA-98-35 | 330850 | 5948420 | Rock outcrops visible within clearcut. Majority of field is covered by a thin till veneer. Mv/R |
| | *330700* | *5948610* | |
| DMA-98-36 | 331315 | 5943862 | Very fine sand with some silt interbeds, occassional pebble seen. Test pit dug. LG |
| | *331250* | *5944090* | |
| DMA-98-37 | 322810 | 5949570 | Bedrock outcrop with Mv on top. Outcrop is quite large. Rock type is Ootsa Lake (flow banded ?). |
| | *322850* | *5949800* | Mv/R |
| DMA-98-38 | 323225 | 5949380 | Bedrock scarp running approximately southwest. Majority is moss covered (Mv?), some outcrop is |
| | *323285* | *5949550* | visible. Mv/R |
| DMA-98-39 | 324040 | 5943760 | Small outcrop along road. Outcrop was too weathered for striae. Areal extent of outcrop is to small |
| | *323850* | *5943960* | to be mapable. There seems to be more blanket than veneer in this clearcut and some outcrops are visible. Mbv |
| DMA-98-40 | 324800 | 5943390 | Small outcrop along road. Outcrop to weathered for striae. Areal extent of outcrop is to small to be |
| | *324600* | *5943640* | mapable. More blanket than veneer in area with some outcrop visible. Mbv |
| DMA-98-41 | 324895 | 5942400 | Ootsa rhyolite (flow banded) with a black, glassy volcanic interbed (approximately 2 m thick). |
| | *324790* | *5942700* | Outcrop is around 10 m high. R |
| DMA-98-42 | 322700 | 5947550 | Weathered Ootsa rhyolite. R |
| | *322510* | *5947780* | |
| DMA-98-43 | 323400 | 5947110 | Small sand and gravel pit. FG (?) |
| | *323200* | *5947340* | |
| DMA-98-44 | 323840 | 5942290 | Large organic area. Ob |
| | *323760* | *5942450* | |
| DMA-98-45 | 321790 | 5947290 | Very rubbly, flat outcrop of Ootsa Lake rhyolite. To rubbly to record striae. R |
| | *321750* | *5947415* | |

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-46 | 321750 | 5946750 | Polygon originally mapped as Mv, upon inspection lots of rock was found, therefore changed |
| | *321750* | *5947010* | polygon to Mv/R. Striae measured was oriented 074°. Rock is Ootsa Lake. Fabulous view of reservoir. Mv/R |
| DMA-98-47 | 321875 | 5945790 | Small outcropping of Ootsa rhyolite covered with Mv. Outcrop is not that prevalent. Area could |
| | *321800* | *5945980* | possibly be mapped as Mv. Mv/R |
| DMA-98-48 | 322310 | 5945005 | Thin drift cover over bedrock (Ootsa Lake). Mv over R |
| | *322250* | *5945150* | |
| DMA-98-49 | 322000 | 5943790 | Small outcrops of weathered bedrock sticking out of till section. Mbv over R |
| | *321890* | *5943980* | |
| DMA-98-50 | 332116 | 5941992 | Rock is Ootsa Lake. Striae measurements are 71-76°. R/Mv |
| | *332050* | *5942160* | |
| DMA-98-51 | 322390 | 5936630 | Approximately 3 m thick cut of szDmm. Looked like FG on the photos. Area has rolling topography, |
| | *322280* | *5936900* | flutes and drumlins. Mb |
| DMA-98-52 | 326050 | 5936630 | In clearcut, small rises and flutes are composed of interbedded clayey silt, silty sand, and sandy silt |
| | *326050* | *5939610* | (glaciolacustrine sediments). This unit is over a meter thick in places but is areally quite small. This unit overlies till that has poor fissility and moderate density. zsDmm |
| DMA-98-53 | 327610 | 5939200 | Large till cut along shoreline (zsDmm). Mb |
| | *327520* | *5939350* | |
| DMA-98-54 | 326300 | 5937600 | Small, poorly exposed sand and gravel pit. Clast supported, very well sorted "pea-sized" gravel |
| | *326150* | *5937900* | interbedded with pebble cobble gravel with a very fine to fine sand matrix. A two meter thick unit of interbedded to laminated silt and fine sand with occassional small pebbles. FGb |
| DMA-98-55 | 326550 | 5937400 | zsDmm, thought sand and gravel might be more extensive. Mb |
| | *326390* | *5937600* | |
| DMA-98-56 | 328050 | 5936700 | (s)zDmm. No gravel in valley bottom. Mb |
| | *327950* | *5936900* | |
| DMA-98-57 | 329100 | 5936720 | Rock outcrops on edge of clearcut. Mv |
| | *328990* | *5936950* | |
| DMA-98-58 | 330550 | 5936900 | Outwash, very sandy with some pebbles and cobbles. Sand was medium to coarse. This unit could |
| | *330470* | *5937120* | possibly be moving into a meltwater channel. FGb |
| DMA-98-59 | 333150 | 5936200 | szDmm. Mb |
| | *333030* | *5936440* | |

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-60 | 328870 | 5934300 | On top of hill just before drop leading approximately southwest. Small outcrops of Ootsa Lake in |
| | *328800* | *5934600* | roadbed and along slope of hill. Not a very extensive unit. Mv |
| DMA-98-61 | 325410 | 5932300 | Large streamlined features (crags ?) to south in clearcut. Mb |
| | *325290* | *5932460* | |
| DMA-98-62 | 324870 | 5932220 | Silty sand (alluvium ?) over Mb. Fv over Mb |
| | *324760* | *5932410* | |
| DMA-98-63 | 323750 | 5931950 | Small quarry, rock is basalt. Top of quarry is covered with Mbv. |
| | *323720* | *5932250* | |
| DMA-98-64 | 329100 | 5930880 | Bedrock outcrop with Mv on top. Lots of rock knobs in this area. Rock is volcanic. Mv over R |
| | *329000* | *5931200* | |
| DMA-98-65 | 329950 | 5931200 | Rock outcrop visible. Striae measurements 80°-251° (non-directional) |
| | *330000* | *5931500* | |
| DMA-98-66 | 331025 | 5931290 | Small sand and gravel pit, poorly exposured. Clast supported pebble, cobble gravel with fine to |
| | *331950* | *5931515* | medium sand matrix. FG |
| DMA-98-67 | 332704 | 5931790 | Ootsa Lake outcrop covered intermittently with Mv. Striae measurements 70°-92°. |
| | *332780* | *5931950* | |
| DMA-98-68 | 323800 | 5937000 | Small excavation approximatley 1.5 m deep. Material is cobble gravel with a medium to coarse sand |
| | *323610* | *5937150* | matrix. Gravel is clast supported. FG |
| DMA-98-69 | 323940 | 5936300 | Small quarry, less than a meter of till over bedrock. Mv |
| | *323880* | *5936600* | |
| DMA-98-70 | 324790 | 5935900 | zsDmm, rolling landscape. Mb |
| | *324800* | *5936200* | |
| DMA-98-71 | 321100 | 5937050 | zsDmm; rolling landscape. Mb |
| | *320990* | *5937290* | |
| Dma-98-72 | 321745 | 5938310 | zsDmm; rolling landscape. Mb |
| | *321640* | *5938600* | |
| DMA-98-73 | 321815 | 5938850 | Over 2 m of pebble, cobble gravel with a medium to coarse sand matrix. Unit is clast supported. FG |
| | *321790* | *5939150* | |
| DMA-98-74 | 325505 | 5939975 | 1.5 m of sandy, poorly fissile diamicton. Diamicton could possibly be washed. Mb |
| | *325450* | *5940200* | |
| DMA-98-75 | 325470 | 5939840 | Oxidized, clast supported pebble, cobble gravel with a coarse sand matrix over szDmm. FGv over |
| | *325280* | *5939970* | Mb |

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-76 | 323600 | 5939300 | Approximately 75 cm of clayey silt and fine sand (glaciolacustrine) veneer mantling 3 m of szDmm. |
| | *323500* | *5939490* | LGv over Mb |
| DMA-98-77 | 323700 | 5940000 | Very thin veneer of till over rhyolite. Lots of angular rock fragments on the hill and road. Thin |
| | *323610* | *5940200* | veneer of colluvium could also be present. Mv over R |
| DMA-98-78 | 322660 | 5939430 | Approximately 2.5 m of sandy till, poor lodgement till. Some fines present and it could be washed. |
| | *322520* | *5939750* | Mb |
| DMA-98-79 | 322500 | 5939575 | Till veneer over Ootsa Lake rhyolite. Mv over R |
| | *322410* | *5939750* | |
| DMA-98-80 | 320520 | 5940460 | Rocky outcrops along shoreline. Moss covered to veneer covered in places. This outcrop has a |
| | *320420* | *5940710* | fairly small areal extent and rock appears to be basalt. R/Mv |
| DMA-98-81 | 320500 | 5940385 | Sand and gravel pit, gravel is clast supported pebble to large pebble gravel in a coarse sand matrix. |
| | *320440* | *5940610* | FG |
| DMA-98-82 | 312300 | 5947780 | Sand and gravel pit. Reconnaissance section DMA-9802 was taken in pit. FG |
| | *312150* | *5948260* | |
| DMA-98-83 | 313550 | 5946900 | szDmm; entire clearcut is heavily drift covered. Mb |
| | *313400* | *5946920* | |
| DMA-98-84 | 313850 | 5946700 | Small ridge dissected by road. Material is matrix supported granule, small pebble gravel. Matrix is |
| | *313750* | *5946750* | coarse sand to very coarse sand. FG |
| DMA-98-85 | 313900 | 5946400 | In bottom of creek valley. Matrix supported pebble, cobble gravel with coarse sand matrix. Note, |
| | *313850* | *5946500* | could be FG or alluvium. F |
| DMA-98-86 | 314900 | 5942710 | Clast supported pebble gravel with coarse sand matrix over (s)zDmm. Approximately 65 cm of FG |
| | *314890* | *5943050* | over 1 m of till. FGv over Mb |
| DMA-98-87 | 314500 | 5941700 | Two ridges (small to medium in size) are dissected by the road. Material is clast supported pebble |
| | *314350* | *5941810* | gravel with a medium to coarse sand matrix. FG |
| DMA-98-88 | 312490 | 5943800 | Lots of discontinuous gravel deposits and till occur within clearcut (and surrounding area). Area |
| | *312400* | *5943900* | could have been washed. Mb/FG or FG over Mb |
| DMA-98-89 | 312910 | 5942390 | 2 m of matrix supported pebble gravel over zsDmm. Note, driving out of clearcut (south) till was |
| | *312830* | *5942510* | quite common, fewer gravel deposits. FG over Mb |
| DMA-98-90a | 313950 | 5940900 | Section cut through small esker (?). Material was clast supported granule , pebble gravel with |
| | *313830* | *594100* | coarse sand matrix. FG |
| DMA-98-90b | 313920 | 5940640 | Small gravel pit. Materials were clast supported pebble, gravel with coarse sand matrix. FG |
| | *313790* | *5940680* | |

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-91 | 313900 | 5939340 | Pronounced till ridge crossing road. Mr |
| | *313750* | *5939430* | |
| DMA-98-92 | 315160 | 5941000 | Marshy area, standing small water bodies and sedge grasses. Digging into subsurface revealed |
| | *315060* | *5941070* | organic sandy silt with some stones. Ov over Mb or Ob. |
| DMA-98-93 | 316160 | 5943510 | Lots of bedrock outcrops visible from main road. Road in clearcut was impassible. Mv |
| | *316080* | *5943750* | |
| DMA-98-94 | 317390 | 5940890 | On top of bedrock controlled hill. Large bedrock knob, lots of angular clasts and little outcrop. |
| | *317260* | *5941090* | Striae 94°. Mv |
| DMA-98-95 | 316710 | 5940850 | Large island of sand and gravel. Did not actually check section because there were 2 grizzlies in |
| | *316600* | *5940970* | clearcut. FG |
| DMA-98-96 | 317790 | 5940250 | Bedrock controlled hill covered with a veneer of till. Some outcrops visible. Mv |
| | *317520* | *5940460* | |
| DMA-98-97 | 317680 | 5941450 | Small outcropping of clast supported pebble gravel. Probably not to extensive. FG |
| | *317520* | *5941610* | |
| DMA-98-98 | 320210 | 5940590 | Small clearing in forest that appears to be an old gravel pit. Most gravel has been excavated so till |
| | *320110* | *5940880* | is exposed along floor in clearing. The gravel is clast supported pebble to large cobble gravel with a coarse sand matrix. FGb over Mb |
| DMA-98-99 | 317720 | 5938420 | Sharp till ridge. Mbr |
| | *317690* | *5938700* | |
| DMA-98-100a | 318400 | 5937850 | Sedge and grass covered bog. Ob |
| | *318290* | *5938100* | |
| DMA-98-100b | 318400 | 5937850 | Sedge and grass covered bog. Ob |
| | *318050* | *5937930* | |
| DMA-98-101 | 319200 | 5936870 | szDmm; cut was approximately 1.5 m thick. Mb |
| | *319080* | *5937140* | |
| DMA-98-102 | 316190 | 5935800 | zsDmm. Mb |
| | *316080* | *5936040* | |
| DMA-98-103 | 316840 | 5935510 | Thin wedge of swampy organics. Ob |
| | *316700* | *5935800* | |
| DMA-98-104 | 317100 | 5934560 | Swampy area extending off south end of lake. Ob |
| | *317000* | *5934750* | |

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-105 | 317510 | 5933850 | Grass field in low below/between ridge forms. O over Mb |
| | *317390* | *5934000* | |
| DMA-98-106 | 317400 | 5932700 | Sand and gravel pit. Most of the material seems to be disturbed, however at the top of the pit large |
| | *317210* | *5932910* | beds of pebble cobble gravel showing faint imbrication could be seen. These beds were interbedded with pebble gravels and very coarse sand. |
| DMA-98-107 | 309350 | 5958610 | Test pit showed colluviated till (45 cm) over lake sediments. Lake sediments appeared massive and |
| | *309300* | *5958850* | were silty to clayey silt. Situated in a low area between some steep slopes. Note, rise to SE (hill in road) possibly marks boundary of this unit. Mv ov |
| DMA-98-108 | 309800 | 5958900 | Looking up from road, large grass covered slope with some rock outcrops. Originally mapped as |
| | *309760* | *5959100* | R. Mv/R |
| DMA-98-109a | 311700 | 5958100 | Area of Mb, however 2 polished rock outcrops were visible beside the road. Unfortunately both had |
| | *311610* | *5958270* | too many bulldozer marks on them to make out striations. Outcrops were very small, probably not areally extensive. Mb |
| DMA-98-109b | 311490 | 5958000 | Low swampy area with lots of spruce trees and poplar. Ob |
| | *311390* | *5958150* | |
| DMA-98-110 | 310850 | 5957430 | Very wet swampy area. O over Mb |
| | *310790* | *5957650* | |
| DMA-98-111 | 315505 | 5955310 | czDmm with granules and pebbles. Mb |
| | *315450* | *5955450* | |
| DMA-98-112 | 319900 | 5954950 | Swampy area extending from lake. Consists of sedge grasses and small shrubs. |
| | *319850* | *5955140* | |
| DMA-98-113 | 319600 | 5920030 | Very thin till veneer over a large outcrop of Ootsa Lake Rhyolite. Mv//R |
| | *319300* | *5952160* | |
| DMA-98-114 | 319090 | 5948550 | Large bedrock controlled hills/knobs are covered in places in thin veneer. Rock outcrops are visible |
| | *319030* | *5948700* | in between grassy slopes. Mv/R |
| DMA-98-115 | 321150 | 5943000 | Forestry barge crossing. There are several large outcrops of rock around this area. Rock looks like |
| | *321000* | *5943200* | basalt and is quite oxidized. Some chunks of Ootsa rhyolite are present. Most of the surficial material in this area has been stripped away. Other outcrops are visible along shoreline. |
| DMA-98-116 | 303044 | 5944264 | Lots of Mb and angular clasts of basalt in this area. Rock close to surface, small outcrop of basalt |
| | *302940* | *5944450* | close by. Area too small to be mapped as Mv. |
| DMA-98-117a | 304000 | 5945150 | Organic marsh south of Loon Lake. Ob |
| | *303900* | *5945400* | |

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-117b | 303720 | 5945010 | We drove a new bush road into a new clearcut (not on air photo). Area was blanketed with till. |
| | *303600* | *5945300* | Some areas had angular clasts of Ootsa rhyolite. Mb |
| DMA-98-118 | 306080 | 5941500 | Outcropping of Hazelton mauve andesite covered by till veneer. Mv over R |
| | *306000* | *5941730* | |
| DMA-98-119 | 305950 | 5941695 | Quarry. Hazelton volcanics were seen. |
| | *305890* | *5941890* | |
| DMA-98-120 | 310729 | 5941548 | (z)sDmm. Mb |
| | *310500* | *5941590* | |
| DMA-98-121 | 310725 | 5942039 | Small hill in clearcut that consists of approximately 2 m pebble cobble gravel over till. FG over Mb |
| | *310320* | *5942190* | |
| DMA-98-122 | 309790 | 5942120 | Marsh/swamp with spruce trees. Ob |
| | *309650* | *5942360* | |
| DMA-98-123 | 308989 | 5941806 | Small outcroppings of basalt bedrock within ditch cut. Over 1 m of till occurs on top of rock. Mb over |
| | *308800* | *5942150* | R |
| DMA-98-124a | 309855 | 5940104 | Quite large streamlined form with rock outcrops. Clearcut appears to have some Mb. Mvb or Mbv |
| | *309690* | *5940140* | |
| DMA-98-124b | 309900 | 5939900 | Swamp area. Ob |
| | *309800* | *5940110* | |
| DMA-98-124c | 309940 | 5940210 | Swamp area off of small lake. Ob |
| | *309820* | *5940400* | |
| DMA-98-125 | 309100 | 5940410 | Road cut has exposed a section of till veneer over basalt bedrock. Mv/R |
| | *309000* | *5940750* | |
| DMA-98-126 | 309001 | 5941103 | Well defined crag and tails in area. |
| | *308900* | *5941390* | |
| DMA-98-127 | 308587 | 5941524 | Till veneer over basalt. Mv/R |
| | *308360* | *5941870* | |
| DMA-98-128 | 308587 | 5941524 | Pebble to large pebble gravel; matrix supported. FG |
| | *302600* | *5948980* | |
| DMA-98-129 | 303310 | 5936380 | Standing on partially covered rock outcrop that appears to be the head of a fluted landform (crag- |
| | *303350* | *5936600* | and-tail). There are many streamlined forms within this clearcut with rock outcrop at their stoss end. Rock appears to be granitic. Note, crags in clearccut are poorly to moderately developed. |

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-130 | 303850 | 5937020 | Sharp slope. Rock outcrops at top and most of the slope is covered. Mv/R |
| | *303790* | *5937250* | |
| DMA-98-131 | 303650 | 5936620 | Striae 76°. Measured at head of crag-and-tail. |
| | *303560* | *5936910* | |
| DMA-98-132 | 305000 | 5935710 | In large depression. Swampy in bottom, however till was close to surface. Rock outcrops present on |
| | *304880* | *5935950* | slope of depression. Mv//R |
| DMA-98-133 | 307500 | 5937580 | Numerous till ridges throughout field. Random orientation, crevasse fillings (?). Mbr |
| | *307500* | *5937660* | |
| DMA-98-134 | 306340 | 5937600 | Till ridge crossing road; linear, approximately 3.5 m deep. Mb |
| | *306300* | *5937720* | |
| DMA-98-135 | 306270 | 5937350 | Small rock outcropping covered in till veneer. Rock is augite porphyry. This unit might not be large |
| | *306230* | *5937510* | enough to map. Mv over R. |
| DMA-98-136 | 305000 | 5938490 | Abundant rock outcrops throughout clearcut. Outcrops appear streamlined and are covered by till |
| | *305000* | *5938450* | veneer in places. Mv/R |
| DMA-98-137 | 305720 | 5935500 | Approximately 2 m of szDmm. Mb |
| | *305610* | *5935560* | |
| DMA-98-138 | 306190 | 5935010 | Mv over rare outcrops of basalt (vesicular). Mvb over R |
| | *306000* | *5935250* | |
| DMA-98-139 | 306210 | 5934600 | Wet, marshy area, however till was the dominant material type. Ov over Mb |
| | *306280* | *5934880* | |
| DMA-98-140 | 306600 | 5934050 | Small area of sand and gravel exposed along roadside. Till is found on the other side of the road. |
| | *306600* | *5934390* | Mb//FG |
| DMA-98-141 | 306810 | 5933610 | Swampy organic area with sedge grasses. Ob |
| | *306700* | *5933800* | |
| DMA-98-142 | 330563 | 5942416 | Clearcut is dominantly Mv/R. Mv/R and Mb boundary runs close to road. Striae 080°. |
| | *330480* | *5942600* | |
| DMA-98-143 | 327480 | 5942420 | Low flat area of glaciolacustrine materials. Sedge/willow vegetation on top. LGb |
| | *327390* | *5942740* | |
| DMA-98-144 | 326875 | 5942600 | 1.5 m trench was present at station. The top 1.0 m was pebble gravel with a coarse sand matrix and |
| | *326780* | *5942800* | the remaining 0.5 m is gritty, clayey silt with some pebbles, probably a diamict. Note, tills in this area (around LGb) are quite washed and pockets of sand and gravel are present. |

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-145 | 325610 | 5941190 | 2 to 3 m of glaciofluvial gravel over till. FGb over Mb |
| | *325580* | *5941400* | |
| DMA-98-146 | 325850 | 5941800 | Washed till. Sandy with little silt. Mb |
| | *325780* | *5942050* | |
| DMA-98-147 | 323980 | 5955430 | Large planar failure block 200m long and 50 m wide on cut bank of Cheslatta river. Active |
| | *323850* | *5955650* | undercutting and removal of toe. At least two generations of slides and a third one is initiating. New block is 15-25 m wide and has a 1-2 m high headscarp. Num |
| DMA-98-148 | 327910 | 5938510 | Large outcrop of microcrystalline, dark blue grey, basalt. Covered by a till veneer. Mv/R |
| | *327810* | *5938760* | |
| DMA-98-149 | 320510 | 5941510 | 2.5 m of silt and fine sand. LGb |
| | *320450* | *5941750* | |
| DMA-98-150 | 320000 | 5938730 | Approximately 3.0 m of silt. LGb |
| | *319880* | *5938940* | |
| DMA-98-151 | 320080 | 5938100 | (z)sDmm observed in small hand dug pit along side of road. Unit was dry and not overly fissile. Mb |
| | *319900* | *5938290* | |
| DMA-98-152a | 319070 | 5932700 | Approximately 2 m of small pebble, very coarse sand. FGb |
| | *319070* | *5932930* | |
| DMA-98-152b | 319010 | 5932750 | Thin veneer of FG over zsDmm. FGv over Mb/FG |
| | *319000* | *5933000* | |
| DMA-98-153 | 318830 | 5933080 | Approximately 1.5 m of szDmm that has good fissility and jointing. Unit is not as dense as expected. |
| | *318890* | *5933380* | Could be slightly slumped (colluviated). Mb |
| DMA-98-154 | 318950 | 5931590 | Approximately 65 cm of lg. pebble gravel. Clast supported and matrix filled, matrix was fine to |
| | *318850* | *5931850* | medium sand. Unit overlies approximately 1.5 m of szDmm that has good fissility and is quite dense. FGv over Mb |
| DMA-98-155a | 317830 | 5932800 | Thin, sharp till ridge that crosses road. Mbr |
| | *317850* | *5932900* | |
| DMA-98-155b | 317860 | 5932700 | Thin, sharp till ridge that crosses road. Mbr |
| | *317800* | *5933000* | |
| DMA-98-156 | 317605 | 5932920 | Very sandy Dmm. Locally covered by a gravel veneer. Area has possibly been washed. sMb |
| | *317580* | *5933280* | |
| DMA-98-157 | 308470 | 5932400 | Till (zsDmm) over 1 m thick. Mb |
| | *308350* | *5932700* | |

