GEOLOGICAL SURVEY OF CANADA
BULLETIN 554

QUATERNARY GEOLOGY OF THE FORT FRASER AND MANSON RIVER MAP AREAS, CENTRAL BRITISH COLUMBIA

A. Plouffe

2000

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Catalogue No. M42-554E
ISBN 0-660-18170-3

Available in Canada from
Geological Survey of Canada offices:

601 Booth Street
Ottawa, Ontario K1A 0E8

3303-33rd Street N.W.
Calgary, Alberta T2L 2A7

101-605 Robson Street
Vancouver, B.C. V6B 5J3

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Cover illustration

View to the northwest from the summit of Murray Ridge, with Pinchi Lake in the foreground and Tezzeron Lake in the background. Photograph by A. Plouffe. GSC 1999-051T

Critical reviewer
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Original manuscript submitted: 1999-10
Final version approved for publication: 2000-03

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QUATERNARY GEOLOGY OF THE FORT FRASER AND MANSON RIVER MAP AREAS, CENTRAL BRITISH COLUMBIA

Abstract

The Fort Fraser and Manson River map areas were last glaciated during the Late Wisconsinan Fraser Glaciation. Quaternary sediments predating this event are rare. The oldest deposits identified are oxidized sand and gravel, which locally contain placer gold. Stratigraphic evidence of a pre-Fraser glaciation was found at one site. Sediments of the Olympia Nonglacial Interval have been identified at three sites. Paleoecological reconstruction indicates climatic conditions cooler than at present for at least part of that nonglacial interval.

The mountainous regions were the first to be glaciated at the onset of Fraser Glaciation. Valley glaciers advanced from three major accumulation centres: the Skeena, Coast, and Cariboo mountains. In easterly draining valleys, sand and gravel accumulated on outwash plains in front of advancing glaciers. In most westerly draining valleys, the drainage was blocked by advancing ice and glacial lakes were formed. The pattern of ice advance was reconstructed primarily from crosscutting relationships of glacial erosion marks measured on bedrock outcrops. Ice from the Coast and Skeena mountains generally flowed easterly, but was deflected to the north and northeast in the eastern part of the study area, where it coalesced with an ice lobe derived from the Cariboo Mountains. Deglaciation proceeded from east to west along an irregular front controlled by topography. Numerous glacial lakes developed behind decaying ice.

Postglacial sediments include colluvium, alluvium, organic, eolian, and anthropogenic deposits. Postglacial aggradation in valleys was followed by incision of valley fills and establishment of the modern drainage.

Résumé

La région d'étude, définie par les feuillets topographiques de Manson River et de Fort Fraser, a été englacée pour la dernière fois lors de la Glaciation de Fraser du Wisconsinien tardif. Les sédiments du Quaternaire antérieurs à cette glaciation sont rares. Les dépôts les plus anciens identifiés sont formés de sables et de graviers oxydés qui contiennent localement de l'or de type placer. Des indices stratigraphiques d'une glaciation antérieure à la Glaciation de Fraser ont été observés à un seul endroit dans la région. Des sédiments de l'Intervalle non glaciaire d'Olympia ont été identifiés à trois sites. Les reconstitutions paléoécologiques indiquent des conditions climatiques plus froides que celles d'aujourd'hui, au moins pour quelque temps au cours de cet intervalle non glaciaire.

Au début de la Glaciation de Fraser, les régions montagneuses ont été englacées en premier. Par la suite, des glaciers de vallée se sont avancés depuis les trois zones d'accumulation principales : les chaînes Côtière, Skeena et Cariboo. Dans les vallées se drainant vers l'est, des sables et des graviers se sont accumulés dans des plaines d'épandage au front des glaciers qui s'avançaient. Dans la majorité des vallées s'ouvrant vers l'ouest, l'écoulement normal des eaux a été obstrué par les glaciers, ce qui a entraîné la formation de lacs glaciaires. Le modèle des avancées glaciaires a été reconstitué principalement à partir de l'âge relatif des marques d'érosion glaciaire mesurées sur des affleurements rocheux. Les glaciers des chaînes Côtière et Skeena se sont écoulés généralement vers l'est et ont été déviés vers le nord et nord-est suite à leur coalescence avec les glaciers de la chaîne Cariboo. La déglaciation s'est déroulée de l'est vers l'ouest le long d'un front glaciaire irrégulier dont la position était régie principalement par la topographie. Plusieurs lacs glaciaires se sont formés derrière les glaciers en retrait.

Les sédiments postglaciaires incluent des dépôts colluviaux, fluviatiles (alluviaux), organiques, éoliens et anthropiques. L'aggradation postglaciaire dans les vallées a été suivie par l'incision des sédiments et l'établissement du réseau hydrographique actuel.

SUMMARY

The Fort Fraser and Manson River map areas, located in central British Columbia, are part of the Interior System of the Canadian Cordillera. The mountainous northern sector (Omineca Mountains) is characterized by arêtes, peaks, cirques, and U-shaped valleys. The Nechako Plateau and Fraser Basin, to the south, consist of rounded hills and flatter terrain incised by tributaries of Fraser River.

Quaternary deposits include, from oldest to youngest: old sediments of unknown age, glacial sediments that predate the last glaciation, Middle Wisconsinan nonglacial sediments, deposits of the Late Wisconsinan Fraser Glaciation, and postglacial sediments. The oldest sediments are oxidized sand and gravel that locally contain placer gold. Evidence for a pre-Fraser glaciation comes from a single site along Necoslie River, where till is overlain by Middle Wisconsinan nonglacial sediments. Three new exposures of Middle Wisconsinan sediments were discovered during this study. East of Chuchi Lake, laminated clay containing bison bones is overlain by Fraser Glaciation drift. The bison bones yielded radiocarbon ages varying between 30 000 and 35 000 BP. Farther south, along Nautley River, Fraser Glaciation till unconformably overlies alluvial sediments containing plant fragments. Radiocarbon ages on two plant fragments indicate that they are 38 000 to 42 000 years old. Along Necoslie River, sand containing dispersed organic matter is overlain by glaciolacustrine sediments and Fraser Glaciation till. Pollen assemblages from the sandy units at the Necoslie and Nautley river sites are similar and dominated by nonarboreal pollen, reflecting tundra-type vegetation. These two units are tentatively correlated on the basis of their similar stratigraphic position and pollen spectra. The pollen indicate a cooler climate than at present, because the region is presently forested. Pollen from the laminated clay at Chuchi Lake also records a cool climate, which suggests that the Middle Wisconsinan climate in central British Columbia was, at least for some time, cooler than at present.

The Fraser Glaciation is divisible into three phases: advance phase, glacial phase, and recessional phase. Advance-phase and recessional-phase sediments each include a glaciolacustrine and glaciofluvial lithofacies. Ice advance blocked west-draining valleys and their tributaries, thereby impounding glacial lakes. In contrast, the drainage in east-draining valleys remained open, and sand and gravel accumulated on outwash plains in front of advancing glaciers. The regional ice-flow pattern was reconstructed from the orientation of macro-scale (drumlins, crag-and-tail features, and glacial flutes) and micro-scale landforms (striations and miniature crag-and-tail features). The main ice-accumulation centres were in the Coast, Skeena, and Cariboo mountains. At the onset of the Fraser Glaciation, valley glaciers advanced down valleys in these mountains.

SOMMAIRE

La région des feuillets topographiques de Manson River et de Fort Fraser, sise au centre de la Colombie-Britannique, fait entièrement partie du système de l'Intérieur de la Cordillère canadienne. La région montagneuse du secteur nord (la chaîne Omineca) est caractérisée par la présence d'arêtes, de pics, de cirques et de vallées en U. Au sud, le plateau de Nechako et le bassin du Fraser sont constitués de montagnes plus arrondies et de terrains plus plats, incisés par des tributaires du fleuve Fraser.

Les dépôts du Quaternaire comprennent, en ordre chronologique, des sédiments anciens d'âge inconnu, des sédiments glaciaires antérieurs à la dernière glaciation, des sédiments non glaciaires du Wisconsinien moyen, les dépôts de la glaciation du Wisconsinien tardif (Glaciation de Fraser) et des sédiments postglaciaires. Les sédiments les plus anciens sont des sables et des graviers oxydés contenant localement de l'or de type placer. Les indices d'une glaciation antérieure à la Glaciation de Fraser proviennent d'un seul site situé le long de la rivière Necoslie, où un till est recouvert de sédiments non glaciaires du Wisconsinien moyen. Trois nouveaux sites où sont mis à jour des sédiments du Wisconsinien moyen ont été identifiés au cours de cette étude. À l'est du lac Chuchi, des argiles laminées contenant des ossements de bison sont recouvertes de dépôts de la dernière glaciation. Les ossements ont fourni trois âges radiocarbone s'échelonnant de 30 000 à 35 000 ans. Plus au sud, le long de la rivière Nautley, le till de la Glaciation de Fraser surmonte en discordance des sédiments alluviaux qui contiennent des fragments de plantes. Les âges radiocarbone de deux fragments de plantes indiquent que ces sables sont vieux d'environ 38 000 à 42 000 ans. Le long de la rivière Necoslie, des sables contenant de la matière organique dispersée sont recouverts par des sédiments glaciolacustres et le till de la Glaciation de Fraser. Les assemblages polliniques des unités sableuses du site de la rivière Nautley et de celui de la rivière Necoslie se ressemblent par leur fort contenu en grains de pollen non arboricole reflétant une végétation de type toundra. Ces deux unités sableuses sont de façon tentative mises en corrélation en se basant sur leur spectre pollinique et leur position stratigraphique. Le pollen indique un climat plus froid que celui d'aujourd'hui puisque la région est présentement occupée par une forêt. Le pollen des argiles laminées du lac Chuchi reflète également un climat froid, ce qui porte à croire que le climat du Wisconsinien moyen dans la partie centrale de la Colombie-Britannique était, au moins pour quelque temps, plus froid que celui d'aujourd'hui.

La Glaciation de Fraser peut être divisée en trois phases : phase d'avancée, phase glaciaire et phase de retrait. Les phases d'avancée et de retrait sont révélées chacune par un lithofaciès glaciolacustre et fluvioglaciaire. L'avancée des glaciers a obstrué les vallées qui se drainent vers l'ouest ainsi que leurs tributaires, formant ainsi des lacs glaciaires. À l'opposé, dans les vallées qui se drainent vers l'est, l'écoulement normal des eaux n'a pas été entravé et des sables et des graviers se sont déposés au front du glacier dans des plaines d'épandage. La configuration de l'écoulement glaciaire à l'échelle régionale a été reconstituée à partir de l'orientation des macro-formes (drumlins, crag-and-tail, flûtes) et des micro-formes (stries et queues-de-rat) glaciaires. Les zones d'accumulation dominantes étaient situées dans les chaînes Côtière, Skeena et Cariboo. Au début de la Glaciation de Fraser, les glaciers se sont avancés dans les vallées de ces régions montagneuses en direction de l'aval. Par la suite, des langues de glace provenant des chaînes Côtière et Skeena

Subsequently, ice tongues derived from the Coast and Skeena mountains coalesced in major valleys and advanced eastward across the Nechako Plateau. In the eastern part of the study area, ice flow was deflected to the north and northeast by glaciers flowing from the Cariboo Mountains.

Fraser Glaciation drift includes a single till sheet, except in Germansen River valley where up to four tills are interbedded with sand and gravel units. The four tills in Germansen River valley were probably deposited during fluctuations of the ice front during glacial advance or retreat. Northeast of Stuart Lake, a clayey diamicton lens, informally referred as the Pinchi Creek lens, was deposited during a late-glacial readvance.

Lateral meltwater channels and glaciofluvial and glaciolacustrine sediments record deglaciation of the map area. Glaciers retreated to the west along an irregular front controlled by topography. Glacial lakes developed in the valleys blocked by retreating ice. Tributaries of Fraser River were inundated by a large glacial lake that was dammed by ice in the Fraser valley to the east. Rhythmites, composed of fine sand, silt, and clay, accumulated in these lakes.

Postglacial sediments include alluvial, colluvial, organic, eolian, and anthropogenic deposits. An attempt to date deglaciation by obtaining radiocarbon ages on basal peat in bogs was unsuccessful, probably because the warm and dry climate of the early Holocene retarded paludification.

Cinnabar (HgS) occurs in bedrock along the Pinchi fault. Till close to and down-ice from this structure contains elevated concentrations of mercury because of detrital glacial transport.

sont entrées en coalescence dans les vallées principales et se sont avancées vers l'est à travers le plateau de Nechako. Dans la partie est de la région d'étude, les glaciers qui s'écoulaient vers l'est ont été déviés vers le nord-est et le nord par ceux de la chaîne Cariboo.

Les dépôts de la Glaciation de Fraser comprennent un seul till, sauf dans la vallée de la rivière Germansen où quatre tills sont interstratifiés avec des unités de sable et de gravier. Ces quatre tills pourraient avoir été mis en place lors de fluctuations du front du glacier pendant l'avancée ou le retrait glaciaire. Au nord-est du lac Stuart, une lentille composée d'un diamicton argileux, et ici informellement nommée «lentille de Pinchi Creek», aurait été mise en place lors d'une réavancée du front du glacier à un stade tardif de la déglaciation.

