

Late Quaternary glacial and interglacial environments of the Nechako River – Cheslatta Lake area, central British Columbia¹

A. Plouffe and V.M. Levson

Abstract: The Quaternary stratigraphy of the Nechako River – Cheslatta Lake area of central British Columbia is described and interpreted to reconstruct the late Quaternary history of the region. Exposures of glacial and nonglacial sediments deposited prior to the last glaciation (Fraser) are limited to three sites. Pollen assemblages from pre-Fraser nonglacial sediments at two of these sites reveal forested conditions around 39 000 BP. During the advance phase of the Fraser Glaciation, glacial lakes were ponded when trunk glaciers blocked some tributary valleys. Early in the glaciation, the drainage was free in easterly draining valleys. Subsequently, the easterly drainage was blocked either locally by sediments and ice or as a result of impoundment of the Fraser River and its tributaries east of the study area. Ice generally moved east and northeast from accumulation zones in the Coast Mountains. Ice flow was influenced by topography. Major late-glacial lakes developed in the Nechako River valley and the Knewstubb Lake region because potential drainage routes were blocked by ice.

Résumé : La stratigraphie du Quaternaire de la région de la rivière Nechako et du lac Cheslatta sise au centre de la Colombie Britannique est décrite et interprétée dans le but de reconstruire l'histoire du Quaternaire tardif de cette région. Seul trois coupes stratigraphiques mettent en évidence des sédiments glaciaires et non-glaciaires mis en place avant la dernière glaciation (Fraser). À deux sites, l'assemblage pollinique des sédiments non-glaciaires prédatant la Glaciation de Fraser reflète un environnement forestier aux environs de 39 000 BP. Lors de l'avancée des glaciers au début de la Glaciation de Fraser, des lacs glaciaires furent retenus dans les vallées secondaires par les glaciers qui occupaient les vallées primaires. Au début de cette glaciation, le drainage vers l'est fut tout d'abord ouvert mais subséquentement, il fut bloqué soit localement par des sédiments et de la glace ou en raison du blocage du fleuve Fraser et ses tributaires à l'est de la région d'étude. Les glaciers se sont écoulés vers l'est et le nord-est à partir de zones d'accumulation centrées sur la Chaîne Côtière. Les écoulements glaciaires furent influencés par la topographie. Des lacs post-glaciaires se sont formés dans la vallée de la rivière Nechako et dans la région du lac Knewstubb suite au blocage du drainage potentiel par la glace.

[Traduit par la Rédaction]

Introduction

The area discussed in this paper covers the northern half of the Nechako River map sheet (National Topographic System (NTS) map sheet 93 F) in central British Columbia, excluding the region covered by Mate and Levson (2001) (Fig. 1). The study area was completely covered by the Cordilleran Ice Sheet during the Late Wisconsinan Fraser Glaciation (Tipper 1963). Lobes of ice, derived from accumulation zones located in the Coast Mountains region, flowed in a generally eastward and northeastward direction (Armstrong and Tipper 1948; Tipper 1971*a*, 1971*b*).

The Quaternary geology of the study area was mapped as part of the Geological Survey of Canada's Nechako NATMAP Project. The purpose of this paper is to present new data on

the late Quaternary stratigraphy and history of this region based on the examination of natural and artificial exposures and on mapping of the surficial sediments and landforms. Emphasis is placed on new chronological and paleoecological data for the Olympia Nonglacial Interval (Middle Wisconsinan) and the retreat-phase glacial lake history of the region.

Physiography, bedrock geology, and drainage

The northern half of the Nechako River map sheet is part of the Interior System of the Canadian Cordillera and includes two physiographic subdivisions as defined by Holland (1976): the Nechako Plateau and the Fraser Basin (Fig. 2). The Nechako Plateau is a region of rounded hills with an av-

Received January 31, 2000. Accepted November 8, 2000. Published on the NRC Research Press Web site on May 1, 2001.

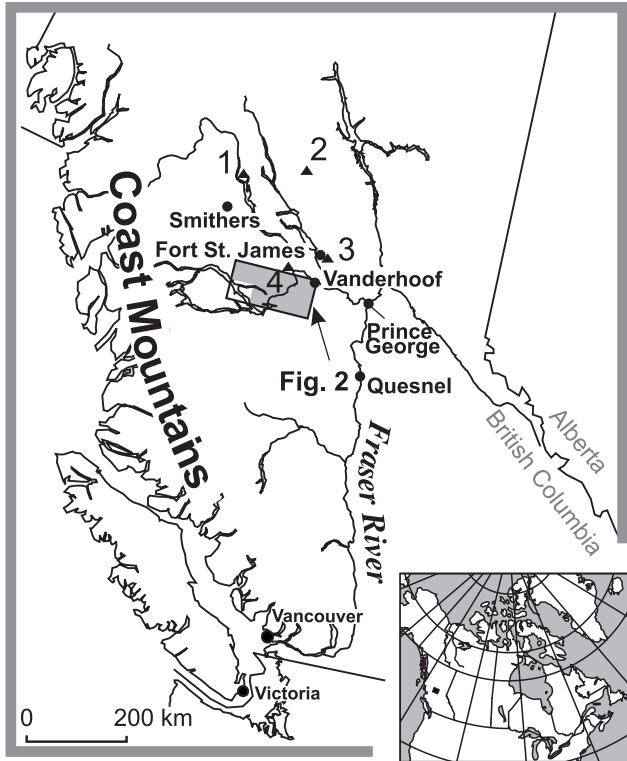
Paper handled by Associate Editors R. Gilbert and M. Church.

A. Plouffe.² Terrain Sciences Division, Geological Survey of Canada, 601 Booth Street, Ottawa, ON K1A 0E8, Canada.
V.M. Levson. British Columbia Geological Survey Branch, 1810 Blanshard Street, Victoria, BC V8V 1X4, Canada.

¹Geological Survey of Canada Contribution 1999202.

²Corresponding author (e-mail: aplouffe@nrcan.gc.ca).

Fig. 1. Location of the study area in British Columbia (shaded). The box delineates Fig. 2. Sites referred in the text (▲) where sediments of the Olympia Nonglacial Interval are exposed include: 1, Babine Lake (Harrington et al. 1974); 2, Chuchi Lake (Harrington et al. 1996); 3, Necoslie River (Plouffe and Jetté 1997); 4, Nautley River (Plouffe and Jetté 1997).



erage elevation of 1200 m above sea level (asl). The Fraser Basin is that part of the Nechako Plateau incised by tributaries of the Fraser River.

The study area is underlain by Triassic to Jurassic volcanic rocks and minor sedimentary rocks, all of which are intruded by a suite of Jurassic, Cretaceous, and perhaps Eocene plutons. These rocks are extensively covered by Eocene felsic and mafic volcanic rocks and Miocene basalt and minor volcanoclastic rocks (Tipper 1963; Anderson et al. 1997, 1998; Wetherup 1997; Anderson and Snyder 1998; Whalen et al. 1998).

The entire region formerly was drained by the Nechako River, a tributary of the Fraser River. The Nechako River drainage was diverted during construction of Kenney Dam in 1952. The Nechako Reservoir, the impoundment behind Kenney Dam, drains in a tunnel through the Coast Mountains to the Pacific Ocean; its level is controlled at the Skins Lake Spillway (Fig. 2).

Previous studies

Dawson (1878) was the first geologist to describe the surficial geology of central British Columbia, after excursions in the area from 1874 to 1877 (see Jackson and Clague 1991 for a summary of early reports). Dawson described landforms, bedrock striations, and surficial sediments and noted the glacial lake sediments of the Nechako River valley,

which he refers to as “White Silts.” A more substantive description of the glacial lake sediments of the Nechako valley was provided by Armstrong and Tipper (1948). More recently, Plouffe (1997) reconstructed the glacial lake history of the region immediately north of the study area.

Tipper (1963) mapped the bedrock geology of the Nechako River area and made significant observations on the region’s surficial geology. He recognized the dominant northeastward movement of ice during the Fraser Glaciation and suggested an earlier north to south ice flow, evidence for which he found on mountain summits in the northwestern part of the area. He also noted distortion and grooving of late-glacial lake sediments in the Nechako River valley, which he attributed to a local ice readvance (see the section titled Quaternary history).

