Quaternary stratigraphy and history of the Ootsa Lake – Cheslatta River area, Nechako Plateau, central British Columbia

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Abstract: Erosion along the Nechako Reservoir and Cheslatta River Spillway has resulted in unusually well-exposed late Quaternary and Holocene stratigraphy. Surficial sediments in the study area are mostly products of Late Wisconsinan glaciation. However, evidence for pre-Late Wisconsinan sedimentation has been found along the shores of the Nechako Reservoir, including till of an older glaciation and organic-bearing, blue-grey, lacustrine sediments of probable Middle Wisconsinan age. Stratigraphic correlation of the lake sediments suggests that an extensive lake system occurred in the region during the Olympia Nonglacial Interval. Late Wisconsinan ice initially moved along major valleys, with glaciofluvial outwash deposited in front of the advancing ice. Advance-phase glaciolacustrine sediments are rare but significant, as slope failures are spatially associated with areas where they are preserved. The distribution of these sediments and associated deltaic deposits indicates that advance-phase glacial lakes occurred up to approximately 855 m asl, at least several metres above the modern reservoir level. Sediments deposited in front of the ice margin were overridden during ice advance and are best preserved in large valleys. At the glacial maximum, ice flowed northeasterly throughout the study region. Crag and tails, flutings, and drumlinoid ridges with a generally consistent northeast trend are the dominant landforms. Till is the most common Pleistocene surficial sediment, covering approximately 80% of the area; large areas of exposed bedrock are rare. Late-glacial glaciofluvial and Holocene fluvial deposits are uncommon and occur mainly along the Cheslatta River valley.

Résumé : De l’érosion le long du réservoir Nechako et du déversoir de la rivière Cheslatta a produit de très beaux affleurements de la stratigraphie du Quaternaire tardif et de l’Holocène. Les sédiments de surface dans la région à l’étude sont surtout des produits de la glaciation du Wisconsinien tardif. Toutefois, des preuves de sédimentation au pré-Wisconsinien tardif ont été retrouvées le long des berges du réservoir Nechako; elles comprennent un till d’une glaciation plus ancienne et des sédiments lacustres gris-bleu contenant de la matière organique, datant probablement du Wisconsinien moyen. La corrélation stratigraphique des sédiments lacustres suggère qu’un système extensif de lacs était en place dans la région durant l’intervalle non glaciaire Olympia. La glace du Wisconsinien tardif a tout d’abord avancé le long des vallées majeures alors que du matériel stratifié fluvio-glaciaire était déposé en avant de la glace qui avançait. Des sédiments glacio-lacustres de phase avancée sont rares mais importants car les ruptures de pentes sont associées aux régions où ils sont préservés. La distribution de ces sédiments et des dépôts deltaïques associés indique que des lacs glaciaires de phase avancée se sont retrouvés à environ 855 m au-dessus du niveau de la mer, au moins plusieurs mètres au-dessus du niveau moderne du réservoir. Lors d’une avancée glaciaire, la glace passe par-dessus les sédiments déposés en avant du front glaciaire et ils sont ainsi mieux conservés dans les grandes vallées. Au maximum glaciaire, la glace coulait vers le nord-est dans toute la région à l’étude. Les formes de terrain dominantes, à direction généralement nord-est, sont les « crag and tail », les rainures glaciaires et les drumlinoides. Le till est le sédiment de surface le plus commun du Pléistocène, couvrant environ 80 % de la région; les grandes aires d’affleurements rocheux sont rares. Les dépôts fluvio-glaciaires tardi-glaciaux et les dépôts fluviaux de l’Holocène sont peu communs et se retrouvent surtout le long de la vallée de la rivière Cheslatta.

[Traduit par la Rédaction]
Introduction

The purpose of this paper is to provide a model of glaciation based on the description and interpretation of the Quaternary geology, stratigraphy, and geomorphology of a portion of the Nechako Plateau in central British Columbia. This work was conducted in conjunction with 1 : 50 000 scale surficial geology mapping and till geochemistry studies (Levson et al. 1999). The study area is centred around the Marilla map sheet (National Topographic System (NTS) map sheet 93 F/12) and includes field data from surrounding areas, mainly the southern half of the Takysie Lake map sheet (NTS 93 F/13) (Fig. 1). This research was conducted as part of the Nechako NATMAP Project of the British Columbia Geological Survey and the Geological Survey of Canada.