Des chenaux marginaux d'eau de fonte ainsi que des sédiments fluvioglaciaires et glaciolacustres reflètent la déglaciation de la région d'étude. Les glaciers se sont retirés vers l'ouest, suivant un front irrégulier dont la position était régie par la topographie. Des lacs glaciaires se sont formés dans plusieurs vallées obstruées par la glace en retrait. Les vallées tributaires du fleuve Fraser ont été envahies par un grand lac glaciaire retenu par la glace dans la vallée du fleuve Fraser, à l'est de la région d'étude. Des rythmites de sable fin, de silt et d'argile se sont accumulées dans ces lacs glaciaires.

Les sédiments postglaciaires comprennent des dépôts fluviatiles (alluviaux), colluviaux, organiques, éoliens et anthropiques. On a essayé de dater la déglaciation en obtenant des âges radiocarbone sur la tourbe basale de tourbières, ce qui s'est révélé infructueux, probablement en raison des conditions climatiques chaudes et sèches du début de l'Holocène qui auraient retardé la paludification.

Du cinabre (HgS) est présent dans le substratum rocheux le long de la faille de Pinchi. Le till présent à l'aval glaciaire et à proximité de la faille contient de fortes concentrations de mercure en raison du transport glaciaire détritique.

INTRODUCTION

The Fort Fraser and Manson River map areas (NTS 93 K and 93 N, respectively) in central British Columbia are rich in natural resources. The forest industry is the major employer in the region, and farming (centred on Vanderhoof) and mining are also important to the economy. Tourism is an important source of revenue: people visit the region to hunt and fish, or to travel through it on their way to Smithers, Terrace, and Prince Rupert.

A proper knowledge of the surficial geology of the region is necessary to 1) guide mineral exploration, 2) locate aggregate resources for highways and forestry roads, 3) identify aquifers within the Quaternary stratigraphic framework, 4) identify areas with high natural-hazard potential (e.g. landslides, avalanches, floods), and 5) minimize adverse human impacts on the environment.

To provide this knowledge, the Geological Survey of Canada (GSC) undertook a surficial geology study in central British Columbia. The study included 1) an investigation of the Quaternary stratigraphy and history, 2) mapping of the surficial geology, and 3) a reconnaissance survey of till geochemistry. This report documents the Quaternary stratigraphy and history of the Fort Fraser and Manson River map areas, with emphasis on reconstructing the Late Wisconsinan Fraser Glaciation. Additional information is provided on some aspects of the environmental and economic geology of the region.

Location and access

The study area includes two 1:250 000 scale map sheets, Fort Fraser (NTS 93 K) and Manson River (NTS 93 N), and is bounded by latitudes 54° and 56°N, and longitudes 124° and 126°W (Fig. 1). It covers an area of approximately 28 900 km^2. Highway 16, which links Prince Rupert and Prince George, extends across the southern part of the region.

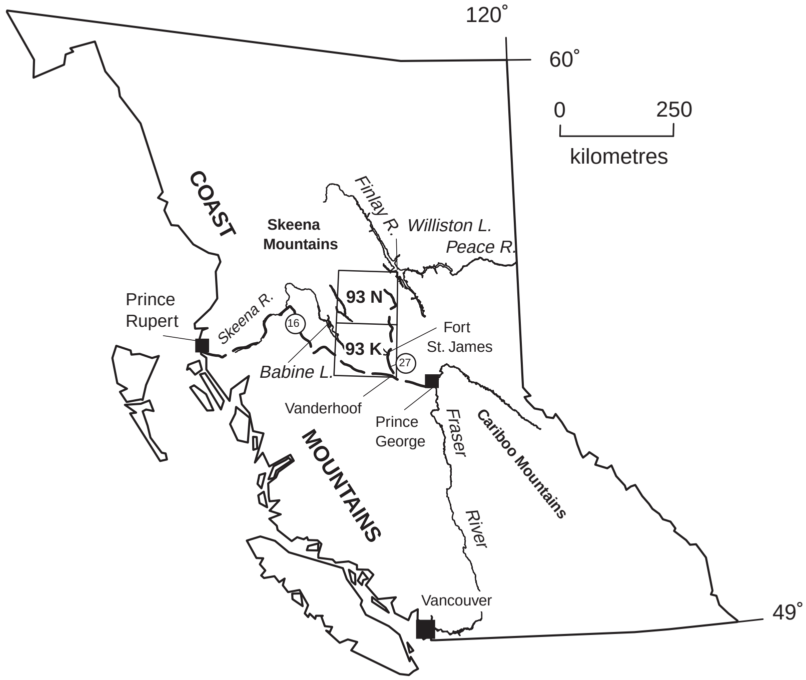

Figure 1.

Location of study area in relation to major physiographic features of British Columbia.

Highway 27 connects Fort St. James and Vanderhoof. A network of forestry roads provides access to most parts of the study area.

Physiography

The study area lies entirely within the Interior System of the Canadian Cordillera and includes parts of four physiographic regions, as defined by Holland (1976): Rocky Mountain Trench, Omineca Mountains, Nechako Plateau, and Fraser Basin (Fig. 2). The Rocky Mountain Trench, a broad valley with an average elevation of 750 m, crosses the northeastern corner of the Manson River sheet. The Omineca Mountains comprise the Hogem and Swannell ranges, with the Wolverine Range being a subdivision of the Swannell Ranges. These mountains are extremely rugged, with steep slopes, arêtes, cirques, and U-shaped valleys. Most peaks are 1800 to 2000 m above sea level (a.s.l.), but a few exceed 2000 m. Valley bottoms range in elevation from approximately 700 m in the south to 900 m in the north. There are no glaciers today in this part of the Omineca Mountains. The Nechako Plateau is a rolling and hilly region; higher parts of the plateau are separated by wide, subdued valleys, which are partly occupied by large, long lakes. The Fraser Basin is generally flatter and lower than the Nechako Plateau and is incised by tributaries of Fraser River. The Nechako Plateau and the adjacent Fraser Basin are referred to as the lake district of British Columbia.

The study area is bordered by a series of high mountain ranges that were major ice-accumulation centres during the last glaciation. They include the Coast Mountains to the west, the Skeena Mountains to the northwest, and the Cariboo Mountains to the southeast (Fig. 1).

Drainage

The main valleys in the region are thought to be Tertiary, but they have been modified during several Pleistocene glaciations. In the south and central portions of the study area, Nechako, Endako, Stuart, Middle, and Tachie rivers drain eastward into Fraser River (Fig. 2). In the north, Omineca, Manson, and Nation rivers flow to the east into Peace River, a tributary of Mackenzie River. In the south-central part, Sutherland River drains to the west into Babine Lake, which is in the headwaters of Skeena River.

Drainage anomalies

The drainage pattern of the study area was developed mainly during Tertiary uplift. Pleistocene glaciers disrupted the preglacial drainage. Three examples of drainage anomalies are described below:

1. Stellako River, between François and Fraser lakes, occupies a deep, narrow, bedrock gorge (Fig. 3a). Three kilometres south of the head of Stellako River, a broad east-trending valley is occupied by Nithi River and Smith and Goldie creeks. This valley extends eastward to Vanderhoof, where it joins the modern Nechako River. This broad valley was probably occupied by an easterly draining, ancestral Nechako River sometime before the last glaciation (Fig. 3a; Plouffe, 1991). The canyon in which Stellako River presently flows, and the narrow portion of Nechako valley east of Fraser Lake, may have been eroded when ice dammed Nithi–Smith–Goldie valley. The location of Nithi–Smith–Goldie valley is obscure near Nechako River because it is partly filled with glaciolacustrine sediments.

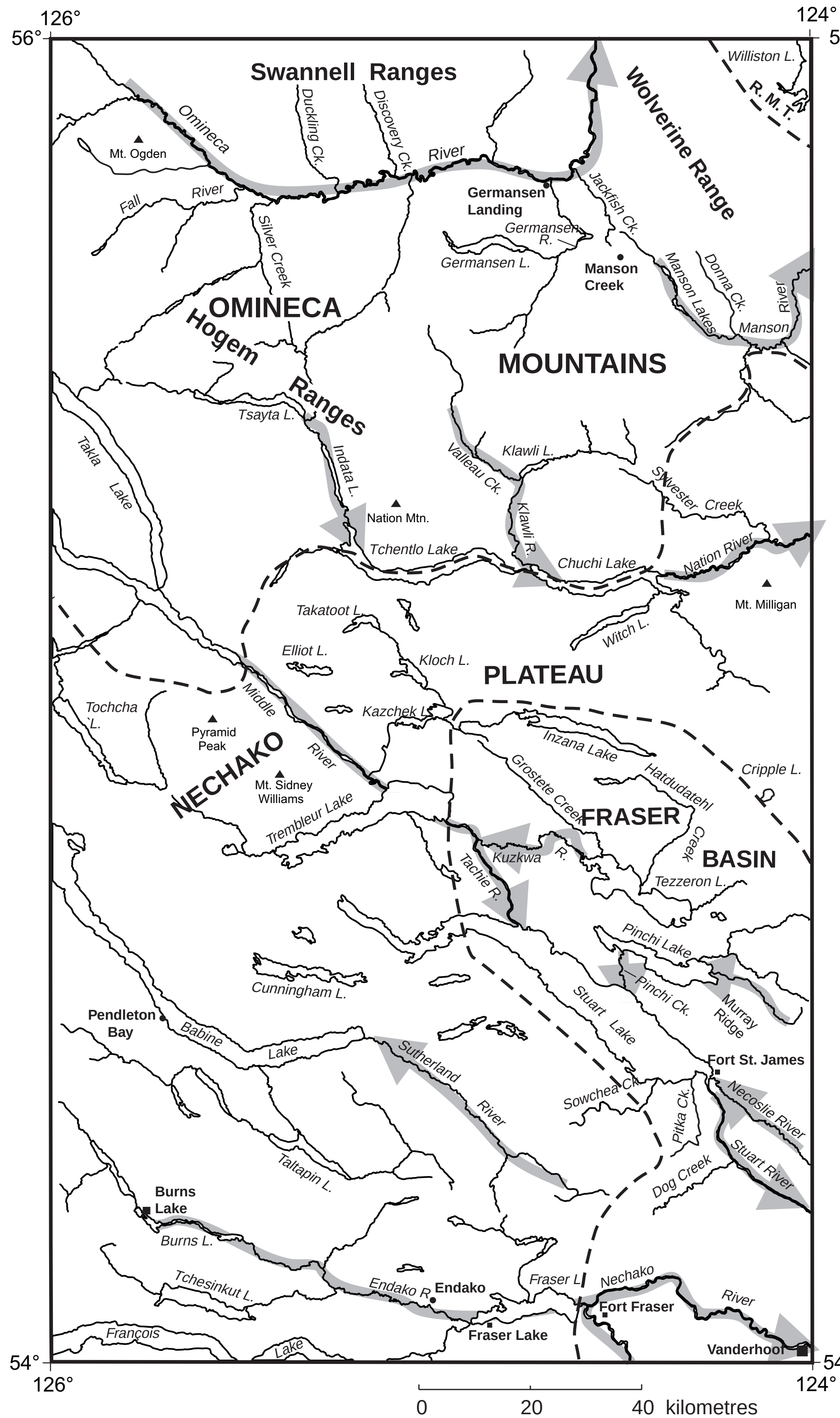

Figure 2. *Drainage and physiography of the study area. Major physiographic divisions are indicated by thick dashed lines (Holland, 1976). R.M.T., Rocky Mountain Trench. Drainage directions are shown by grey arrows.*