More recently, the British Columbia Geological Survey Branch published four 1 : 50 000 scale surficial geology maps (Levson and Giles 1994; Giles and Levson 1995; Weary et al. 1995; Mate and Levson 2000) and a combined bedrock and surficial geology map (Diakow and Levson 1997) of the southern half of the Nechako River map sheet. Surficial geology mapping also has been done north of the Nechako River map sheet under the Canada – British Columbia Agreement on Mineral Development (1991–1995; Plouffe 1996a, 1996b, 2000). The surficial geology of the region directly east and southeast of the study area was mapped by Clague (1998a, 1998b).

Methods

Surficial sediment types and landforms were mapped using 1 : 60 000 to 1 : 70 000 scale black and white airphotos. Preliminary interpretation was done prior to each field season and was subsequently checked in the field.

Quaternary stratigraphic sections exposed at 94 sites in riverbanks and road cuts were described during the 1996, 1997, and 1998 field seasons. The most significant sections are reported here. Each stratigraphic unit was characterized with respect to its texture, sedimentary structures, color, degree of weathering, clast composition, contact relationships, and lateral continuity. Paleocurrent directions were determined from orientations of planar cross-beds, cross-laminations, and clast imbrication. Elevations were measured with a Wallace and Tiernan altimeter and were corrected for variations in temperature. The instrument was calibrated daily at points of known elevation (e.g., lake level, bench marks). Elevations are considered accurate to within ± 5 m. Clast fabrics of till were determined on cleaned exposures by measuring the trend and plunge of elongated clasts (*a*-axis greater than 2 cm, and *a*:*b* ratio greater than 1.5:1).

Pollen samples were collected from nonglacial sediments beneath Fraser Glaciation till at two sites. Pollen separation was done following the method developed by Erdtman (1960).

Stratigraphy

The Quaternary stratigraphic framework of British Columbia has been established in the more densely populated and more accessible southern portions of the province (see Ryder and Clague 1989 and Ryder et al. 1991 for recent overviews). The stratigraphy presented in this paper is tied

Fig. 2. Map of the northern half of Nechako River map sheet. A–A' shows the location of the Swanson Creek cross section (Fig. 5). Regional ice flow (arrows) reconstructed from the orientation of glacial striations, drumlins, flutings, and crag and tails (Plouffe 1998a, 1998b).

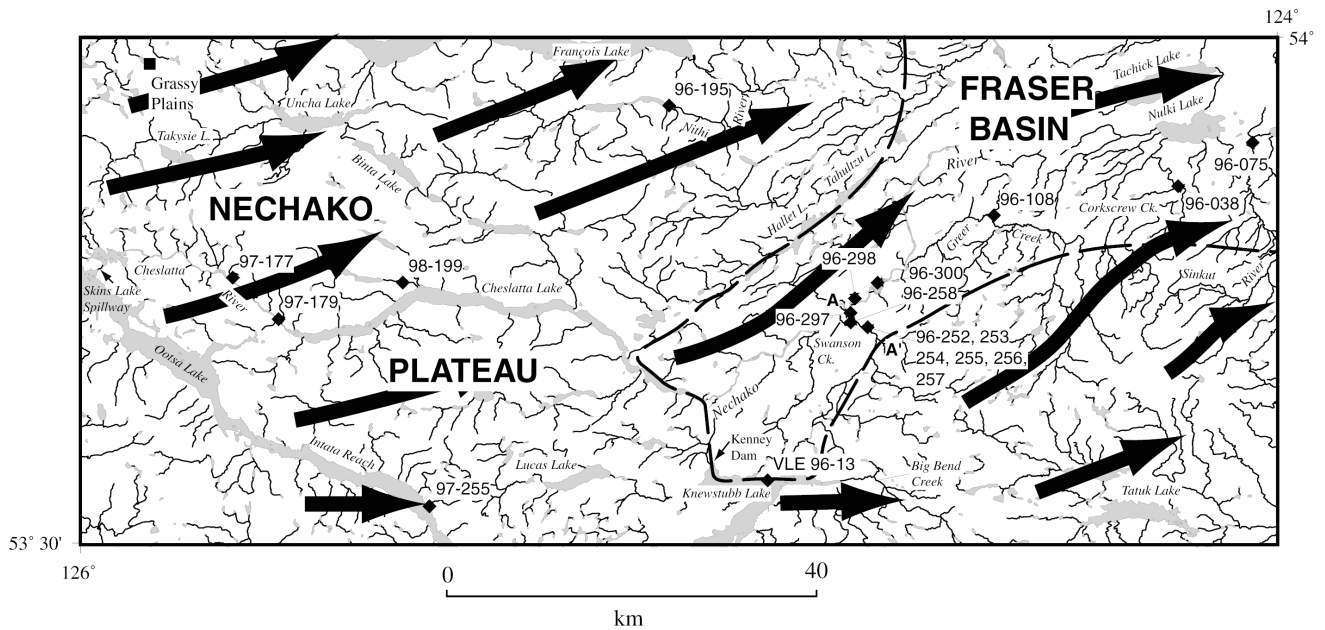
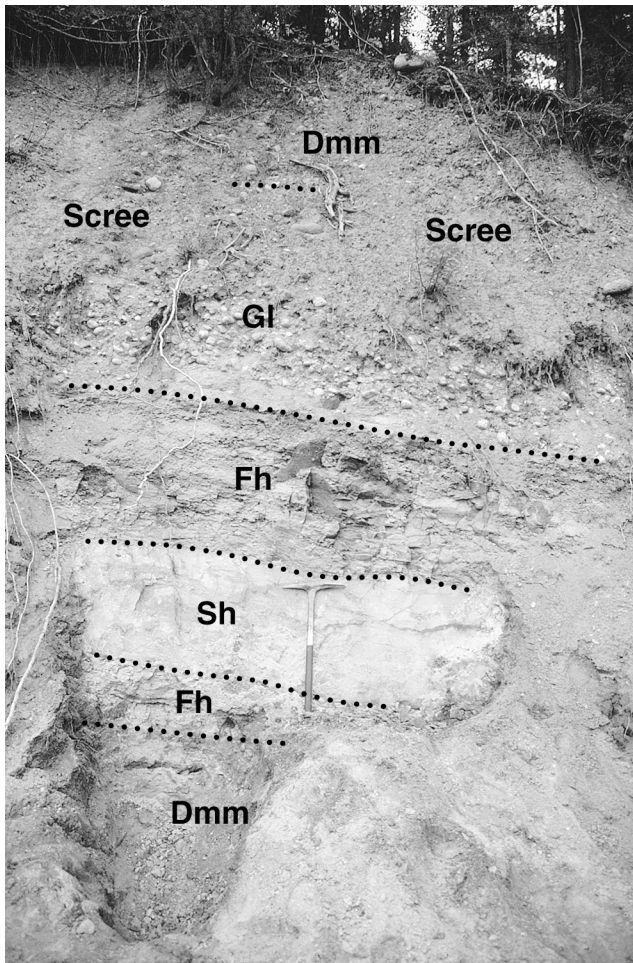


Fig. 3. Section at site 96-038 in Corkscrew Creek valley. See Fig. 2 for location. The pick is 65 cm long. Unit labels as defined in Fig. 4.



to this stratigraphic framework, which includes one of the best recorded Quaternary events in the province, the Late Wisconsinan Fraser Glaciation (Armstrong et al. 1965; Clague 1981). Sediments deposited prior to this glaciation are referred to as pre-Fraser sediments. They include deposits of the Olympia Nonglacial Interval, which is the nonglacial period that preceded the Fraser Glaciation (Armstrong et al. 1965).

Pre-Fraser sediments

Most of the Quaternary sediments deposited prior to the Fraser Glaciation have been removed by glaciers or are covered by younger deposits. Glacial and nonglacial sediments of pre-Fraser age were found at only three sites. They are thought to have been deposited prior to the Fraser Glaciation, rather than during the advance phase of this glaciation, because (i) they are unconformably overlain by sediments that are related to the last glaciation, and (ii) they are generally more weathered than Fraser Glaciation deposits. In addition, deposits of glacial or nonglacial origin are interpreted to be of pre-Fraser age where they are overlain by nonglacial organic-rich sediments that are in turn overlain by Fraser Glaciation sediments.