Before this work, little was known about the Quaternary geology of the study area. Previous research (Tipper 1963, 1971; Howes 1977) was based mostly on the interpretation of air photographs. Very little ground data describing the various Pleistocene materials and information about the stratigraphy and glacial history of the region have been compiled and interpreted.

Description of the study area

The study area is approximately 70 km south of Burns Lake in central British Columbia and lies just east of Tweedsmuir Provincial Park. Quaternary stratigraphic sections in this region are unusually abundant and well exposed (Fig. 2) due to the development of shoreline bluffs on Ootsa Lake (part of the Nechako Reservoir) and downcutting along the Chelsatta River, which is an artificial spillway for the reservoir. The river has provided an excellent cross section through the Quaternary sequence in the area and has exposed the entire Holocene sequence in some places, including sections through a number of drained Holocene lakes and deltas. Work in progress on these lake sediments will provide new paleoenvironmental data for the Holocene Epoch in this area.

The study area lies entirely within the Nechako Plateau physiographic region (Holland 1976), an area of low relief with flat or gently rolling topography and a thick drift cover with little bedrock outcrop. Highest elevations within the study area range from 1160 to 1370 m asl and are found within the Windfall Hills and Henson Hills (see Fig. 1). The elevation of the Nechako Reservoir is 850 m asl. Road access is good in parts of the study area, consisting mostly of forest service roads and some well-maintained secondary roads. A private barge is needed to access forestry roads south of Ootsa Lake.

Tipper (1963) first mapped the bedrock geology of the Nechako River map area (NTS 93 F) at a scale of 1 : 250 000. Recent 1 : 50 000 scale bedrock mapping of the Marilla and Takysie Lake map sheets was completed by Anderson et al. (2000a, 2000b). Eocene Endako Group basalt and Ootsa Lake Group rhyolite are the most widespread rock types in the study area and are common north of Ootsa Lake. Occasional Neogene volcanic centres and basalt flows are also present. Mesozoic, informally designated volcanic units of the Naglico and Entiako formations belonging to the Hazelton Group are more common south of Ootsa Lake. Sedimentary Bowser Lake Group and Late Cretaceous Skins Lake plutonic rocks are rare. Structurally, northeast-to northwest-trending Eocene block faults crosscut an older northwest-trending reverse fault north of Ootsa Lake.

Previous work

Some of the earliest Quaternary geology mapping in the Nechako Plateau was presented by Tipper (1963). He inferred that, during the Fraser Glaciation, the Nechako River map area (NTS 93 F) was covered by glacial ice up to approximately 1500 m thick and that ice flow direction, based on the orientation of streamlined landforms, varied from northeast to east. Terrain mapping at a scale of 1 : 100 000 was completed by Howes (1977) directly south and east of the study area. Recent 1 : 100 000 scale mapping in regions adjacent to the study area was completed by Plouffe (1998a, 1998b). The study area was mapped at 1 : 50 000 scale by Mate and Levson (2000) as part of this research. Plouffe (2000) summarized the Quaternary geology of the Fort Fraser (NTS 93 K) and Manson River (NTS 93 N) 1 : 250 000 map areas, north of the study region.

Previous Quaternary stratigraphy and ice-flow studies in the Nechako River map area (NTS 93 F) have been provided by Giles and Levson (1994), Weary et al. (1995), Levson and Giles (1997), Plouffe (1998a, 1998b), Huscroft and Plouffe (1999), Levson et al. (1999), and Mate and Levson (1999a).