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-158 | 309090 | 5932500 | Till ridge dissected by road. Till is zsDmm with good fissility, jointing and moderate density. A thin, slightly winnowed diamict layer drapes form. Mr |
| | *308990* | *5932730* | |
| DMA-98-159 | 309530 | 5932550 | Same as DMA-98-158. Approximately 1 m of diamict with poor fissility, jointing and low density overlies this unit. Almost appears to be a gravel however it is to poorly sorted and contains many subangular, striated clasts. Note, upper 0.5 m of till surface in this area appears to be winnowed or slightly washed. |
| | *309450* | *5932820* | |
| DMA-98-160 | 310680 | 5932070 | Small area of rock exposed from road work. Rock is andesite. Till surrounding area is quite thick. Mbv over R |
| | *310510* | *5932320* | |
| DMA-98-161 | 310300 | 5933500 | Long narrow, slightly sinous ridge bissected by many smaller ridges. Other ridges can also be seen throughout the clearcut. Small exposure dug into one of these ridges shows that the form is composed of till. However, in places a highly weathered (orange), very poorly sorted gravel unit can be found at surface. Unit can be as thick as 60-100 cm and seems to drape form. Gravel consists of a variety of clasts and many large, angular clasts are present. Large erratics are visible within ridges and lows. Some ridges seem to be armoured with lare pebbles and small to medium cobbles. |
| | *310100* | *5933850* | |
| DMA-98-162 | 310920 | 5933300 | Thin diamict (till) veneer over oxidized (rusty) andesite. Some pyrite mineralization visible in rock. Area is quite undulating. Small swamps are present and many small scale streamlined forms are rock controlled. Mv/R/O |
| | *310900* | *5933590* | |
| DMA-98-163 | 311290 | 5933260 | Small, fairly linear ridge of sand and gravel. Matrix supported medium to coarse sand with small to large pebbles. FG |
| | *311200* | *5933450* | |
| DMA-98-164 | 311500 | 5933200 | czDmm with many large cobbles and erratics present. Mb |
| | *311310* | *5933410* | |
| DMA-98-165a | 311800 | 5932500 | Striae site, striae oriented 015-195°. Note, striated surface might actually be slickensides. Outcrop is to small to be useable. |
| | *311690* | *5932760* | |
| DMA-98-165b | 311750 | 5932410 | Striated outcrop, striae oriented 70-73°. |
| | *311630* | *5932700* | |
| DMA-98-166 | 312080 | 591690 | Streamlined, bedrock controlled knob not oriented with ice flow. Most of the knob is drift covered, however rock is exposed in ditch cuts and rare outcrops can be seen on slope. Mbv//R |
| | *311960* | *5931900* | |
| DMA-98-167 | 314790 | 5931710 | Very small sinuous till ridges within clearcut. No FG mantle/veneer on top. Mb//Mr |
| | *314650* | *5932000* | |
| DMA-98-168 | 320100 | 5938400 | czDmm; polygon may be mapped as Mb/LG. Mb |
| | *319950* | *5938650* | |

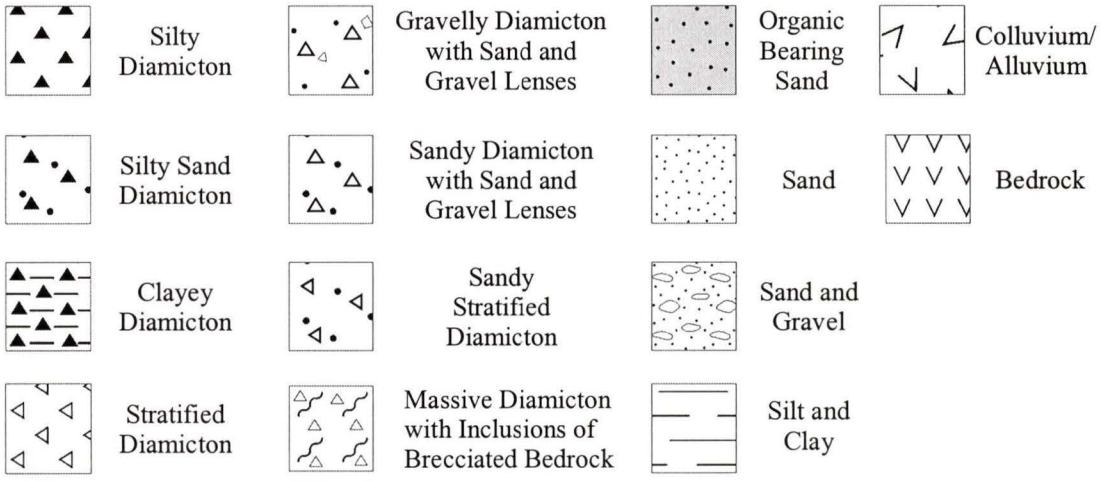
| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-169 | 307485 | 5943197 | Striae on conglomerate bedrock 75°-80°. A younger set of striations is oriented 060°Outcrop is |
| | *307350* | *5943410* | fluted in an 080° direction. Area around striae is heavily till covered. Parts of till cover are quite wet. |
| DMA-98-170 | 305105 | 5944522 | Quarry along Ootsa Main forestry road close to the intersection of a new road onto UDUK property. |
| | *305100* | *5944770* | Quarry has andesite, some type of small pebble conglomerate and mudstone/siltstone (?). Section in profile shows at least half a meter of till over bedrock. Road into Uduk property is heavily till covered. Mvb over R |
| DMA-98-171 | 304750 | 5947630 | Subdued till ridges within clearcut that are covered in glaciofluvial veneer. Till ridges have a steep |
| | *304820* | *5947950* | front end and shallow back slopes. Note, could be recessional moraines or crevasse fillings. FGv over Mb |
| DMA-98-172 | 303500 | 5951080 | Materials in area are quite variable. Units change quickly from till, to silts, to sands, to gravel, to till. |
| | *303500* | *5951400* | Till is the dominant material in this area. Note, possibly an ice contact area (?). Mb/FG |
| DMA-98-173 | 303210 | 5951250 | Sand and gravel pit. Interbedded gravels and silts; flat area. Note, low areas within polygon are Z |
| | *302900* | *5951800* | and fsd, polygon also includes some till ridges. Material within polygon is highly variable, some sand ridges (subglacial?). FG |
| DMA-98-174 | 313700 | 5934810 | Thin gravel veneer over till. Probably not extensive enough to map. South end of cut seems to have |
| | *313550* | *5935020* | been washed a little. One mound of ice contact gravel was observed. FGv over Mb |
| DMA-98-175 | 309300 | 5936450 | Very subdued ridges/flutes in clearcut, not much topography. Road into clearcut was quite wet and |
| | *309190* | *5936700* | swampy. Two small till ridges were dissected by the road and were fairly steep walled. Possibly crevasse fills. Mb |
| DMA-98-176 | 310390 | 5937290 | Large, steep sided till ridge. Photo 1 to 3 taken on roll DMA-98-05. Clearcut consists of very |
| | *310300* | *5937470* | subdued flutes with shallow furrows between them. Mb |
| DMA-98-177 | 308790 | 5935590 | Clearcut dominated by till. Some, stand alone till ridges in field with fairly steep sides. Mb |
| | *308700* | *5935510* | |
| DMA-98-178 | 309400 | 5935610 | Very pronounced till ridges at end of clearcut. Steep sided with hummocky tops. Mbr |
| | *309190* | *5935720* | |
| DMA-98-179 | 311120 | 5937350 | Numerous till ridges crossing road. Some appear to have pronounced steep sides. Mrb |
| | *311000* | *5937490* | |
| DMA-98-180 | 302020 | 5950200 | Sinuous ridges and channels parallel to ice flow direction, 3-4 m of relief. Ridges are made |
| | *302190* | *5950600* | dominantly of till. Rare FG visible; FG found on ridge tops and gullies. Clearcut sloping towards Ootsa Lake. Mb-V |

| Station Number | UTM East | UTM North | NOTES |
|---|---|---|---|
| DMA-98-181 | 301850 | 5949840 | Up to 2-3 m of poorly sorted sands and sandy pebbly gravel; in ridges 10-15 m wide. FGr |
| | *301980* | *5950260* | |
| DMA-98-182 | 307430 | 5952250 | Fluted ridge visible, topography is very gently undulating. Photo VLE-98-12 # 8 taken. Note, |
| | *307380* | *5952530* | alongside of flute is what appears to be a meltwater furrow (linear) that has been diverted (possibly by an ice dam) and follows a new path. Mb |
| DMA-98-183 | 326920 | 5936200 | 1 to 4 m high ridge composed of till. Poorly sorted pebble gravel locally overlies and is beside till. |
| | *326700* | *5936430* | This station is located near a small, subparallel meltwater channel. Mb |
| DMA-98-184 | 330550 | 5936910 | Bedrock knob at head of crag and tail. Lee-side of knob is polished but not striated; scour marks |
| | *330000* | *5937110* | visible along polished surface. Note, meltwater/subglacial flood eddy currents behind obstruction/knob. |
| DMA-98-185a | 308410 | 5937700 | Till ridge 3-5 m high. West facing slope dips 15-25° and the east facing slope dips 30°. Ridge is |
| | *308280* | *5937900* | approximately 30 m wide across base and is roughly oriented 190°. A grain size sample was taken from form. There is approximately 2 m of relief across top of form. Lack of poorly sorted sand and gravel on ridge. |
| DMA-98-185b | 308290 | 5937700 | Approximately 3-5 m high. West facing slope dips 23° while east facing slope dips 30°. Ridge was |
| | *308140* | *5937880* | approximatley 25 m wide at its base. A grain size sample was taken. Form had approximately 2 m of relief along its surface and draped underlying topography. |
| DMA-98-186 | 307600 | 5934070 | Crevasse filling. csMr |
| | *307480* | *5934300* | |
| DMA-98-187 | 313250 | 5934650 | Numerous, small (2-4 m relief) ridges and hummocks with very poorly sorted sandy to boulder |
| | *313080* | *5934810* | gravel. Some closed depressions with organic bogs (not deep kettles). Depressions are flat bottomed. Note, lots of large, striated clasts around. |
| DMA-98-188 | 305131 | 5954615 | Roche moutonee with westerly ice flow indicators. Striae are non-directional 125°-305° |
| | *304980* | *5954820* | |

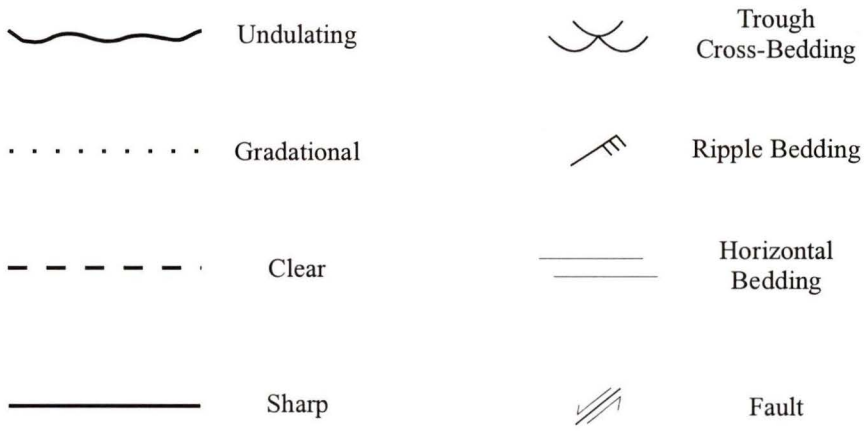
# Appendix B

## Section descriptions and stratigraphic columns of Quaternary sections in the study area

### MATERIAL TYPES




### CONTACTS & SYMBOLS



## SECTION DMA-9801

Date: June 26, 1998
Location: Exposure in a small island at the mouth of Cheslatta River at Cheslatta Lake 325940E, 5954360N (NAD 27); 325800E, 5954600N (NAD 83).
Description: Section described from the bottom up.

*UNIT 1:* 1 m thick

Cobble gravel, massive with a chaotic fabric. Bimodal with moderately well sorted medium sand matrix. Lower contact is covered.

*UNIT 2:* 1 m

Interbedded coarse sand and medium pebble gravels. Trough crossbeds. Lower contact is sharp and trough shaped.

*UNIT 3:* 1 m thick

Small to medium pebble gravel. Massive with chaotic fabric. Lower contact is clear to subhorizontal.

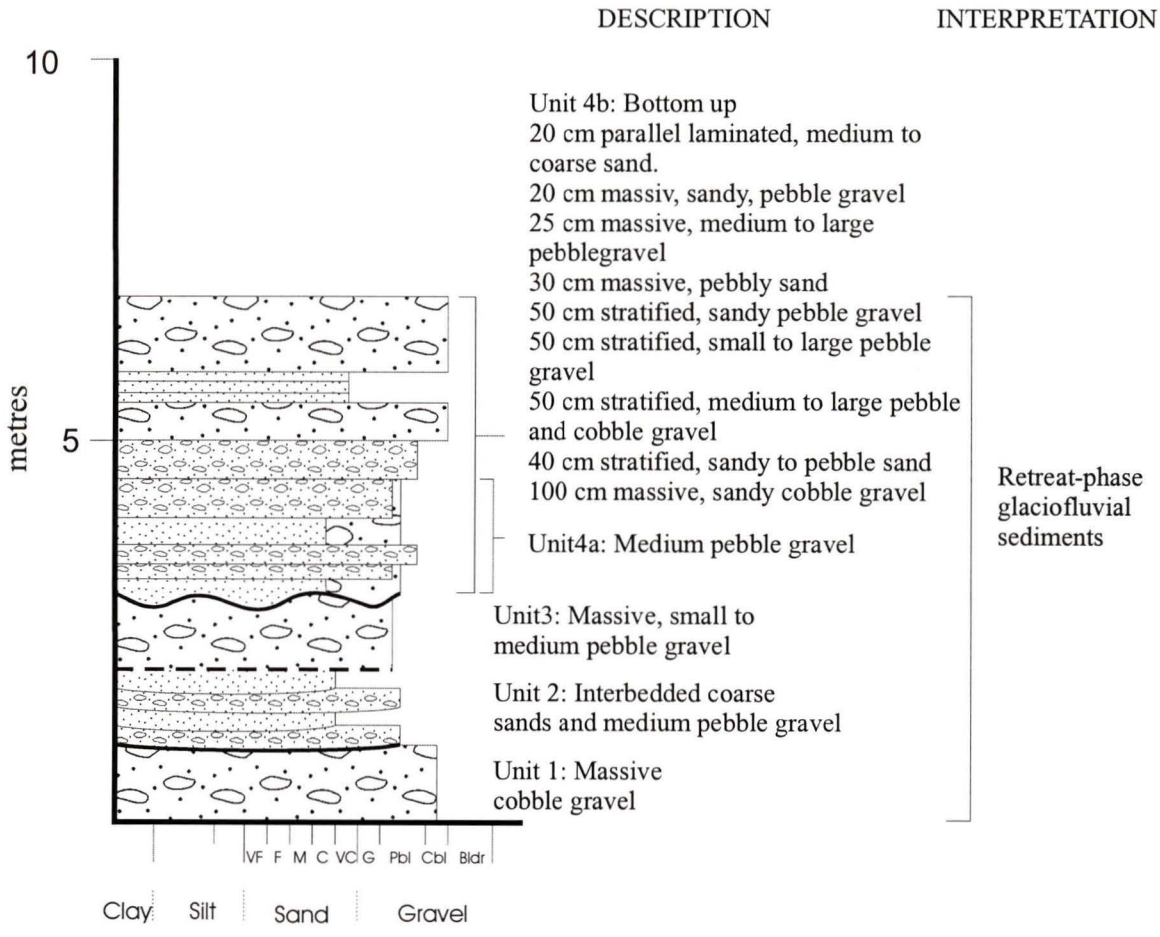
*UNIT 4a:* 2 m thick, south side of section

Medium pebble gravel; moderately well sorted with a sandy matrix. Some open worked beds. Beds dip 15 – 20° southward. Crudely bedded. Lower contact is sharp and erosional dipping southward.

*UNIT 4b:* 3.85 m thick, north side of section

From bottom up, 20 cm of parallel laminated medium to coarse sand. 20 cm massive sandy, pebble gravel. 25 cm massive medium to large pebble gravel. 30 cm massive pebbly sand. 50 cm stratified sandy pebble gravel. 50 cm stratified small to large pebble gravel, open worked to matrix filled. 50 cm stratified medium to large pebble and cobble gravel, open worked and matrix filled. 40 cm stratified sandy to pebble sand. 1 m of massive sandy cobble gravel that is matrix supported

# SECTION DMA-9801



## SECTION DMA-9802

Date: July 4, 1998
Location: Small gravel pit off of forestry road 312332E, 5947777N (NAD 27); 312105E, 5948200N (NAD 83).
Description: Section described from bottom up.

*UNIT 1:* 1.2 m

Planar bedded very coarse sand and gravel. Lower contact is covered.

*NOTE:* Some cross-beds were found giving a rough paleoflow of 355° to 020°. Beds are dipping between 19° - 24°.

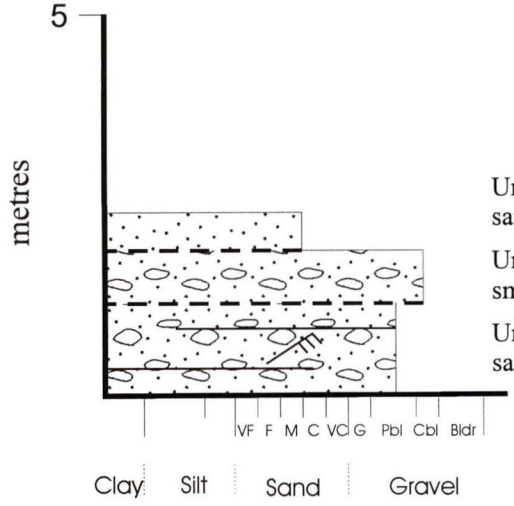
*UNIT 2:* 70 cm

Clast supported pebble to small cobble gravel. Matrix is coarse sand to very coarse sand. Chaotic fabric to crude imbrication. Some rusty oxidation is present in the upper 25 cm. Lower contact is subhorizontal and clear.

*UNIT 3:* 50 cm thick

Black, organic, medium sand with pebbles and small cobbles. Lower contact is clear to subhorizontal.

# SECTION DMA-9802




| DESCRIPTION | INTERPRETATION |
|---|---|
| Unit 1: Black, organic, medium sand with pebbles and cobbles | Retreat-phase glaciofluvial sediments |
| Unit 2: Clast supported pebble to small cobble gravel | |
| Unit 3: Planar bedded very coarse sand and gravels | |

**SECTION DMA-9803**

Date: July 24, 1998
Location: Shoreline exposure on Ootsa Lake 325400E, 5941160N (NAD 27); 325300E, 5941380N (NAD 83)
Description: Section described from the bottom up.

*UNIT 1:* 1.7 m thick (varies from 0 – 2 m)

Silty sand diamicton. Clasts subangular to subrounded with a modal size ranging from medium to large pebble and up to cobble. Unit thins to the south (toward lake centre). Medium to high density, medium to high fissility, well jointed, grey brown colour, unoxidizied. Unit coarsens up to sandy diamicton locally with low density, low fissility, weak jointing and a dark brown colour. Several vertical sand and gravel dykes with sharp contacts. Dykes narrow upwards and pinch out in unit 2. They are 10 – 15 cm wide and up over 1 metre long. Sand and gravel is mainly clast supported and sometimes matrix supported. It locally contains laminated fine to medium sand that shows steep strata parallel to the dyke and wrap around cobbles. Dykes are probably injections from below. Unit 1 must have been semi-consolidated to fracture and open up for dyke emplacement.

*UNIT 2a:* 2.5 m thick

Sandy diamicton with numerous lenses and interbeds of sand and gravel. Diamicton beds are typically 0.25 – 2 m thick while sand and gravel beds/lenses are up to 40 cm thick and several metres wide. This unit thickens towards the lake center (south). Diamict is weakly fissile, has low density, matrix is sandy with minor silt clasts. Clasts are subrounded to subangular with the dominant size being medium to large pebble. Some boulders were seen and some clasts were striated. Diamict beds were fairly continuous with numerous small (10 cm wide and 1 m long) deformed sand lenses with injections.

Sand lenses are up to 45 cm thick and 2.5 m wide. Lenses are comprised of thinly bedded very fine to fine sand and also some poorly sorted fine to coarse sand. Strata is deformed (sheared?) and lenses dip 10° towards the lake center. Local thin (5 cm) sandy diamicton interbeds with sharp lower contacts. Gravel lenses are clast supported with coarse sand matrix and are 25 cm thick and 2.5 m long. They are also massive to crudely bedded, poorly sorted and have flat-lying clasts with weak or absent imbrication. Some poorly sorted pebble to cobble gravel with coarse sand matrix mainly at base of unit. Approximately 1 m thick and 10 m long. Lower contact is generally sharp and undulating, troughs are approximately 1 metre deep and 3 – 4 m wide.

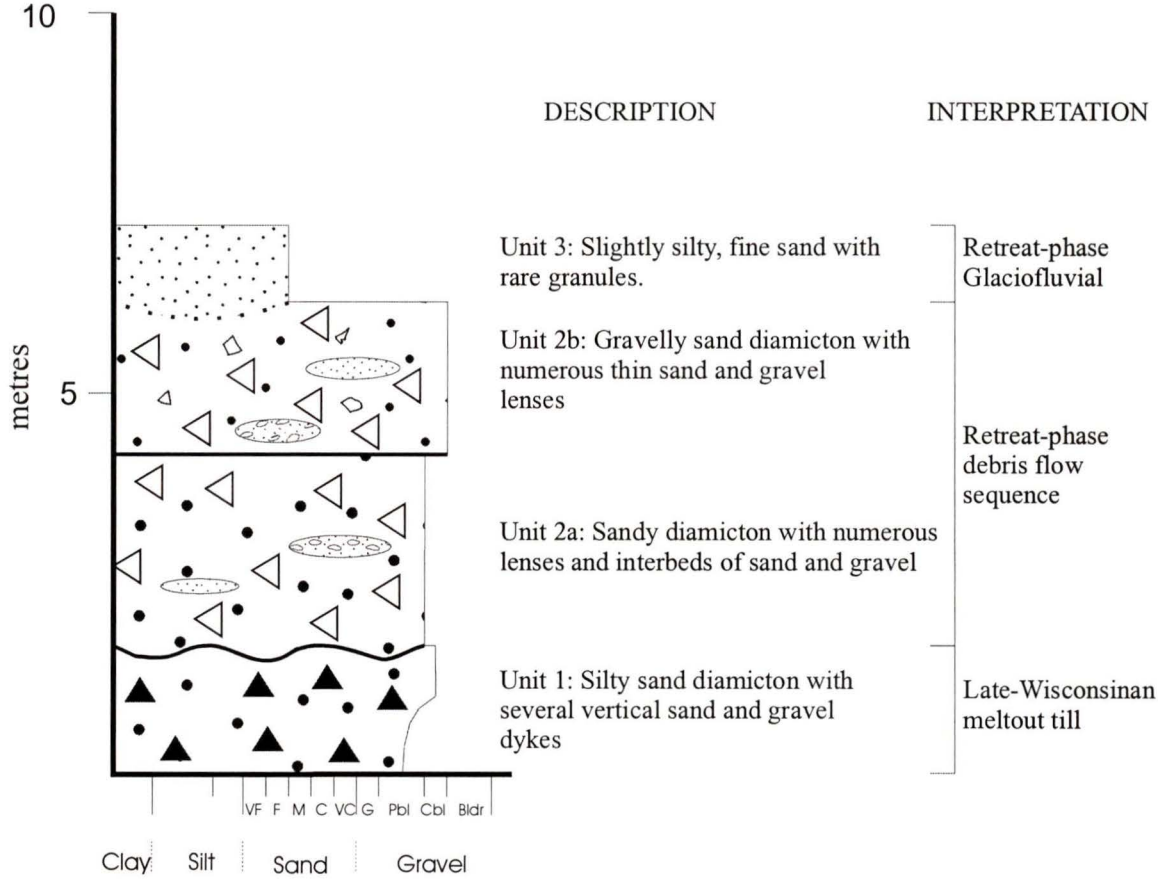
*UNIT 2b:* 2 m thick

Gravelly sand diamicton with numerous thin sand and gravel lenses (10 cm thick and 25 cm wide). Sand lenses are variable in texture ranging from fine to very fine laminated sands to massive coarse to granular sand. Lenses are often deformed and generally dip parallel to the lower contact. Numerous fine sand injections (5 cm thick and 15 – 20 cm long). Sand lenses increase up section, in the upper 1 m there is little or no diamicton but some scattered pebbles (dropstones) occur. This unit overlies unit 2a and has a sharp, steeply dipping (approximately 26°) lower contact that truncates all of unit 2a. Unit 2b increases from 0 to 2 m thick towards the lake center (south).

*UNIT 3:* 1 m thick

Slightly silty, fine sand with rare granules. Lense shaped unit approximately 10 m wide. It is poorly exposed and has a covered lower contact. *NOTE:* Topography along section top is gently undulating with several gravel pits behind section.

## SECTION DMA-9803



## SECTION DMA-9804

Date: July 26, 1998
Location: Cheslatta River 324180E, 5955080N (NAD 27); 324080E, 5955300N (NAD 83)
Description: Described from the bottom up

**Section DMA-9804a**
*UNIT 1:* 50 cm thick

Large pebble to cobble gravel; clast supported and matrix filled with fine sand matrix. Lower contact is covered.

*UNIT 2:* 1.5 m thick

Well sorted medium sands with crude horizontal bedding; some granular and small pebbly sands in lower half meter. Lower contact is sharp and horizontal.