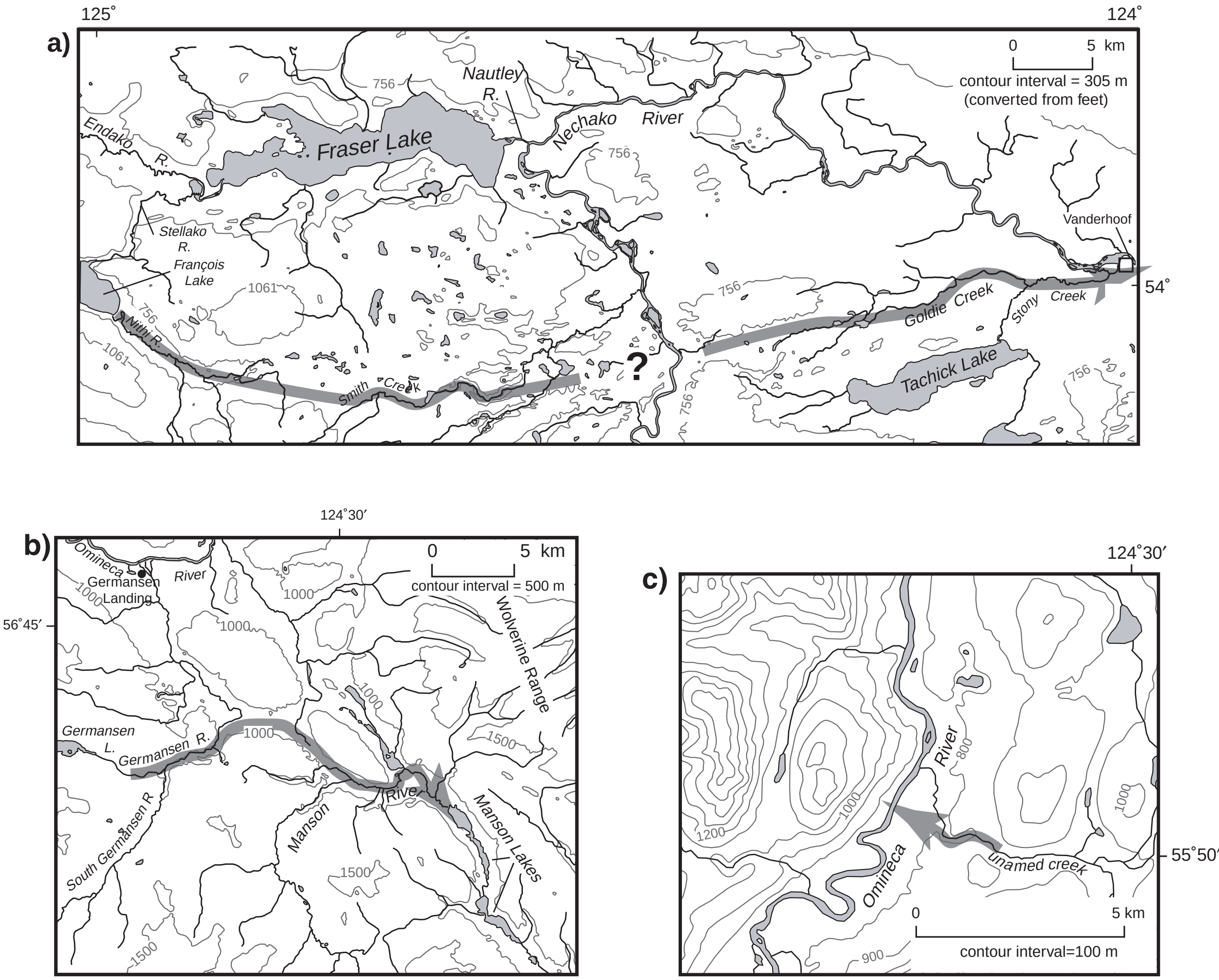

Figure 3. Three drainage anomalies in the study area: ***a)*** *François Lake–Vanderhoof area,* ***b)*** *Germansen River area, and* ***c)*** *Omineca River valley. Thick grey arrows show old drainage routes.*

2. Germansen River flows easterly from Germansen Lake, but then swings abruptly to the northwest and enters the northwesterly trending valley that links Omineca and Manson valleys (Fig. 3b). At one time, Germansen River was probably a tributary of a southeasterly flowing trunk river that occupied the valley of present-day Manson River and Manson Lakes. Germansen River was perhaps diverted when a mixture of ice and sediments blocked part of its old course sometime during the Quaternary. Alternatively, a southerly flowing ancestral Germansen River may have been captured by a north-flowing stream as a result of Tertiary uplift.

3. Several tributary streams have unusually sharp bends where they enter trunk valleys and flow subparallel to the axis of the main valley. An example is an unnamed tributary of Omineca River northeast of Germansen Landing (Fig. 3c). This drainage pattern is thought to have developed because of ice or sediment blockage of tributary streams during deglaciation. Some of these tributary streams are now flowing in meltwater channels that had been eroded subparallel to the slope of the trunk-valley wall.

Vegetation

The study area lies within the sub-boreal spruce zone (Meidinger et al., 1991) and the transitional zone between the subalpine and montane forest regions (Rowe, 1972). The dominant trees are *Picea* spp. (spruce), *Abies lasiocarpa* (subalpine fir), and *Pinus contorta* (lodgepole pine); *Populus tremuloides* (trembling aspen) and *Betula papyrifera* (paper birch) are common in some areas. Vegetation changes little with latitude in the study area, but important altitudinal variations occur in tree species and size; black spruce and lodgepole pine decrease in abundance with increasing elevation, whereas subalpine fir becomes more abundant. Airphoto interpretation is facilitated by relationships between vegetation assemblages and substrate types; these relationships are summarized in the ‘Description of map units’ section.

Previous studies and Quaternary stratigraphic framework

Dawson (1878, 1881, 1888) was first to publish data on the Quaternary deposits and glacial history of central British Columbia. His ideas about the glaciation of British Columbia evolved from an early theory that the land had subsided beneath 1520 m of water (Dawson, 1878, 1881) to a glacial-ice theory involving a Cordilleran glacier (Dawson, 1888, 1889). Dawson noted the thick, fine-grained sediment accumulations above till in some valleys of central British Columbia and postulated that a late-glacial lake had inundated the Fraser River valley, and those of some of its tributaries, at the end of the last glaciation.

More than half a century later, Armstrong and Tipper (1948a) interpreted glacial landforms in central British Columbia from the first available airphotos and reconstructed ice-flow patterns in the region. They showed that the major mountain ranges (e.g. Coast, Cariboo, and Omineca mountains) were the main ice-accumulation centres during the last glaciation. While mapping bedrock, Armstrong (1949) made important observations on Quaternary sediments and landforms of the Fort Fraser and Manson River map areas. Twenty years later, Tipper (1971a, b) presented a synthesis of the ice-flow history, proposed evidence for two glaciations, and suggested that the penultimate glaciation was more extensive than the last one.

Following the late Quaternary chronology established in southern British Columbia (cf. Ryder and Clague (1989) and references therein), the Quaternary deposits in the study area can be assigned to four geological-climatic units, from oldest to youngest: 1) penultimate ((?)Early Wisconsinan) glaciation, 2) Olympia Nonglacial Interval, 3) Late Wisconsinan Fraser Glaciation, and 4) postglacial (Holocene) period. Old, possibly Early Pleistocene or even (?)Tertiary sediments have been found in placer mining pits near Germansen Landing and Manson Creek.

Penultimate glaciation

This is an informal term applied to the last, pre-Fraser glaciation (Ryder and Clague, 1989). Clague (1988) identified three tills, separated by sand and gravel units, beneath the Fraser Glaciation succession in Fraser River valley, approximately 10 km north of Quesnel (Fig. 4, site 1). Two tills were identified at Mexican hill and Bullion pit, east and southeast of Quesnel (Fig. 4, sites 5, 6; Clague et al., 1990). Sediments deposited during the advance and retreat phases of the penultimate glaciation are present in the Williams Lake region farther south (Fig. 4, sites 7, 8; Clague, 1987; Eyles and Clague, 1991). The stratigraphy along upper Peace River was originally interpreted to record four glacial events (Rutter, 1976, 1977), but Bobrowsky (1989) concluded that only two glaciations are represented: the Fraser Glaciation and the penultimate glacial event (Fig. 4, site 2). At Mount Milligan, a diamicton beneath a basalt flow was intercepted in a drillhole (Fig. 4, site 3; Kerr and Bobrowsky, 1991). The diamicton

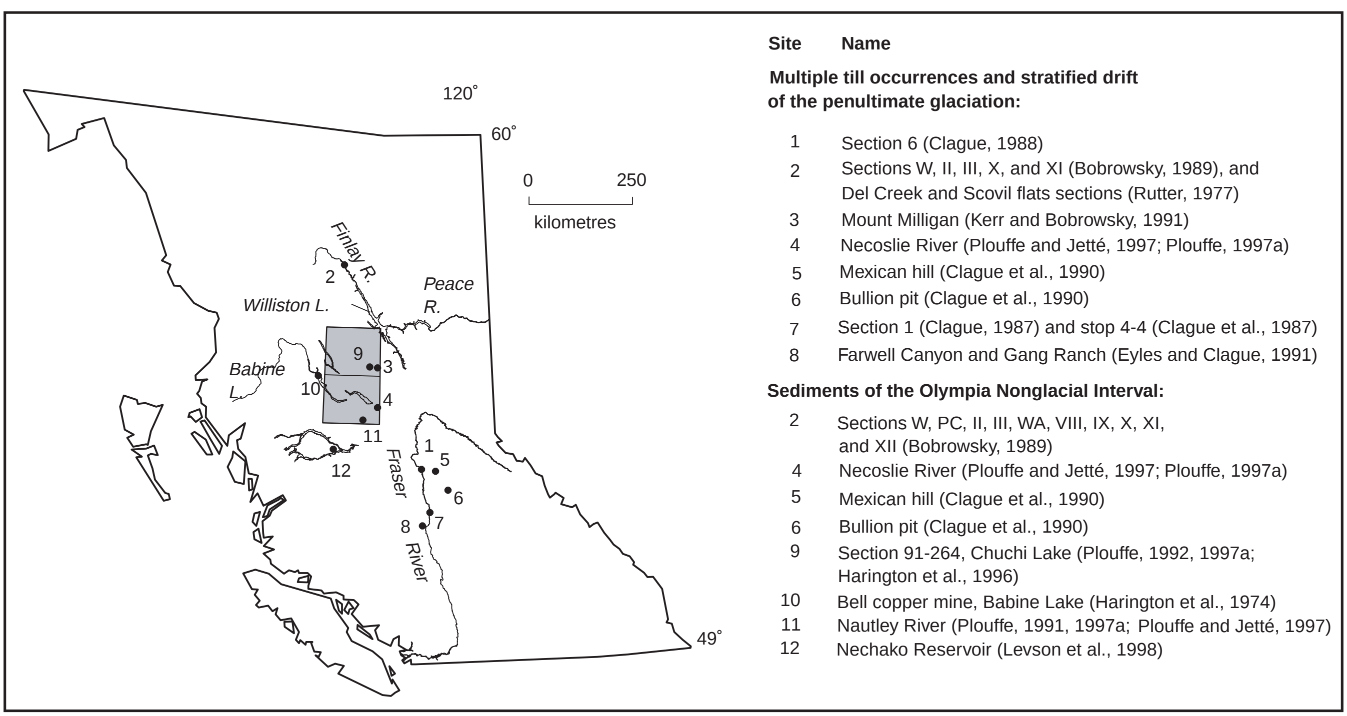

Figure 4. *Occurrences of multiple tills and Olympia Nonglacial Interval sediments in central British Columbia (*modified from *Plouffe, 1997a).*

was tentatively interpreted as a till. In the absence of dating on the basalt, the best interpretation is that the till records a pre-Fraser glacial event of unknown age.

Because pre-Fraser drift in different areas commonly cannot be correlated, the term 'pre-Fraser glaciation' will be used in this report, instead of penultimate glaciation, when referring to a glacial event that predates the Late Wisconsinan Fraser Glaciation.

Olympia Nonglacial Interval

This was the Middle Wisconsinan ice-free period in British Columbia, which started before 59 000 BP and ended around 25 000 BP in the interior (Armstrong et al., 1965; Clague, 1981; Ryder and Clague, 1989). Nonglacial sediments of this age have been reported (Fig. 4) from Finlay River (Bobrowsky, 1989), the Quesnel region (Clague et al., 1990), Babine Lake (Harington et al., 1974), Chuchi Lake (Harington et al., 1996), Necoslie River and Nautley River valleys (Plouffe, 1991; Plouffe and Jetté, 1997), and Nechako Reservoir (Levson et al., 1998). Paleoecological data from these sites indicate that the Middle Wisconsinan climate was, at times, colder than at present.

Fraser Glaciation

This was the last glaciation in British Columbia (Armstrong et al., 1965), spanning the period from 25 000 BP to 10 000 BP (Fulton, 1971; Clague, 1981). At the height of the Fraser Glaciation, glaciers derived from the high mountain ranges in the Cordillera coalesced to form the Cordilleran Ice Sheet. Most of the unconsolidated surface sediments in the study area are products of this glacial event.

Postglacial period

This period was initiated with the deglaciation of the area. Glacial sediments were reworked by fluvial and mass-wasting processes, which resulted in sediment aggradation in valleys and at the foot of mountain slopes. Aggradation was followed by a period of degradation, during which streams incised the valley fills and established their modern courses.

Other studies

Many investigations have been conducted on Fraser Glaciation and postglacial sediments in central British Columbia, west of the Rocky Mountains. The subjects of these studies include till geochemistry, surficial geology mapping, stratigraphic studies, and glacial history reconstruction (Armstrong and Tipper, 1948b; Clague, 1984, 1985, 1998a, b; Broster and Clague, 1987; Clague et al., 1987; Eyles, 1987; Eyles and Clague, 1987, 1991; Eyles et al., 1987; Leslie, 1988; Kerr, 1991; Ryder and Maynard, 1991; Kerr and Sibbick, 1992; Huntley and Broster, 1993a, b, 1994, 1997; Giles and Levson, 1994, 1995; Levson and Giles, 1994, 1995, 1997; Levson et al., 1994, 1997a, b; Ryder, 1994; Tipper, 1994; Giles et al., 1995; O'Brien et al., 1995; Weary et al., 1995; Huntley et al., 1996a, b; Stumpf et al., 1996a, b; West, 1997). During the evolution of the project, data were published by the author on 1) stratigraphy and paleoecology (Plouffe, 1991, 1992; Harington et al., 1996; Plouffe, 1997a; Plouffe and Jetté, 1997); 2) surficial geology maps (Plouffe, 1994a, b, 1996a, b, c, d, e, f), and 3) till geochemistry (Plouffe and Ballantyne, 1993; Plouffe, 1995a, b, 1998).