Corkscrew Creek valley exposure

A natural bluff in the Corkscrew Creek valley (site 96-038; Fig. 2) exposes, from bottom to top, pebbly sandy diamicton; horizontally laminated silt and clay; parallel- and cross-laminated, folded and faulted sand; planar-laminated silt to coarse sand; sand and gravel; and compact diamicton containing abundant striated clasts (Figs. 3, 4). The sand unit has a distinctive white to yellowish-white color due to the presence of iron oxide staining. The pollen assemblage of a sand sample is dominated by arboreal taxa, chiefly *Pinus* (43%) and *Picea* (21%) (Table 1). Shrub pollen, dominantly *Alnus*, is also present in appreciable amounts (21%), but herb pollen is practically absent (1.5%). Several pollen grains are oxidized, rendering their identification difficult, and some

Fig. 4. Summary stratigraphy at sites where pre-Fraser sediments are exposed (see Fig. 2 for section locations). Orientations of elongated clasts in till are depicted in lower hemisphere, equal-area stereograms (contour intervals = 4 and 8%).

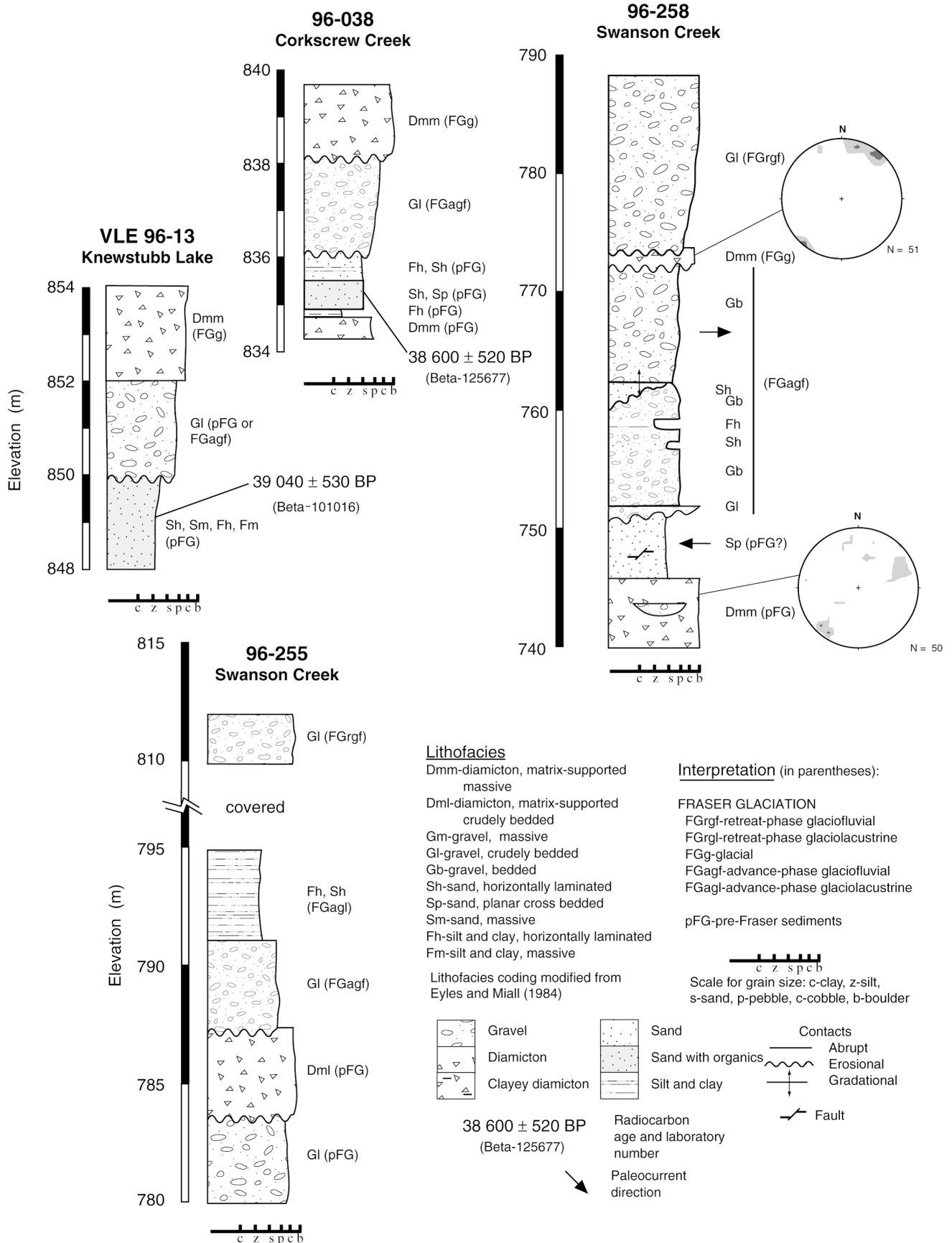


Table 1. Pollen and spore of Olympia Nonglacial Interval sediments.

	Corkscrew Creek site 96-038	Knewstubb Lake site VLE 96-13
Trees		
<i>Picea</i> (spruce)	76 (20.9)	61 (36.3)
<i>Pinus</i> (pine)	156 (43.0)	95 (56.5)
<i>Abies</i> (fir)		10 (6.0)
<i>Betula</i> (birch)	8 (2.2)	
<i>Tsuga canadensis</i> (eastern hemlock)	2 (0.6)	
<i>Ulmus</i> (elm)	1 (0.3)	
Coniferous (undifferentiated)	31 (8.5)	
<i>Corylus</i> (?)		1 (0.6)
Shrubs		
<i>Alnus crispa</i>	62 (17.1)	
<i>Alnus rugosa</i>	14 (3.9)	
<i>Alnus viridis</i> type		1 (0.6)
<i>Alnus</i> (undifferentiated)	1 (0.3)	
<i>Salix</i> (willow)	1 (0.3)	
Ericaceae (heath family)	1 (0.3)	
Herbs		
Gramineae (grass family)	2 (0.6)	
Rosaceae (rose family)	3 (0.8)	
<i>Cornus</i> (dogwood, cornel)	1 (0.3)	
Unidentified	4 (1.1)	
Total	363 (100.0)	168 (100.0)
Aquatics		
<i>Sparganium</i> (bur-reed)	1	
Spores		
<i>Selaginella</i>		1
Monolete spore	1	
Trilete spore	5	

Note: Common names are given when they apply to a single species. Percentages are given in parentheses.

pollen may have been destroyed by weathering. Small fragments of plant material recovered from the sand unit yielded a radiocarbon accelerator mass spectrometry (AMS) age of $38\,600 \pm 520$ BP (Beta-25677).

The lower diamicton is interpreted as a debris-flow deposit. The overlying clay was deposited in a low-energy environment (ponded water). The high pollen content of the overlying sand and the finite AMS radiocarbon age on the contained organic material ($38\,600 \pm 520$ BP) suggest that the sand was deposited in nonglacial conditions (Olympia Nonglacial Interval). The pollen assemblage indicates that the area was forested at the time of deposition. The oxidation of the pollen grains and their potentially selective preservation prevent any further interpretation or comparison with modern assemblages. The silt-sand unit above the sand may have been deposited in a nonglacial or proglacial environment. The overlying gravel and diamicton units are interpreted to be advance outwash and till of the Fraser Glaciation, respectively.