*UNIT 3:* 1.0 m thick

Small pebble to granule gravel with some coarse sand beds; horizontally bedded to low angle trough cross-bedding; beds are 5 to 15 cm thick; troughs are 10 to 20 cm deep and 3-4 cm wide, fining upwards; lots of iron staining present; rare lenses of granular silts to fine sands approximately 2 cm thick and 25 cm wide. Lower contact is sharp and horizontal.

*UNIT 4:* 1.0 m thick

Medium to large pebble gravel; Unit fines upwards with rare sand lenses that are 10 cm thick and 50 cm wide. Crude bedding with scoured lower contact with medium to large pebble lag.

*UNIT 5:* 50 cm thick

Cobble gravel; clast supported and matrix filled; poorly exposed. Possibly a terrace gravel; overlain by 1 m of mainly fine sand with numerous buried Ah layers (overbank sediments). Lower contact is sharp and planar.

**Section DMA-9804b**

**Note:** Numerous thrust faults occur between units 1 to 4. The faults dip direction is 269° west and is dipping 23°. Faults are traceable for several metres top to bottom. True displacement of a maximum of 1 m. Fault does not carry into unit 5.

**Note:** Short distance away (approximately 20 m to the west) there is a section of diamict which is in steep contact with units 1 to 4. Contact zone dips steeply to the west and somewhat parallel to thrusts in units 1 to 4. Diamict has 4 distinct units (base up):

*UNIT 1:* 1.5 m thick

Dense, cemented silty diamicton with steeply dipping fissility (30°-45°) dipping both westward and eastward. Contact zone between diamict (west) and gravel (east) is about 1 metre thick and includes a complex mixture of diamict with deformed lenses and pods of sand and gravel.

*UNIT 2:* 2 m thick

Small gravelly silt diamicton; deformed sand lense separates unit 2 from unit 3. Sand lense is 10 to 20 cm thick and 5 m wide dipping 25° westward.

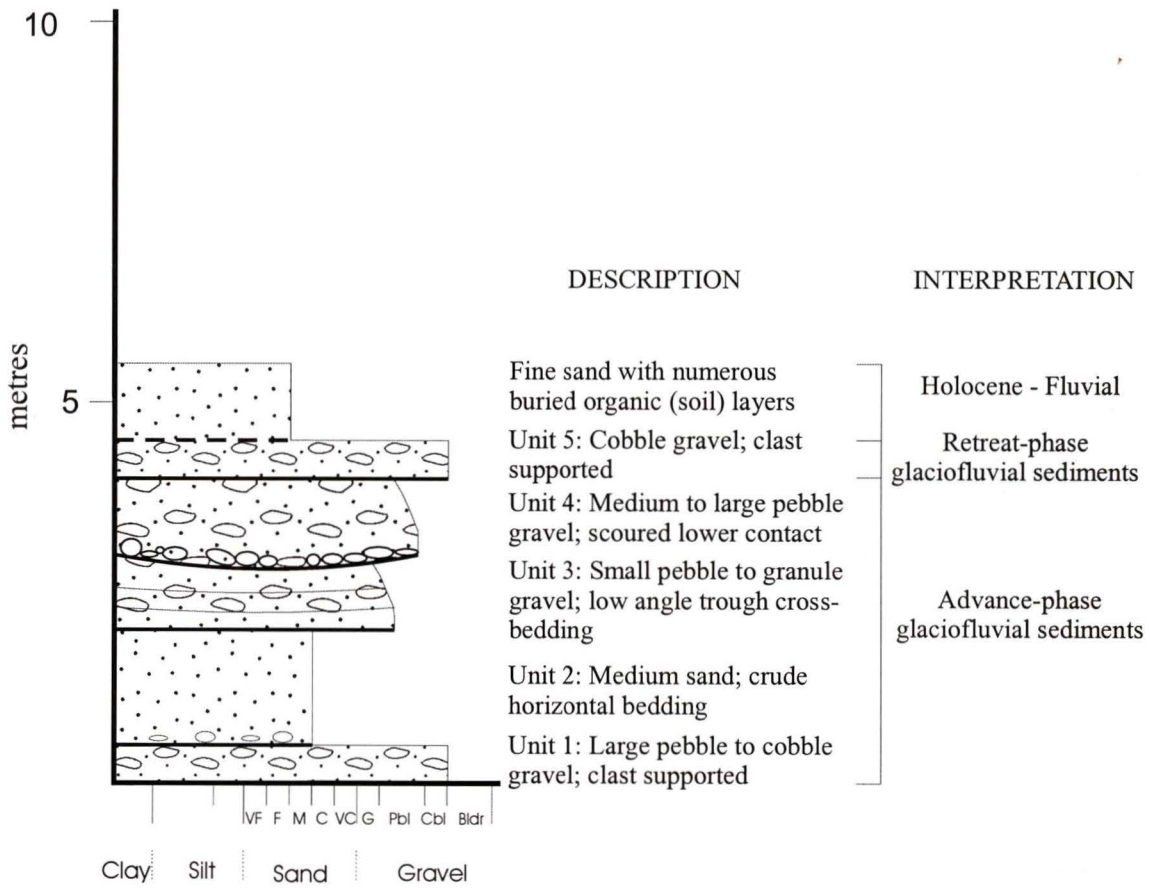
*UNIT 3:* 1.5 m thick

Dense and blocky silty diamicton (good lodgement till); Unit wedges to east with lower contact a thrust contact; it is overlain by unit 4.

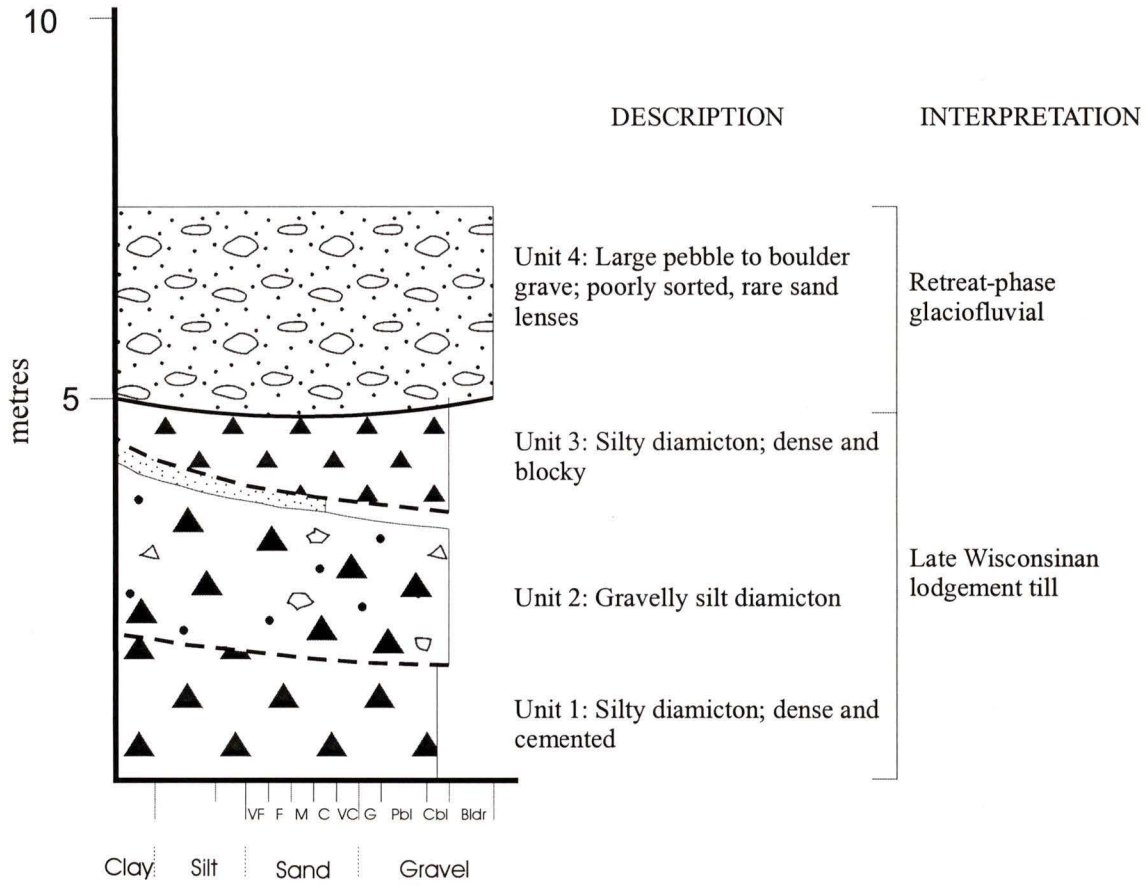
*UNIT 4:* 2.5 m thick

Large pebble to boulder gravel with rare sand lenses; gravel is poorly sorted. Lower contact is sharp and trough shaped; troughs are 20 cm thick and 3 m wide.

## SECTION DMA-9804a



# SECTION DMA-9804b



**SECTION DMA-9805**

Date: July 26, 1998
Location: Cheslatta River, 150 m upstream of section DMA-9804 324150E, 5955125N (NAD 27); 324050E, 5955330N (NAD 83)
Description: Described from the bottom up

*UNIT 1:* 6 m

Slightly silty sand diamicton; low to moderate horizontal fissility and strong vertical jointing (fissility); very dense; unoxidized; clasts are medium to large pebble with maximum size of 45 cm; clasts were commonly striated and of varied lithologies (roughly 10 % andesite, 30 % basalt, 10 – 15 % granitics and 10 % feldspar porphyry). Lower contact is covered. Unit laterally continuous for a few hundred meters and commonly extends to surface.

*UNIT 2:* 2.5 m thick

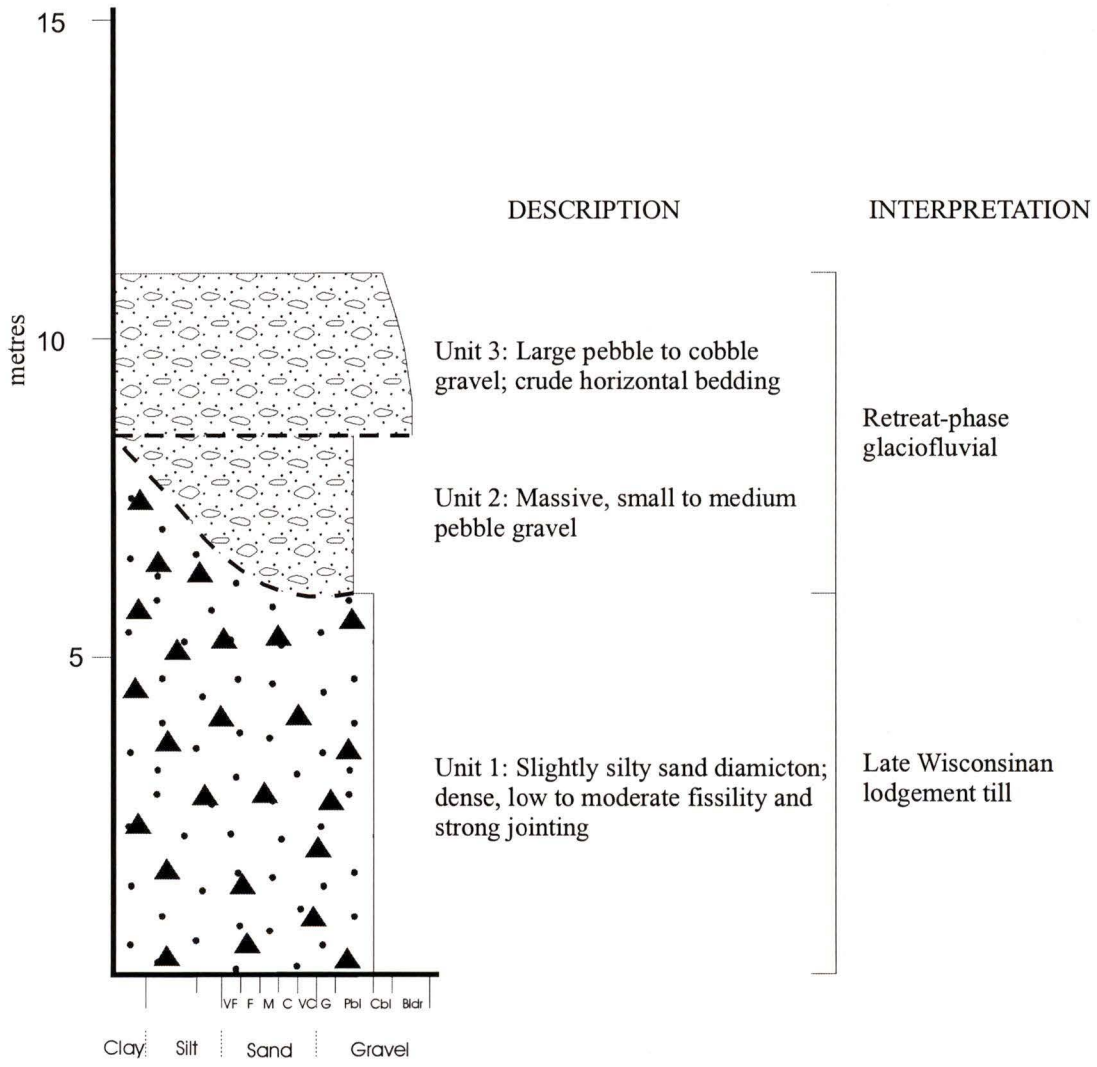
Massive, small to medium pebble gravel; clast supported and matrix filled; matrix is fine to coarse sand; clasts up to 3 cm and are subrounded; no obvious imbrication; unit is a trough shaped lense at least 5 m wide. Lower contact is clear and trough shaped (erosional).

*UNIT 3:* 2.5 m thick

Large pebble to cobble gravel; clast supported and matrix filled; matrix is coarse sand; weak imbrication; crude horizontal bedding; cobble to boulder lag in lower 0.5 m; some pebble gravel lenses at top that are 1.5 m thick and greater than 3 m wide. Lower contact is clear and subhorizontal.

**Note:** Units 2 and 3 are probably meltwater channel gravel, not present upstream.

# SECTION DMA-9805



## SECTION DMA-9806

Date: July 26, 1998
Location: Exposure in gravel pit close to Cheslatta River 323974E, 5955155N (NAD 27); 323840E, 5955400N (NAD 83)
Description: Described from the bottom up

*UNIT 1:* 1.5 m thick

Interbedded medium to large pebble gravel and medium sand; gravel is clast supported and matrix filled; matrix is fine sand; rare cobbles; beds dip 14°. Lower contact is covered; it is a poorly exposed unit.

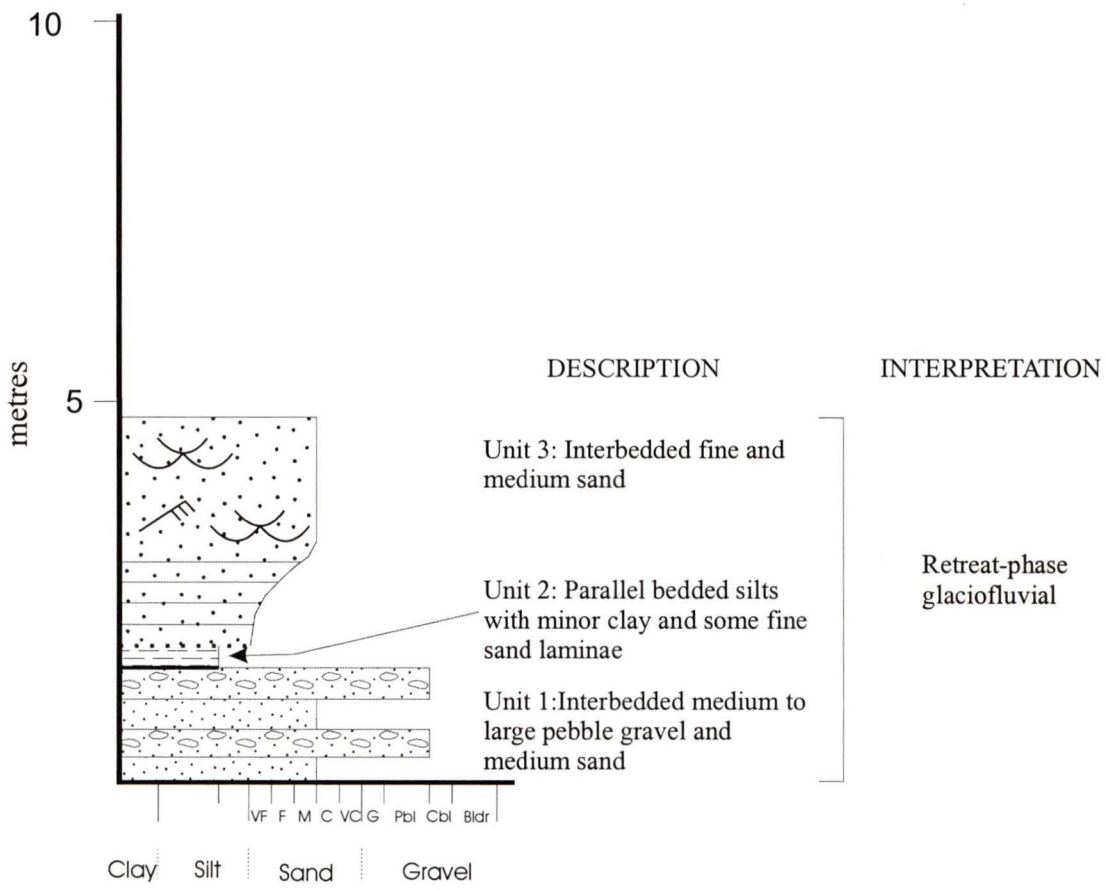
*UNIT 2:* 25 cm thick

Parallel bedded silts with minor clay and some fine sand laminae. Lower contact is sharp and planar, conforming to underlying beds.

*UNIT 3:* 3 m thick

Fine sand interbedded with medium sand and coarsening upwards; lower metre is mainly rhythmically laminated very fine sand and fine sand with near horizontal laminae; upper 2 m is mainly trough cross laminated and ripple bedded sands; apparent paleoflow was southwest. Lower contact is planar and gradational.

# SECTION DMA-9806



**SECTION DMA-9807**

Date: August 8, 1998
Location: Section exposed along south shore of Intata Reach, Nechako Reservoir 327300E, 5939650N (NAD 27); 327180E, 5939800N (NAD 83)
Description: Described from bottom up

*UNIT 1:* 2.5 m thick

Medium to large pebble gravel; large pebble gravel is clast supported and matrix filled with a chaotic fabric and a matrix consisting of medium to coarse sand; lower contact of large pebble gravel is sharp and undulating. Medium gravel was clast supported with a rare silt to medium sand matrix (almost clean gravel); chaotic fabric with subrounded to rounded clasts. Southwest corner of unit contains large injection structure; structure consists of fine and coarse pebbly sands and terminates in unit 2; lenses of fine sand and silt approximately 50 cm thick and 3 m wide occur within unit; lense is cross trough laminated with some small discontinuous lenses of sand. Crude cross trough laminations occur in coarse pebbly sand lenses; unit varies in thickness from 10-70 cm and is approximately 4 m wide. Coarse pebbly sand lense occurs on top of fine sand and silt lense; contact between them is sharp and undulating, while contact between fine sand lense and underlying gravel is sharp and undulating; contact between coarse pebble lense and gravel is clear to gradational and undulating. Unit 1 dips approximately 11° towards the lake and pinches to the southwest.

*UNIT 2:* 3 - 5.5 m

Massive silty sand diamicton; moderate fissility; well jointed; high density; some fine and coarse pebbly lenses occur in unit. Lower contact of unit is sharp and undulating.

## SECTION DMA-9808

Date: August 8, 1998
Location: Section exposed along south shore of Intata Reach, Nechako Reservoir 328500E, 5938320N (NAD 27); 328390E, 5938550N (NAD 83)
Description: Described from the bottom up

*UNIT 1:* 0 – 25 cm

Clayey silt diamicton with some sand; well jointed ; oxidized along joints; clast size ranges from granule to cobble with a modal size of medium to large pebble; brown colour; moderate to high density; clasts subangular to subrounded and commonly striated. Lower contact is covered. Reconnaissance Pebble Count taken (DMA-98-08-1) and grain size sample (DMA-98-08-1A).

*UNIT 2:* 0 – 65 cm

Blue-grey, very fine sand and silt and clay; very fine sand is 1 – 10 cm thick with some silty clay rip-ups and a clear and undulating lower contact; silt and clay laminations are up to 1 cm thick with slickensides on subhorizontal surfaces (058° - 048°). Unit exposed for approximately 10 m with a maximum thickness of 65 cm; thins southward; clay/silt laminations present with some small scale normal faults; wavy and discontinuous lenses and laminae of organics and small chunks of organics are present in the very fine sand and silt and clay.

*UNIT 3:* 15 – 25 cm thick

Small to medium pebble gravel; clast supported and matrix filled; matrix is coarse sand; chaotic fabric; some normal faults with approximately 10 cm displacement (continuous into unit 2 and flattens out) towards lake (NE); apparent dip 060° towards 030°; clasts are subangular and subrounded. Lower contact is sharp and gently undulating.

*UNIT 4:* 2.05 m thick

Fine to coarse sand, coarsen upwards; poorly preserved subhorizontal beds; some poorly preserved ripple bedding and trough cross-beds; numerous small-scale normal faults oriented as in unit 3 (lakeward).

Base up:

**4a:** 15 cm of fine to very fine sand.

**4b:** 10 cm of medium to coarse sand; Mn and Fe oxides

**4c:** 35 cm fine sand with rare silt laminae on top

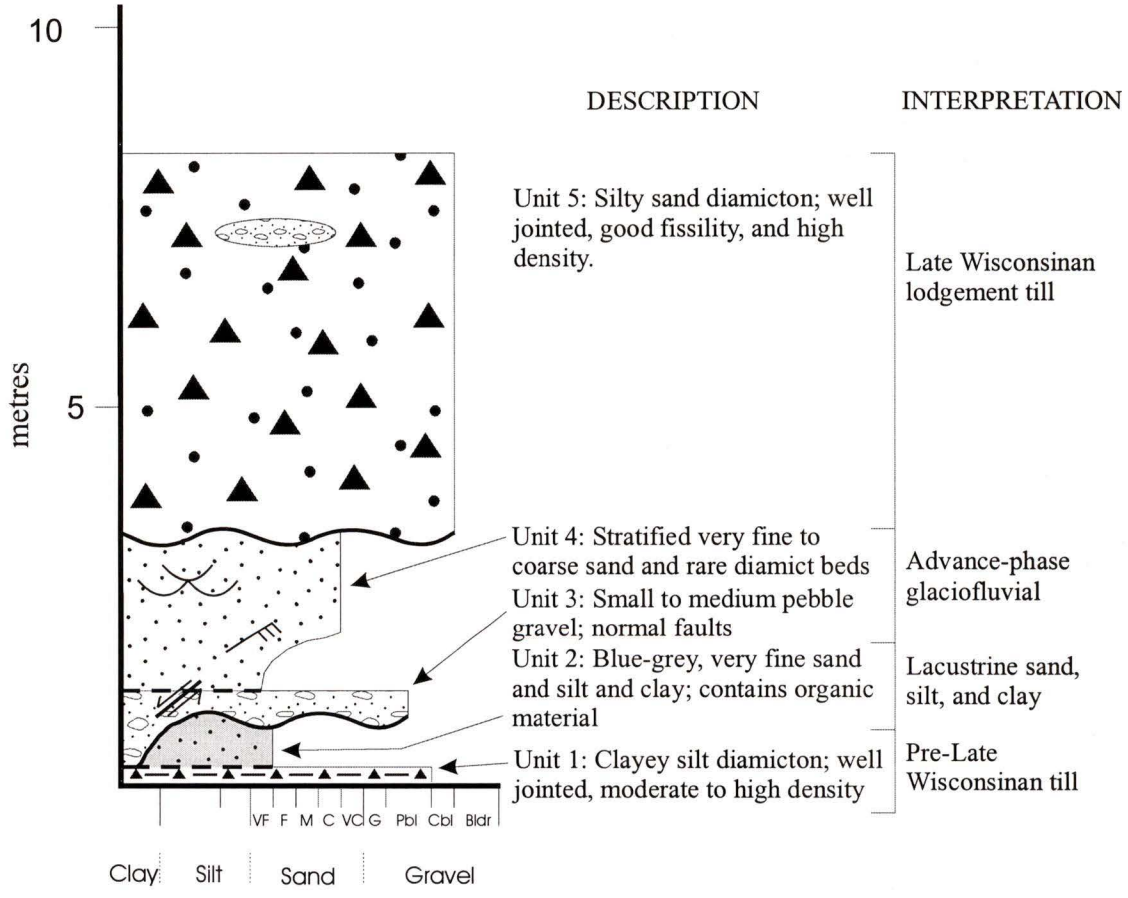
**4d:** 125 cm of medium to coarse sand; includes two 5 cm thick sandy gravel stratified diamict beds; 1 approximately 20 cm from the base and 1 approximately 60 cm from the top; upper stratified diamict bed has overlying silt and clay laminations

**4e:** 20 cm coarse sand with very fine sand lenses; granular sands at base.

*UNIT 5:* 5 m thick

Silty sand diamicton; well jointed with good fissility and high density; modal clast size is medium to large pebble; maximum clast size is large cobble; striated clasts are common, clasts subangular to subrounded; lower 10 cm is loose, sandy diamict; matrix is approximately 60%. Poorly preserved slope parallel slicks; well preserved lakeward dipping fissility; true dip is 36° and dip direction is 035°; possibly a crude slope parallel fabric. Lower contact is sharp and dips lakeward (035°) with a true dip of 9°. Some gravelly pods within unit; 50 cm to 100 cm thick. Almost clast supported and matrix is fine sand up; rare sand lenses near top of unit. Reconnaissance Pebble Count taken (DMA-98-08-05) and grain size sample (DMA-98-08-5A).