Methods

Mapping in the study area included description of surficial materials at over 180 field stations. Field checking was essential because heavy tree cover made identification of surficial sediments from air photographs difficult. The terrain classification system for British Columbia (Howes and Kenk 1997) was followed. Stratigraphic studies were conducted at all large Quaternary exposures within the region. In total, stratigraphic information was collected from 20 Quaternary sections in the study area (see Fig. 1). Thirteen sections are along a portion of the Chelsatta River between Ootsa Lake and Chelsatta Lake, and seven sections are along the shores of Ootsa Lake, Intata Reach, and Chelsalsie Arm of the Nechako Reservoir. At each section, different lithologic units were described and data on unit thickness, texture, lower contacts, and sedimentary structures were collected. Geochemical analysis of tills involved the use of instrumental neutron activation analysis (INA) and inductively coupled plasma (ICP) analysis.

Surficial geology and geomorphology

The distribution of surficial sediments in the Marilla map area is illustrated in Fig. 3. Surficial geological mapping has shown that till accounts for approximately 80% of the ground cover in the map area. Till veneers (<1 m thick) usually drape bedrock-controlled topography and are common at elevations above about 900 m, where steeper slopes predominate. Till blankets (>1 m thick) occur at a range of ele-
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, whereas 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. Streamlined land-

**Fig. 1.** Location of the study area, straddling Ootsa Lake (part of the Nechako Reservoir) in the Nechako Plateau south of Burns Lake. Quaternary sections investigated during this study are labelled as are sites where Olympia Nonglacial sediments occur in relation to the study area.
forms are 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 streamlined forms. Sometimes they are eroded to bedrock. They resemble crescentic scours and lateral furrows described by Shaw and Sharpe (1987) and Shaw (1994). 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. 3; see the section titled Quaternary history for discussion).

Unusual linear till ridges occur in the southwest portion of the map area. They are hundreds of metres long, locally with sharp bends, 4–8 m high, and steep sided, and have relief along ridge tops of 1–4 m. The till matrix in these forms is consistently finer grained, with a clayey silt texture, than most tills in the 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, accounting 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. Localized glaciolacustrine sediments are rare within the study area and most were too small to be mapped separately. When present they are characteristically massive to lamli-
Fig. 3. Simplified surficial geology and ice-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 ice-flow direction is to the northeast; evidence for westerly flow occurs only in the northwest corner of the map area and directly west of the Marilla map area.

**Stratigraphy**

Seven representative sections from the Cheslatta River and Nechako Reservoir illustrate the Quaternary stratigraphy of the study region (Figs. 2, 4). From these sections, 10 different stratigraphic units have been identified and grouped into five main stratigraphic packages: (i) pre-Late Wisconsinan sediments, (ii) Late Wisconsinan advance-phase sediments, (iii) Late Wisconsinan glacial sediments, (iv) Late Wisconsinan retreat-phase sediments, and (v) Holocene sediments.

**Pre-Late Wisconsinan sediments**

*Unit 1: Early Wisconsinan (or older) till*

Pre-Late Wisconsinan sediments are represented by two units exposed in a single section (DMA-9808, Fig. 5). Unit 1 consists of till and is overlain by organic-bearing nonglacial lacustrine sediments (unit 2). Unit 1 till is the oldest Pleistocene sediment discovered in the study area. It is a brown, slightly sandy, clayey silt diamicton with moderate to high
Fig. 4. Representative sections illustrating the stratigraphy within the study area. Section locations are shown in Fig. 1. Some sections illustrated in Fig. 2. Sand: VF, very fine; F, fine; M, medium; C, coarse; VC, very coarse. Gravel: G, granule; Pbl, pebble; Cbl, cobble; Bldr, boulder.

**MATERIAL TYPES**
- Silty Diamicton
- Gravelly Diamicton with Sand and Gravel Lenses
- Sandy Diamicton with Sand and Gravel Lenses
- Clayey Diamicton
- Sandy Stratified Diamicton
- Organic Bearing Sand

**CONTACTS & SYMBOLS**
- Colluvium/Alluvium
- Undulating
- Gradational
- Clear
- Sharp
- Trough
- Cross-Bedding
- Ripple Bedding
- Horizontal Bedding
- Fault

**INTERPRETATIONS**
A) Pre-Late Wisconsinan Sediments:
- till (unit 1) and lacustrine (unit 2)

B) Late Wisconsinan Advance-Phase Sediments:
- glaciofluvial (unit 3),
- debris flow (unit 4), and glaciallacustrine (unit 5)

C) Late Wisconsinan Glacial Sediments:
- till (unit 6)

D) Late Wisconsinan Retreat-Phase Sediments:
- debris flow (unit 7),
- glaciofluvial (unit 8), and glaciallacustrine (unit 9)

E) Holocene Sediments:
- fluvial, colluvial (unit 10)
density and is well jointed with oxidation along the 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. Tills underlying organic-bearing sands and Fraser Glaciation sediments are rarely seen in the Nechako Plateau.