Swanson Creek valley exposures

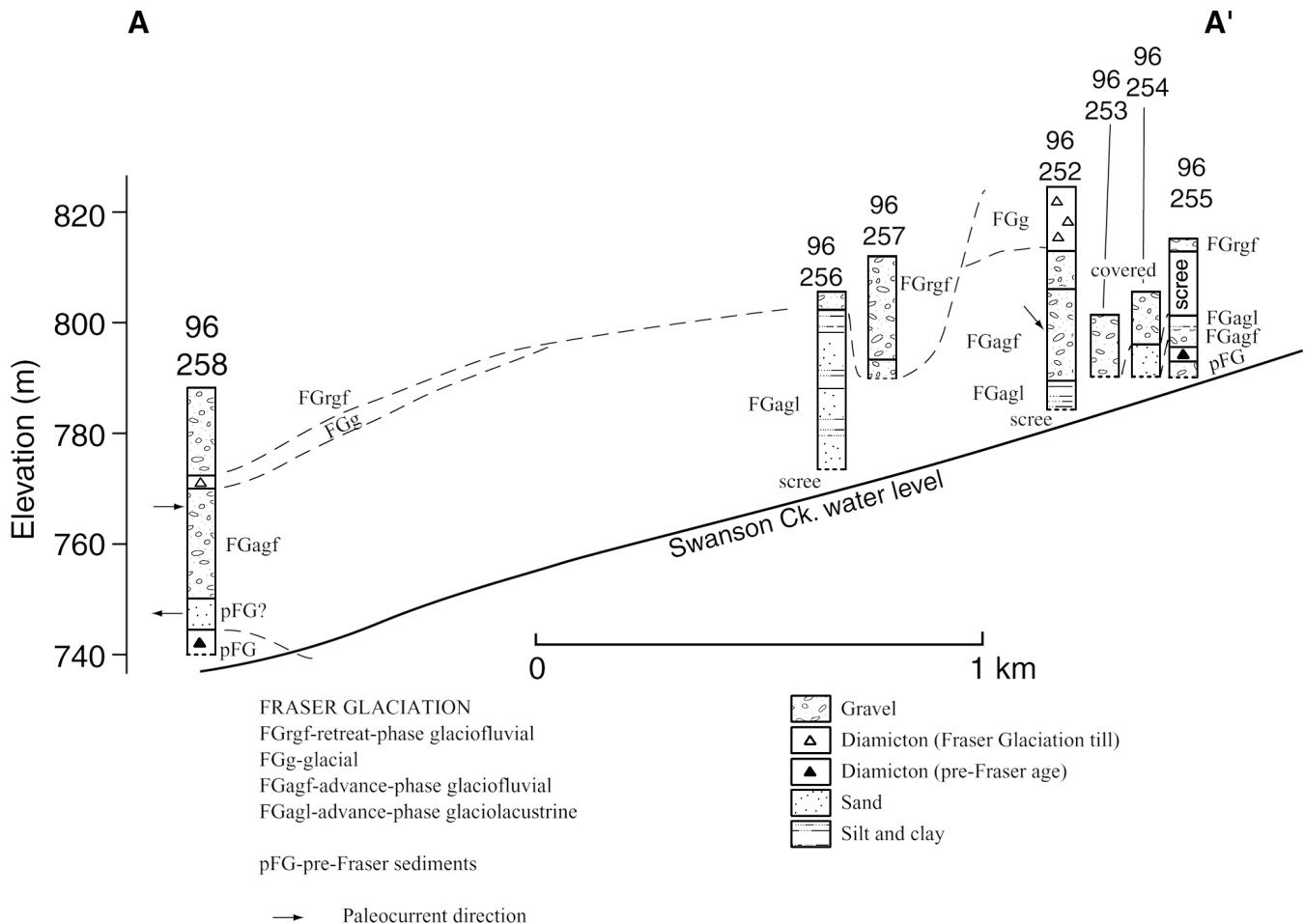
Pre-Fraser sediments are preserved in Swanson Creek valley, which is oriented transverse to the dominant Fraser Glaciation ice-flow direction (Fig. 2). The stratigraphy of the Swanson Creek valley was constructed from seven natural exposures (Fig. 5).

At site 96-255, at the southeast end of the valley (Figs. 4, 5), cobbly to pebbly, clast-supported and crudely bedded sand and gravel is unconformably overlain by a very crudely bedded, compact diamicton containing abundant striated clasts (Fig. 4). Both units are oxidized: clasts are coated with iron and manganese oxides and the sediment matrix is yellow to red. These sediments are overlain by sand and gravel and fine sand, silt, and clay (Fig. 4).

At site 96-258, near the northwest end of the valley, the lowest exposed unit is a massive, compact, oxidized diamicton containing striated clasts (Figs. 4, 5). The diamicton has a bimodal fabric with most elongated clasts dipping shallowly to the northeast or southwest. Clasts are dominantly volcanic rocks with less than 1% diorite. The diamicton is overlain by several sand and pebble gravel units, which are, in turn, overlain by a second diamicton. This upper diamicton contains abundant striated clasts. Its clast fabric and lithologies are similar to those of the lower diamicton (Fig. 4). The upper diamicton is overlain by crudely bedded, cobble to boulder gravel.

At site 96-255, the lowest gravel unit probably aggraded in a stream under glacial or nonglacial conditions. The overlying diamicton could be a till or a debris flow resulting from the reworking of a till, as evidenced by the abundance of striated clasts in this deposit. These two units are thought to have been weathered during nonglacial conditions that

Fig. 5. Stratigraphy of seven sections in Swanson Creek valley (see Fig. 2 for locations). Along much of its course, Swanson Creek is flowing on advance-phase glaciolacustrine sediments.



preceded the last glaciation. The overlying units are thought to have accumulated during the advance and retreat of glaciers of the Fraser Glaciation (Figs. 4, 5).

Both diamictons at site 96-258, near the west end of Swanson Creek valley, are interpreted to be tills based on their compaction, poor sorting, striated clast content, and well-developed clast fabric. The Brooks Diorite Complex crops out northeast and east of Swanson Creek (Wetherup 1997; Anderson et al. 1998). The near absence of diorite clasts in the lower and upper till along with general northeast-southwest fabrics indicate that ice was probably flowing to the northeast during the deposition of the lower and upper tills. Given the stratigraphic position of the upper till, it is interpreted as Fraser Glaciation till. This interpretation implies that the lower till was either deposited during a glacial advance (ice front fluctuation) at the onset of the Fraser Glaciation or during a separate, earlier glaciation.

Knewstubb Lake exposure

At site VLE 96-13, the stratigraphy consists of, from bottom to top, fine sand and silt, pebble gravel, and massive diamicton (Figs. 2, 4). The lowest unit contains some charcoal and rare, small organic fragments. Charcoal recovered from the sand and silt yielded a radiocarbon age of $39\,040 \pm 530$ BP (Beta-101016). The pollen spectrum of the sand and silt is dominated by *Pinus* (56%), *Picea* (36%), and *Abies*

(6%), with almost no herbaceous pollen (Table 1). Pollen grains are poorly preserved, which limits paleoecological interpretation.

The lowest exposed sand and silt unit in the section, at site VLE 96-13, is interpreted as a nonglacial, lacustrine or low-energy fluvial deposit. A nonglacial origin is indicated by the presence of organic material and pollen in the sand. The fine grain size of the sediments and horizontal and parallel bedding indicate a low-energy, depositional environment with standing or slowly moving water. The radiocarbon age of $39\,040 \pm 530$ BP on charcoal within the sediments suggests that they date to the Olympia Nonglacial Interval. High arboreal pollen (*Pinus*, *Picea*, and *Abies*) with almost no herbaceous pollen suggests a relatively extensive forest cover in the region at about 39 000 BP. The pollen assemblage from pre-Fraser nonglacial sediments at the Corkscrew Creek site corroborates the interpretation from the Knewstubb Lake site, namely that a forested environment existed at least for some time during the Olympia Nonglacial Interval in central British Columbia. The pebble gravel and diamicton above the nonglacial sand and silt are interpreted as advance-phase outwash and Fraser Glaciation till, respectively.

Sediments of the Fraser Glaciation

Sediments deposited during the Fraser Glaciation can be

divided into three phases: advance, full glacial, and recessional. Sediments directly underlying till of the last glaciation that show a degree of weathering similar to that of the overlying till, contain lithologies of distant origin, and contain deformations suggestive of glacier overriding are interpreted to be advance-phase sediments. However, the possibility that some of these deposits may be much older than the last glaciation cannot be completely eliminated, because there is generally an erosional contact at the base of the till, which represents a hiatus of unknown duration.

Advance-phase sediments

Glaciolacustrine and glaciofluvial sediments associated with the advance phase of the last glaciation have been observed mainly in areas protected from glacial erosion, for example in deep valleys or valleys oriented transverse to ice flow. These sediments are well compacted, commonly crop out in vertical bluffs, and contain faults and folds.

Fine-grained sediments that underlie till of the last glaciation include well-sorted sand, silt, and minor clay. Sandy beds are horizontally stratified, planar cross-stratified, or massive. Silt and clay units are horizontally laminated to massive. Clast-supported and crudely bedded gravel lenses and beds are interbedded with these finer sediments. In places, the sand, silt, and clay grade upward into pebbly to bouldery gravel that contains silt and clay interbeds.