# SECTION DMA-9808



**SECTION DMA-9809**

Date: August 8, 1998
Location: Section exposed along the south shore of Intata Reach, Nechako Reservoir 329000E, 5938050N (NAD 27); 328930E, 5938270N (NAD 83)
Description: Described from the bottom up

*UNIT 1:* 1.5 m thick

Fine to medium sand; medium scale trough cross-beds; some normal faults; various orientations with 1 – 2 cm displacement (45° - 85° angle faults). Lower contact is covered; unit poorly exposed.

*UNIT 2A:* 2.0 m thick

Small to large pebble gravel; clast supported and matrix filled; matrix is medium to coarse sand; poorly sorted; chaotic fabric; crude, large scale trough cross-bedding; clasts are subrounded to rounded; unit fines upward. Lower contact is sharp and undulating.

*UNIT 2B:* 0.6 m thick

Small pebble gravel with medium to large pebble interbeds; clast supported with some very coarse sand matrix; crude medium scale trough x-bedding; chaotic fabric. Lower contact is clear and gently undulating.

*UNIT 3:* 5 – 6 m thick

Silty sand diamicton; unit is dense; well jointed with moderate to high fissility; unit is sandier in the lower 25 cm; parallel fabric; unit has several clean gravel (10 – 15 cm thick and 50 cm wide) and fine (1 cm thick and 25 cm wide) and coarse (20 – 25 cm thick and 100 cm wide) sand lenses; coarse sand lenses have crude, distorted (wavy) beds; crude laminations present in fine sand lenses; sand and gravel lens dip 0 – 45° (mainly horizontal, 2 lenses dip steeply towards 020°). Lower contact is sharp and subhorizontal.

*UNIT 4A:* 1 m thick

Sandy stratified diamict; unit interbedded with very fine sand and silt and clay; faint trough cross laminations within very fine sand; both silt and clay beds are massive. Lower contact is sharp and subhorizontal with small undulations.

*UNIT 4B:* 1 m thick

Medium sands with very fine sand and mud interbeds; mud interbeds are clayey silt and contain some brecciated clay clasts about 1 – 2 cm thick and are undulating; very fine sand interbeds vary in thickness from 1.5 to 15 cm. Lower contact is sharp and horizontal.

*UNIT 5:* 1 m thick

Coarse sand and pebbly sand that is planar bedded; Beds vary from 1 – 10 cm in thickness; clasts are subrounded. Lower contact is sharp and subhorizontal to undulatory.

**150 – 200 m northeast of this section**:

Description: Described from the top down.

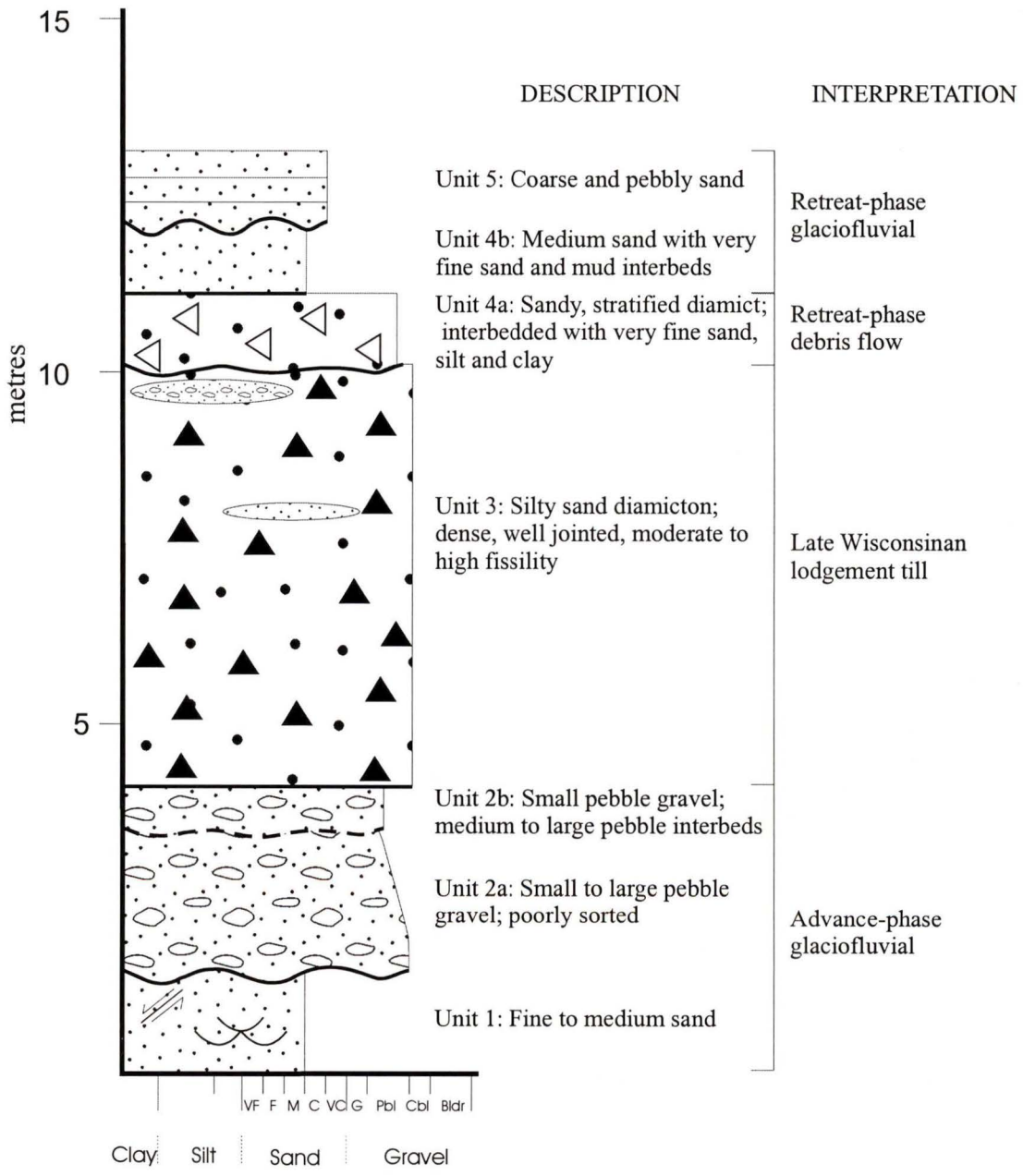
*UNIT 1:* 2.5 – 3.0 m thick

Small pebble gravel; clast supported and matrix filled; matrix is coarse sand; large clasts of mud breccia as well as medium sands and silts in unit; mud breccia interbeds are undulating and 1.5 – 10 cm thick; mudflow breccia and mud and silt appear crudely interbedded within unit; medium sand beds are 3 – 5 cm thick, wavy and discontinuous. They show normal faulting; small normal faults have a displacement of 1 cm in medium sands. Lower contact is covered. This unit possibly correlates with unit 5 (above) or overlies unit 5.

**Note:** Under brecciated silts there are approximately 1 – 2 m of poorly exposed sand and gravel. Under that lies a lens of interbedded fine sands and silts (up to 1 m thick) with

disturbed bedding that is mainly subhorizontal but dips NE up to approximately 15° (probably late slumping towards lake). Many normal faults dip towards the lake approximately 45° with displacement up to 20 cm. Lower contact is covered.

## SECTION DMA-9809



**SECTION DMA-9810**

Date: August 21, 1998
Location: South side Cheslatta River near ALCAN spillway 302785E, 5962319N (NAD 27)
Description: Described from the bottom up.

*UNIT 1:* 8 m thick

Bedrock; possibly andesite.

*UNIT 2:* 3 m thick

Sandy clay diamicton; massive; well jointed; strong fissility; high density; most clasts lie horizontal; good sub-horizontal fabric that shows a general NE flow direction (070°). Lower contact is sharp and undulating; unit sits on top of striated bedrock (striations oriented 075°). Upper 2 m of this unit is poorly exposed.

*UNIT 3:* 5 m thick

Silty sand diamicton; strong fissility and well jointed; high density; clast size is small to large pebble with largest clast approximately 10 – 15 cm long; concretions present; discontinuous medium to coarse sand lenses throughout unit; lenses are wavy and discontinuous and are approximately 10 – 20 cm thick and 1 – 8 m wide; lenses appear as wet spots within unit; some sand lenses appear to be horizontal while others are dipping up to 26° in a direction of 345°; some lenses are clast supported and matrix filled small to medium gravel; matrix is medium to coarse sand; some trough shaped (10 – 45 cm thick and 2 – 5 m wide) and rare clean gravel lenses; lenses become more abundant and larger upwards within unit; gravel lenses in upper part of unit are oxidized and gravel/diamict contacts are locally loaded (soft sediment deformation). Lower contact is gradational and poorly exposed.

*UNIT 4A:* 50 –150 cm thick

Medium to large pebble gravel; clast supported and matrix filled; matrix is coarse sand; medium scale trough cross-bedding; overall unit has a large trough shape, pinching out towards 207°. Unit width is approximately 20 m. Lower contact is trough shaped and clear to sharp.

*UNIT 4B:* 1 m thick

Interbedded very fine sand and silt, medium sand and small pebble gravel; very fine sand and silt are horizontally laminated and have lower contacts that are clear and horizontal to gently undulating; thickness of these beds range from 5 – 20 cm; small scale normal faulting (only in one bed) dips 52° toward 070°; small pebble gravel beds show small to medium scale trough cross-bedding; beds are 20 – 30 cm thick and 2 –15 m wide; lower contact of these beds are clear and undulating; medium sand beds have small to medium scale planar cross-beds; lower contact of unit is clear and undulating. Lower contact for entire unit is clear and subhorizontal to gently undulating.

**Note:** About 100 m from this section unit 4B thickens towards the top; beds become approximately 15 – 20 cm thick and are thinly laminated to thinly bedded with small and medium pebble gravel; very little diamict seen above.

*UNIT 5:* 2 m thick

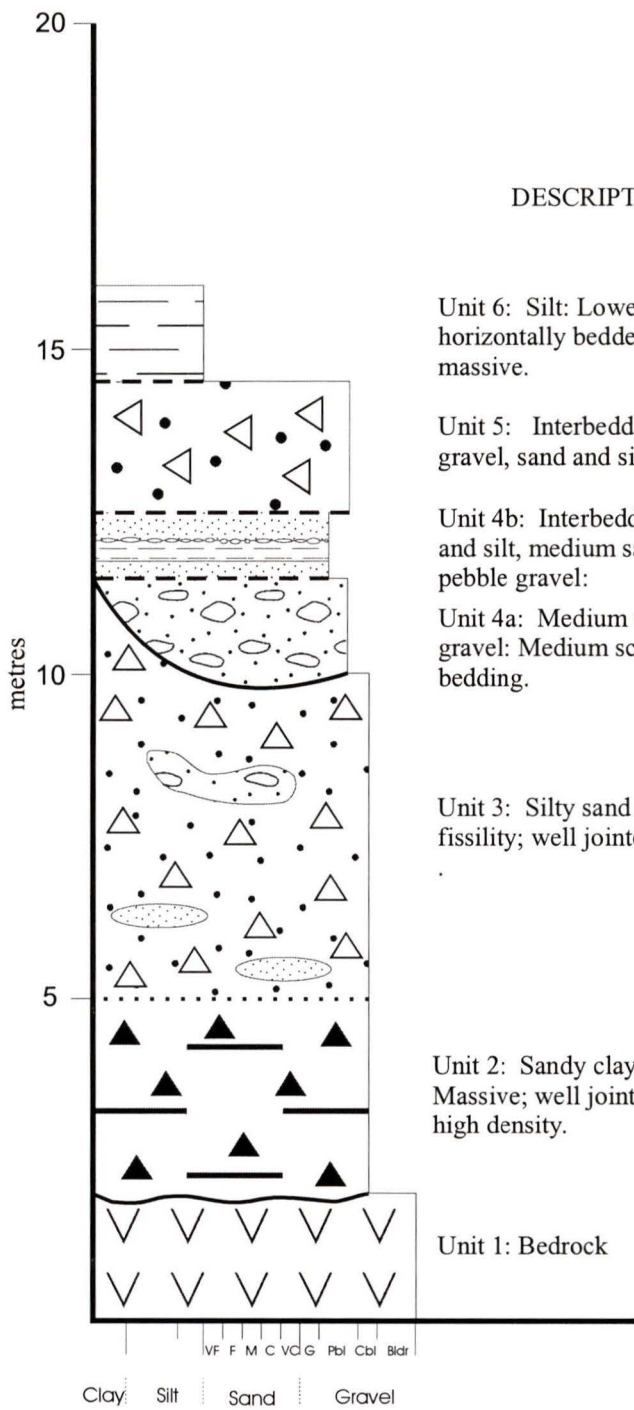
Interbedded sandy diamict, gravel, sand and silt; clast size of diamict beds is medium to large pebble with the largest clast around 10 – 15 cm; sand lenses and small to large pebble gravel common; sand lenses are 5 to 20 cm thick and 30 to 45 cm wide; small pebble gravel lense was 50 – 100 cm thick and 50 – 600 cm wide; medium to large pebble gravel lenses are 30 - 100 cm thick and 50 – 300 cm wide; some sand intraclasts

are within diamict and silt beds; they are slightly folded with various orientations. Lower contact is clear and subhorizontal.

*UNIT 6:* 1.5 m thick

Laterally to the south section is capped by silts; lower quarter to half of this unit is horizontally bedded with the rest massive; stratigraphically this unit probably overlies unit 5. Lower contact is clear and horizontal.

# SECTION DMA-9810




| DESCRIPTION | INTERPRETATION |
|---|---|
| Unit 6: Silt: Lower half of unit is horizontally bedded, the rest is massive. | Retreat-phase glaciolacustrine |
| Unit 5: Interbedded sandy diamict, gravel, sand and silt: | Retreat-phase debris flow |
| Unit 4b: Interbedded very fine sand and silt, medium sand and small pebble gravel: | Retreat-phase glaciofluvial |
| Unit 4a: Medium to large pebble gravel: Medium scale trough cross-bedding. | |
| Unit 3: Silty sand diamicton: Strong fissility; well jointed; high density. | Late-Wisconsinan meltout till |
| Unit 2: Sandy clay diamicton: Massive; well jointed; strong fissility; high density. | Late-Wisconsinan lodgement till |
| Unit 1: Bedrock | Bedrock |

## SECTION DMA-9811

Date: August 26, 1998
Location: North side of Cheslatta River near ALCAN spillway 302930E, 5962482N (NAD 27)
Description: Section described from the bottom up

*UNIT 1:* 1.5 m thick

Sandy silt diamicton; massive; high density; well jointed with strong fissility; lower 50 – 60 cm of unit has been scoured by high water marks. Clast size of diamict is small pebble to small cobble; maximum clast size is 25 – 30 cm; lots of angular striated clasts in diamicton; subhorizontal fabric. Unit is quite gravelly with many granule size pebbles; bedrock outcrops on west (225°) and east side of section; bedrock outcrop to the east is streamlined towards 065°. Lower contact is covered.

*UNIT 2a:* 3.8 m thick

Gravelly sand diamicton; high density; moderate fissility and jointing. Parts of diamicton become quite gravelly (abundant granules and small pebbles, clast content varies from 20 – 50%); largest clasts are approximately 20 – 25 cm; small pebble and medium to large pebble gravel lenses; some fairly clean small pebble and medium to large pebble gravel pods. Lower contact is gradational and subhorizontal and undulatory, it is possibly interbedded with unit 1.

*UNIT 2b:* 1.2 m thick

Sandy silt diamicton to silty sand diamicton; low to moderate density; well jointed and strong fissility; has thin discontinuous sand laminations. Lower contact is clear and undulatory.

*UNIT 3:* 1.8 m thick

Interbedded granular to small pebble gravel, medium sand and laminated fine sand and silty very fine sand; unit appears to be a large lense shape extending laterally for 15 m. Fine sand and silty very fine sand laminations are wavy and discontinuous; some 1 cm thick silty very fine sand units present (up to 35 – 40 cm thick); granular small pebble gravel is wavy and discontinuous, clast supported and clean, pinching out within unit; medium sand has planar cross-beds. Lots of thrust faults within unit (1 – 5 m displacement, some overturned chevron folds); folding and faulting is intrastratal; syndepositional deformation. A 2 – 5 cm thick bed of brecciated silt with a fine sand matrix was present near the top of the unit. It was several meters long, locally folded, thrust faulted and injected into overlying sands. Lower contact is sharp and horizontal, not well exposed.

*UNIT 4a:* 0.5 m thick

Slightly silty, sandy gravel diamicton; lower contact is sharp and undulatory with convex surfaces.

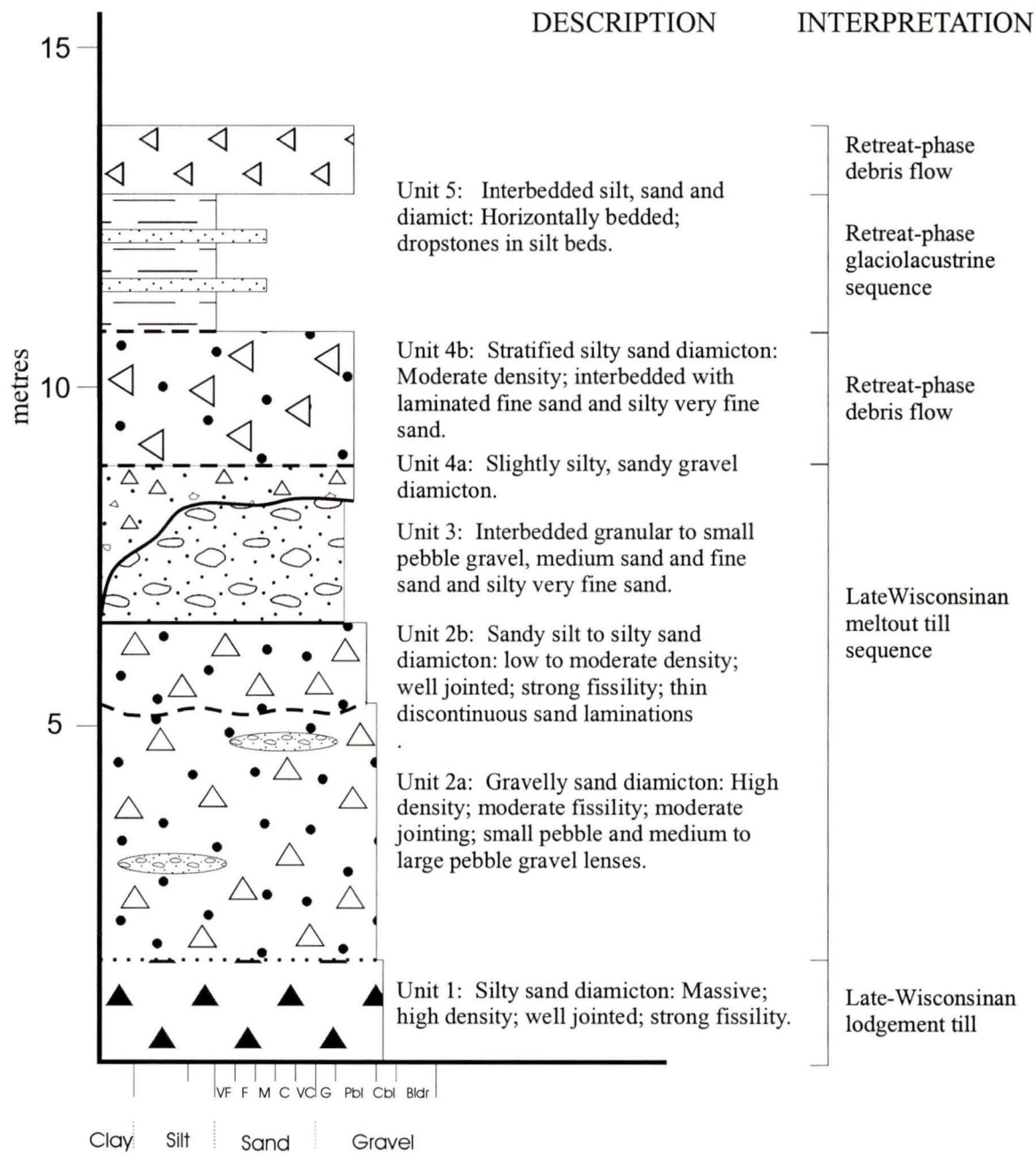
*UNIT 4b:* 2 m thick

Stratified silty sand diamicton; unit interbedded with laminated fine sand and silty very fine sand; moderate density; three stratified silty sand diamicton beds. Bottom two beds (lower 25 cm and middle of unit) are moderately jointed with moderate to high fissility and moderate density; third bed (upper 25 – 30 cm) had moderate fissility, jointing and density and was sandier than the bottom two. Lower contact is clear and subhorizontal with gentle undulations.

*UNIT 5:* 2 – 3 m thick

Horizontally bedded silts, sands and diamict; silt beds are 10 – 50 cm thick showing crude internal bedding and locally have clasts up to cobble size (dropstone ?); sands are mainly lenses 10 cm x 2 m; upper meter poorly exposed but appears to be diamict. Laterally unit appears to be massive silt with scattered clasts (silty diamict ?). Note this unit was described from a distance.

SECTION DMA-9811



**SECTION DMA-9812**

Date: August 22, 1998
Location: North side of Cheslatta River half way between Skins Lake and upper Cheslatta Falls 313783E, 5963433N (NAD 27)
Description: Section described from the bottom up

*UNIT 1:* 3.5 m thick

Silty sand diamicton; high fissility; well jointed; moderate to high density; dark grey-red to purplish grey colour; colour possibly reflects bedrock lithology. Note numerous mauve shale clasts along shoreline. Lower contact is covered, unit pinches out towards 170°.

*UNIT 2:* 4 m thick

Silty sand diamicton; moderate density; well jointed; strong fissility; some medium – very coarse sand and granule to small pebble lenses 50 cm thick and 2 m wide; rare clean small pebble gravel lenses 15 cm thick and 30 cm wide. Diamict becomes more gravelly in areas and also appears crudely bedded; it has a mauve colour. Lower contact is poorly exposed, gradational and subhorizontal to undulatory.

*UNIT 3:* 0.5 – 1.6 m thick

Poorly sorted small to large pebble gravel; clast supported and matrix filled; matrix is fine to coarse sand; unit has some highly oxidized small to medium pebble gravel beds. Stratified silty sand diamict bed occurs in the top 10 cm of this unit and is interbedded with fine and medium sand with some small pebbles; stratified diamict has a dark grey-red colour. Lower contact is clear and subhorizontal. Unit is slump covered and poorly exposed, overall it is trough shaped.