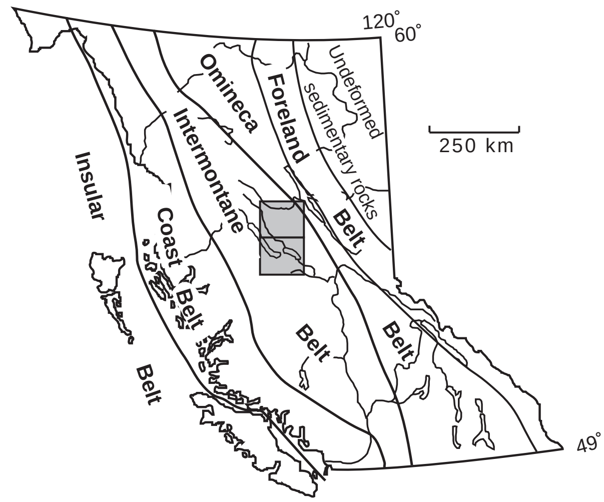

Figure 5. *Tectonic belts of the Canadian Cordillera (*after *Sutherland Brown et al., 1970; Monger et al., 1972; Wheeler and Gabrielse, 1972; Gabrielse et al., 1991).*

Bedrock geology

The Canadian Cordillera has been divided into five morphogeological belts (Fig. 5; Sutherland Brown et al., 1970; Monger et al., 1972; Wheeler and Gabrielse, 1972; Gabrielse et al., 1991). The study area lies largely within the Intermontane Belt, which consists of a series of crustal fragments (terranes) that were accreted to the North American craton during the Middle Jurassic and later (Monger, 1984). The northeastern sector of the study area is in the Omineca Belt, a metamorphic and plutonic welt that is considered part of the ancestral North American craton (Monger et al., 1982; Gabrielse et al., 1991).

Intermontane Belt

The Intermontane Belt consists mainly of interbedded volcanic and sedimentary rocks, which form several northwesterly trending oceanic lithosphere and island-arc terranes (Fig. 6). Oceanic lithosphere rocks include the Late Paleozoic and Early Mesozoic Slide Mountain and Cache Creek terranes (Armstrong, 1949; Monger and Paterson, 1974; Ferri et al., 1988, 1989; Ferri and Melville, 1990, 1994). Island-arc rocks include the Mississippian to Lower Jurassic Takla Group (Quesnel Terrane; Meade (1974), Nelson et al. (1991b)) and the Permian to Late Jurassic Hazelton and Tachek groups (Stikine Terrane; Armstrong (1949)). Large plutons include the Early Jurassic Hogem intrusive suite and the Early Cretaceous Germansen batholith in the north, and the Late Triassic to Early Cretaceous Fraser Lake, François Lake, Stag

Lake, and Boer plutonic suites in the south. Granodiorite is the predominant rock type, but these intrusions show a broad compositional spectrum.

Pre-Tertiary rocks are unconformably overlain by Early to Late Tertiary basaltic, andesitic, and dacitic lava flows (Armstrong, 1949; Ferri and Melville, 1990; Nelson et al., 1991b; Struik et al., 1996, 1997; Haskin et al., 1998). Tertiary sedimentary rocks occur in grabens and are therefore poorly exposed (Nelson et al., 1991a, b).

Omineca Belt

The Omineca Belt, within the study area, is composed of a sequence of Proterozoic to Paleozoic metamorphosed clastic rocks, intruded by Cretaceous and younger granitic plutons (Ferri and Melville, 1994) and Devonian to Mississippian carbonatite dykes (Pell, 1987).

Faults

The three main structural elements in the area (Fig. 6) are the Wolverine, Manson (Armstrong, 1949; Ferri and Melville, 1994), and Pinchi fault zones (Paterson, 1977; Albino, 1988). The Wolverine fault is a moderately to steeply dipping normal fault that separates high-grade and lower grade metamorphic rocks within the Omineca Belt (Ferri and Melville, 1994). The Slide Mountain and Quesnel terranes are separated by the Manson fault, a vertical transcurrent fault (Ferri and Melville, 1994). The Pinchi fault zone extends diagonally through the middle of the study area; along most of its 450 km length, this fault forms the eastern edge of the Cache Creek Terrane.

Mineral showings and deposits

Several mines have been active in the region and many mineral showings are currently known, a few of them having the potential to become mines. The main mineralization types are listed below, along with the names of relevant deposits and showings.

1. Circulation of meteoric waters along the Pinchi fault introduced low-temperature mineralizing fluids that deposited cinnabar (HgS; Freeze (1942), Armstrong (1966), Nesbitt et al. (1987)). There are several cinnabar occurrences along the fault (Armstrong, 1944, 1946, 1948, 1949) and two have been developed into mines: the Pinchi and Bralorne–Takla mines (Fig. 6). Both mines were active in the 1940s and Pinchi reopened for a brief period in the 1970s. They are the only two commercial mercury mines to have been active in Canada.
2. Placer gold deposits have been mined since the late nineteenth century in the Manson Creek–Germansen Landing area (Fig. 2). Although not as important as the richer deposits of the Cariboo district and Yukon Territory, these placers have yielded significant amounts of gold (*see* Armstrong, 1946).
3. Molybdenum is mined near Endako village (Fig. 2). The porphyry mineralization occurs in Late Jurassic intrusive rocks.
4. A small antimony mine was active in 1939 and 1940 on the south shore of Stuart Lake, approximately 10 km west of Fort St. James.
5. Chromite has been found in the ultramafic rocks of the region (Whittaker, 1982, 1983).
6. The Mount Milligan copper-gold porphyry deposit is probably the most significant mineral exploration discovery in the region in recent years.
7. Several amphibole jade (nephrite) deposits have been discovered in ultramafic rocks of the Cache Creek Group since the late 1960s. The two most important deposits are located in the Mount Sidney Williams and Mount Ogden areas (Fig. 2; Leaming, 1978). Nephrite jade extracted from the Mount Ogden property is among the finest in British Columbia (Leaming, 1978). Mining at that site continued until as late as 1992 (Schiarizza and Payie, 1997).

Methods

Surficial geology mapping

The surficial geology of the area was originally compiled on 1:100 000 scale topographic maps, following interpretation of 1:60 000 scale, black-and-white airphotos produced in 1987 by the British Columbia Ministry of Environment, Lands and Parks. Preliminary interpretation of airphotos was completed in the office before each field season. Final interpretation was done in the field and later in the office from field notes. Linework and symbols were transferred from the airphotos onto sepia topographic bases, which were then scanned and digitized using a geographic information system. Preliminary maps were published as GSC Open Files (Plouffe, 1994a, b, 1996a, b, c, d, e, f). The Open File maps were modified following more detailed fieldwork in certain areas, and then combined to produce 1:250 000 scale maps (Maps 1986A, 1987A, in pocket).

Field methods

Fieldwork was conducted during the summers of 1990 through 1994. Much of the area was surveyed by driving forestry roads. Key sections along streams were reached by foot and boat. A helicopter was used to access natural bluffs located far from roads. Observation and data sites were located on airphotos and then transferred to topographic maps to determine UTM co-ordinates. Sections were logged by recording the texture, sedimentary structures, colour, clast composition, contact relationships, and lateral continuity of stratigraphic units.

Clast fabrics of diamictons were measured at selected sites to determine the genesis of the sediment and, in the case of till, to estimate the direction of ice flow during deposition. Each data set comprised 50 rod-shaped pebbles with a-axis longer than 2 cm, and an a:b ratio greater than 1.6. The trend and plunge of each pebble were measured with a compass.

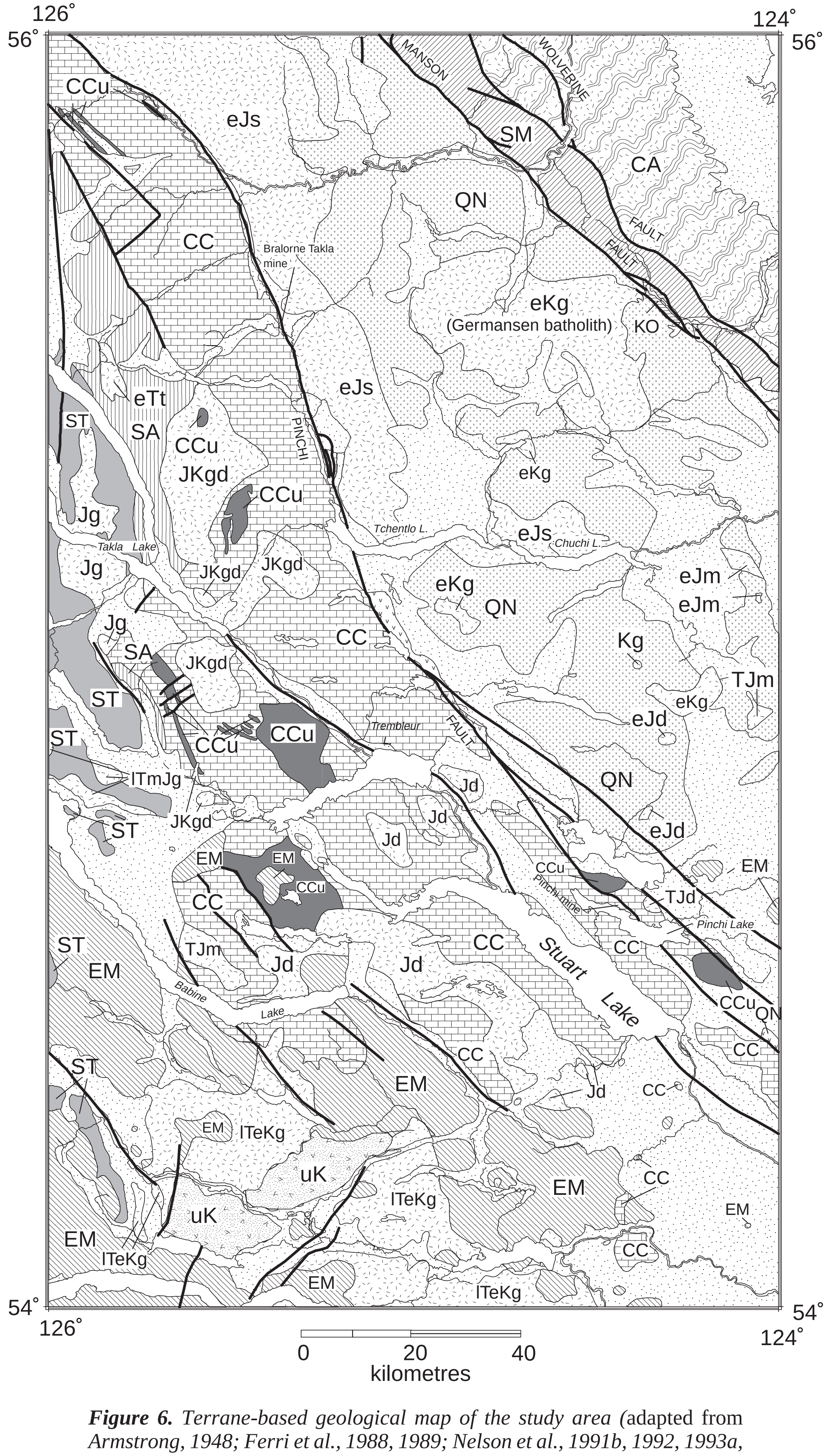

Figure 6. *Terrane-based geological map of the study area (*adapted from *Armstrong, 1948; Ferri et al., 1988, 1989; Nelson et al., 1991b, 1992, 1993a, b; Ash et al., 1993; Bailey et al., 1993; Ferri and Melville, 1994; Bellefontaine et al., 1995; Struik et al., 1996, 1997; Whalen and Struik, 1997; Hrudey and Struik, 1998; Whalen et al., 1998).*

Maximum elevations of glaciolacustrine and deltaic sediments were determined from 1:50 000 scale topographic maps and by using an altimeter. The precision of elevations determined from topographic maps is ±20 m. Altimeter measurements were calibrated to bench marks or points of known elevation (e.g. bridge, maximum lake level) and were corrected for variations in air temperature. These measurements are accurate to within ±5 m.

A GSC piston corer (cf. Mott, 1966) was used to collect the lowest 3 cm of peat bogs.