These sediments were probably deposited in glacial lakes that developed as a result of blockage of the drainage by advancing glaciers. Some of these sediments coarsen upward, reflecting the advance of glaciers into the area. At some sites, however, the sediments fine upward due to deepening of water during the transition from glaciofluvial to glaciolacustrine conditions. Advance-phase glaciolacustrine sediments were found in the valleys of an unnamed tributary of Cheslatta Lake, Cheslatta River, Sinkut River, Nithi River, Swanson Creek, Greer Creek, and Intata Reach (Fig. 6).

Units of massive to well-bedded, clast-supported, pebbly to bouldery gravel underlie Fraser Glaciation till at several sites (Figs. 6, 7). The gravels range from moderately to poorly sorted. They contain crudely layered, discontinuous diamicton interbeds that generally increase upward in abundance and thickness. Well-sorted sand beds and lenses are also present in the gravels. Beds in the upper part of these sorted sediments are truncated by the overlying till. Some of the beds below the till are also cut by thrust faults.

These deposits are interpreted as glaciofluvial sediments deposited in channels on outwash plains in front of advancing glaciers. Diamicton interbeds likely represent debris flows derived from adjacent steep slopes (reworked till) or ice (flow till). Deformation structures in the upper part of the advance-phase glaciolacustrine and glaciofluvial sediments are thought to be glaciotectonic in origin, because their orientation can be related to the direction of ice flow during the last glaciation. The presence of advance-phase glaciofluvial sediments indicates that valleys were free-draining for some time during the advance of glaciers. In some valleys, glaciofluvial sedimentation was followed by glaciolacustrine sedimentation, when advancing glaciers blocked the drainage (e.g., Nithi River valley, section at site 96-195; and Cheslatta River valley, section at site 97-179; Figs. 2, 6, 7).

Full glacial sediments

A compact massive diamicton containing 20–40% pebble- to boulder-sized clasts and 60–80% matrix is present throughout the study area. The diamicton contains abundant striated and faceted clasts, many of which are lithologies derived from distant sources. The diamicton is commonly less than 5 m thick, but can reach up to 12 m in places. Discontinuous, clast-supported, and generally massive sand and gravel lenses have been observed within the diamicton. Such lenses can reach a thickness of 1 m.

The diamicton is interpreted to be a till, based on its widespread distribution and physical characteristics (compaction, poor sorting, striated and faceted clasts, and lithologies of distant origin). Sub-till radiocarbon ages at Corkscrew Creek and Knewstubb Lake ($38\,600 \pm 520$ BP and $39\,040 \pm 530$ BP, respectively) indicate that the till was deposited during the Fraser Glaciation. It was dominantly deposited by a combination of lodgment and meltout processes (see Mate and Levson 2001). In Swanson Creek valley, Fraser Glaciation till is discontinuous (Fig. 5), perhaps due to (i) glaciofluvial erosion of the till at the base of the ice or following ice retreat, (ii) nondeposition, or (iii) poor sediment exposure. Similarly, a discontinuous and a generally thin Fraser Glaciation till was also noted by Clague (1988) in the Fraser River valley east of the study area.

Recessional-phase sediments

As during the advance phase, the retreat phase of the last glaciation was marked by extensive glaciolacustrine and glaciofluvial sedimentation. Recessional-phase sediments are the best exposed glacial deposits, because they were not overridden by glaciers or buried by great thicknesses of postglacial sediments.

Well-sorted sand, silt, and minor clay occur abundantly as massive beds and rhythmites in the Nechako River, northern Knewstubb Lake, and Big Bend Creek valleys. These deposits locally attain thicknesses of several tens of metres. In the Nechako River valley, they are rhythmically stratified, consisting of repeated couplets of fine sand and silt and thin laminated silt and clay. Some fine sand and silt beds fine upward, whereas others coarsen upward. These beds also contain parallel laminations and planar cross-laminations. Couplets become progressively finer and thinner upward. They range in thickness from up to 1.8 m at the base of sections to 10 cm near the top (Fig. 8). The maximum observed number of rhythmites was 29, at a section in the Nechako River valley.

In the northern Knewstubb Lake and Big Bend Creek valleys, fine-grained glacial recessional deposits are composed of massive and stratified beds of coarse to medium sand with minor silt and clay laminations. These sediments lack well-developed rhythmic stratification. In the Knewstubb Lake area, the sediments are kettled (Plouffe 1998b) and faulted and folded (Huscroft and Plouffe 1999).

The maximum elevation of these fine-grained sediments varies within the study area. In the Nechako River valley, they are present up to approximately 770 m asl, and in the Knewstubb Lake and Big Bend Creek valleys, they are present up to 880 and 975 m asl, respectively (Huscroft and Plouffe 1999; Fig. 9).

These fine-grained sediments are interpreted to be recessional-phase sediments.

Fig. 6. Sections exposing advance-phase glaciolacustrine and glaciofluvial sediments. Section locations are shown in Fig. 2. See Fig. 4 for legend.

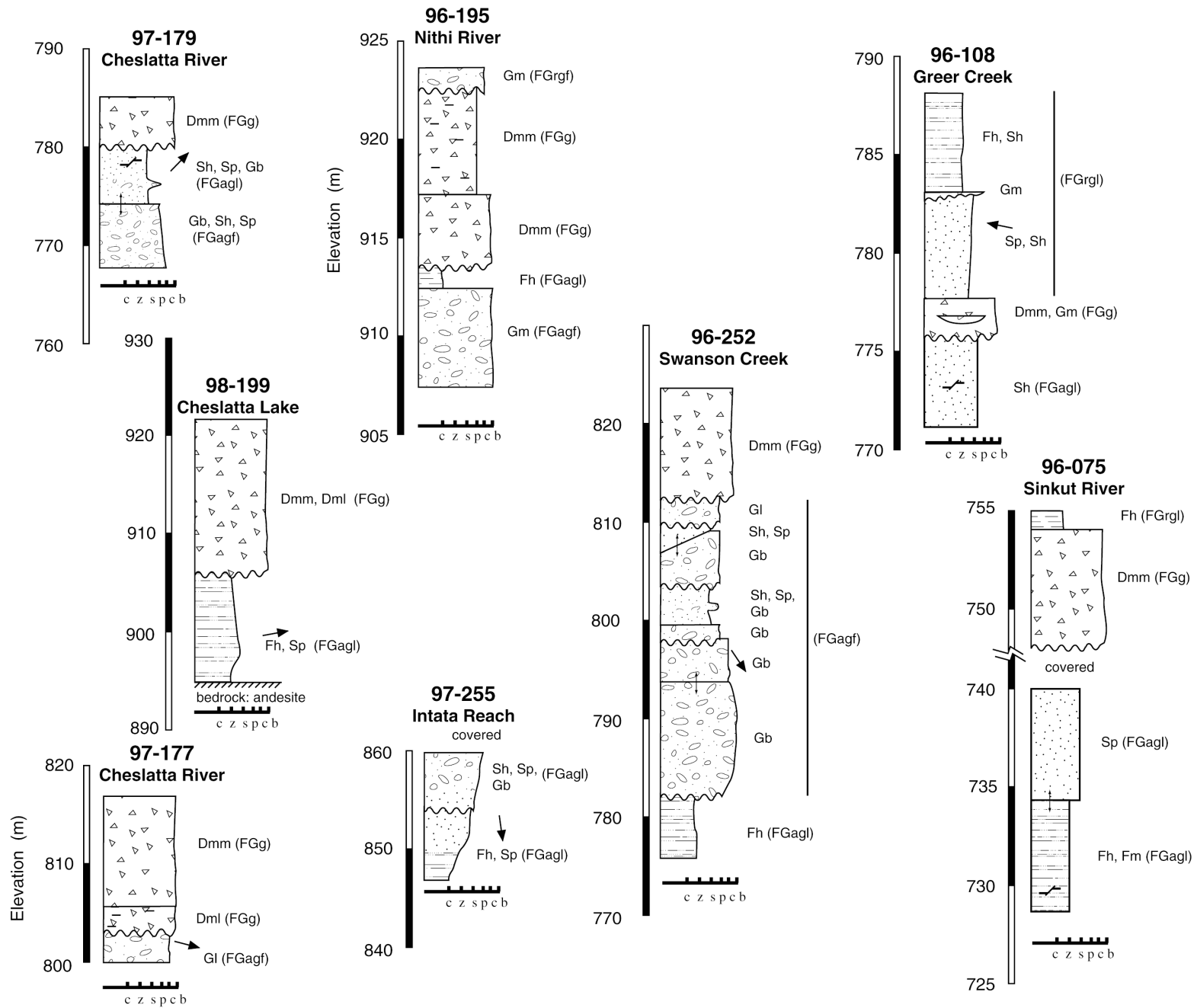


Fig. 7. Advance-phase glaciofluvial and glaciolacustrine sediments exposed in the section at site 97-179 in Cheslatta River valley. See Fig. 4 for lithofacies abbreviations.