*UNIT 4:* 0 –2.5 m thick

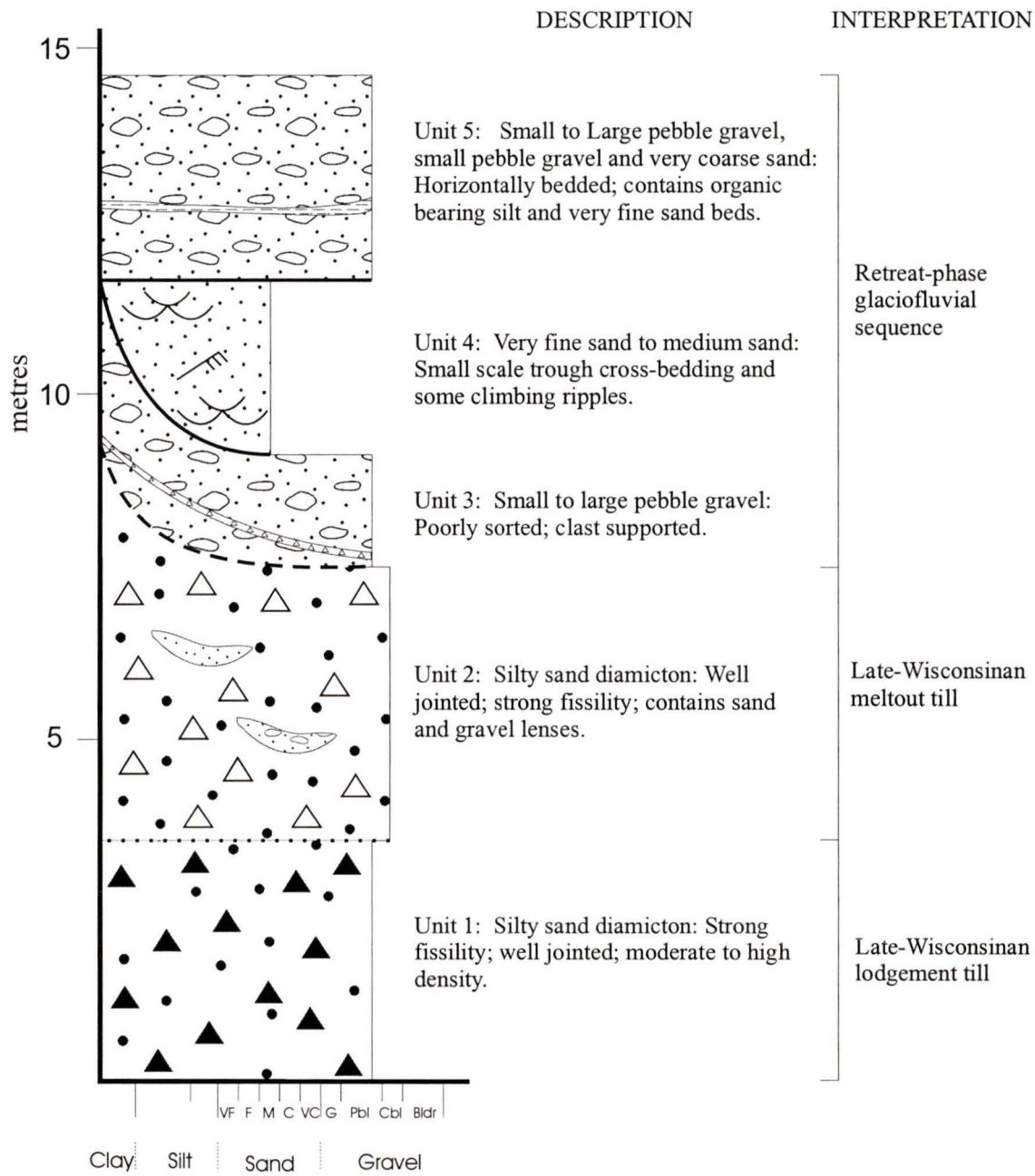
Interbedded very fine sand to medium sand; small scale trough cross-bedding and some climbing ripples; dominant apparent paleoflow is 170° (trough cross laminations); one bed close to top of unit had paleoflow of 310°; reverse flow directions visible. Unit visible for 50 m with an orientation of 170°; pinches out towards 320° and beds have an apparent dip of approximately 26 – 30° towards 170°. Lower contact is sharp and trough shaped.

*UNIT 5:* 2 – 3 m thick

Horizontally bedded small to large pebble gravel, small pebble gravel and very coarse sand; some small pebble gravel beds are highly oxidized showing deep iron staining. One meter from base of unit a bed of gritty silt containing small organic flecks and clay clasts occurs; pronounced organic horizon; frequency of silt and very fine sand beds increase toward the top Lower contact is sharp and horizontal

**Note:** Moving south approximately 100 m unit 4 is seen overlying unit 1. Units 2 and 3 are no longer visible. Moving 315° from section approximately 100 – 150 m a large trough cross-bedded gravel sequence occurs over till.

# SECTION DMA-9812



**SECTION DMA-9813**

Date: August 22, 1998
Location: North side of Cheslatta River just below the upper Cheslatta Falls 319012E, 5960365N (NAD 27)
Description: Section described from the bottom up.

*UNIT 1:* 1 m thick

Interbedded medium to large pebble gravel and granule to small pebble gravel; Medium to large pebble gravel is clast supported and matrix filled; matrix is silt to coarse sand; granule to small pebble gravel is clast supported and clean with crude imbrication and shows large scale cross-bedding. Lower contact is covered.

*UNIT 2b:* 2 m thick

Stratified silty sand diamicton; poorly jointed; strong fissility; stratified with silty clay, granule to small pebble gravel and small to medium pebble gravel beds. Note, diamict beds are thin compared to those in unit 2a, diamict beds are approximately 8 – 15 cm thick. Lower contact is subhorizontal to gently undulating and is clear to gradational. Beds in unit 2a and 2b extend for 10's of meters laterally.

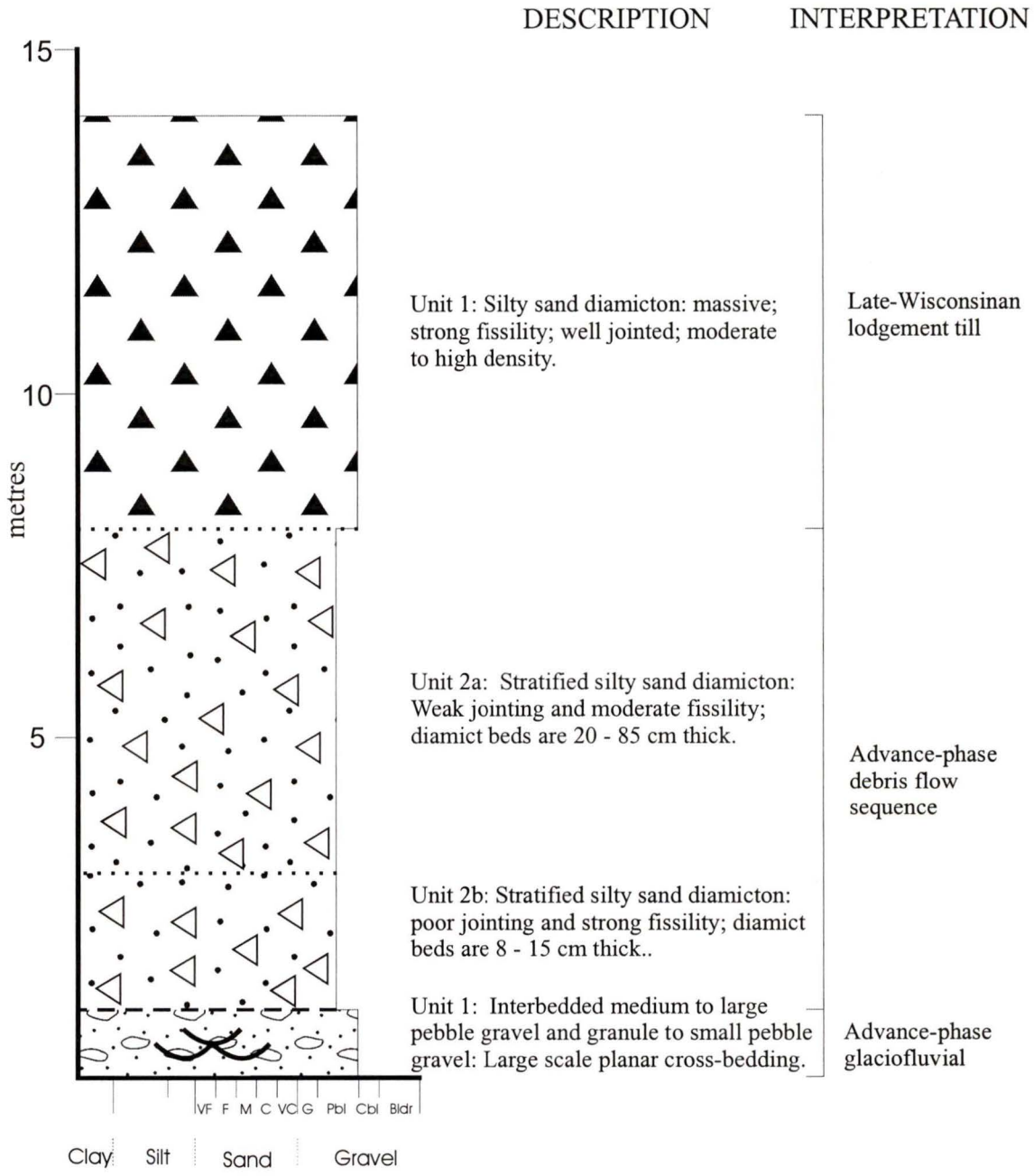
*UNIT 2a:* 4 – 5 m thick

Stratified silty sand diamicton; stratified diamict is weakly jointed with moderate fissility; clast size is small to medium pebble; largest clast is 5 – 10 cm; unit is stratified with pebbly coarse sand, clayey silt and pebbly fine to medium sand beds. Diamict beds have a thickness of 20 –85 cm. Lower contact is subhorizontal and gradational.

*UNIT 3:* 6 m thick

Silty sand diamicton; strong fissility; well jointed; moderate to high density; clast size is small to large pebble, largest being 20 –25 cm. Unit appears massive. Lower contact is gradational.

# SECTION DMA-9813



**SECTION DMA-9814**

Date: August 25, 1998
Location: South of slump 2 on Cheslatta River 324050E, 5955400N
Description: Described from the bottom up. Note, base of exposure is heavily slump covered, therefore base of this section is 10 m above river level.

*UNIT 1A:* 1.6 m thick

Silty sand diamicton; brown to dark grey; massive; well jointed with moderate fissility; high density; small to large pebble clast size; largest clasts are approximately 15 cm; clasts are subrounded and striated clasts are rare; some tabular clasts dip at high angles (45°); clast content is unusually high, approximately 40 – 50 % making this diamict almost clast supported in places. Laterally in upper meter of unit there are thinly bedded sand lenses about 5 – 10 cm thick and 20 cm wide; lenses are undeformed and well sorted. Lower contact is covered.

*UNIT 1B:* 0.85 m thick

Silty sand, clast supported and stratified diamict; interbedded with rare pebbly laminated silts and very fine sand; these beds are 5 – 10 cm thick and 1 – 2 m wide; clast supported, stratified diamict has poorly developed jointing and moderate fissility; diamict is approximately 10 – 20 cm thick; rare small pebble gravel beds. Lower contact is clear and subhorizontal with gentle undulations.

*UNIT 2:* 1.5 – 2 m thick

Large pebble gravel; poorly sorted and crudely bedded; clast supported; rare silty sand stratified diamicton beds. Lower contact is clear and undulatory, undulations are up to 1 m deep and 1 – 2 m wide; scour like contact eroding some sand beds in unit 1b below.

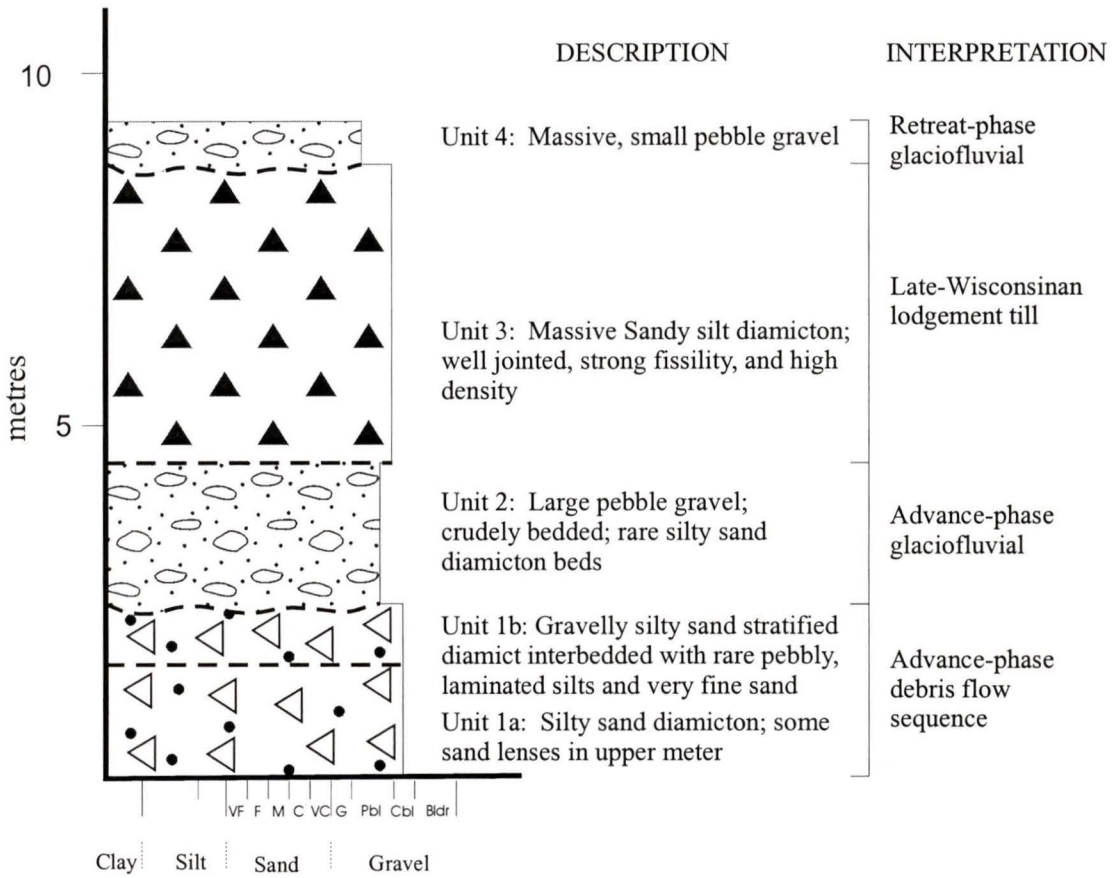
*UNIT 3:* 3 – 4 m thick

Sandy silt diamicton; well jointed with strong fissility; massive; high density; small to large pebble clast size with largest clast approximately 15 – 20 cm; clast percentage is 15 – 20 %. Lower contact is clear and horizontal with some undulations.

*UNIT 4:* 0.3 – 0.5 m thick

Thin cap of small pebble gravel; gravel is clast supported and matrix filled, matrix is silt to coarse sand; unit is poorly sorted, chaotic fabric; no imbrication; unit overlain by approximately 0.15 – 0.2 m of clean pebbly, very coarse sand. Lower contact is clear and undulating.

# SECTION DMA-9814



## SECTION DMA-9815

Date: August 27, 1998
Location: North side of Cheslatta River between Skins Lake and Upper Cheslatta Falls 313265E, 5963556N (NAD 27)
Description: Section described from the bottom up.

*UNIT 1:* 1.75 m thick

Peat; horizontally to undulatory bedded; beds are 5 – 20 cm thick; mostly decomposed peat; some beds are charcoal rich (woody charcoal) and some reed fragments were seen. Weathers light grey to white; some clay, silt and fine sand strata; uppermost bed is almost totally woody material 10 cm thick and 50 cm wide; wood is flattened. To west unit rises where 1.5 m of open worked gravels and another 1.5 m of woody peat underlie it. Lower contact is covered.

*UNIT 2:* 0.8 m thick

Large pebble gravel; mainly open worked with some coarse sand matrix; well imbricated with an approximate paleoflow direction of 120°; clasts have varied lithologies and lots of iron staining; clasts are angular to well rounded. Lower contact is sharp and trough shaped.

*UNIT 3:* 0.2 m thick

Coarse sand; crudely bedded; lots of woody fragments. Lower contact is clear and subhorizontal.

*UNIT 4:* 0.15 cm thick

Woody peat; wood fragments approximately 2 cm thick and 10 – 20 cm wide; discontinuous lense shaped unit. Lower contact is sharp and trough shaped.

*UNIT 5:* 3 m thick

Small to medium pebble gravel; medium to large scale trough cross-bedding; unit generally fines upwards; some large pebble beds near base; both matrix filled and open worked gravels; unit is poorly exposed. Lower contact is sharp and undulatory.

*UNIT 6:* 1.4 m thick

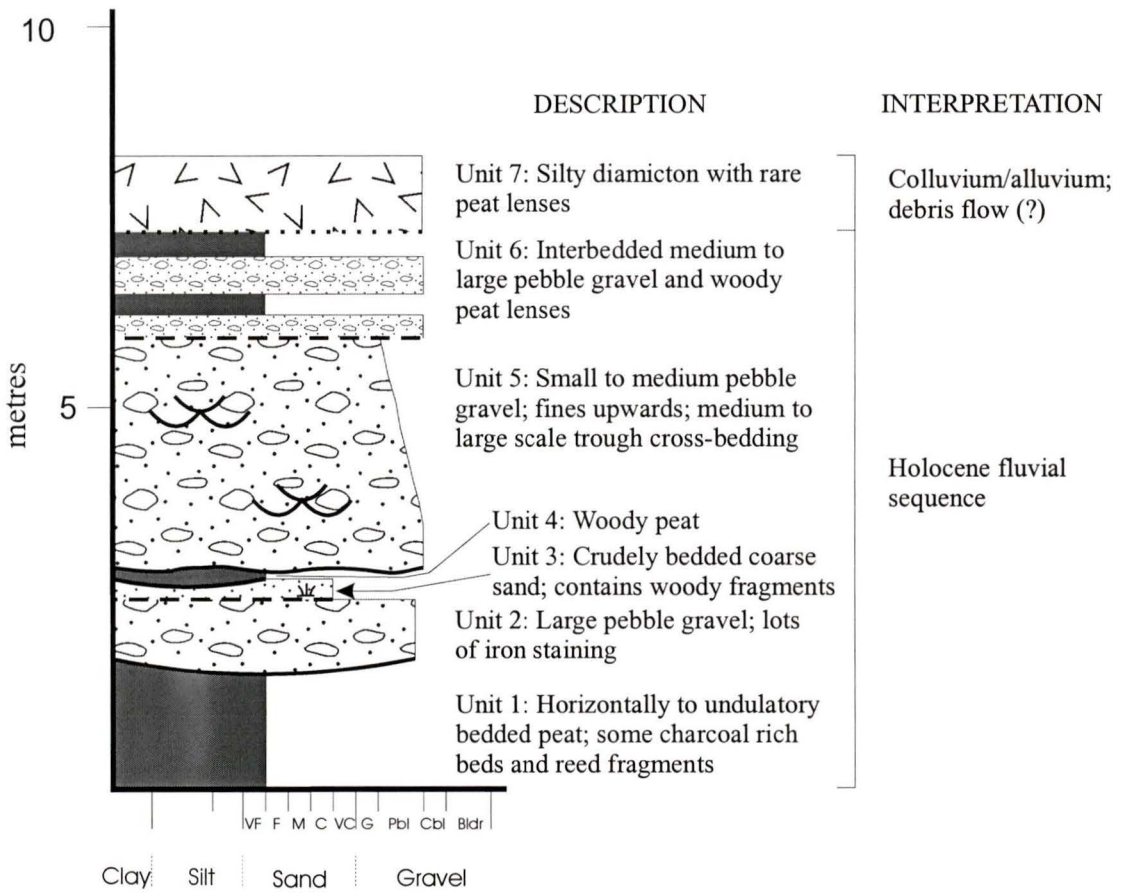
Interbedded medium to large pebble gravels and woody peat lenses; some sand lenses; peat lenses approximately 25 cm thick and 2 m wide; gravels same as in unit 5 below; unit has more or less subhorizontal stratification. Lower contact is clear and subhorizontal.

*UNIT 7:* 1 m thick

Silty diamicton with rare peat lenses; unit is laterally discontinuous, taken over by underlying unit in places. Lower contact is gradational.

**Note:** To the east peat beds with abundant shell fragments (gastropods ?) are present. Unit could rest on top of unit 7.

# SECTION DMA-9815



**SECTION DMA-9816**

Date: August 27, 1998
Location: Upper Cheslatta Falls, south of section DMA-9813 319150E, 5960300N (NAD 27)
Description: Described from bottom up

*UNIT 1*a: 0.25 m to 3 m thick

Diamicton, clast content varies from 15 – 40%; diamicton is well jointed; very dense and characterized by irregularly shaped lenses and beds of diamicton enriched with local bedrock lithologies. Numerous undulating clay-rich beds that are sheared; locally deformed inclusions of clay as well as irregular shaped beds of diamicton with very low coarse clast content; almost totally granules and small pebbles; bed contacts locally are steeply dipping (45°, 250°) but subhorizontal contacts are the norm. Some inclusions of brecciated bedrock, pebble to cobble size and lense shaped, with diamict. Bedrock below diamict has vertical fractures 2 – 10 m long and about 1 – 3 cm wide, they pinch out laterally; most prominent set oriented at 150°; fractures range from 150° - 165°; second set is oriented 45 – 50°. Fractures are infilled with a sandy gravel diamict (slightly coarser than adjacent diamict).

*UNIT 1b*: 2 m thick

Laterally unit 2 gravels have not scoured as deep allowing this unit to be preserved. It is a silty sand diamicton with some lenses and beds of fine sand, silt and clay. Diamicton is 1-1.5 m thick. Beds and lenses are up to 2.5 cm thick, several metres wide and contain numerous dropstones. In some silt and clay beds laminations are undisturbed. Lower contact is sharp and subhorizontal and marked by the first clay, silt or sand bed.

*UNIT 1*c*:* 3m thick

Silty sand diamicton that is massive, dense, well jointed with moderate fissility. It contains 15-20% clasts and has a gradational lower contact.

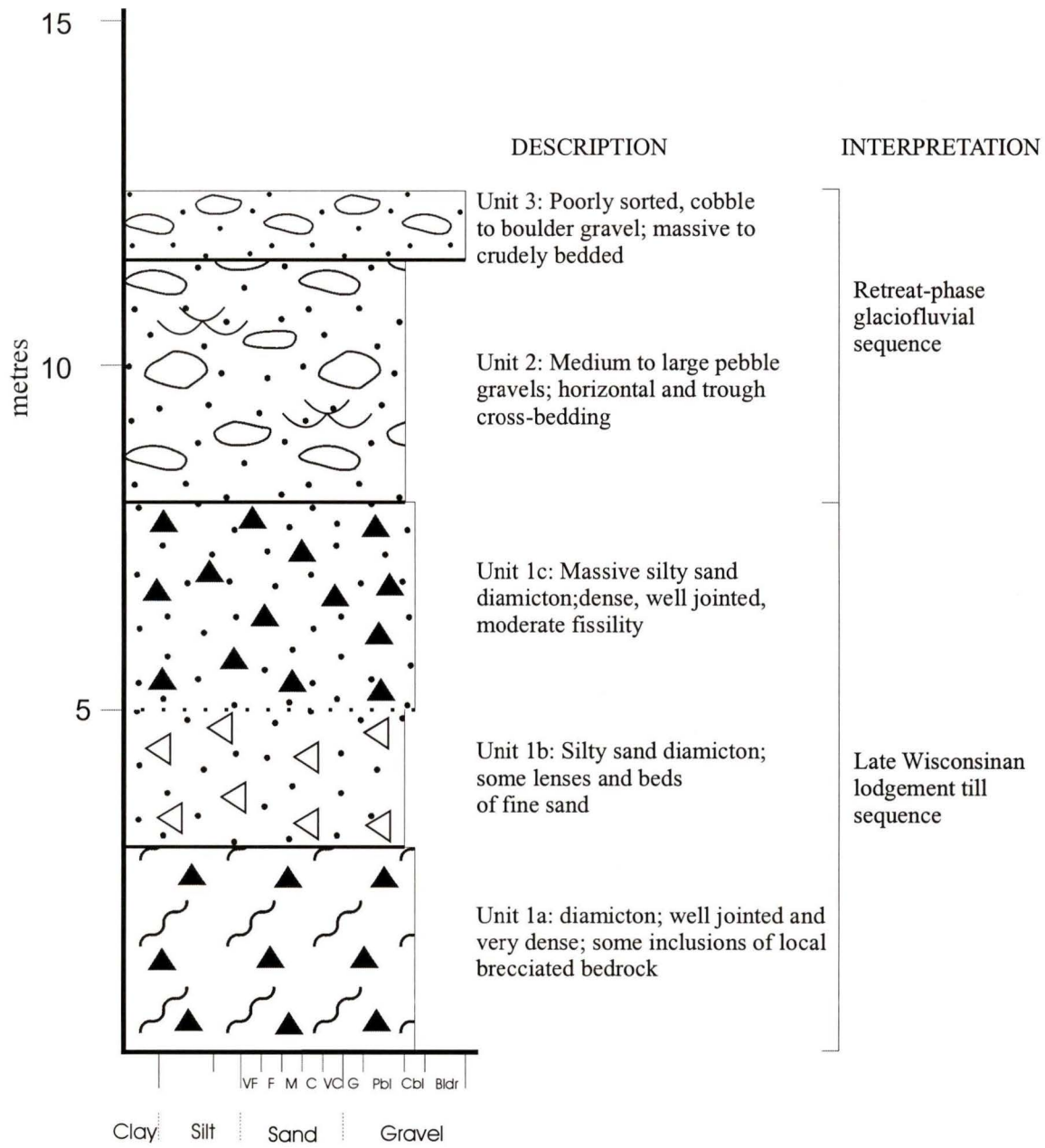
*UNIT 2:* 3.5 m thick

Medium to large pebble gravels, horizontally bedded. Medium to large scale trough cross-bedding. Clast supported and matrix filled, open worked gravel present. Some granule to small pebble gravel beds. All beds are poorly sorted. Lower contact is sharp (erosional).