Unit 2: lacustrine sands

This unit consists of dark, blue-grey, very fine sand with silt and clay laminations and contains pollen and finely disseminated organics. It occurs at an elevation of about 855 m, just a few metres above modern lake level. The unit is up to 65 cm thick at this site 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 Reach of the Nechako Reservoir (048°–058°). Several small-scale normal faults have up to 5 cm of displacement.

This unit is believed to have a lacustrine origin. Organic material and pollen provide evidence that this sediment may have been deposited during a period when glacial ice was absent from the area. It also lacks rhythmic bedding and dropstones characteristic of glaciolacustrine environments. Due to the position of this unit beneath Late Wisconsinan sediments (units 3 and 6, Fig. 5), it is believed to have been deposited during the Olympia Nonglacial Interval. There was insufficient organic detritus for conventional radiocarbon dating.

Late Wisconsinan advance-phase sediments

Unit 3: advance-phase glaciolacustrine

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. 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. 6). These features are inferred to be associated with Holocene slope movements. 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 local landslides. Thrust blocks are separated by slickensided shear surfaces.

Sils and clays of unit 3 are interpreted to be glaciolacustrine sediments deposited in proglacial lakes. Factors that may have been responsible for proglacial lake formation in the region are discussed by Plouffe (2000). Although not well exposed in the map area, advance-phase glaciolacustrine sediments are more extensive in other parts of the Nechako Plateau (Levson and Giles 1997; Levson et al. 1999; Plouffe and Levson 2001). The stratigraphic assignment of this unit to the advance phase of the Fraser Glaciation is based on corre-
generally has a high clast content (up to 50%) and is channelized deposition in outwash plains. More common and units often have lens shapes that reflect ice-proximal sedimentation. Distal outwash deposits are sand, debris-flow diamictons, suggesting a shift from distal clast supported. These sand and gravel sequences generally characterized by subrounded to rounded clasts, poor sorting, trough cross-bedding and ripple bedding. Gravel deposits are crude horizontal to subhorizontal bedding, and locally have an advance-phase delta sequence. Laminated sand, silt, and clay bottomset beds, representing dipping sand and gravel foreset beds grade laterally into Lake valley. At one section (DMA-9817, Fig. 1), steeply subaqueously as outwash infilled the lake basin in the Ootsa section DMA-9808, Fig. 5), this unit was probably deposited pebble- to cobble-sized gravel interpreted to be advance-phase glacigenic sediments similar to those deposited near modern glaciers (e.g., Lawson 1979). Diamicton beds locally thicken upwards, possibly reflecting the advance of glacier ice into the study area.

Late Wisconsinan glacial sediments

Unit 6: till
Sediments belonging to this unit are widespread within the study area. This unit includes two facies. The first is a grey-brown, clayey to silty, massive diamicton interpreted to be lodgement till. It has moderate to high density, high fissility, and moderate to strong jointing. Clasts are commonly angular to subrounded, striated, of varied lithologies, and generally small pebble to small cobble sized. Clast percentage varies from 10 to 20%, and lower contacts are usually clear to sharp and undulating. Where this unit overlies bedrock, striae are common with generally northeast orientations. This facies is commonly enriched in local bedrock lithologies in both the coarse and fine fractions. For example, in some areas the till matrix is reddish in colour, reflecting local maroon mudstones belonging to the Bowser Lake Group.