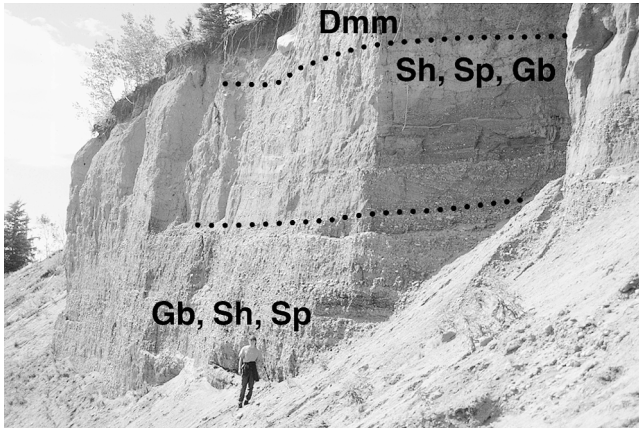
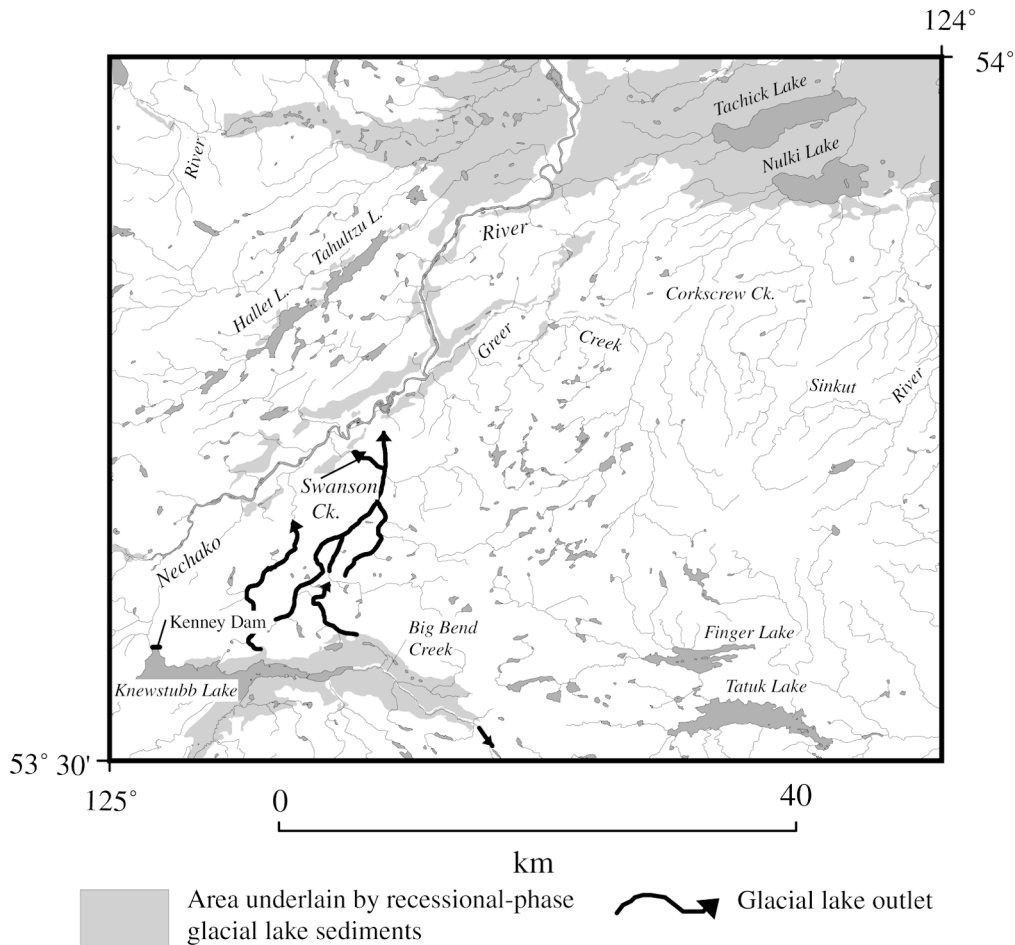


Fig. 8. Recessional-phase glaciolacustrine sediments in Nechako River valley (site 96-298; Fig. 2). Note that the rhythmites thin upwards. Person for scale (arrow).



Fig. 9. Distribution of recessional-phase glacial lake sediments and glacial lake outlets in the study area.



sional-phase glacial lake deposits. Based on the areal distribution and elevations of these sediments, it is thought that two regional glacial lakes developed in the study area during ice retreat: one lake in the Nechako River valley and another, higher lake in Knewstubb Lake valley (see glacial and postglacial history later in the paper).

The rhythmites observed in the Nechako River valley may

have been deposited distally from the retreating glacier or in the deeper portion of the glacial lake. The deformed sandy glacial lake sediments in the Knewstubb Lake and Big Bend Creek areas probably were deposited adjacent to or on top of dead ice (Huscroft and Plouffe 1999). A similar deglaciation scenario was proposed for the Tezzeron Lake region north of the study area (Plouffe 1997).

Gravel associated with sand, silt, and clay is thought to have been deposited in proximity to the retreating glacier or to stagnant ice blocks, or from adjacent valley walls. Some of the gravel might have been deposited subaqueously at the mouth of meltwater conduits on subaqueous outwash fans (Rust and Romanelli 1975).

Well-stratified to massive, clast-supported sand and gravel deposits above Fraser Glaciation till are interpreted to be recessional-phase glaciofluvial sediments. They occur mainly in valleys as terraces, but 1–3 m thick blankets of glaciofluvial gravel were observed elsewhere in the study area, for example near the mouths and sides of meltwater channels. In some valleys, hummocky glaciofluvial deposits are associated with glaciofluvial terraces. Where exposed, these sediments contain high-angle reverse and normal faults indicative of sedimentation on or against ice.

Postglacial sediments

Postglacial sediments include organic deposits, colluvium, alluvium, and eolian deposits. Organic deposits consist of plant matter in various stages of decomposition that accumulates in poorly drained areas such as fens, bogs, and swamps. Colluvium is present mainly at the toe of steep slopes. Modern alluvium consists of sand and gravel and forms flood plains, low terraces, and fans. These sediments are generally better sorted than glaciofluvial deposits, except in alluvial fans. Glaciolacustrine, glaciofluvial, and alluvial deposits in the Nechako River valley are overlain by a discontinuous and hummocky veneer of well-sorted massive fine sand and minor silt interpreted to be eolian in origin. Much of the surface of these wind-blown deposits is presently vegetated, and eolian sedimentation today is very limited.

Quaternary history

Pre-Fraser ice advance

Stratigraphic evidence of a pre-Fraser ice advance has been found only in Swanson Creek valley. Clast fabric and till-pebble lithologies indicate that ice generally flowed to the northeast during that glacial event, i.e., more or less in the same direction as the Fraser Glaciation ice flow. Mate and Levson (1999, 2001) described a site along the shore of Ootsa Lake that also shows evidence of a pre-Fraser ice advance: a diamicton interpreted to be a till is overlain successively by organic-bearing, fine-grained sediments (Olympia Nonglacial sediments ?) and Fraser Glaciation till.