A total of 1155 till samples was collected at a depth of at least 1 m (below the zone of most intense weathering) from natural bluffs, roadcuts, and hand-dug pits. Average sample spacing in accessible areas was 5 km, but was much greater in areas where access was limited. Detailed sampling was done near known mineral occurrences, including the Pinchi Lake mine (past-producing mercury mine) and two copper-gold

LEGEND FOR FIGURE 6

Drift-covered areas

Post-accretionary sedimentary and volcanic rocks

Eocene to Miocene

EM Chilcotin, Endako, and Ootsa Lake groups
Basalt, andesite, dacite, rhyolite with minor related sediments

uK *Undifferentiated sedimentary and volcanic rocks*

Accreted terranes

Permian to Upper Jurassic

ST **Stikine Terrane**
Hazelton, Bowser Lake, Tachek, Asitka, and Takla groups
Mafic to felsic volcanic rocks, sandstone

Permian to Jurassic

SA **Sitlika assemblage**
Basalt, dacite, rhyolite, sandstone, slate, and conglomerate

Carboniferous to Lower Jurassic

CC **Cache Creek Terrane**
Cache Creek Group
Limestone, argillite, siltstone, chert, phyllite, basalt

CCu Trembleur ultramafic rocks
Harzburgite, peridotite, serpentinite, and other ophiolitic rocks

Mississippian to Lower Jurassic

QN **Quesnel Terrane**
Takla Group and Lay Range assemblage
Mafic volcanic rocks and related sedimentary rocks

Mississippian to Permian

SM **Slide Mountain Terrane**
Nina Creek Group and Manson Lakes ultramafic rocks
Basalt, argillite, gabbro, chert, and siltstone; serpentine and serpentine schist

Ancestral North America

Proterozoic to Permian

CA **Cassiar Terrane**
Ingenika, Atan, Razorback, Echo Lake, Otter Lakes, and Big Creek groups (includes the Wolverine Complex)
Siliciclastic rocks and carbonates (metamorphic and intrusive rocks of the Wolverine Complex)

Proterozoic to (?) Paleozoic

KO **Kootenay Terrane**
Boulder Creek Group
Siliciclastic rocks, marble, and minor amphibolite

Intrusive rocks

CRETACEOUS

Kg *Granite*

Early Cretaceous

eKg *Granite to granodiorite*

JURASSIC to CRETACEOUS

JKgd *Granite, granodiorite, minor diorite*

JURASSIC

Jd *Diorite, tonalite*

Early to Middle Jurassic

Jg *Granite, monzonite, diorite*

Early Jurassic

eJs **Hogem intrusive suite**
Syenite, monzonite, granodiorite, diorite, gabbro

eJm *Monzonite*

eJd *Diorite*

TRIASSIC TO CRETACEOUS
Late Triassic to Early Cretaceous

lTeKg **Fraser Lake, François Lake, Stag Lake, and Boer plutonic suites**
Granite, monzonite, granodiorite, diorite, tonalite, gabbro, minor gneiss

TRIASSIC TO JURASSIC

TJm *Monzonite*

TJd *Diorite*

Late Triassic to Middle Jurassic

lTmJg *Granite, monzonite, aplite, diorite*

TRIASSIC
(?) Early Triassic

eTt *Tonalite*

showings, one north of Witch Lake and the other northwest of Valleau Creek. Detailed sampling was also undertaken in the Manson River area to determine the rare-earth element distribution in till (West, 1997).

Laboratory methods

Weight percentages of sand, silt, and clay in the till matrix (<2 mm) were determined using a Brinkmann particle-size analyzer at the GSC Sedimentology Laboratory. Carbonate content was calculated for the silt+clay fraction (<0.063 mm) with a Leco apparatus. These analyses were done on several samples selected to reflect the various types of bedrock in the study area.

Fossil plant material was radiocarbon dated at the GSC Radiocarbon Laboratory, Ottawa (conventional method); the Isotrace Laboratory, University of Toronto (accelerator mass spectrometry (AMS) method); Beta Analytic Inc., Miami, Florida (conventional method); and the Lawrence–Livermore National Laboratory, Livermore, California (AMS method). All radiocarbon ages reported here are in radiocarbon years before AD 1950.

Pollen assemblages in basal peat samples were determined in the GSC Environmental Service Laboratory. Samples were sealed in plastic bags in the field to prevent contamination. Pollen processing was done according to standard procedures described by Erdtman (1960): digestion with 10% KOH, 49% HF, and 50% HCl, and acetolysis. Pollen grains of *Eucalyptus globulus*, an exotic species, were added to the samples so that pollen concentrations could be calculated (Benninghoff, 1962).

Geochemical analyses were carried out on the clay (<0.002 mm) and silt+clay (<0.063 mm) fractions of till. Clay separations were done by centrifugation and decantation, following procedures outlined in Lindsay and Shilts (1995). Silt+clay separations were done by dry sieving. Both size-fractions were digested in aqua regia and analyzed by inductively coupled plasma–atomic emission spectrometry (ICP–AES) for Ag, Al, As, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cu, Fe, Ga, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Rb, Sb, Sc, Sn, Sr, Ta, Te, Ti, Tl, U, V, W, Y, Zn, and Zr. The clay fraction only was analyzed for Hg by cold-vapour atomic absorption (CV–AA) after an aqua regia digestion. The silt+clay fraction was analyzed by instrumental neutron activation analysis (INAA) for Au, Ag, As, Ba, Br, Ce, Co, Cr, Cs, Eu, Fe, Hf, Ir, La, Lu, Mo, Na, Ni, Rb, Sb, Sc, Se, Sm, Sn, Ta, Tb, Th, U, W, Yb, and Zn.

Acknowledgments

Motivating discussions on the deglaciation of the study area with R.J. Fulton helped to improve and strengthen the interpretation of the data. During field visits to the area, J.J. Clague, R.J. Fulton, and W.W. Shilts provided helpful comments on the stratigraphy. Comments and suggestions from M.A. Bouchard and J.J. Clague resulted in significant improvements to the manuscript. Pollen analyses on basal peat samples were carried out by T.W. Anderson, A. Grenier, and S.E. Hipwell. Diatom-flora analysis was done by C. Prévost. Grain-size and carbonate-content analyses were conducted under the supervision of P.J. Lindsay and M. Wygergangs. Radiocarbon dating at the Geological Survey of Canada was done by R.N. McNeely. Mollusks were identified by J. Toping of the Canadian Museum of Nature. Capable field assistance was provided by E. McDonald, T. McKay, C. McPhee, A. Mouton, S. Pohl, C. West, and K. Whitemore. The 'Quaternary stratigraphy' and 'Quaternary history' sections of this bulletin were part of the author's Ph. D. thesis, completed at the Université de Montréal under the supervision of M.A. Bouchard and W.W. Shilts. The author is indebted to all the above-mentioned people for their help.

The project was funded primarily under the Canada–British Columbia Agreement on Mineral Development (1991–1995) and, to a lesser degree, under the Nechako NATMAP project (1995–2000). Airphotos depicted in this report were used with the permission of Geographic Data BC, British Columbia Ministry of Environment, Lands and Parks, Victoria, British Columbia.

DESCRIPTION AND GENESIS OF MAP UNITS AND LANDFORMS

The surficial geology was mapped using a two-letter coding system simplified from that presented by Ryder and Howes (1984). Map units are designated first by a capital letter signifying material genesis. Materials are then further subdivided, using a lowercase letter, on the basis of thickness (e.g. veneer, blanket) or surface expression (e.g. terrace, fan).

Map units are grouped in the legend (Maps 1986A, 1987A) under two major headings, Quaternary and pre-Quaternary, which essentially correspond to the unconsolidated deposits and bedrock, respectively. Quaternary deposits are organized under two geological-climatic units: Fraser Glaciation and post-Fraser Glaciation (postglacial). The term Holocene is not used in the legend because the ages of some sediments are unknown. For instance, some postglacial deposits may have been emplaced at the very end of the Pleistocene.

Map units

Eight map units have been defined for this region.

Bedrock

Bedrock (unit R) polygons designate areas of bare bedrock outcrop or rock with patches of till or colluvium. 'Steep bedrock slopes' (unit Rs) occur in cirques and arêtes, and on steep (>45°) mountain slopes. Below steep escarpments, bedrock is commonly mantled by till and colluvium, which increase in thickness downslope. Steep rock slopes are prone to snow avalanches and landslides. Bedrock outcrops that are too small to be shown at the scale of mapping are depicted on the maps by an 'x' symbol.

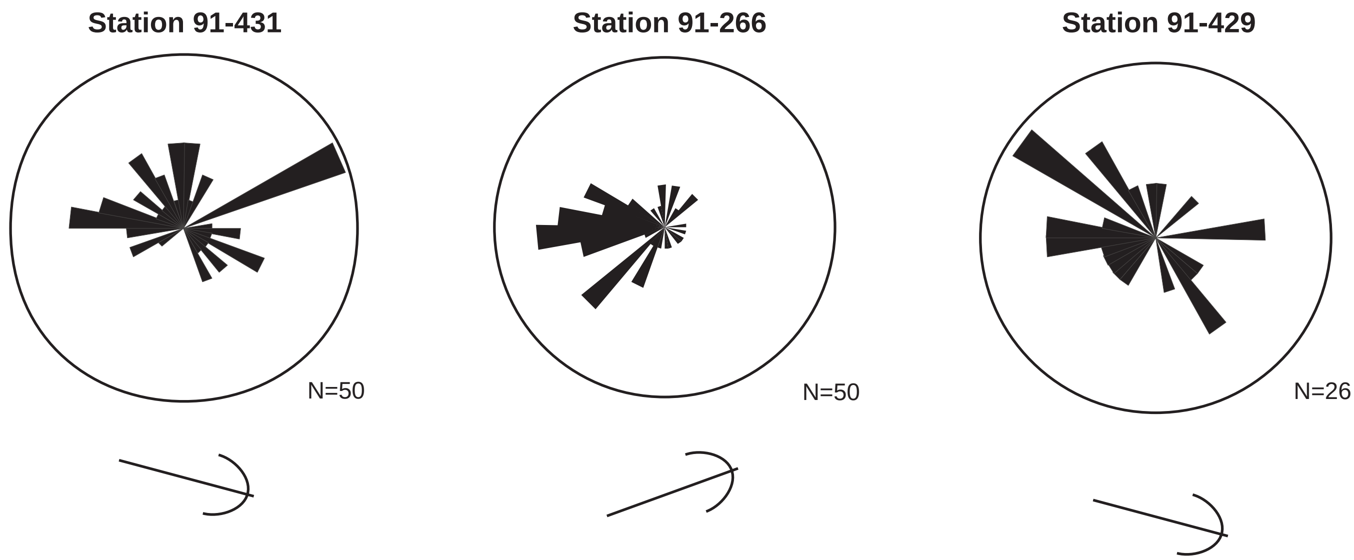

__Figure 7.__ Examples of pebble fabrics in Fraser Glaciation till from the study area. Station locations are shown on Figure 39 (in pocket). Number of clast-orientation measurements indicated by 'N'. Orientation of striation symbol indicates dominant ice-flow direction.

Till

Surface till was deposited during the Late Wisconsinan Fraser Glaciation and is the most areally extensive surficial sediment. Till is a matrix-supported diamicton deposited directly by glacier ice with little or no reworking by meltwater or gravitational processes. Till contains abundant striated and faceted clasts, some of which are of distant origin. Discontinuous lenses of sand and gravel, generally less than 50 cm thick and laterally discontinuous, occur sporadically within the till. Clast fabrics range from well developed to poorly developed (Fig. 7). In most cases, elongated pebbles in till are parallel to the direction of ice flow and preferentially plunge up-ice. Where clasts are plunging in an odd direction unrelated to ice-flow movement (Fig. 7), the till may have been gravitationally reworked after its deposition by ice, or the ice may have been locally deflected because of a concealed bedrock obstacle.