Gravel and fine to coarse sand lenses locally occur within this facies. Barnett (1992) notes that sand lenses can be formed in lodgement tills by periodic draining of subglacial meltwater in channels scoured into till. Rarely, deformation till occurs within this facies, with irregular-shaped lenses and beds enriched with local bedrock lithologies and inclusions of local brecciated bedrock (Fig. 7).

The second facies is a massive to very crudely bedded, gravelly (up to 50% gravel) to sandy melt-out till. It has a high density and strong fissility and is well jointed. Clasts are mainly pebble-sized. 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 and larger towards the top of the unit. Some lenses have sharp, horizontal lower contacts and convex-upward tops, suggesting deposition by subglacial meltwater in a tunnel carved into overlying ice (Levson and Rutter 1988). Locally, gravel lenses and diamicton contacts are loaded, showing signs of soft-sediment deformation. Melt-out tills in this area can be distinguished from lodgement tills, 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.

Late Wisconsinan retreat-phase sediments

Unit 7: retreat-phase debris flow
Unit 7 consists of diamicton interstratified with sand, gravel, and silt. Sediments belonging to this unit are interpreted to be retreat-phase glacigenic debris flows. The diamicton is commonly sandy and has lithologic characteristics similar to those of unit 5 (described earlier). Diamicton beds generally thin towards the top, possibly reflecting the retreat of glacier ice from the study area.

Unit 8: retreat-phase glaciofluvial
This unit consists of sand and gravel that was deposited as glacier ice retreated from the study area. Sand units have a variety of textures and are commonly interbedded. Sedimen-
Fig. 4). Interbedded silt and clay with occasional dropstones. They occur below 890 m and are interpreted to be retreat-phase glaciolacustrine sediments deposited in localized proglacial lakes. The presence of dropstones (ice-rafted debris) indicates that at least some of these lakes were probably in contact with ice. Silts are horizontally bedded to massive (e.g., top of section DMA-9811, Fig. 4). Some gravels contain silty sand diamicton beds.

Retreat-phase glaciofluvial sediments have relatively lower densities than advance-phase glaciofluvial sediments, probably because glacier ice did not override them. The common lens shape of beds suggests deposition as channelized outwash deposits. Debris-flow diamicton within gravels provides evidence of deposition in a proximal environment.

Unit 9: retreat-phase glaciolacustrine

Sediments in this unit are dominated by silt and locally by interbedded silt and clay with occasional dropstones. They occur below 890 m and are interpreted to be retreat-phase glaciolacustrine sediments deposited in localized proglacial lakes. The presence of dropstones (ice-rafted debris) indicates that at least some of these lakes were probably in contact with ice. Silts are horizontally bedded to massive (e.g., top of section DMA-9810, Fig. 4) and are occasionally interbedded with sand (e.g., top of section DMA-9811, Fig. 4).

The best exposure of retreat-phase glaciolacustrine sediments occurs at section DMA-9819 on Ootsa Lake (Fig. 8). Silt and clay couplets generally fine upwards, with silt in sharp contact with overlying clay. Medium to coarse sand beds occur in the lower part of this section. Topography around this section is hummocky and some overturned folds of silt and clay may relate to collapse or movement towards hollows between hummocks. Glaciolacustrine sedimentation on buried blocks of stagnant ice is likely responsible for the deformed bedding of silt and clay and the hummocky topography. Deposition of retreat-phase glaciolacustrine sediments elsewhere within the Nechako River map area (NTS 93 F) has been described in detail by Plouffe (1997), Huscroft and Plouffe (1999), and Plouffe and Levson (2001).

Holocene sediments

Unit 10: fluvial sediments

Holocene sand and gravel overlie all other units described. These sediments are fluviatile deposits formed after Fraser Glaciation ice left the area. Gravel is usually clast-supported and imbricated, and clasts are angular to well rounded and sometimes heavily oxidized. Sand beds sometimes contain numerous buried organic horizons interpreted to be overbank sediments.