Olympia Nonglacial Interval

The pollen spectra of the organic-bearing sediments at Corkscrew Creek and Knewstubb Lake suggest that a forest environment existed during at least part of the Olympia Nonglacial Interval in central British Columbia. Climate may have resembled that of the present, because the area is currently occupied by a forest dominated by spruce and pine, which is well represented in modern pollen records (MacDonald and Ritchie 1986). In contrast, pollen spectra from Olympia Nonglacial Interval sediments at other nearby localities in the region generally reflect cooler climatic conditions. Two radiocarbon ages ($38\,230 \pm 410$ BP

(Beta-88557) and $42\,460 \pm 670$ BP (Beta-88558); Plouffe and Jetté 1997) on plant debris from nonglacial sediments at the Nautley River site, 40 km northwest of Corkscrew Creek, are similar to those at Corkscrew Creek and Knewstubb Lake ($38\,600 \pm 520$ BP and $39\,040 \pm 530$ BP, respectively), yet the pollen assemblage of the Nautley River sediments suggests tundra to forest-tundra environments. Similar chronology and tundra-like paleoecological reconstruction have been established for two other sites: Babine Lake and Chuchi Lake (Harington et al. 1974, 1996; Fig. 1). It is very unlikely that a drastic change of vegetation from a forest to a forest-tundra to tundra environment would occur over such a short distance (40 km) and that high pollen producers, such as *Pinus*, would not be better represented to the north, if it were growing in the region. However, the Babine Lake, Chuchi Lake, and Nautley River sites all show evidence of at least a partial tree cover, and it is possible that a more extensive forest cover may have developed, at least locally in the region, in a fairly short time period during the Olympia Nonglacial Interval. Harington et al. (1974) inferred that spruce, fir, and aspen or poplar trees grew as local stands on suitable sites at Babine Lake. Fragments of spruce and fir wood found at the site confirm that these trees were growing in the area. Plouffe and Jetté (1997) found higher proportions of spruce (5.9%) and pine (12.9%) pollen at Nautley River than were present at Babine Lake (3.5% and 0.7%, respectively), and they also inferred the presence of local stands of spruce.

Nevertheless, differences in paleoecological reconstruction among these sites can be attributed to the reduced precision associated with radiocarbon ages that approach the limit of radiocarbon dating and poor pollen preservation. It is possible, for example, that the cited finite radiocarbon ages are actually nonfinite and the associated sediments may, therefore, have been deposited earlier in the Olympia Nonglacial Interval or possibly even in the last interglacial (Sangamonian). If so, this would suggest that the differences in forest cover between these sites may reflect paleoenvironmental conditions over much wider periods of time than the radiocarbon ages indicate. Clearly, more detailed work is required at Corkscrew Creek and Knewstubb Lake sites to better decipher the paleovegetation and the paleoclimate of the Olympia Nonglacial Interval in central British Columbia. Such research should include two other sites, also discovered during the Nechako NATMAP Project, where organic sediments are potentially related to the Olympia Nonglacial Interval (cf. Levson et al. 1998; Mate and Levson 2001).

Fraser Glaciation

At the onset of Fraser Glaciation, ice lobes advanced in a general easterly direction from ice-accumulation zones in the Coast Mountains. The presence of advance-phase glacial lake sediments in some tributary valleys indicates that the drainage in these valleys was blocked by ice tongues moving along the trunk valleys. Early in the Fraser Glaciation, drainage was free-flowing in easterly draining valleys, so deposits of sand and gravel accumulated on outwash plains near the ice front (e.g., Cheslatta River valley). The stratigraphic evidence from the Cheslatta River suggests that the easterly drainage was blocked prior to the valley being overridden by

ice (section at site 97-179; Figs. 6, 7). The drainage may have been blocked at the valley mouth by ice or sediment. Alternatively, the lake may be part of a larger impoundment of the Fraser River and its tributaries east of the study area (Eyles and Clague 1991; Huntley and Broster 1994).

At the time of formation of the drumlins, drumlinoid ridges, flutings, crag and tails, and glacial striations, ice was thick enough to cover the highest mountains of the region, but was not thick enough to flow independently of topography. Ice-flow indicators on mountain summits and flanks show that ice was deflected around topographic obstacles and flowed parallel to major valleys (Fig. 2; see also Plouffe 1998a, 1998b).

Large glacial lakes inundated some of the major valleys during deglaciation, notably in the Knewstubb Lake and Nechako River valleys. The glacial lake in the Knewstubb Lake valley was probably not continuous with the glacial lake in the Nechako River valley, because the level of the former was much higher and was controlled by various outlets located at progressively lower elevations as deglaciation progressed (Fig. 9). Initially, the outlet was along Big Bend Creek. Later, the lake drained through three major meltwater channels eroded in the Cut Off Creek area (Plouffe 1998b; Huscroft and Plouffe 1999). The glacial lake in the Nechako River valley may have been continuous with the glacial lake system occupying the Nechako River and Fraser River valleys, north and northeast of the study area (Clague 1987; Plouffe 1997). If the rhythmites in the Nechako River valley are annual layers (varves), the glacial lake existed for at least 29 years. However, if the rhythmites are not varves, the duration of the glacial lake may have been shorter.

As noted previously, Tipper (1963) suggested a late-glacial readvance northeast of Tachick Lake, based on deformation of the glacial lake sediments and their fluted surface, which he identified on airphotos. However, contortion and deformation of the glacial lake sediments were found only at sporadic sites and can be ascribed to postdepositional soft-sediment gravity deformation rather than glacial overriding. The deformation structures are highly variable in orientation, suggesting that they were not produced by a readvance. Exposures through the purported flutes in glacial lake sediments show these to be composed of till veneered by glacial lake sediments. There is, thus, no evidence to support the hypothesis of a late-glacial readvance northeast of Tachick Lake.

Postglacial period

Postglacial time was marked by the accumulation of peat in poorly drained areas and aggradation and incision of fluvial deposits. The presence of eolian sediments on alluvial terraces suggests that terraces were not readily vegetated during postglacial time, which could be related to a dryer and slightly warmer climate than at present during the early to mid-Holocene (cf. Hebda 1995).

Conclusions

Most of the Quaternary sediments in the northern half of the Nechako River map sheet area were deposited during the Late Wisconsinan Fraser Glaciation. However, there is some evidence for (i) a pre-Fraser glacial event, during which ice

flowed northeast, and (ii) a forested nonglacial environment about 39 000 BP during the Olympia Nonglacial Interval. However, the forest may have been localized, because other sites in central British Columbia supported a forest-tundra to tundra environment at about the same time. Nevertheless, these new data should be viewed with caution because of the poor preservation of pollen and the reduced precision of radiocarbon dating near its limit. More detailed work is required before a more definitive reconstruction of the paleoclimate and paleogeography of this nonglacial interval can be done.

During the last glaciation, ice flowed generally to the east across the area, with sources in the Coast Mountains. Advancing glaciers ponded glacial lakes in tributary valleys, but the drainage was free, at least initially, in the major east-draining valleys. The entire study area was covered by glaciers at the peak of the Fraser Glaciation, but ice was deflected around the highest topographic obstacles. During deglaciation, glacial lakes were impounded by retreating glaciers in the Knewstubb Lake region and the Nechako River valley.

Acknowledgments

This research was conducted as part of the Nechako NATMAP Project under the leadership of L.C. Struik and D.C. MacIntyre. A. Grenier (Environmental Services Laboratory of the Geological Survey of Canada, Ottawa, Ontario) completed the pollen count on the sample from the Corkscrew Creek site and commented on its interpretation. The pollen count on the sample from Knewstubb Lake was completed by R.W. Mathewes. Capable field assistance was provided by J. Bjornson, H. Keyes, and F. Thérien. A draft of the manuscript was reviewed by L.E. Jackson, Jr., and A.J. Stumpf. Journal referees J.J. Clague and L.E. Jackson, Jr., further improved the manuscript.

References

- Anderson, R.G., and Snyder, L.D. 1998. Jurassic to Tertiary volcanic, sedimentary, and intrusive rocks in the Hallett Lake area, central British Columbia. *In* Current research 1998-A. Geological Survey of Canada, Paper 1998-A, pp. 135–144.
- Anderson, R.G., L'Heureux, R., Wetherup, S., et al. 1997. Geology of the Hallett Lake map area, central British Columbia: Triassic, Jurassic, Cretaceous, and Eocene? plutonic rocks. *In* Current research 1997-A. Geological Survey of Canada, Paper 1997-A, pp. 107–116.
- Anderson, R.G., Snyder, L.D., Resnick, J., et al. 1998. Geology of the Big Bend Creek map area, central British Columbia. *In* Current research 1998-A. Geological Survey of Canada, Paper 1998-A, pp. 145–154.
- Armstrong, J.E., and Tipper, H.W. 1948. Glaciation in north central British Columbia. *American Journal of Science*, **246**: 283–310.
- Armstrong, J.E., Crandell, E.R., Easterbrook, D.J., et al. 1965. Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington. *Geological Society of America Bulletin*, **76**: 321–330.
- Clague, J.J. 1981. Late Quaternary geology and geochronology of British Columbia, Part 2: summary and discussion of radiocarbon-dated Quaternary history. Geological Survey of Canada, Paper 80-35.