Till is a very poorly sorted sediment that contains clasts ranging from boulder (>256 mm) to granule (<2 mm) size in a sandy, silty matrix with a clay content generally less than 30% (Fig. 8). The texture of the till matrix varies considerably through the region, reflecting different types of bedrock and unconsolidated sediments that were overridden and eroded by the glaciers. For example, the high clay content of several till samples east and southeast of Fort St. James (Fig. 9) is attributed to entrainment of fine glacial-lake sediments by a glacier during the advance phase of the Fraser Glaciation. This interpretation is supported by two observations: 1) in Necoslie River valley, Fraser Glaciation till is underlain by advance-phase glacial-lake sediments; and 2) in other regions underlain by the same bedrock type (Cache Creek Group), the till is not as clayey. The extent of the area covered by this advance-phase glacial lake remains undetermined. Till matrix is generally sandy directly above or down-ice from intrusive

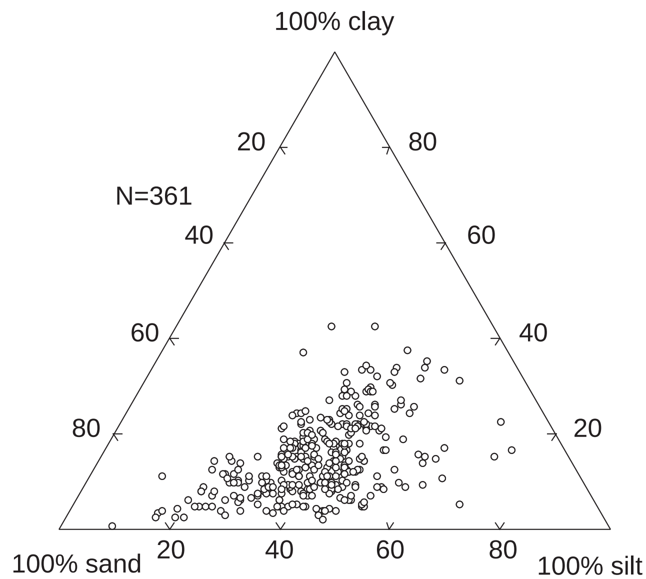

__Figure 8.__ Sand, silt, and clay content of Fraser Glaciation till samples from the study area. Number of samples indicated by 'N'.

rocks. For example, seven of eight till samples collected about 20 km north of Tchentlo Lake, on or near Early Jurassic intrusive rocks, have more than 50% matrix sand (Fig. 9). Bedrock influences not only till texture but also till composition. Plouffe (1995a) showed that the geochemistry, lithology, mineralogy, and gold-grain content of till are related to up-ice bedrock types and mineralization. The carbonate content of the silt+clay fraction of till is closely related to the distribution of calcareous rocks (Fig. 10), chiefly limestone of the Cache Creek Group and the Kootenay and Cassiar terranes (Fig. 6).

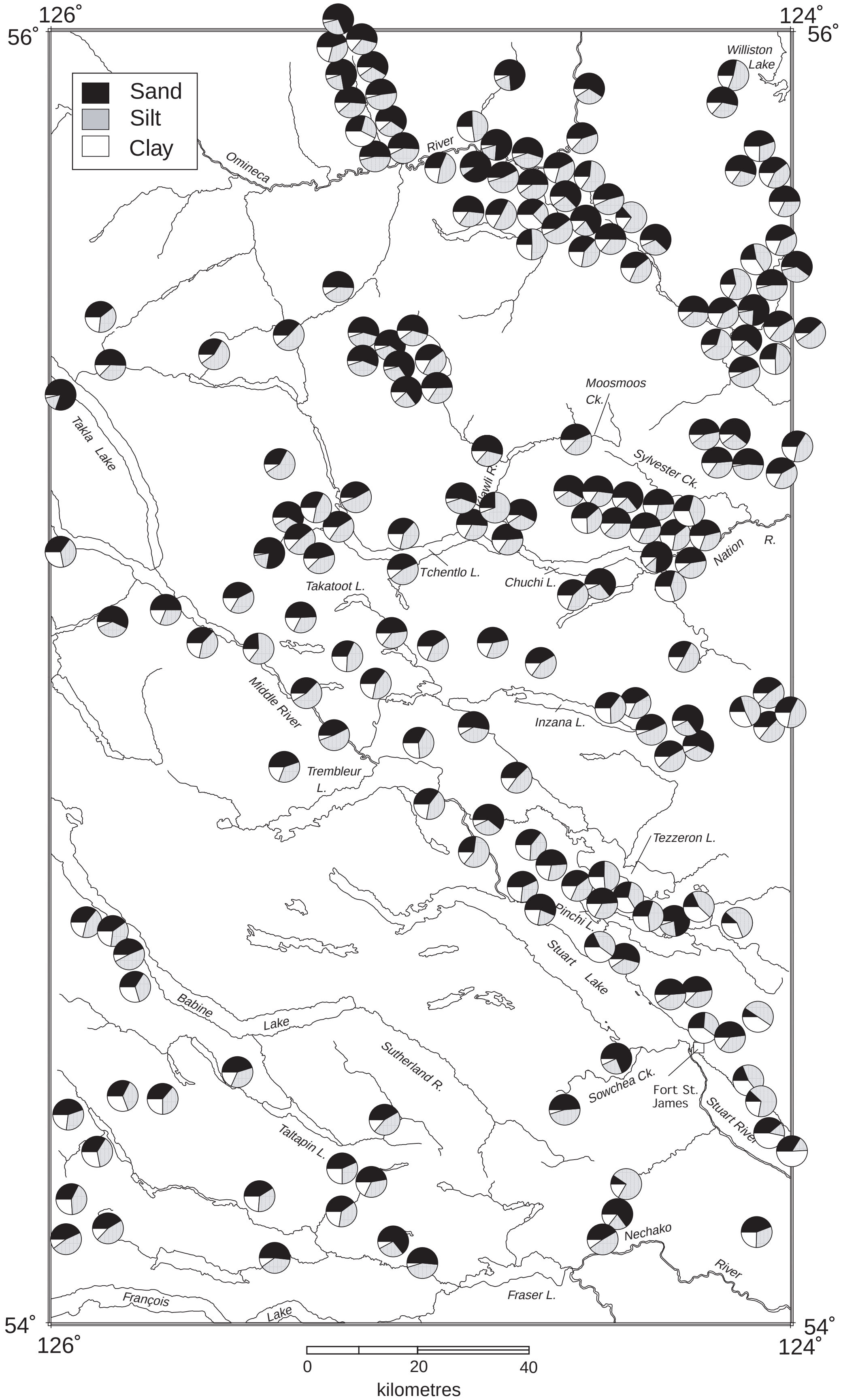

Figure 9. *Matrix texture of 361 Fraser Glaciation till samples from the study area.*

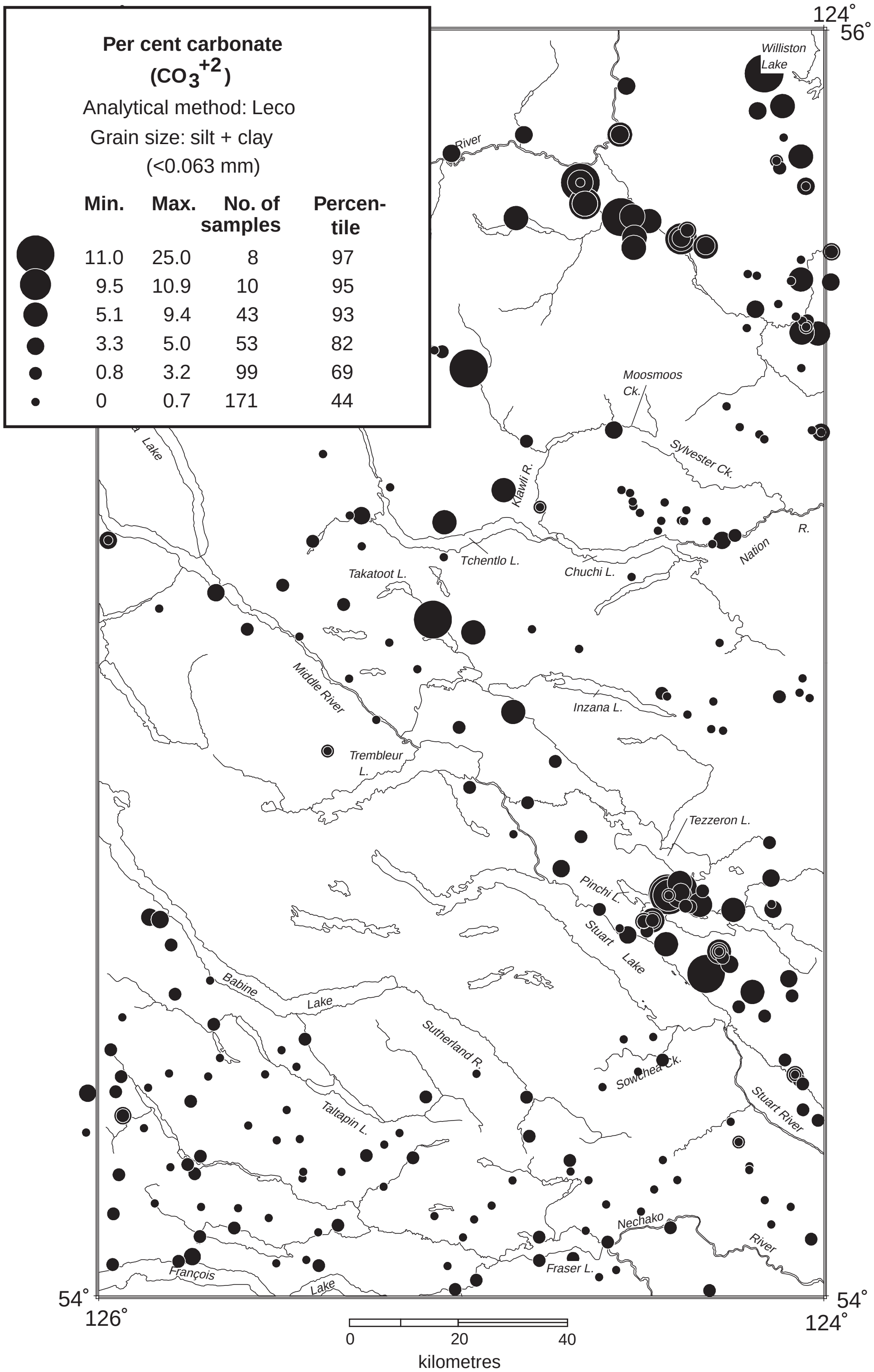

Figure 10. *Carbonate content of silt+clay fraction of 403 Fraser Glaciation till samples from the study area.*

Close to limestone, carbonate content of the silt+clay fraction of till can be as high as 25%, whereas it is generally less than 3% far from such rocks.

Fraser Glaciation till was likely deposited by a combination of melt-out and lodgment processes. The presence of sorted sediment lenses in several till exposures suggests deposition by melt-out, but the till is generally devoid of any sorted sediments and shows a well developed unimodal fabric more typical of lodgment till.

Areas mapped as till were subdivided, on the basis of sediment thickness and texture, into the following map units.

Thick till (unit Tm*)*

Thick till is more than 3 m thick, it masks the form of the underlying unit, and has a rolling surface with gentle hillocks and depressions. Bedrock outcrops are rare in areas of thick till. All till units can include areas of sand and gravel too small to show at the scale of mapping. Such sand and gravel deposits associated with till are common near meltwater channels.

Till blanket (unit Tb*)*

Till blanket is 1 to 3 m thick and locally obscures the form of the underlying unit. It covers the lower parts of the Nechako Plateau and lower mountain slopes, and is also present in many valleys. Drumlins and flutings are common in areas of till blanket.

Pinchi Creek lens (unit c-Tb*)*

A massive diamicton with a clayey matrix (85–90%) and a low clast content (10–15%) is the surficial sediment northeast of Stuart Lake (Map 1986A). The diamicton contains striated clasts up to boulder size and unconsolidated clay intraclasts. It is informally referred to as the 'Pinchi Creek lens'. The term 'lens' is preferred to 'till' because the unit in question is geographically restricted and occurs within a formation (Fraser Glaciation till; cf. North American Commission on Stratigraphic Nomenclature, 1983). As discussed later in the 'Quaternary stratigraphy' section, the Pinchi Creek lens was deposited during a late-glacial readvance. It is characterized by a higher clay content than the Fraser Glaciation till (Fig. 11) because the readvance took place in a glacial lake where fines were readily available for glacial erosion. The extent of the Pinchi Creek lens was mapped entirely from ground observations, as this deposit is not recognizable on airphotos. Therefore, in poorly accessible regions, contacts of the Pinchi Creek lens with adjacent units are approximate. The Pinchi Creek lens is locally overlain by a discontinuous veneer of glacial-lake sediments.

Till veneer (unit Tv*)*

Till veneer has an average thickness of 1 m and conforms to the topography of the underlying unit, which is generally bedrock. It occurs on high ground of the Nechako Plateau and represents the transitional zone between valley fill and bare bedrock at high elevations in the mountainous regions. Crag-and-tail features are abundant in areas of thin till.

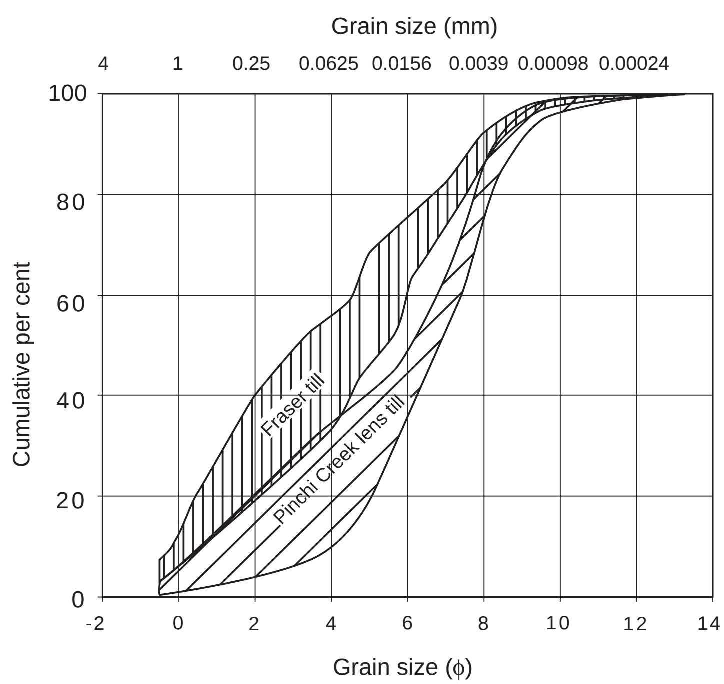

Figure 11.