An unusual Holocene sequence occurs at section DMA-9815 along the Cheslatta River (Fig. 9). At this section, interbedded pebble gravel and peat overlie up to 4 m of gyttja and peat. Geomorphic evidence shows that interbedded gravel and peat at this section were deposited in a small raised delta. The delta was probably formed by a tributary that flowed into the Cheslatta River when water levels were much higher, prior to the construction of the spillway. Gravel units represent active distributary channel deposition along the delta front. As these channels shifted, quiet-water conditions followed, allowing for the development of organic material and formation of peat. As distributary channels shifted back, peat deposits were overlain by outwash gravels. If this interpretation is correct, then channels shifted several times at this site.

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. These sediments are probably colluvial debris-flow deposits or alluvium.

Discussion

Rare, pre-Late Wisconsinan till (unit 1) and organic-bearing lacustrine sediments (unit 2) occur within the Ootsa Lake valley. This valley is transverse to the regional glacial flow direction (see Fig. 3), allowing for their preservation. Till underlying organic-bearing sediments along Ootsa Lake provides stratigraphic evidence of glacial activity in this area before the Late Wisconsinan and Olympia Nonglacial Interval. At section DMA-9808 (see Fig. 5), this till has characteristics similar to those of the main till unit above it, which is assigned to the Fraser Glaciation.

Pebble counts and till geochemistry were used to determine if these tills had any diagnostic characteristics. The dominant pebble lithologies of unit 1 till are rhyolite, greywacke, basalt, and andesite and in the overlying till (unit 6) the most common pebbles are andesite, basalt, and volcanic breccia (Table 1). Geochemical data for both tills from section DMA-9808 indicate that element concentrations between these units are very similar, with some being identical (both units have 12 ppm cobalt and 7 ppm molybdenum). Geochemically, units 1 and 6 are more similar to each other than they are to other tills in the surrounding area. However, slightly higher concentrations of most elements occur in unit 1 (e.g., 26, 8, 63, and 20 ppm Cu, Pb, Zn, and Ni, respectively, compared with 22, 4, 60, and 17 ppm in unit 6). Elements in till from the local area vary from 21 to 26 ppm Cu, 3 to 10 ppm Pb, 50 to 61 ppm Zn, and 15 to 20 ppm Ni (n = 6).
There is enough variation in pebble lithologies between the two tills to possibly indicate different source areas. A large area of Ootsa Lake Group rhyolite occurs in the vicinity of this section (Anderson et al. 2000a), suggesting a local derivation for the lower till. The source of the abundant greywacke in the lower till is unknown, but is most likely Hazelton Group rocks to the south. The numerous breccia clasts in the upper till may be derived from any of three sources, all of which occur a few to several kilometres 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, the geochemistries of the fine fractions are quite similar. This suggests that the matrix is locally derived, whereas the clast content reflects more distal and hence more variable sources. Thus both tills are inferred to have the same general transport direction.

This has implications for mineral exploration in the region, because Fraser-aged and pre-Fraser-aged tills probably have similar transport histories and therefore share similar geochemical signatures. As a result, a mineralized zone is likely to produce similar geochemical anomalies in the matrix of both tills, and the recognition of the older till unit in drilling programs will not be as critical as it would if source directions were significantly different.

Unit 1 could also be interpreted as basal till deposited during the Fraser Glaciation, with the overlying till (unit 6) representing a readvance. Although possible, the presence of organic-bearing sands between these two units (see Fig. 5) suggests deposition during a warmer period, which is unlikely to have occurred in a minor readvance. 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 are stable. Finally, the distinct pebble lithologies of units 1 and 6 suggest that they are not the same unit repeated by faulting.

Unit 2 at section DMA-9808 on Ootsa Lake has characteristics similar to those of fluvial, pollen- and 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; see Fig. 1 for location). At all three sites, fine sands containing finely disseminated organics within stratified silts and clays underlie advance-phase glaciofluvial sediments and till deposited during the Fraser Glaciation. A radiocarbon date of organic material taken from lacustrine sediments in a section along Chelaslie Arm produced a date of 27 790 ± 200 BP (Beta-101017; Levson et al. 1998). The lacustrine sediments at Chelaslie Arm (e.g., Fig. 2e) are...
Mate and Levson

3–4 m thick and exposed over a distance of approximately 15 km. The proximity of section DMA-9808 to the Chelaslie Arm section and the similar stratigraphic position suggest that unit 2 is correlative with the dated nonglacial sediments at Chelaslie Arm.