*UNIT 3:* 1 m thick

Cobble to boulder gravel, poorly sorted, clast supported and matrix filled. Massive to very crudely bedded. Lower contact is sharp and subhorizontal.

# SECTION DMA-9816



**SECTION DMA-9817**

Date: August 28, 1998
Location: Shoreline along Ootsa Lake 317800E, 5945250N (NAD 27); 317740E, 5945610N (NAD 83)
Description: Section described from the bottom up

*UNIT 1:* 3 m thick

Interbedded granule to small pebble gravel and fine sand. Beds dip steeply (approximately 20°) towards the north and flatten out near the top of the unit and there are some medium too large pebble gravel lenses in the upper metre. Also some deep scour-fills in the upper part of the unit occur to the north. Laterally (northward, down dip) this unit is replaced by horizontally bedded laminated fine sand, silt, and rare clay laminations at least 2 m thick. Gravel beds are clast supported and open worked to matrix filled and 5 cm to 1 m thick. Sand beds are 2 to 10 cm thick, faintly laminated, with some medium sands. It has medium to large-scale trough cross bedding, low to moderate density. Rare syn-depositional, high angle normal faulting with displacement of 5 cm (towards north and south). Faults cross several beds (approximately 40 cm) near the base of this unit. One large fluid escape structure, 2 vertical m high x 10 – 20 cm wide shows both collapse and upward movement. Lower contact is covered.

*UNIT 2:* 1.5 m thick

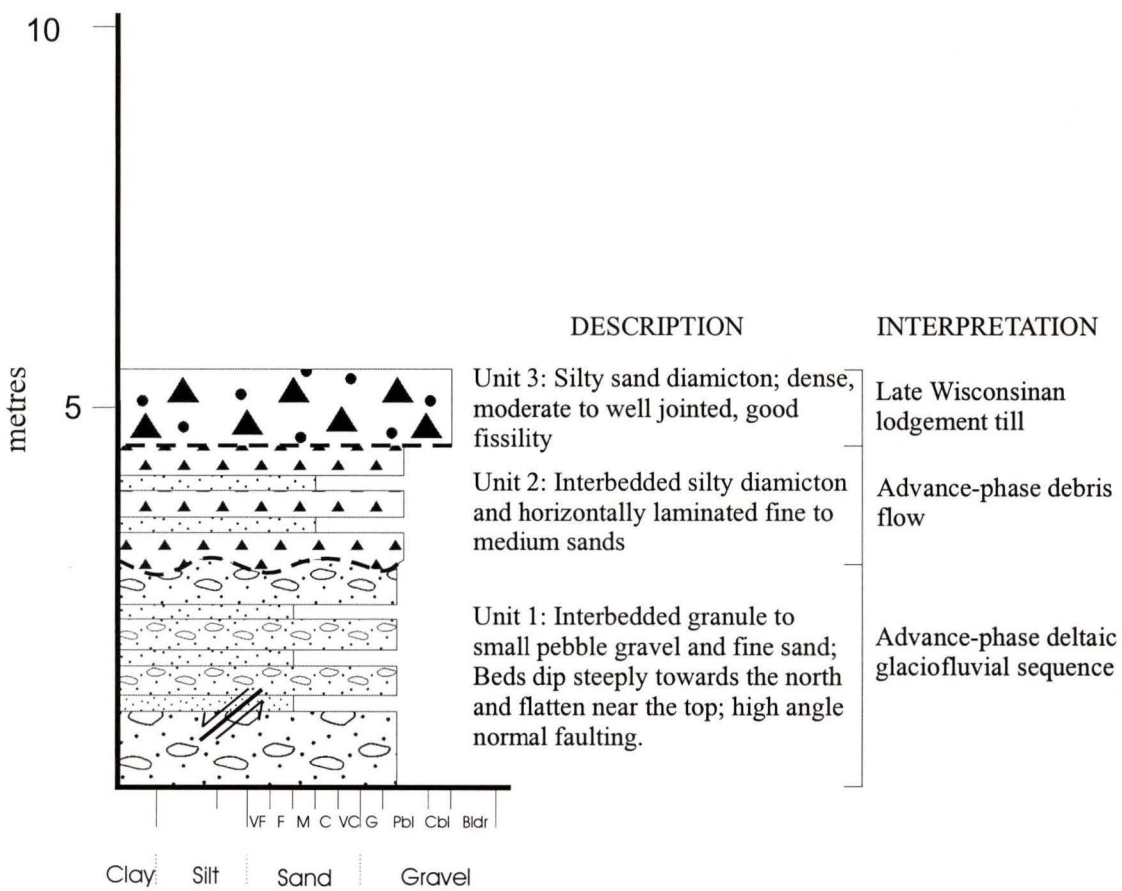
Interbedded silty diamicton and horizontally laminated fine to medium sands. Diamict has 10 – 40% gravel and beds are discontinuous and 30 – 35 cm thick. Sand beds are 15 – 20 cm thick. Lower contact is clear and undulatory.

*UNIT 3:* 1 m thick

Silty sand diamicton, dense, moderate to well jointed, fissile, 10 – 15% clasts, largest approximately 15 cm. Modal clast size is small to medium pebble. Lower contact is clear and horizontal.

*NOTE:* Bedded sand, silt and clay to the west of the section probably underlies unit 1. Lots of open worked gravel in section.

# SECTION DMA-9817



**SECTION DMA-9818**

Date: September 7, 1998
Location: Taken from a crevasse fill just south of NTS map sheet 93 F/12 on 93 F/5 309691E, 5931144N (NAD 27)
Description: Section described from the bottom up

*UNIT 1:* 0 – 2 m thick

Silty clay diamicton coarsening upwards into silty fine sand diamicton. Diamicton has approximately 20% clasts that are subrounded to subangular and striated clasts common. Good well developed vertical jointing with about 1 cm spacing and little or no vertical fissility. Lower contact is covered.

*UNIT 2:* 1.5 m thick

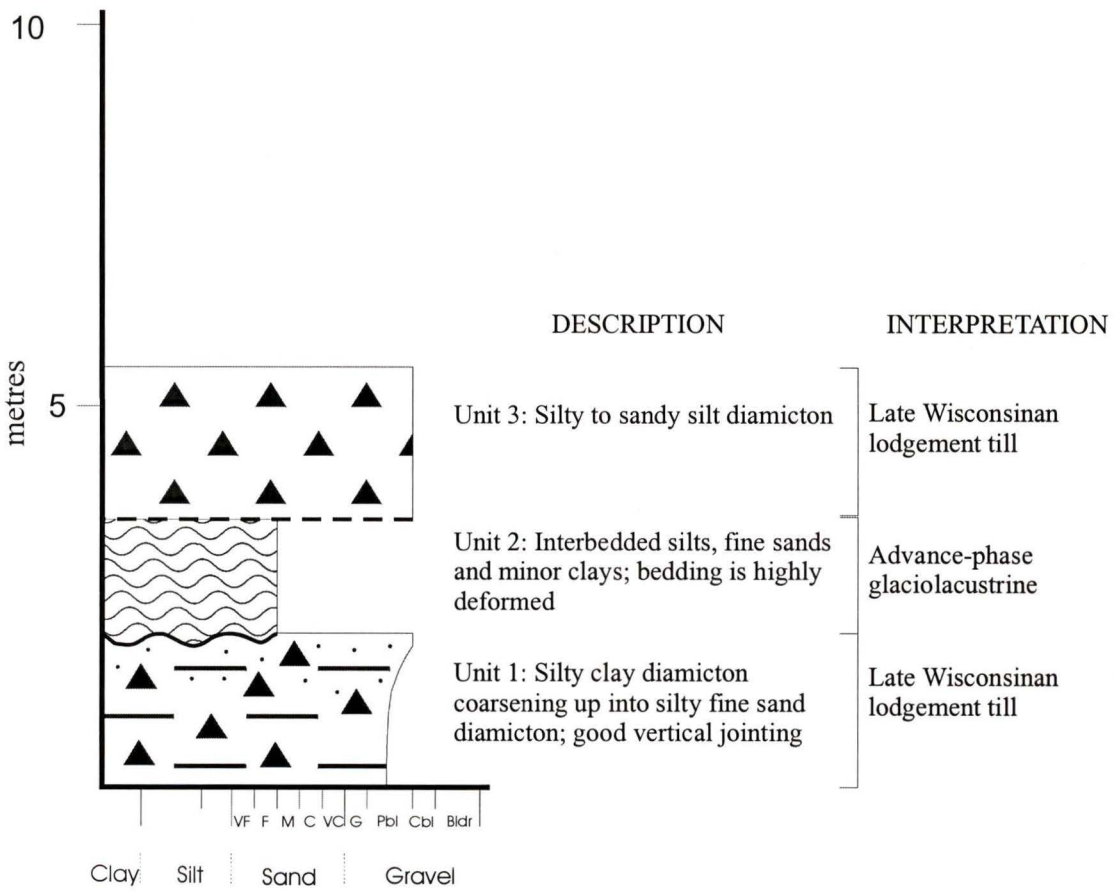
Interbedded silts, fine sand and minor clays. Upper half metre is mainly silts and clays. Unit beds vary from thinly laminated to thinly bedded. Thickest beds are 2 cm (sand beds) and bedding is highly deformed varying from near vertical to steeply dipping. Predominant dip and dip direction is 55° towards 350°; lots of overturned folds with a near vertical axial plane striking 070°. Unit is lense shaped and has an apparent dip of 25° towards NE (070°). Some near vertical oxidized zones and some high angle normal faults with displacement of 2 – 3 cm and steeply dipping towards the northeast. Laminae are sometimes only traceable for 20 cm then they become brecciated. Unit pinches out to the southwest. Lower contact is highly undulatory and sharp, showing "load-like" deformation; rare diamict injections from below approximately 20 cm into unit.

*UNIT 3:* 2 m thick

Silty to sandy silt diamicton. 20% clasts, lots of which are striated, clasts are subangular to subrounded and some are well rounded. Average clast size is large pebble. Lower contact is clear and dips northeast.

*NOTE:* Crevasse fill is slightly sinuous and trending approximately 350° (north). At section it trends 040° and varies from 350° - 075° (where it is visible). Vertical relief on top of ridge is 3 – 4 m. Section to north (25 m away) there is similar laminated silt and fine sand bed that is about 20 cm thick overlain and underlain by a silty clay diamicton. Slope steepness varies significantly on both sides of the ridge, west of section DMA-9818 slope is approximately 16° and to the east it is 30°. There is an absence of sand and gravel in the ride and it is approximately 18 m wide.

# SECTION DMA-9818



**SECTION DMA-9819**

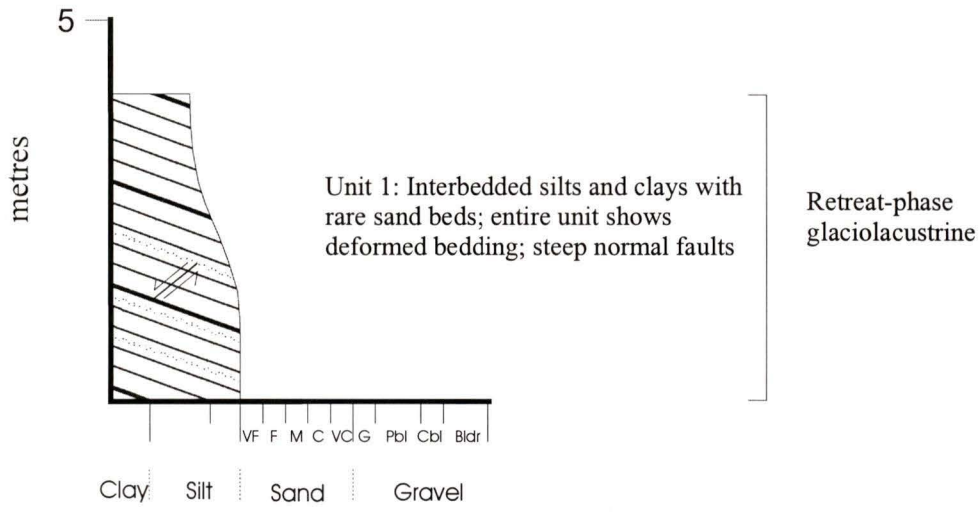
Date: September 12, 1998
Location: Ootsa Lake 310400E, 5954380N (NAD 27); 310310E, 5954600N (NAD 83)
Description: Section described from the bottom up

*UNIT 1:* 3 – 4 m thick

Interbedded silts and clays with rare sand beds. Silt beds are generally 5 cm thick but vary from 2 –15 cm. Clay beds vary from 0.5 – 3 cm and are generally 1 cm thick. Sand beds are medium to coarse sand and about 0.5 – 1 cm thick. Silt and clay beds fine upward and silts sharply overlie clays. Silts have thin (1 – 2 mm) internal laminations showing bedding parallel laminae, while clays have thick (2 – 5 mm) internal lamination. Surface relief around section is 3 – 4 m with large hummocks 20 – 50 m wide across. Entire unit shows deformed bedding. In one hummock beds dip steeply (20°) towards 350°, in another hummock beds are anticlinally folded with axial plane near center of hummock. On north side of this hummock beds dip 60° while on the south side beds are mainly horizontal to gently folded. Steep normal faults also dipping (56°) southward (150°) towards hollow. Near vertical faults were also on the south side of this hummock but sediment was to deformed to decipher displacement. Fault zone juxtaposes steeply dipping beds with subhorizontal beds. Locally, clay beds show shear surfaces (generally N – S oriented slicks). Also local soft sediment deformation structures (small-scale load structures and overturned folds) appear to be syndepositional except for some overturned folds that may relate to collapse towards hollows. Silts are white in colour and clays are light brown.

*NOTE:* Wave cut bench below section exposes diamicton.

# SECTION DMA-9819



## SECTION 97-PMA-178

*** Note : This section described by Dr. Alain Plouffe from the Geological Survey of Canada**
Location: 321700E, 5957700N (Lat.: 53.7394, Long.: -125.703)
Description: Section described from bottom up

*UNIT 1:* 10 m thick

Maroon diamicton, very well compacted and dry; loamy; the upper 3 m is clayey-loamy and contains less clasts; clasts are sub-angular and vary from pebbles to boulders; some are striated. Dominant pebble lithologies are volcanic rocks with a much lesser amount of granodiorite. Interpretation: till of the Fraser Glaciation.

*UNIT 2:* 0.6 m thick

Poorly sorted, clast-supported pebbly to bouldery gravel; massive; sandy matrix.This unit as well as the overlying ones is only exposed at the SSE end of the section. Lower contact is erosional. Interpretation: retreat-phase glaciofluvial sediments.

*UNIT 3*: 1.5 m thick

Fine sand, silt and clay parallel bedded; well bedded and laminated; well sorted; rich in plant fragments; this unit contains few pebbly gravel interbeds; no sample was submitted for radiocarbon dating given the potential chance of contamination by modern organic rootlets on the section. Abrupt lower contact. Interpretation: alluvial sediments

Unit 4 : 0.3 m thick

Sandy diamicton, massive, matrix supported, sub-angular clasts. Erosional lower contact. Interpretation: debris flow (colluvium).

*UNIT 5*: 1.2 m thick

Peat, abrupt contact. Interpretation: Holocene organic matter accumulation

## SECTION 97-PMA-179

*** Note : This section described by Dr. Alain Plouffe from the Geological Survey of Canada**
Location: 323975E, 5955650N (Lat.: 53.7217, Long.: -125.668)
Description : Section described from the bottom up.

*UNIT 1*: 9 m thick

Pebble to cobble gravel; clast supported; horizontal and parallel bedded; the unit generally fines upward from cobble gravel at base to pebble gravel near the top of unit; moderately sorted; a few thin sand lenses (thickest one: 30 cm) near the base of the unit. Interpretation: advance-phase glaciofluvial sediments.

*UNIT 2 :* 2.5 m thick

Pebble gravel with fine sand interbeds; pebbles vary in diameter from 3 to 4 cm; parallel and cross-bedded; paleocurrent to the NE according to cross-stratification; numerous faults in this unit, dominantly reverse and some normal faults. Lower contact is gradational. Interpretation: advance-phase glaciofluvial or proximal glaciolacustrine sediments.

*UNIT 3:* 5 m thick

Diamicton, matrix-supported, massive, well compacted, loamy; contains striated clasts; one large boulder 1 metre in diameter. Lower contact is erosional. Interpretation: till of the Fraser Glaciation

Note: Can the fining upward sequence underneath the till reflect the formation of an advance-phase glacial lake ???

# APPENDIX C
# LANDSLIDE CLASSIFICATION AND TYPES

**Classification:** (Varnes 1978)

| 7 TYPE OF MOVEMENT | | | 7.1 TYPE OF MATERIAL | | |
|---|---|---|---|---|---|
| | | | 7.2 BEDROCK | 7.3 ENGINEERING SOILS | |
| | | | | Predominantly Coarse | Predominantly fine |
| Falls | | | Rock fall | Debris fall | Earth fall |
| Topples | | | Rock topple | Debris topple | Earth topple |
| Slides | Rotational | Few Units | Rock slump | Debris slump | Earth slump |
| | Translational | Few Units | Rock block slide | Debris block slide | Earth block slide |
| | | Many Units | Rock Slide | Debris slide | Earth slide |
| Lateral Spreads | | | Rock Spread | Debris spread | Earth spread |
| Flows | | | Rock flow (deep creep) | Debris flow (soil creep) | Earth flow (soil creep) |
| Complex | | | Combination of two or more principal types of movement. | | |

**Slope Movement Types:** Modified after Cruden and Varnes (1996). See next page for diagrams illustrating each type.

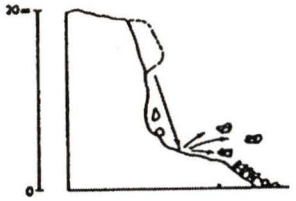
Falls: Detachment of material (soil or rock) from a steep slope along a surface on which little or no shear displacement takes place. Material moves mainly through the air by falling, bouncing and/or rolling.

Topples: Forward rotation of a mass of soil or rock out of a slope. Rotation occurs on a point or axis below the center of gravity of the displaced mass.

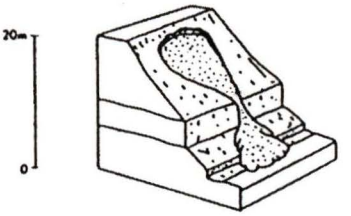
Slides: Downslope movement of a soil or rock mass occurring dominantly on surfaces of rupture or on relatively thin zones of intense shear strain. Slumps have curved or concaved surfaces of rupture while translational slides rupture along planar surfaces.

Lateral Spreads: Extension of a cohesive soil or rock mass combined with a general subsidence of the fractured mass of cohesive material into softer underlying material.

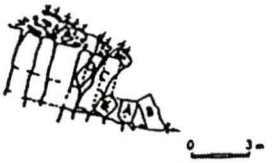
Flows: Spatially continuous movement in which surfaces of shear are short-lived, closely spaced, and usually not preserved.



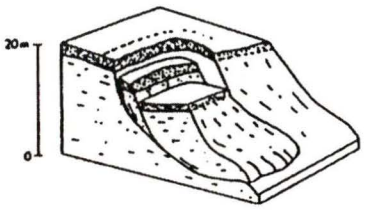

Fall



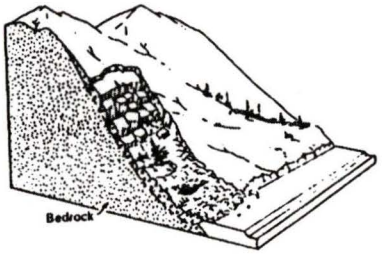

Flow



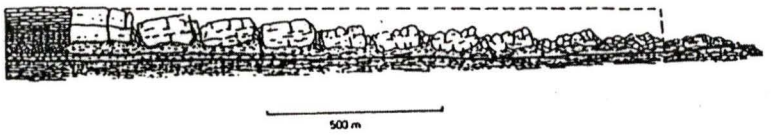

Topple




Rotational Slide




Translational Slide




Lateral Spread

Diagrams of the 6 different types of slope movements as described in the chart on the preceding page (after Cruden and Varnes 1996).

APPENDIX D
SLOPE MOVEMENT CAUSES (Cruden and Varnes 1996)

| Causes | Factors Involved |
|---|---|
| **Geological** | Weak materials |
| | Sensitive materials |
| | Weathered materials |
| | Sheared materials |
| | Jointed or fissured materials |
| | Adversely oriented structural discontinuity (bedding, schistosity, etc.) |
| | Adversely oriented structural discontinuity (fault, unconformity, contact, etc.) |
| | Contrast in permeability |
| | Contrast in stiffness (stiff, dense material over plastic materials) |
| | |
| **Morphological** | Tectonic or volcanic uplift |
| | Glacial rebound |
| | Fluvial erosion of slope toe |
| | Wave erosion of slope toe |
| | Glacial erosion of slope toe |
| | Erosion of lateral margins |
| | Subterranean erosion (solution, piping) |
| | Deposition loading slope or its crest |
| | Vegetation removal (by forest fire, drought) |
| | |
| **Physical** | Intense rainfall |
| | Rapid snow melt |
| | Prolonged exceptional precipitation |
| | Rapid drawdown (of floods and tides) |
| | Earthquake |
| | Volcanic eruption |
| | Thawing |
| | Freeze-and-thaw weathering |
| | Shrink-and-swell weathering |
| | |
| **Human** | Excavation of slope or its toe |
| | Loading of slope or its crest |
| | Drawdown (of reservoirs) |
| | Deforestation |
| | Irrigation |
| | Mining |
| | Artificial vibration |
| | Water leakage from utilities |

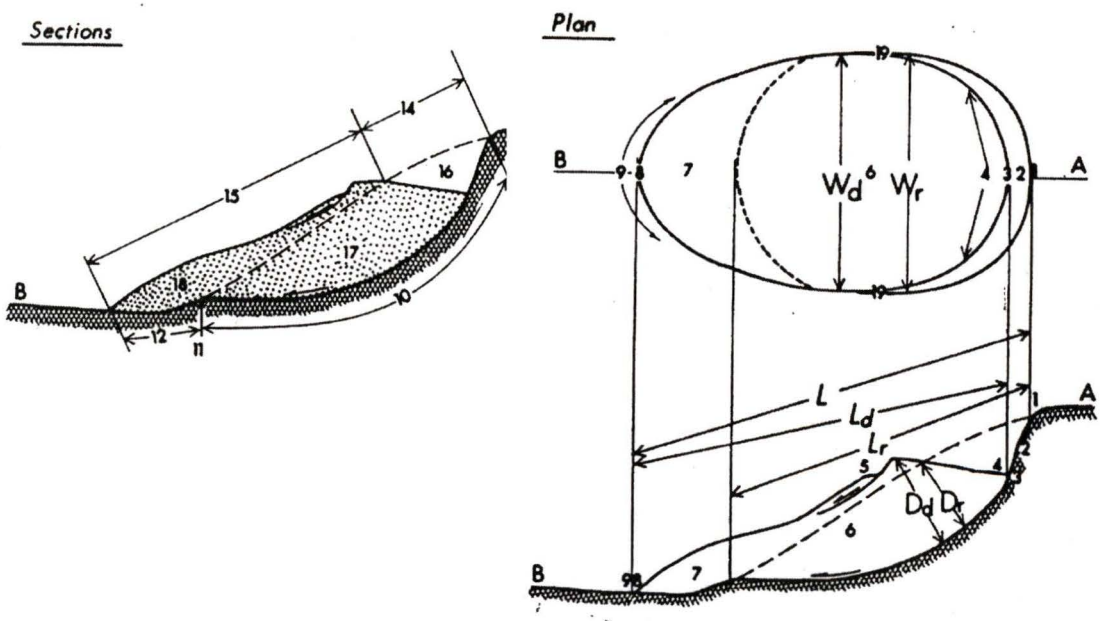
# APPENDIX E
# LANDSLIDE NOMENCLATURE

**Landslide Features** (IAEG Commission on Landslides 1990)

| Feature | Description |
|---|---|
| Crown (1) | Undisplaced material that is in place and adjacent to the highest parts of the main scarp. |
| Main scarp (2) | Steep surface on the undisturbed ground at the upper edge of the landslide. Caused by movement of slide material away from undisturbed ground. |
| Top (3) | Highest point of contact between displaced material and main scarp. |
| Head (4) | Upper part of landslide along the contact between displaced material and main scarp. |
| Minor scarp (5) | Steep surface on displaced material of the landslide that is produced by differential movements within the sliding mass. |
| Main body (6) | Part of the displaced material of a landslide that overlies the surface of rupture between the main scarp and the toe of the surface of rupture. |
| Foot (7) | Portion of landslide that has moved beyond the toe of the surface of rupture and overlies the original ground surface. |
| Tip (8) | Point of the toe farthest from the top of the landslide. |
| Toe (9) | Lower, usually curved margin of the displaced material of a landslide, it is the most distant from the main scarp. |
| Surface of rupture (10) | Projection of the main scarp surface under the displaced material of a landslide. |
| Toe of surface of rupture (11) | Intersection (sometimes buried) between the lower part of the surface of rupture of a landslide and the original ground surface. |
| Surface of separation (12) | Part of the original ground surface overlain by the foot of the landslide. |
| Displaced material (13) | Material displaced from its original position on the slope by movement in the landslide. |
| Zone of depletion (14) | Area of the landslide within which the displaced material lies below the original ground surface. |
| Zone of accumulation (15) | Area of the landslide within which the displaced material lies above the original ground surface. |
| Depletion (16) | Volume bounded by the main scarp, the depleted mass and the original ground surface. |
| Depleted mass (17) | Part of the displaced material which overlies the rupture surface but underlies the original ground surface. |
| Accumulation (18) | Volume of the displaced material which lies above the original ground surface (Cruden 1980). |
| Flank (19) | Side of the landslide. |

**Landslide Dimensions** (IAEG Commission on Landslides 1990)

| Dimension | Description |
|---|---|
| $L_r$ | Length of rupture surface. Distance from toe of the surface of rupture to the crown above. |
| $L_d$ | Length of displaced mass. Distance from tip to the top. |
| L | Total length. Distance from tip to top. |
| $W_r$ | Width of rupture surface. Maximum width between the flanks of the landslide perpendicular to the length ($L_r$). |
| $D_r$ | Depth of the rupture surface. Maximum depth of rupture surface below the original ground surface measured perpendicular to the original ground surface. |
| $D_d$ | Maximum depth of displaced mass, measured perpendicular to the surface of displaced material. |
| $W_d$ | Width of displaced mass. The maximum breadth of the displaced mass perpendicular to the length, $L_d$. |




Cross-section and plan view showing the features and dimensions of a simple slope movement. Numbers and letters from diagrams correspond to features and dimensions described in the preceding tables

# APPENDIX F
# LANDSLIDE ACTIVITY (WP/WLI 1993)

| Activity | Types |
|---|---|
| State | Active |
| | Reactivated |
| | Suspended |
| | Inactive Dormant<br>Abandoned (Hutchinson and Gostelow 1976)<br>Stabilized<br>Relict |
| Distribution | Retrogressing |
| | Advancing |
| | Widening |
| | Confined |
| | Enlarging |
| | Diminishing |
| | Moving |
| Style | Complex |
| | Composite |
| | Multiple |
| | Successive |
| | Single |

**State of Activity:** Explains what is known about the timing of movements.

Types:

**Active:** Slope movements that are currently moving. Morphological features have not been modified by weathering or erosion and are sharp and well defined.