Cumulative grain-size curves for 13 samples of Pinchi Creek lens till and 6 samples of Fraser Glaciation till from the study area. Analyses performed on material finer than 2 mm. Phi (ϕ) scale defined (Krumbein, 1934) as -$\log_2$(particle diameter in mm).

Glaciofluvial deposits

Glaciofluvial deposits include sand, gravel, and minor silt deposited by meltwater streams at the close of the last glaciation. The deposits consist of bouldery to pebbly, clast-supported, poorly sorted to well sorted gravel, locally grading into well sorted sand. They are generally stratified, but thick massive units of glaciofluvial deposits have also been observed. Most clasts in these deposits are subrounded to rounded. The deposits generally range from 1 to 10 m in thickness, but are up to 30 m thick in the esker complex south of Fort St. James (Map 1986A). Southeast of Chuchi Lake, 100 m of glaciofluvial gravel and sand have been intersected in a drillhole on a terrace (British Columbia Ministry of Mines and Petroleum Resources, Assessment Report 19296). Some deposits contain postdepositional faults and folds produced by the melting of supporting ice. Areas underlain by glaciofluvial sand and gravel commonly have uniform stands of sparse lodgepole pine (Fig. 12), a situation that facilitates photogeological identification.

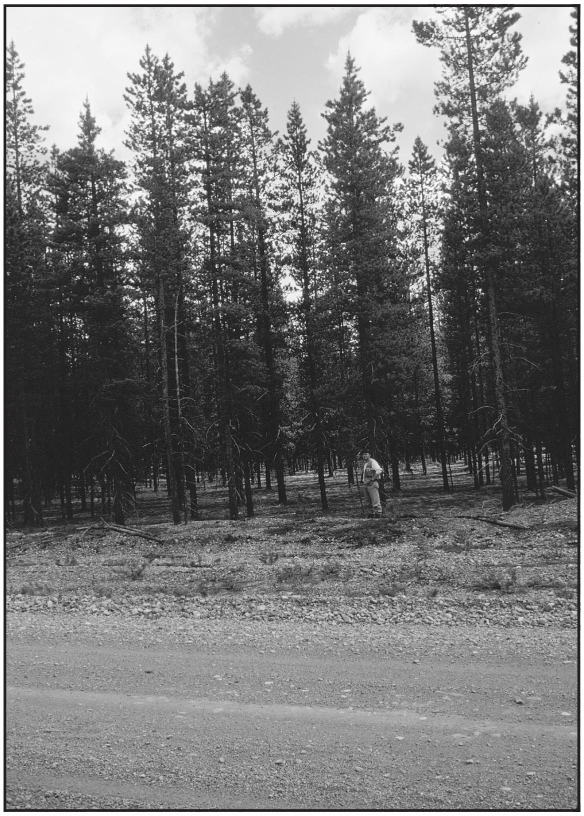

Figure 12. *Lodgepole pines (*Pinus contorta*) on an understorey of lichen growing on glaciofluvial sand and gravel, approximately 10 km northwest of Cripple Lake. Note the small size of the trees. Photograph by A. Plouffe. GSC 1999-051M*

Glaciofluvial deposits are graded to a base level higher than the present one and, as mentioned above, contain evidence of ice-contact sedimentation, including kettle holes (e.g. glaciofluvial terraces with abundant kettles southeast of Manson Lakes, Map 1987A) and internal sediment faulting. Such criteria distinguish glaciofluvial deposits from alluvial deposits. In addition, the presence of unusually large boulders, which could not have been transported by the flows that deposited the surrounding sediment, suggests glaciofluvial rather than fluvial sedimentation. The boulders were probably transported on top of a glacier and ended up on the glaciofluvial sediments after the ice melted.

Glaciofluvial deposits have been subdivided, on the basis of their associated landforms, into the following map units.

Glaciofluvial terrace sediments (unit Gt*)*

Glaciofluvial terraces consist of planar, often kettled surfaces located well above present-day base level and underlain by 1 to 10 m of sand and gravel (Fig. 13, 14). The terraces are generally unpaired. Some of them were formed by meltwater that flowed between retreating glaciers or stagnant ice and the adjacent ice-free valley walls. After the ice melted, the terraces (kame terraces) were left standing above the valley floor. Other glaciofluvial terraces formed when streams incised the valley fill.

Figure 13.

Glaciofluvial terraces (unit Gt*) in the upper Sowchea Creek area. Photograph by A. Plouffe. GSC 1999-051N*

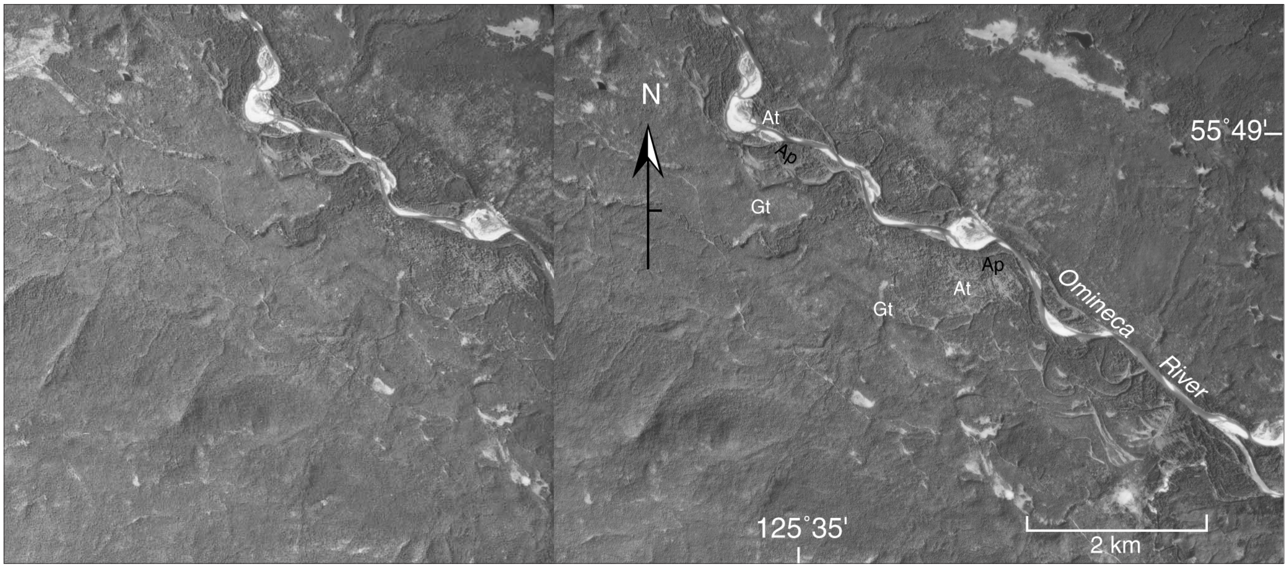

Figure 14. *Stereo pair showing glaciofluvial (unit* Gt*) and alluvial (unit* At*) terraces, and an alluvial floodplain (unit* Ap*) of the Omineca River. Used with permission, Geographic Data BC, Ministry of Environment, Lands and Parks. British Columbia Government airphotos BC87097-040, -041*

Glaciofluvial blanket (unit Gb*)*

Areas mapped as glaciofluvial blanket are underlain by a continuous cover of sand and gravel that partly masks the topography of underlying units. Glaciofluvial blankets are 1 to 5 m thick and occur mainly in upland regions.

Proglacial deltaic sediments (unit Gd*)*

Proglacial deltaic sediments were deposited at the mouths of streams that entered former glacial lakes. These sediments include inclined beds of moderately to well sorted sand and gravel (delta foresets), overlain by horizontal beds of silt and sand (delta topsets). Delta foresets overlie rhythmically bedded sand, silt, and clay (delta bottomsets). Such a complete delta sequence (bottomsets to topsets) has seldom been observed in the study area.

Proglacial deltaic sediments are commonly 5 to 10 m thick, but may be thicker beneath some of the larger deltas, such as the one on the south shore of Stuart Lake that was built at the end of the last glaciation (Fig. 15; Map 1986A). This delta is interpreted as glacial in origin because it is associated with ice-contact glaciofluvial sediments and its surface is pitted with kettles. This delta was incised and a postglacial delta constructed after the glacial lake drained but before Stuart Lake reached its current level. The higher phase of Stuart Lake is marked by a series of elevated beaches (Fig. 15). Many glaciofluvial deltas identified in the field but not extensive enough to be shown on the surficial geology maps have been included within units of glaciolacustrine sediments.

Ice-contact deposits (unit Gh*)*

Glaciofluvial ice-contact deposits are characterized by hummocky topography, which developed following the melting of buried or marginal ice (Fig. 16). Sediment deformation, including normal and reverse faults, is common in ice-contact deposits (Fig. 17). Because of the proximity of ice and rapid changes in water flow, the properties of ice-contact deposits change rapidly, both vertically and laterally. Diamictons deposited by debris flow off the ice surface (flowtill) are commonly interbedded with the sand and gravel.

Glaciolacustrine deposits

The most volumetrically abundant glacial-lake sediments consist of rhythmically bedded and laminated, fine sand, silt, and clay with sporadic dropstones. Interbeds and lenses of diamicton, sand, and gravel occur locally within the finer grained sediments. Carbonate concretions of all shapes (Fig. 18) are abundant, especially near and down-ice from outcrops of Cache Creek Group limestone, the main source of the carbonate. These sediments were deposited in former glacial lakes that developed at the end of the Fraser Glaciation, when drainage was blocked by decaying ice masses. The fine sand, silt, and clay were deposited from suspension and bottom flow at some distance from the glacier. Coarser sediments accumulated in ice-proximal environments. Diamicton lenses were deposited from debris flows derived from ice or steep slopes at the margins of the former glacial lakes. Sand and gravel lenses accumulated at the mouths of subglacial channels that terminated in the glacial lakes. Dropstones in the fine-grained sediments suggest the presence of icebergs.

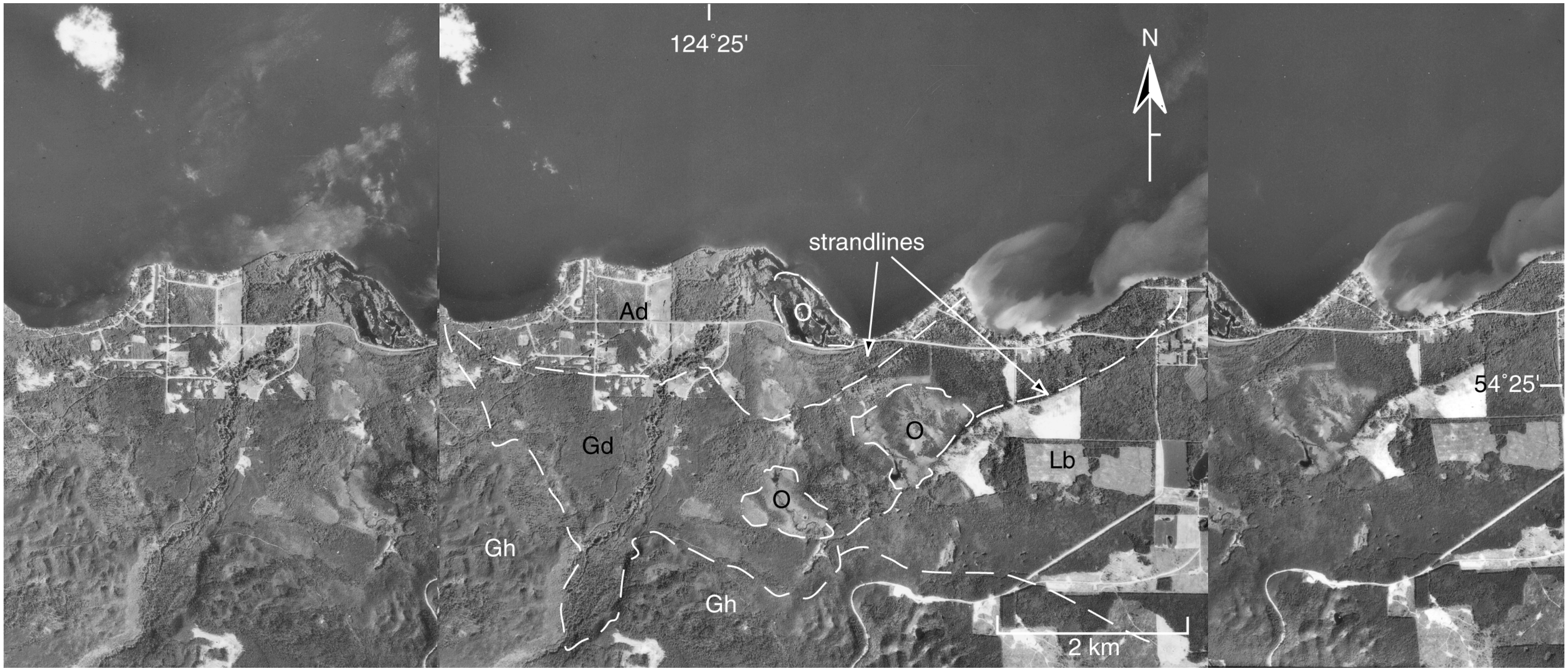

Figure 15*. Stereo triplet showing proglacial (unit* Gd*) and alluvial (postglacial; unit* Ad*) deltas southwest of Fort St. James. The proglacial delta was built into a former glacial lake, and the postglacial delta formed when Stuart Lake was higher than today. Note the elevated strandlines and the abundance of kettles in the area mapped as unit Gh. Explanation of units:* O, *organic deposits;* Lb, *blanket of glaciolacustrine sediments;* Gh, *glaciofluvial ice-contact deposits. Used with permission, Geographic Data BC, Ministry of Environment, Lands and Parks. British Columbia Government airphotos BC88038-047, -048, -049*

Glacial-lake deposits extensive enough to be mapped occur only in valleys. Small areas of supraglacial glaciolacustrine sediments, found locally and too small to be mapped, are included in till units. Glaciolacustrine sediments have been incised by some streams (e.g. Nechako River), producing bluffs that are prone to landsliding (*see* 'Natural hazards' section). Terrain underlain by fine-grained glacial-lake sediments commonly supports stands of poplars and shows a dendritic drainage pattern, which facilitates mapping of these materials in less accessible regions.