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 may reflect a higher regional base level before Late Wisconsinan erosion along the Nechako River or another outlet. Alternatively, the lake at Intata Reach may have been a locally ponded lake, but the valley-side position of the sediments suggests that this is less likely.

The discovery of Olympia Nonglacial sediments within the Interior Plateau of central British Columbia has been limited to very few sites. One possible reason for this is that they were eroded during the Fraser Glaciation and only occur as erosional remnants in specific areas. Limited access within the Nechako Plateau has probably also made the discovery of Olympia-age sediments difficult. Clague (1987) and Eyles and Clague (1991) also hypothesize that significant amounts of sediment were not deposited during the Olympia Nonglacial Interval, accounting for their scarcity.

Quaternary history

A sequence of schematic cross sections of the study area, illustrating the events that took place during Fraser Glaciation, is found in Fig. 10. Prior to the Fraser Glaciation, Olympia Nonglacial lacustrine sediment was deposited within the Ootsa Lake valley (Fig. 10a, left). Similar sediments were not observed within the Chelaslie River valley, however, it is possible that they were deposited there but are not exposed. As ice entered into the area, drainage was disrupted and localized glacial lacustrine sedimentation began in low-lying areas (Fig. 10a, right). Advance-phase glacial lacustrine sediments were formed in both ice-contact lakes and more distal glacial lakes. Subsequent glaciofluvial sedimentation in valleys occurred as a result of either draining of the lakes followed by glaciofluvial aggradation or gradual infilling of the lakes by subaqueous outwash. Evidence of advance-phase glaciofluvial sedimentation occurs in most major valleys within the region (Plouffe and Levson 2001).

Ice confined to the Ootsa Lake valley (Fig. 10b) at the onset of glaciation in this area dammed local tributaries and deposited advance-phase glaciofluvial, glaciolacustrine, and glacigenic debris-flow sediments. Ice-proximal glacigenic debris flows, interbedded with and overlying outwash, are also widespread in most other major valleys in the region. Similar advance-phase glaciofluvial and glaciolacustrine sediments have been described in other valleys in central British Columbia (Clague 1987; Huntley and Broster 1994).

Late Wisconsinan glacial ice advancing into the study area most likely originated in the Coast Mountains (Tipper 1971) and the Quanchus Range, which lies immediately west of the study area in Tweedsmuir Provincial Park. During early and probably late phases of glaciation, ice was topographically controlled and moved through major valleys like Ootsa Lake (Fig. 10b, left). Rare, valley-parallel striation directions along the shoreline of Ootsa Lake (125° to 150°; Fig. 3) support this interpretation.

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 (Fig. 10c). This resulted in the dominant northeasterly ice flow direction, which is supported by striation and streamlined landform orientations that have a strong northeasterly trend. Striation measurements from bedrock outcrops have an average orientation of 75° (range 60–94°). Streamlined landforms have an average orientation of 70° (range 60–80°). As ice overrode the area multiple till facies were deposited as lodgement, melt-out, deformation, and subglacial flow tills. Thick
lodgement tills are most common and were deposited over extensive portions of the study area.

Although easterly ice-flow indicators dominate in the study area, rare westerly ice-flow indicators are locally preserved along the most northwestern edge of the study area and just beyond. For example, on the steep, easterly exposed lee side of a roche-moutonné, in the northwest corner of the study area (see Fig. 3), there are weak west-trending rat-tails and striations indicating northwesterly (approximately 300°) flow. Striations on the stoss side (facing west) trend north-easterly (070°). Evidence of anomalous westward flow also has been identified in adjacent areas of the Nechako Plateau and is 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 that is generally considered to have been 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 (Levson et al. 1998; Stumpf et al. 2000).