- Clague, J.J. 1987. Quaternary stratigraphy and history, Williams Lake, British Columbia. *Canadian Journal of Earth Sciences*, **24**: 147–158.
- Clague, J.J. 1988. Quaternary stratigraphy and history, Quesnel, British Columbia. *Géographie physique et Quaternaire*, **42**: 279–288.
- Clague, J.J. 1998a. Surficial geology, Westroad (Blackwater) River, British Columbia. Geological Survey of Canada, Open File 3639, map scale 1 : 100 000.
- Clague, J.J. 1998b. Surficial geology, Cluculz Lake, British Columbia. Geological Survey of Canada, Open File 3638, map scale 1 : 100 000.
- Dawson, G.M. 1878. On the superficial geology of British Columbia. *Quarterly Journal of the Geological Society of London*, **34**: 89–123.
- Diakow, L.J., and Levson, V.M. 1997. Bedrock and surficial geology of the southern Nechako Plateau, central British Columbia. British Columbia Ministry of Employment and Investment, Geoscience Map 1997-2, scale 1 : 100 000.
- Erdtman, G. 1960. The acetolysis method, a revised description. *Svensk Botanisk Tidskrift*, **54**: 561–564.
- Eyles, N., and Clague, J.J. 1991. Glaciolacustrine sedimentation during advance and retreat of the Cordilleran Ice Sheet in central British Columbia. *Géographie physique et Quaternaire*, **45**: 317–331.
- Eyles, N., and Miall, A.D. 1984. Glacial facies. *In Facies models. Edited by R.G. Walker. Geological Association of Canada, Geoscience Canada Reprint Series 1*, pp. 15–38.
- Giles, T.R., and Levson, V.M. 1995. Surficial geology and Quaternary stratigraphy of the Tsacha Lake area (NTS 93 F/2). British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1995-10, map scale 1 : 50 000.
- Harrington, C.R., Tipper, H.W., and Mott, R.J. 1974. Mammoth from Babine Lake, British Columbia. *Canadian Journal of Earth Sciences*, **11**: 285–303.
- Harrington, C.R., Plouffe, A., and Jetté, H. 1996. A partial bison (*Bison cf. B. latifrons*) skeleton from Chuchi Lake, and its implications for the middle Wisconsinan environment of central British Columbia. *Géographie physique et Quaternaire*, **50**: 73–80.
- Hebda, R.J. 1995. British Columbia vegetation and climate history with focus on 6 ka BP. *In Paleogeography and paleoecology of 6000 yr BP in Canada. Edited by H. Jetté. Géographie physique et Quaternaire*, **49**: 55–79.
- Holland, S.S. 1976. Landforms of British Columbia, a physiographic outline. British Columbia Department of Mines and Petroleum Resources, Bulletin 48.
- Huntley, D.H., and Broster, B.E. 1994. Glacial Lake Camelsfoot: a Late Wisconsinan advance stage proglacial lake in the Fraser River valley, Gang Ranch area, British Columbia. *Canadian Journal of Earth Sciences*, **31**: 798–807.
- Huscroft, C., and Plouffe, A. 1999. Field investigations of a late glacial lake of the Fraser Glaciation, central British Columbia. *In Current research 1999-A. Geological Survey of Canada, Paper 1999-A*, pp. 179–184.
- Jackson, L.E.J., and Clague, J.J. 1991. The Cordilleran Ice Sheet: one hundred and fifty years of exploration and discovery. *Géographie physique et Quaternaire*, **45**: 269–280.
- Levson, V.M., and Giles, T.R. 1994. Surficial geology and Quaternary stratigraphy of the Fawnie Creek area (NTS 93 F/3). British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1994-9, map scale 1 : 50 000.
- Levson, V.M., Stumpf, A.J., and Stuart, A.J. 1998. Quaternary geology and ice-flow studies in the Smithers and Hazelton map areas (93 L and M); implications for exploration. *In Geological fieldwork 1997. British Columbia Ministry of Employment and Investment, Paper 1998-1*, pp. 5-1 – 5-8.
- MacDonald, G.M., and Ritchie, J.C. 1986. Modern pollen spectra from the western interior of Canada and the interpretation of late Quaternary vegetation development. *New Phytologist*, **103**: 245–268.
- Mate, D.J., and Levson, V.M. 1999. Quaternary geology of the Marilla map sheet (NTS 93 F/12). *In Geological fieldwork 1998. British Columbia Ministry of Energy, Mines, and Petroleum Resources, Paper 1999-1*, pp. 25–32.
- Mate, D.J., and Levson, V.M. 2000. Quaternary geology of the Marilla map area (93 F/12). British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 2000-9, map scale 1 : 50 000.
- Mate, D.J., and Levson, V.M. 2001. Quaternary stratigraphy and history of the Ootsa Lake – Cheslatta River area, Nechako Plateau, central British Columbia. *Canadian Journal of Earth Sciences*, **38**(4): 751–765.
- Plouffe, A. 1996a. Surficial geology, Burns Lake, British Columbia (NTS 93 K/SW). Geological Survey of Canada, Open File 3184, map scale 1 : 100 000.
- Plouffe, A. 1996b. Surficial geology, Fraser Lake, British Columbia (NTS 93 K/SE). Geological Survey of Canada, Open File 3182, map scale 1 : 100 000.
- Plouffe, A. 1997. Ice flow and late glacial lakes of the Fraser Glaciation, central British Columbia. *In Current research 1997-A. Geological Survey of Canada, Paper 1997-A*, pp. 133–143.
- Plouffe, A. 1998a. Surficial geology, Binta Lake, British Columbia (93 F/11, 13, and 14). Geological Survey of Canada, Open File 3640, map scale 1 : 100 000.
- Plouffe, A. 1998b. Surficial geology, Tahultzu Lake, British Columbia (93 F/NE). Geological Survey of Canada, Open File 3620, map scale 1 : 100 000.
- Plouffe, A. 2000. Surficial geology, Fort Fraser, British Columbia. Geological Survey of Canada, Map 1986A, scale 1 : 250 000.
- Plouffe, A., and Jetté, H. 1997. Middle Wisconsinan sediments and paleoecology of central British Columbia: sites at Necoslie and Nautley rivers. *Canadian Journal of Earth Sciences*, **34**: 200–208.
- Rust, B.R., and Romanelli, R. 1975. Late Quaternary subaqueous outwash deposits near Ottawa, Canada. *In Glaciofluvial and glaciolacustrine sedimentation. Edited by A.B. Jopling and B.B. McDonald. Society of Economic Paleontologists and Mineralogists, Special Publication 23*, pp. 177–192.
- Ryder, J.M., and Clague, J.J. 1989. British Columbia (Quaternary stratigraphy and history, Cordilleran Ice Sheet). *In Quaternary geology of Canada and Greenland. Edited by R.J. Fulton. Geological Survey of Canada, Geology of Canada, No. 1*, pp. 48–58.
- Ryder, J.M., Fulton, R.J., and Clague, J.J. 1991. The Cordilleran Ice Sheet and the glacial geomorphology of southern and central British Columbia. *Géographie physique et Quaternaire*, **45**: 365–377.
- Tipper, H.W. 1963. Nechako River map-area, British Columbia. Geological Survey of Canada, Memoir 324.
- Tipper, H.W. 1971a. Glacial geomorphology and Pleistocene history of central British Columbia. Geological Survey of Canada, Bulletin 196.
- Tipper, H.W. 1971b. Multiple glaciation in central British Columbia. *Canadian Journal of Earth Sciences*, **8**: 743–752.
- Weary, G.F., Giles, T.R., Levson, V.M., et al. 1995. Surficial geology and Quaternary stratigraphy of the Chedakuz Creek area (NTS 93 F/7). British Columbia Ministry of Energy, Mines and Petroleum Resources, Open File 1995-13, map scale 1 : 50 000.
- Wetherup, S. 1997. Geology of the Nulki Hills and surrounding area, central British Columbia. *In Current research 1997-A. Geological Survey of Canada, Paper 1997-A*, pp. 125–132.

- Whalen, J.B., Struik, L.C., and Hrudey, M.G. 1998. Bedrock geology of the Endako map area, central British Columbia. *In* Current research 1998-A. Geological Survey of Canada, Paper 1998-A, pp. 113–123.