**Reactivated:** Slope movement that becomes active after a period of inactivity.

**Suspended:** Slope movement that has failed during the same year and is not moving at the present time. Described by Varnes (1978).

**Inactive:** Slope movement that is older than one year.

- *Dormant:* Presently not moving, but causes for movement still remains.
- *Abandoned:* Occurs when the cause(s) acting on a slope movement change eg. A river that originally was eroding along the toe of a slump changes course.
- *Stabilized:* Slope movement that has been treated with mitigative techniques.
- *Relict:* Old slope movements that developed thousands of years ago under different geomorphological and climatic conditions. Cannot repeat themselves presently. May be covered by vegetation.

**Distribution of Activity:** Descriptive terms used to describe where the landslide is moving.

Types:

**Retrogressing:** When rupture surface extends in the opposite direction to the movement of displaced material.

**Advancing:** When rupture surface extends in direction of movement.

**Widening:** When rupture surface extends at one or both lateral margins.

**Confined:** Have visible scarp but no rupture surface in foot of displaced mass (Hutchinson 1988).

**Enlarging:** When rupture surface of landslide is enlarging in two or more directions.

**Diminishing:** When the displaced material of a landslide decreases in volume.

**Moving:** Slope movements whose displaced material continues to move but whose rupture surfaces show no visible changes.

**Style of Activity:** Describes how different movements contribute to a slope movement.

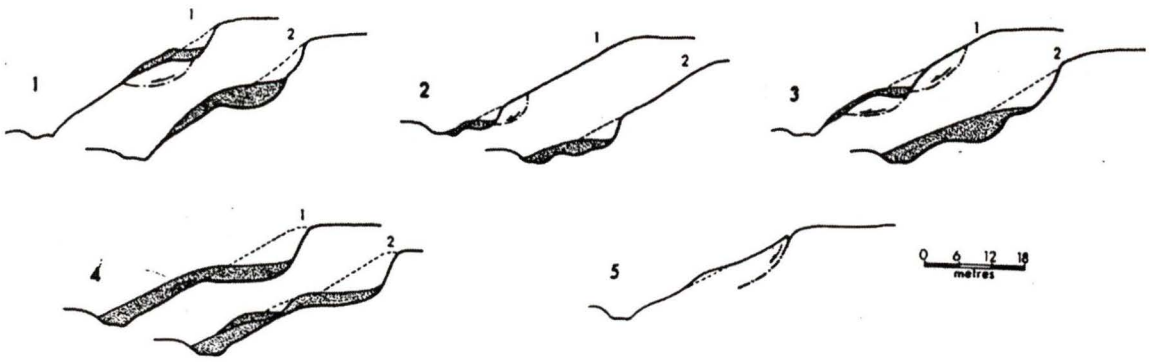
**Complex:** Describes a slope movement that exhibits at least two types of movement. Limit to movements in which types are in sequence.

**Composite:** Slope movements in which different types of movement occur in different areas of the displaced mass

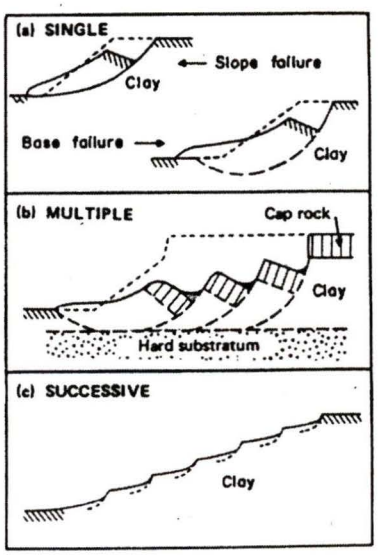
**Multiple:** Slope movements where the same type of movement is repeated. First described by Hutchinson (1968).

**Successive:** Possess the same type of movement of an earlier failure except it does not share the displaced material or the rupture surface.

**Single:** Consists of a single movement of displaced material.




Cross-sections through slope movements showing various distributions of activity. 1) Advancing 2) Retrogressing 3) Enlarging 4) Diminishing and 5) Confined (WP/WLI 1993).




Cross-sections showing various styles of activity that commonly occur in slumps (Varnes 1978).

# APPENDIX G
# LANDSLIDE PROFILE DMA-98-PA

Date: August 23, 1998

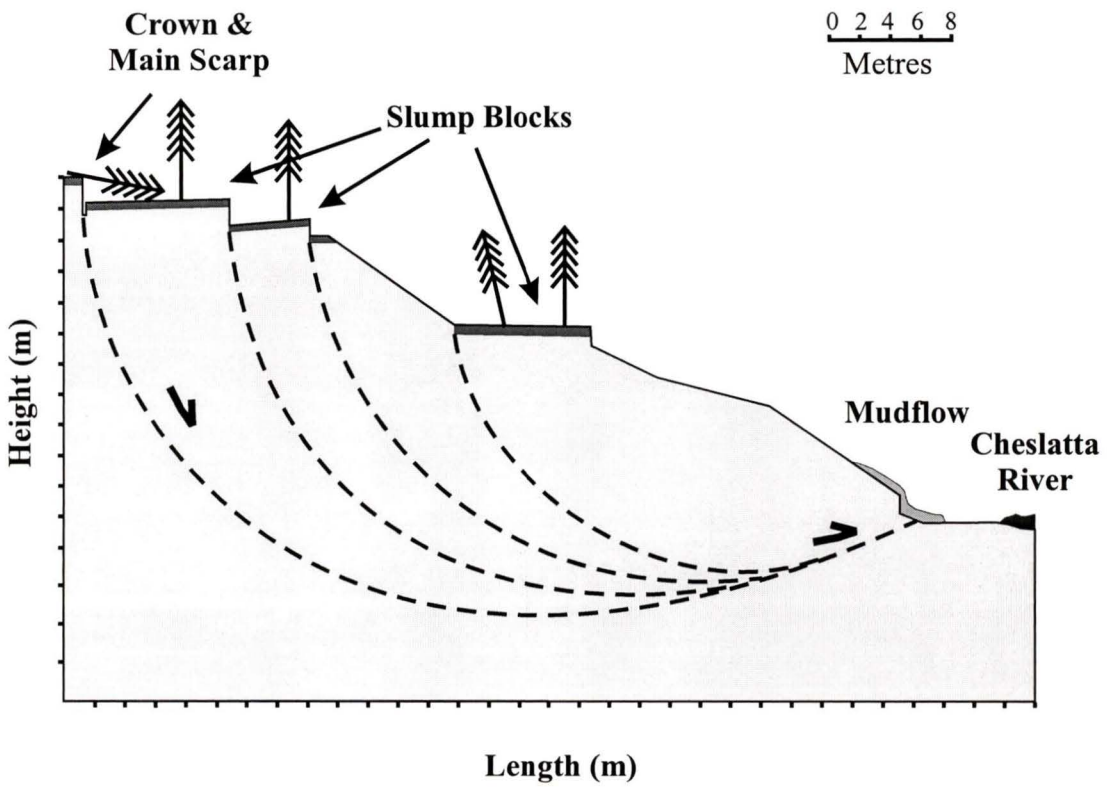
Location: Slump 2 along Cheslatta River 323929E, 5955322N

Description: Profile described from the top down, oriented at 041°

| Profile Start Position | Profile Stop Position | Slope Distance (m) | Percent Grade | Slope (°) | Field Notes |
|---|---|---|---|---|---|
| PA0 | PA1 | 1.3 | - 12 | - 6.8 | Stable ground above slide; natural forest floor preserved. |
| PA1 | PA2 | 2.4 | Vertical Drop | Vertical | Drop down main scarp; drop to top of first slump block is 1.7 m; fracture extends another 0.7 m below slump block; fracture is approximately 40 cm wide. One meter of poorly sorted large pebble gravel capped by very coarse granule sand overlying silty clay diamicton is exposed in face. |
| PA3 | PA3 | 9.2 | 2 | 1.1 | Upper surface of slump block; natural forest floor preserved (mosses, shrubs and soil); trees standing vertical; spalled trees from above are lying on surface |
| PA3 | PA4 | 1.6 | Vertical Drop | Vertical | Material in face is sand and gravel; slump covered. |
| PA4 | PA5 | 4.95 | 8 | 4.6 | Natural forest floor preserved (mosses and small shrubs); trees standing straight; Young pine trees approximately 14 years old are growing; new trees are growing straight. |
| PA5 | PA6 | 1 | Vertical Drop | Vertical | Material exposed in face is sand and gravel. |
| PA6 | PA7 | 0.55 | - 5 | - 2.9 | Very small slump block; natural forest floor preserved (mosses); small poplar tree growing. |
| PA7 | PA8 | 10.5 | - 69 | - 34.6 | Slump covered slope; gravelly slump material; very small blocks of preserved forest floor on slope; large pebbles and small cobbles at base of slope. |

| Profile Start Position | Profile Stop Position | Slope Distance (m) | Percent Grade | Slope (°) | Field Notes |
|---|---|---|---|---|---|
| PA8 | PA9 | 8.7 | - 3 | - 1.7 | Upper surface of slump block; natural forest floor preserved; most trees standing vertical, some lean back ( 8° - 13°) toward main scarp. |
| PA9 | PA10 | 1.1 | Vertical Drop | Vertical | Approximately 65 cm of large pebble gravel and very coarse to granule gravel over silty sand diamicton. |
| PA10 | PA11 | 4.6 | - 48 | - 25.6 | Slump covered slope |
| PA11 | PA12 | 7.2 | - 27 | - 15.1 | Wet areas along this portion; some tension cracks visible; mostly mineral soil. |
| PA12 | PA13 | 10.5 | - 67 | - 33.8 | Mineral soil exposed along slope; small earthflows initiated down slope; texturally earthflows are sandy mud. |
| PA13 | PA14 | 1.1 | Vertical Drop | Vertical | |
| PA14 | PA15 | 1.6 | - 39 | - 21.3 | |
| PA15 | PA16 | 4.7 | 0 | 0 | Distance to water level. |

**PROFILE DMA-98-PA**
**(SLUMP 2)**



# APPENDIX G
# LANDSLIDE PROFILE DMA-98-PB

Date: August 23, 1998

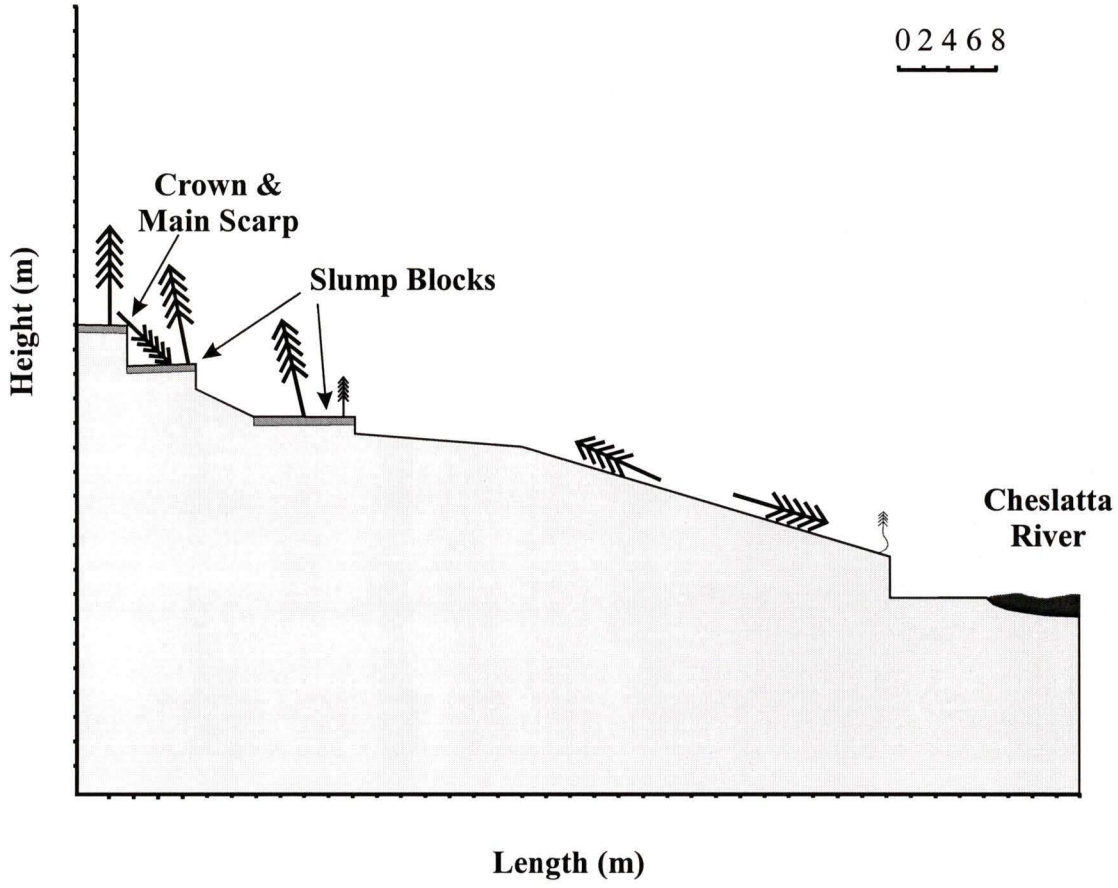
Location: Slump 2 along Cheslatta River 323929E, 5955322N

Description: Profile described from the top down, oriented at 060°

| Profile Start Position | Profile Stop Position | Slope Distance (m) | Percent Grade | Slope (°) | Field Notes |
|---|---|---|---|---|---|
| PB0 | PB1 | 4 | - 3 | - 1.7 | Forested area, stable ground; trees standing straight; no cracks or fractures present in ground. |
| PB1 | PB2 | 3.3 | Vertical Drop | Vertical | Material in face is silty sand diamicton; high density, well jointed, moderate to strong fissility; clasts are small to medium pebble; some large pebbles; largest clast size is 15 – 20 cm; good basal till; spalled trees abundant along face. |
| PB2 | PB3 | 5.6 | 4 | 2.3 | Upper surface of slump block; two large Lodgepole pine trees lean back towards main scarp; trees lean 11° and 12° from vertical; spalled trees from above rest on slump block; preserved forest floor (soil horizons, moss and small shrubs) |
| PB3 | PB4 | 2 | Vertical Drop | Vertical | Material exposed in face is silty sand diamicton; well jointed, moderate to strong fissility; spalled trees along face from slump block and crown. |
| PB4 | PB5 | 5.2 | - 49 | - 26.1 | Slumped surface below vertical drop; made of loose gravel and diamict; some fallen trees on its surface. |
| PB5 | PB6 | 8.4 | - 0.5 | - 0.28 | Upper surface of slump block; preserved forest floor (soil, mosses, shrubs); some trees lean 13° and 5° back into slope; other small trees growing vertical. |

| Profile Start Position | Profile Stop Position | Slope Distance (m) | Percent Grade | Slope (°) | Field Notes |
|---|---|---|---|---|---|
| PB6 | PB7 | 1.3 | Vertical Drop | Vertical | Material in face is silty sand diamicton, well jointed with moderate to strong fissility; base drop is slump covered. |
| PB7 | PB8 | 13.8 | - 7.5 | - 4.3 | Area has very undulating topography; appears to be numerous small slump blocks with vertical faces and slopes of various size and grade; blocks range from 1-2 m wide and have vertical to sloping faces less than 1 meter long; wet areas occur in depressions; many fallen trees; some trees have fallen back towards main scarp and forward toward the river; material is loosely consolidated diamict |
| P8 | PB9 | 32 | - 30 | - 16.7 | Trees have fallen back toward main scarp and forward toward river; rare small slump blocks visible; along contact between PB9 and PB10 were trees (coniferous) that had bow shaped bases; tension cracks visible; appears new failures are starting, new scarps present. |
| PB9 | PB10 | 3.2 | Vertical Drop | Vertical | Till along face has been heavily washed by fluctuating river water levels, it is extremely hard and cemented; water level scours visible along surface. |
| PB10 | PB11 | 6.7 | 0 | 0 | Shoreline area |

**PROFILE DMA-98-PB**
**(SLUMP 2)**



# APPENDIX G
# LANDSLIDE PROFILE DMA-98-PC

Date: August 24, 1998

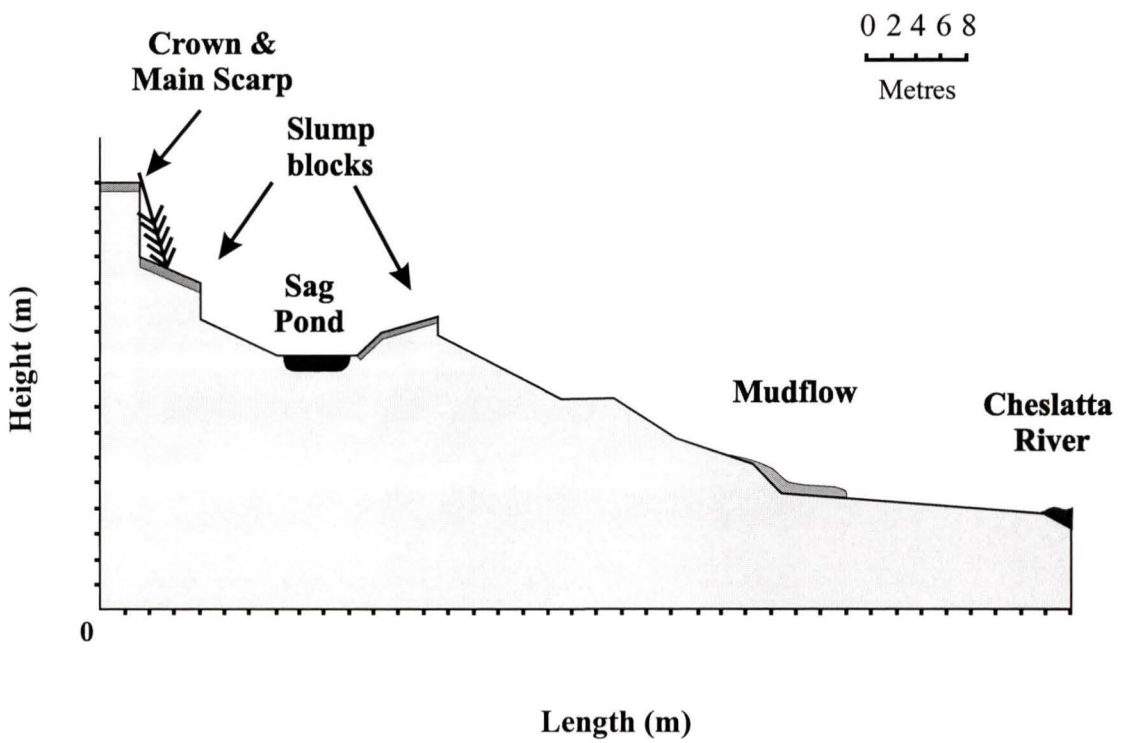
Location: Slump 2 along Cheslatta River 323929E, 5999322N

Description: Profile described from the top down, oriented at 147°

| Profile Start Position | Profile Stop Position | Slope Distance (m) | Percent Grade | Slope (°) | Field Notes |
|---|---|---|---|---|---|
| PC0 | PC1 | 3 | 0 | O | Level surface above crown and main scarp; spalled trees occur along edge of PC1. |
| PC1 | PC2 | 4-6 | Vertical Drop | Vertical | Material is till overlain by approximately 1 meter of poorly sorted large pebble gravel capped by horizontally bedded fine to coarse sands. |
| PC2 | PC3 | 5.5 | - 43 | - 23.3 | Upper surface of slump block; to the west it splits into 2 smaller blocks; some spalled trees from above; one tree standing vertical. |
| PC3 | PC4 | 3.2 | Vertical Drop | Vertical | Material exposed in face appears to be till. |
| PC4 | PC5 | 7.2 | - 46 | - 24.7 | Slumped surface below vertical drop; numerous spalled trees on surface. |
| PC5 | PC6 | 6 | 0 | 0 | Sag pond, less than 1 m deep; approximately 1 meter on both sides of pond was damp (not covered by water). |
| PC6 | PC7 | 2.5 | 100 | 45 | Start to climb up upper surface of large rotational slump block; many trees have spalled back towards main scarp; slump block is steeply sloping. |
| PC7 | PC8 | 5 | 29 | 16.2 | Upper surface of slump block; trees spalling back into slope. |
| PC8 | PC9 | 1.8 | Vertical Drop | Vertical | Vertical drop along front of slump block; note: back of this slump block is failing into sag pond. |

| Profile Start Position | Profile Stop Position | Slope Distance (m) | Percent Grade | Slope (°) | Field Notes |
|---|---|---|---|---|---|
| PC9 | PC10 | 11.5 | - 50 | - 26.5 | Slump covered slope with some tension cracks; large slump block appears to be pooling water of sag pond. |
| PC10 | PC11 | 3.5 | 3 | 1.7 | Flatter surface with small wet areas; wet areas could be partly responsible for initiating mudflows; seepage from sag pond may have caused wet areas; lots of tension cracks. |
| PC11 | PC12 | 6.5 | - 61 | - 31.2 | 4.5 m vertical face to west; mudflow unit present along slope; unit is localised, probably to where drainage is trapped; mudflow has a sandy mud texture; actively failing surface; slicks present close to face with a dip of 69 and dip direction of 070. |
| PC12 | PC13 | 6 | - 31.5 | - 17.5 | All exposed mineral soil; lots of tension fractures up to 50 cm wide and several meters long; some logs buried by approximately half a meter of sediment |
| PC13 | PC14 | 3.5 | - 97 | - 44.1 | Over half of face is below high water mark. |