During deglaciation, ice stagnation occurred in parts of the study area (Fig. 10d). Linear landforms interpreted to be crevasse fills, in the southwest corner of the study area, provide evidence for stagnant ice. These forms are believed to have been created as clay-rich till was squeezed up into cracks between downwasting blocks of ice. During stagnation, melt-out till facies were deposited and commonly overlie lodgement tills. Also, areas of poorly sorted pebble and cobble gravel commonly occur as thin veneers throughout the study region. These deposits probably reflect winnowing of fine material as surface materials were washed by glacial meltwater.

Retreat-phase glaciolacustrine sediments were formed in small proglacial lakes dammed by stagnating ice blocks or sediment. Unlike areas mapped in the Vanderhoof region (Plouffe 1996, 1998b; Plouffe and Levson 2001), these sediments are very localized. Since their areal extent is small, late-glacial glaciolacustrine sediments (silt and clay) are not considered to be a widespread problem for slope instability in the study area. However, slope movements have been observed in thick silts and clays of retreat-phase glacial Lake Knewstubb, roughly 62 km east of the study area (Huscroft and Plouffe 1999). 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, which was probably ice-free and fed by meltwater from ice still occupying the Ootsa Lake valley. Meltwater was also responsible for localized ice-marginal erosion and subglacial erosion, such as probably occurred in the Ootsa Lake valley during deglaciation.

Finally, during the Holocene Epoch, peat and marl accumulated in poorly drained areas throughout the study area. Peat deposits often occur adjacent to lakes and at the stoss end and along the sides of streamlined landforms. Thick sediment fills within the Ootsa Lake and Cheslatta River valleys were eroded first by fluvial processes and later (after 1952) by Nechako Reservoir (Ootsa Lake) and spillway (Cheslatta River) erosion (Fig. 10e). Reservoir and spillway erosion is largely responsible for the excellent Quaternary and Holocene exposures in the study area. Both peat and marl are well exposed in sections, up to 4 m high, along the Cheslatta River. This erosion is also an important factor in initiating slope instability.

Conclusions

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

Massive, poorly sorted diamicton with strong fissility, jointing, and a high density, interpreted as till, is the most common Pleistocene sediment within the study area. It typically has a lodgement or melt-out genesis and occurs as thick blankets that obscure the bedrock topography or as veneers that mantle relatively high relief, bedrock areas. Till commonly forms flutes and drumlinoid ridges and occurs on the lee sides of crag and tail landforms.

Late Wisconsinan ice moved through the area in a north-easterly direction. Glaciofluvial, glacigenic debris-flow and rare glaciolacustrine sediments, deposited in front of the ice margin, were overridden during ice advance and are locally preserved in valleys, such as Ootsa Lake and Cheslatta River. Lodgement till was deposited during the active phases of glaciation. Most melt-out till was probably deposited as ice stagnated during early phases of deglaciation. Local retreat-phase glaciolacustrine deposits were formed in small
Fig. 10. Model of glaciation and deglaciation for the Ootsa Lake – Cheslatta River area comparing major valleys (e.g., Ootsa Lake valley), low-lying areas (e.g., Cheslatta River area), and uplands. (a) Lacustrine sedimentation during the Middle Wisconsinan in the Ootsa Lake valley with localized glaciolacustrine sedimentation (e.g., in the Cheslatta River valley) probably at the beginning of the Fraser Glaciation. (b) Early advance of Late Wisconsinan ice in major valleys and glaciofluvial sedimentation in other low-lying areas. (c) Widespread till deposition and topographically unconfined ice flow during the Late Wisconsinan glacial maximum. (d) Ice stagnation in major valleys and adjoining areas, glaciofluvial sedimentation in ice-free low-lying areas (e.g., Cheslatta region), and localized glaciolacustrine sedimentation. (e) Retreat-phase Late Wisconsinan glaciofluvial and Holocene fluvial erosion and subsequent Nechako Reservoir lakeshore and spillway erosion exposing Quaternary sections.
glacial lakes dammed by stagnating ice blocks. Exposure of Holocene sediments, from downcutting along the Chesselatta River, will provide new Holocene paleoenvironmental data for this part of British Columbia.

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 Chesselatta River occur only where advance-phase glaciolacustrine sediments were identified. This stratigraphic information is useful for forestry terrain stability mapping within the Interior Plateau.

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