**PROFILE DMA-98-PC**
**(SLUMP 2)**



# APPENDIX G
# LANDSLIDE PROFILE DMA-98-PD

Date: August 26, 1998

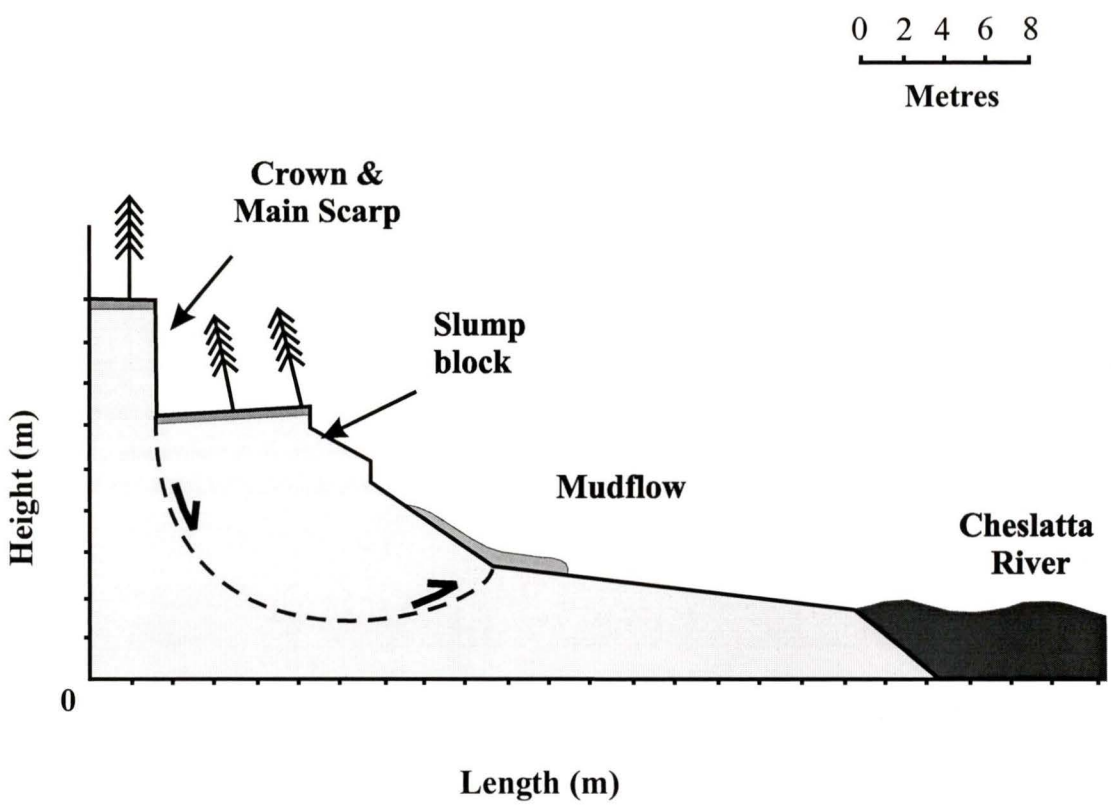
Location: Slump 1 along Cheslatta River 302831E, 5962277N

Description: Profile described from the top down, oriented at 332

| Profile Start Position | Profile Stop Position | Slope Distance (m) | Percent Grade | Slope (°) | Field Notes |
|---|---|---|---|---|---|
| PD0 | PD1 | 3 | 0 | 0 | Level ground above slide; natural surface and forest floor preserved; trees are alders, pine and spruce. |
| PD1 | PD2 | 5.8 | Vertical Drop | Vertical | Some spalled trees along top of drop; material in face is silty sand diamicton; diamicton is very sandy with a high density; has small gravel pods and medium to coarse sand lenses; material could be the same as unit 5 in section DMA-9810; diamicton is capped by lake sediments; bottom of drop is slump covered with loose diamict and sand. |
| PD2 | PD3 | 7.4 | 8 | 4.6 | Upper surface of slump block; natural forest floor preserved; poplar trees lean back into slope at 39 and 5; pine trees leaning 20 and 30; some trees spalled downslope. |
| PD3 | PD4 | 1.3 | Vertical Drop | Vertical | Exposed material is massive silts with some granules and small pebbles (unit 6 DMA-9810?); silts are well jointed and fissile. |
| PD4 | PD5 | 2.5 | - 48 | - 25.6 | Slump covered slope; mostly mineral soil exposed; some tension cracks along edge of vertical drop. |
| PD5 | PD6 | 1 | Vertical Drop | Vertical | In places drop is as much as 1.5 - 2.0 m; drop is covered in slump material. |

| Profile Start Position | Profile Stop Position | Slope Distance (m) | Percent Grade | Slope (°) | Field Notes |
|---|---|---|---|---|---|
| PD6 | PD7 | 7.3 | - 68 | - 34.2 | Two large mudflows visible along this slope; flows are a muddy sand and are quite fluid. |
| PD7 | PD8 | 16.9 | - 11 | - 6.3 | Shoreline area covered by high water levels. |

**PROFILE DMA-98-PD**
**(SLUMP 2)**



Appendix H - Grain Size Characteristics from Lateral Furrows and Crescentic Scours.

| | | % wt. csd | % wt. msd | % wt. fsd | % wt. vfsd | % wt. mud |
|---|---|---|---|---|---|---|
| **DMA-FS-1A** | **Depression along side of streamlined landform** | | | | | |
| 0-5 cm | Natural forest soil, moss covered | | | | | |
| 5-25 cm | Large pebble to small cobble gravel; clast supported; 60-70% gravel; SA-SR | | | | | |
| 25-55 cm | Small pebbly sand, minor silt; sample taken at 35-40 cm | 21.57 | 14.97 | 20.56 | 15.48 | 27.41 |
| 55-70 cm | Silty sand diamicton; high density; some clay; sample taken at 50-65 cm | 27.91 | 16.70 | 18.39 | 14.38 | 22.62 |
| | | | | | | |
| **DMA-FS-1B** | **Depression along side of streamlined landform** | | | | | |
| 0-10 cm | Natural forest soil; decomposed woody material | | | | | |
| 10-30 cm | 90% large pebble to large cobble gravel; clast supported | | | | | |
| 30-50 cm | Small pebbly sand with minor silt; moist; sample at 30-45 cm | 19.17 | 14.45 | 17.70 | 15.34 | 33.33 |
| 50-65 cm | Dense, sandy silt diamicton; some clay; sample at 50-65 cm | 30.60 | 18.15 | 19.57 | 13.17 | 18.51 |
| | | | | | | |
| **DMA-FS-1C** | **Depression along side of streamlined landform** | | | | | |
| 0-15 cm | Natural forest soil; thickness varies from 5-15 cm | | | | | |
| 15-25 cm | Large pebble to large cobble gravel; clast supported (90% clasts); | | | | | |
| 25-80 cm | Small pebbly sand with minor silt; sample taken at 25-40 cm | 28.34 | 18.10 | 19.93 | 13.35 | 20.29 |
| | Same as above, sample taken at 45-60 cm | 25.15 | 17.02 | 20.12 | 14.89 | 22.82 |
| 80-100 cm | silty sand diamicton; high density; sample at 80-100cm | 26.1 | 17.3 | 19.1 | 14.6 | 22.8 |

| | | % wt. csd | % wt. msd | % wt. fsd | % wt. vfsd | % wt. mud |
|---|---|---|---|---|---|---|
| **DMA-FS-1D** | **From Flute** | | | | | |
| 0-10 cm | Natural forest soil | | | | | |
| 10-25 cm | Gravelly sand; highly oxidized; sample at 15-25 cm | 17.00 | 16.26 | 23.15 | 17.98 | 25.62 |
| 25-55 cm | Sandy diamicton (?); sample at 40-50 cm | 19.74 | 13.41 | 16.57 | 14.71 | 35.57 |
| > 55 cm | Silty sand diamicton; dense, strong fissility and jointing; sample at 60-70 cm | 23.80 | 16.43 | 21.53 | 14.16 | 24.08 |
| 30-50+ cm | Sandy silt diamicton; dense; clasts small to large pebble, SA-SR; mod. to high fissility and jointing; sample at 35-45 cm | 22.28 | 15.98 | 18.16 | 14.29 | 29.30 |
| | | | | | | |
| **DMA-FS-5B** | **Depression along side of streamlined landform** | | | | | |
| 0-20 cm | Natural forest soil | | | | | |
| 20-35 cm | Large pebble to cobble gravel; couple cobbles thick; rootlet and organic silt matrix | | | | | |
| 35-55 cm | silty sand diamicton; dense; moderate fissility; grey with orange mottling; matrix approx. 60%; clasts med.-lg. Pebble; sample at 40-50 cm | 20.59 | 21.32 | 24.63 | 13.24 | 20.22 |
| | | | | | | |
| **DMA-FS-5C** | **From Flute** | | | | | |
| 0-5 cm | Natural forest soil | | | | | |
| 5-25 cm | Loose silty sand diamicton; weak to moderate fissility | | | | | |
| 25-100 cm | Sandy silt diamicton; strong fissility; dense; clasts up to boulder size; lots striated | 30.36 | 17.35 | 17.35 | 12.77 | 22.17 |
| | | | | | | |
| **DMA-FS-5D** | **Cresecent shaped depression at stoss-end of streamlined landform** | | | | | |
| 0-25 cm | Organic peat with scattered cobbles and boulders | | | | | |
| 25-35 cm | Sandy, lg. pebble to sm. pebble gravel | | | | | |
| 35-70 cm | Poorly sorted fine-coarse sd. with sm.-med. pebbles | 29.8 | 21.7 | 20.1 | 12.0 | 16.4 |
| 70-75 cm | Black clay (silty clay) | | | | | |
| 75-95 cm | Grey, silty sand diamicton; lg. pebbles to sm. cobbles | 30.8 | 19.1 | 17.7 | 11.4 | 21.1 |
| 95-100 cm | Brown, sandy silt diamicton; dense | 31.8 | 17.6 | 19.4 | 13.0 | 18.2 |

| | | % wt. | % wt. | % wt. | % wt. | % wt. |
|---|---|---|---|---|---|---|
| | | csd | msd | fsd | vfsd | mud |
| **DMA-FS-6** | **From Flute** | | | | | |
| | Silty diamicton; sample taken 1.5 m below surface | 33.6 | 17.8 | 17.1 | 10.8 | 20.6 |
| | | | | | | |
| **DMA-FS-8A** | **Depression along side of streamlined landform** | | | | | |
| 0-30 cm | Natural forest soil; clayey peat | | | | | |
| 30-40 cm | Lg. Pebble to cobble lag; 1-2 clasts thick; clasts SA-SR | | | | | |
| 40-60 cm | Pebbly fine to coarse sand; becomes siltier towards base; low density or loose feel | | | | | |
| 60-80 cm | sandy clay; high density | | | | | |
| | | | | | | |
| **DMA-FS-8B** | **From flute** | | | | | |
| | Sandy clay diamicton; dense; strong fissility and jointing | | | | | |
| | | | | | | |
| **DMA-FS-8C** | **Depression along side of streamlined landform** | | | | | |
| 0-50 cm | Clayey, organic peat | | | | | |
| 50-80 cm | Cobble to boulder lag; boulders up to 50 cm; matrix is coarse sand to pebble gravel; clasts A-R but most are SR | | | | | |
| 80-130 cm | Sandy, sm.-med. pebble gravel | | | | | |

# VITA

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| | |
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Degrees Awarded:

| | | |
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| B.Sc. (Honours) | Laurentian University | 1997 |

Publications:


Barnett, P.J. and Mate, D.J., 1998. Quaternary geology, Beaverton area; Ontario Geological Survey, Map 2560, scale 1:50 000.

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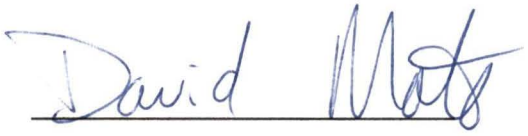
Author 

David John Mate

September 28, 2000

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Author

David John Mate

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Geological Survey Branch

OPEN FILE 2000-9

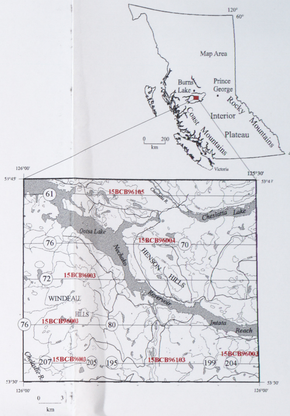
# QUATERNARY GEOLOGY OF THE MARILLA MAP AREA (93F/12)

Geology by D.J. Mate and V.M. Levson (P.Geo)

Scale 1:50 000

2 0 2 4 km

NATMAP
CARTNAT




## LEGEND

### QUATERNARY

HOLOCENE

**O** — **ORGANIC:** Black, organic rich peat; commonly occurs as blankets; found in bogs occurring in low-lying, poorly drained areas; bogs support sedges, sphagnum moss, and small willow vegetation.

**F** — **FLUVIAL:** Sands and gravels; commonly occur as terraces and floodplains in Cheslatta and Chelaslie river valleys; occur in flood prone areas.

**C** — **COLLUVIAL:** Poorly sorted, sandy to gravelly diamicton with angular clasts; found along slopes and at the base of steep bedrock cliffs.

**U** — **UNDIFFERENTIATED:** Colluvial, morainal, glaciofluvial, fluvial, and/or bedrock occurring along steep, erosional slopes.

PLEISTOCENE

**LG** — **GLACIOLACUSTRINE:** Massive to laminated silts and clayey silts with thin, fine sand beds; rarely occur in areas large enough to be mapped at this scale; sometimes occur within other units.

**FG** — ***GLACIOFLUVIAL:*** *Fine to coarse sand and pebble to cobble-sized gravels; gravel is subrounded to rounded, poorly sorted, and clast supported; deposits are typically found in terraces and outwash plains and in association with meltwater channels.*

**MORAINAL:** Clayey to silty, poorly sorted, massive, dense, well jointed, and strongly fissile diamicton; contains striated clasts; interpreted as subglacial lodgement till, meltout till and/or glacigenic debris flows; grey-brown colour that in places is dark grey-red to purple reflecting varied local bedrock lithologies.

**Mb** — **Blanket:** Morainal deposits greater than 1 m thick.

**Mv** — **Veneer:** Morainal deposits less than 1 m thick.

**Mm Mr** — **Rolling (Mm) or Ridged (Mr):** Morainal deposits dominated by crag-and-tails, flutings, drumlinoid ridges, and steep sided till ridges.

PRE-PLEISTOCENE

**R** — **BEDROCK:** Volcanic, intrusive, and sedimentary rock that is Mesozoic to Cenozoic in age.

**NOTE: Polygons in Nechako Reservoir delineate flooded areas.**

### SYMBOLS

drumlin
crag and tail
fluting
striae

Gravel Pit
Quarry
Outcrop
Mapping Station
Stratigraphic Section
Site (ie DMA-9801)
Till Sample Site
(ie 98-6343)

Roads
Escarpment
Esker
Crevasse Filling
Meltwater channel
Geological Boundary
(approximate)

## TERRAIN SYMBOL

Surface Expression

Texture → **zsMb-E** ← Geomorphological Process

Surficial Material

### TERRAIN CHARACTERISTICS

**Texture**

| Name | Symbol |
|---|---|
| Cobbles | k |
| Pebbles | p |
| Sand | s |
| Silt | z |
| Clay | c |
| Gravel | g |

**Surface Expression**

| Name | Symbol |
|---|---|
| Moderate Slope | a |
| Blanket | b |
| Fan | f |
| Hummock | h |
| Moderately Steep Slope | k |
| Rolling | m |
| Ridge | r |
| Steep Slope | s |
| Terrace | t |
| Undulating | u |
| Veneer | v |

**Surficial Material**

| Name | Symbol |
|---|---|
| Colluvium | C |
| Fluvial | F |
| Glaciofluvial | FG |
| Glaciolacustrine | LG |
| Morainal (Till) | M |
| Organic | O |
| Bedrock | R |
| Undifferentiated | U |

**Geomorphological Process**

| Name | Symbol |
|---|---|
| Gully Erosion | V |
| Washing | W |
| Irregularly Sinuous Channel | I |
| Channeled by Meltwater | E |
| Kettled | H |
| Meandering Channel | M |
| Inundation | U |

**Delimiters:** Indicate relative amounts of surficial material occurring in a polygon.

/ Material type in front of "/" is more extensive than the material type that comes after.

// Material type in front of "//" is much more extensive than the component that follows.

• Materials on either side of the symbol are approximately equal

(Modified from Howes and Kenk 1997)

CREDITS

GIS support provided by Pat Desjardins

Field assistance provided by Andrew Stuart, Stephen Mate, and Crystal Huscroft.

Edited by Gib McArthur Brian Grant

Andrew Stumpf conducted reconnaissance surficial mapping and till sampling in the map sheet.

Mapping was conducted by the British Columbia Geological Survey and the University of Victoria as part of the Nechako *NATMAP project.*

Geology based on air photo interpretation by D. Mate

1:40 000 scale air photos were used in mapping

0.4 field checks per square kilometer

20 % of the polygons were field-checked on this map.

Magnetic declination in 1984 was 26°48'.
Annual change decreasing 8.8'

North American Datum 1983, UTM Zone 10.

Map base from digital 1:50 000 NTS data.

Map projection is UTM.

***This map was produced over the internet and can be accessed from the Ministry of Energy and Mines web site at http://www.em.gov.bc.ca/Mining/Geolsurv/Surficial.***

## INTRODUCTION

The Quaternary geology of the Marilla map area was mapped in conjunction with 1:50 000 scale till geochemistry studies (Levson *et al. 1999)* and is part of the Nechako National Mapping (NATMAP) program conducted jointly by the British Columbia Geological Survey and the Geological Survey of Canada. Unlike other regions in the Nechako Plateau, the stratigraphy in this area is exceptionally well exposed. The completion of the Nechako Reservoir (1952) is largely responsible for the abundance of large Quaternary sections. Development of shoreline bluffs on the Nechako Reservoir and downcutting along the Cheslatta River Spillway have provided excellent cross-sections through Quaternary sequences and in some places the entire Holocene sequence, including sections through a number of drained Holocene lakes and deltas. A total of 12 Quaternary sections along the Cheslatta River and Nechako Reservoir were described from this map sheet. An overview of the stratigraphy in the Marilla map area is provided by Mate and Levson (1999; in prep).

## DESCRIPTION OF STUDY AREA

The map area is approximately 70 km south of Burns Lake in central British Columbia and lies east of Tweedsmuir Provincial Park. Besides the reservoir, which was built to generate power for aluminum refineries in Kitimat, other types of land use are forestry and ranching. Access is reasonable in parts of the map area, consisting mostly of logging roads and some well maintained secondary roads. A private barge is needed to access forestry roads south of Ootsa Lake.

This area lies entirely within the Nechako Plateau physiographic region (Holland 1976), an area of low relief with large surfaces of flat or gently rolling topography and elevations up to 1500 m (see photo). Most of the ground surface is covered by thick glacial sediments and very little bedrock is exposed. The Quanchus Range (including Mt. Wells, Tweedsmuir Peak, and Michel Peak) lie immediately west of the map area in Tweedsmuir Provincial Park, while the Fawnie and Nechako ranges occur to the southeast. Highest elevations within the Marilla map sheet range from 1160 m - 1370 m a.s.l. and are found within the Windfall and Henson hills (see location figure).

## QUATERNARY STRATIGRAPHY

Stratigraphic units identified within the map area are:

**Pre-Late Wisconsinan Sediments:**

*Early Wisconsinan Till:* Massive, slightly sandy, clayey silt diamicton is the oldest Pleistocene sediment in the map area. This unit underlies organic bearing nonglacial sediments and sediments deposited during the Late Wisconsinan (Fraser) Glaciation. It is exposed at the base of section DMA-9808 on Ootsa Lake.

*Lacustrine Sediments:* This unit consists of dark, blue-grey, very fine sand, with silt and clay laminations. Wavy and discontinuous lenses, laminae, and finely disseminated organics are present within this unit. It overlies Early Wisconsinan till at section DMA-9808 and lies beneath Late Wisconsinan sediments. Therefore this unit is believed to have been deposited during the Olympia Nonglacial Interval. These sediments are rare within the Nechako Plateau because they were eroded during the Fraser Glaciation and only occur as erosional remnants in specific areas. Recently, several new Olympia Nonglacial sites have been discovered in the general region (Plouffe and Jetté 1997; Levson et al. 1998; Mate and Levson 1999).

**Late Wisconsinan Advance-Phase Sediments:**

*Till:* This sediment is commonly found in Quaternary exposures and is the most widespread unit within the map area. It has two facies, the first of which is a clayey to silty, massive diamicton with a moderate to high density, high fissility, and moderate to well jointing. This facies is interpreted to have a lodgement origin. The second facies is a massive to crudely bedded, gravelly to sandy diamicton. It generally has a high density, strong fissility, and is well jointed. Thin, wavy and discontinuous sand and gravel lenses are common in this facies. This facies is interpreted as having a subglacial melt-out origin.

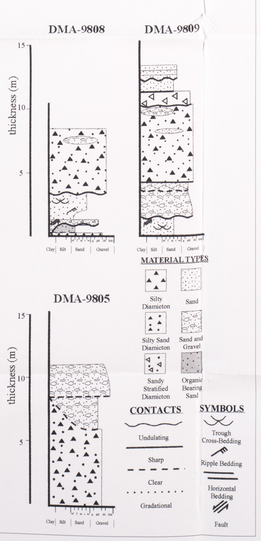
*Glaciofluvial:* This unit consists of fine to coarse sands and pebble to cobble-sized gravels. Sands are moderately to well sorted, show crude horizontal to subhorizontal bedding, and locally have small to medium scale trough cross-bedding and ripple bedding. Gravels are characterized by subrounded to rounded clasts, poor sorting, and crude medium to large-scale trough cross-bedding. Both sands and gravels occur above and below till and often have lense shapes.

*Glaciolacustrine:* This unit is dominated by silt and interbedded silts and clays. Occasionally silts are interbedded with sands. Bedded silts and clays above till are commonly deformed and occur in areas of hummocky topography. Glaciolacustrine silts and clays below till are also deformed and have sheared slickenside surfaces on bedding planes.

*Glacigenic Debris Flows:* This unit is characterized by stratified silty to silty sand diamicton with high density, moderate to strong fissility, and poor jointing. The unit is commonly interstratified with sands, gravels, and silts and occurs above and below till.

**Holocene Sediments:**

This unit includes organic, fluvial, and colluvial deposits. These sediments overly all other stratigraphic units in the map area. Organic sediments dominate and occur as fens and bogs, some of which resemble string bogs. Fluvial sands and gravels sometimes contain numerous buried organic horizons and are interpreted to be floodplain deposits.




## QUATERNARY HISTORY

Late Wisconsinan glacial ice originated in the Coast Mountains west of the map area (Tipper 1971). Orientations of streamlined landforms and striae within the Marilla map area have a general northeasterly trend. Some striation directions from the shoreline of Ootsa Lake are valley parallel indicating that during early or late phases of glaciation ice moved through the Ootsa Lake valley system.

Ice confined to major valleys (Ootsa Lake valley) was responsible for damming local tributaries like the Cheslatta River (see location figure). Rare, advance-phase glaciolacustrine sediments were formed in local proglacial lakes due to this damming. Aggradation in this valley by glaciofluvial outwash soon followed. Glacigenic debris flows overlying the outwash probably originated from the ice margin as it advanced into the area. Ice advancing from the Coast Mountains, coalesced and thickened in the Interior Plateau and the influence of topographic control on its movement diminished. This movement probably resulted in the dominant subglacial flow in the map area which is northeast. During this phase thick lodgement tills were deposited over extensive areas of the map sheet.

During deglaciation ice stagnation occurred in some areas. Evidence of stagnant ice is provided by till ridges, found in the southwest portion of the map area, that are interpreted to be crevasse fillings. Also, areas of poorly sorted pebble to cobble gravel commonly occur as thin veneers throughout the study region. These deposits probably reflect the winnowing of fine material from surficial sediments washed by glacial meltwater during ice stagnation. Rare retreat-phase glaciolacustrine and occasional glaciofluvial sediments were formed in retreat-phase proglacial lakes dammed by stagnant ice blocks and small outwash plains.

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# MARILLA
# 93 F/12

Scale 1:50 000

1 0 1 2 3 4 5 km

Magnetic declination in 1984 was 26°48'.
Annual change decreasing 8.8'

North American Datum 1983, UTM Zone 10.

Map base from digital 1:50 000 NTS data.

Map projection is UTM.

Figure 4. Name and location of the 198 field mapping stations within the study area.
Transects used to create topographic profiles in Figs. 49 and 50 are shown.

Mapping Station — Mapping Station Name

▲ DMA-98-101