The following three subunits of glaciolacustrine sediment have been defined on the basis of thickness. The contacts between these subunits and adjacent units are gradational.

Glaciolacustrine plain (unit Lp*)*

Relatively flat areas underlain by more than 10 m of fine-grained glaciolacustrine sediments have been mapped as glaciolacustrine plain. The topography of underlying units is completely masked by the glaciolacustrine sediments.

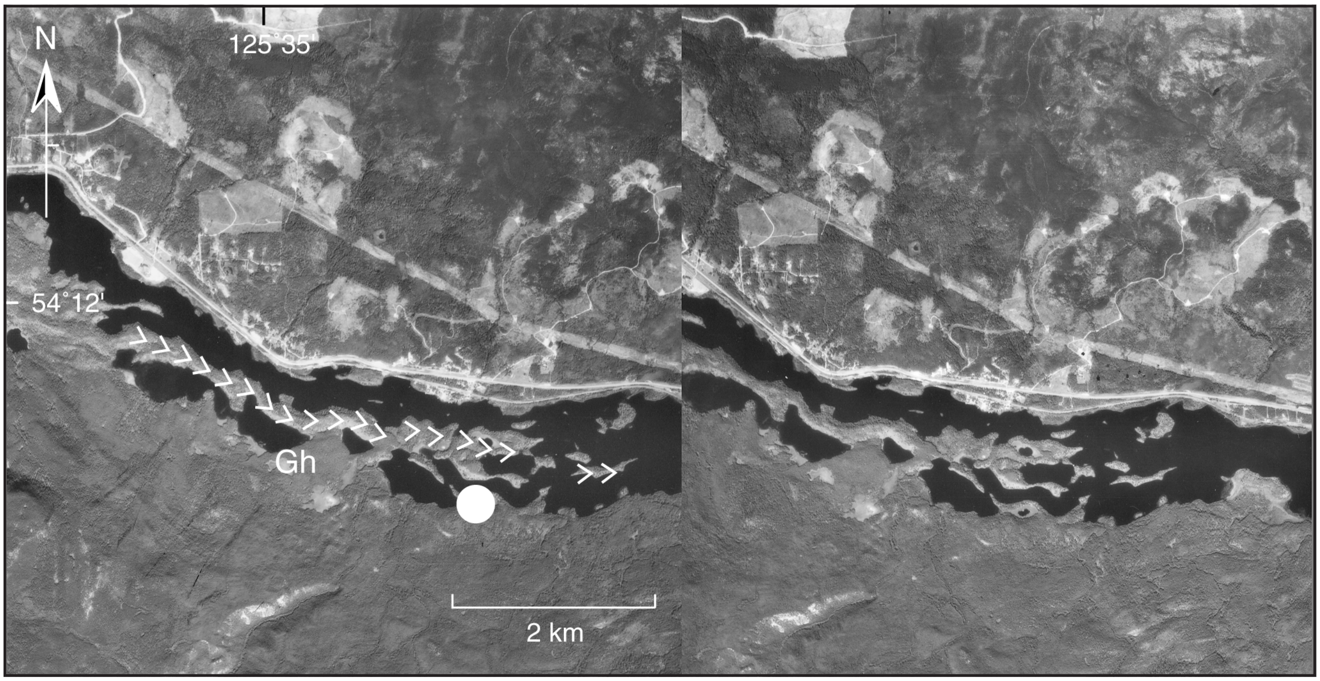

Figure 16. *Stereo pair showing an esker composed of glaciofluvial ice-contact deposits (unit* Gh*), Burns Lake valley. The esker is depicted with the same symbols as on the surficial geology maps (Maps 1986A, 1987A). Kettle lakes (K) formed after the melting of buried ice. Used with permission, Geographic Data BC, Ministry of Environment, Lands and Parks. British Columbia Government airphotos BC88074-240, -241*

Figure 17. *Normal faults in ice-contact glaciofluvial sand and gravel, east of Burns Lake. Photograph by A. Plouffe. GSC 1999-051O*

Figure 18*. Carbonate concretions found in glacial-lake sediments, Necoslie River valley. Lens cap is 55 mm in diameter. Photograph by A. Plouffe. GSC 1999-051P*

Glaciolacustrine plains have been locally incised by streams, resulting in gullies that are susceptible to landslides. The largest farms in the region are on glaciolacustrine plains (e.g. around Vanderhoof, Map 1986A).

Glaciolacustrine blanket (unit Lb*)*

Glaciolacustrine blanket averages 3 to 10 m in thickness and partly obscures the topography of the underlying unit. West of Vanderhoof, for example, drumlins and crag-and-tail features within areas of units Lb and Lv are still visible beneath the blanket and veneer of glaciolacustrine sediments. Sedimentation in glacial lakes locally took place on buried ice. Following the melting of that ice, horizontal beds of fine-grained sediment were folded and tilted (Fig. 19), and kettle depressions developed at the surface (e.g. in Stuart River valley south of Fort St. James and in Kuzkwa River valley, Map 1986A).

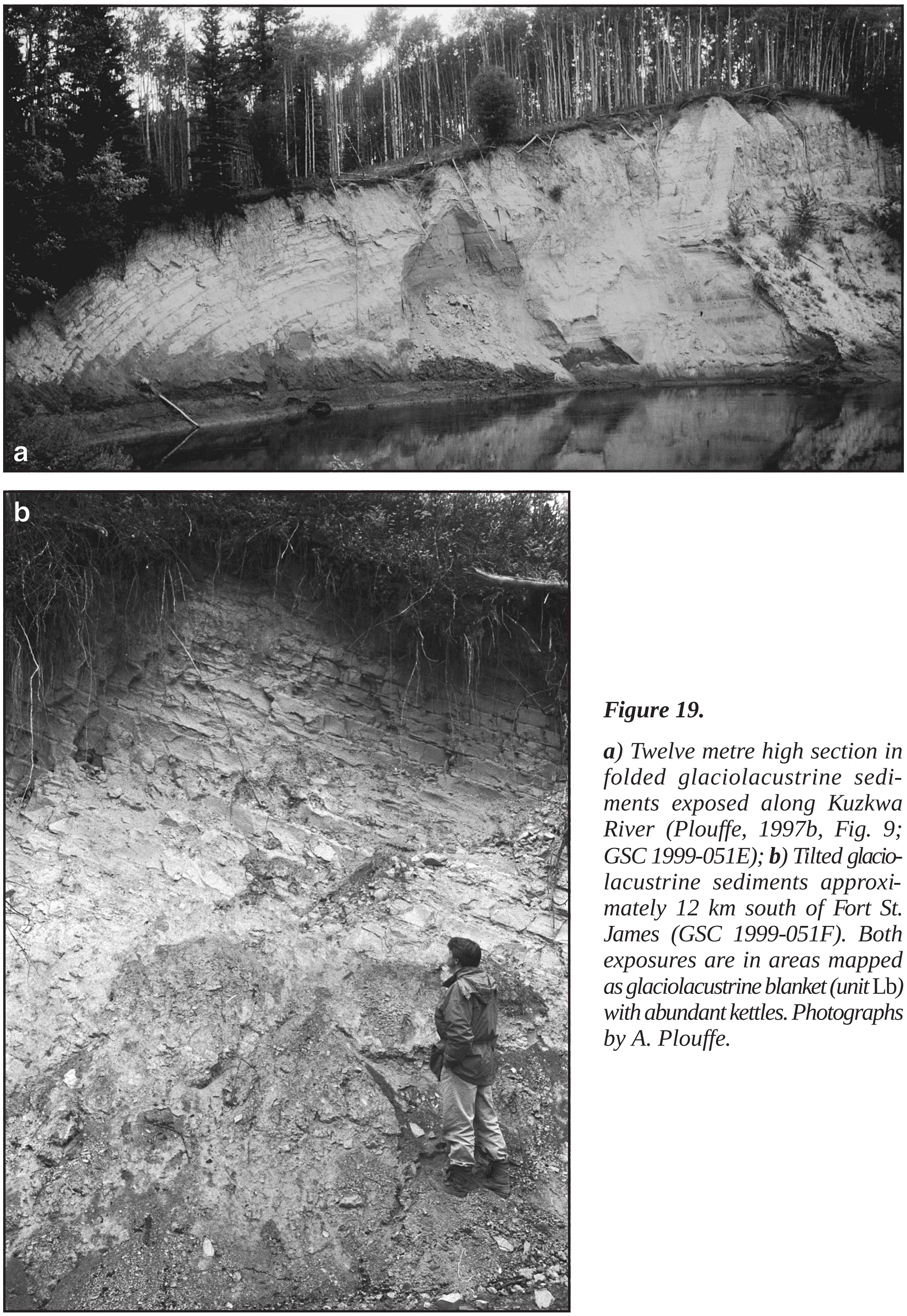

Figure 19.

a*) Twelve metre high section in folded glaciolacustrine sediments exposed along Kuzkwa River (Plouffe, 1997b, Fig. 9; GSC 1999-051E);* ***b****) Tilted glaciolacustrine sediments approximately 12 km south of Fort St. James (GSC 1999-051F). Both exposures are in areas mapped as glaciolacustrine blanket (unit* Lb*) with abundant kettles. Photographs by A. Plouffe.*

Figure 20.

Colluvium northwest of Burns Lake. Note the crude bedding that dips at a slightly steeper angle than the slope. The arrow indicates a person for scale. Photograph by A. Plouffe. GSC 1999-051G

Glaciolacustrine veneer (unit Lv*)*

Areas mapped as glaciolacustrine veneer are near the upper limit of former glacial lakes. These areas were covered by only shallow water and, as a result, the glaciolacustrine sediments are thin, averaging 1 to 3 m in thickness. The underlying till is exposed in many places within terrain mapped as unit Lv. The topography reflects that of the underlying unit.

Deposits of well sorted sand (possibly beach deposits) and deltaic sand and gravel occur near the mouths of meltwater channels close to the upper limit of the glacial lakes. These coarse deposits are usually not extensive enough to be mapped separately and have therefore been included within the glaciolacustrine veneer unit. A symbol is used on the map to identify beaches that have been observed in the region (e.g. along Highway 27 north of the town of Vanderhoof, Map 1986A).

Colluvial deposits

Colluvial deposits are those that accumulated by mass-wasting processes. The characteristics of these sediments depend on the nature of the source material. At the base of steep bedrock slopes, colluvium consists of angular local rock fragments of various sizes (talus). On valley walls where glacial sediments are abundant, colluvium generally consists of a mixture of reworked till and glaciofluvial sediments. Colluviated till is less compacted and more porous than the till from which it was derived, and often shows a crude bedding subparallel to the slope (Fig. 20). Furthermore, the matrix of colluviated till is commonly very sandy because some of the fines have been washed away (Fig. 21). The thickest and the most continuous colluvial deposits occur on steep slopes in the Omineca Mountains.

Colluvial deposits have been subdivided, on the basis of associated landforms, into the following map units.

Landslide material (unit Ch*)*

Landslides large enough to be mapped are characterized by hummocky topography and spoon- or bowl-shaped profiles with prominent breaks in their upper part. A symbol is used on the surficial geology maps to indicate large and small landslide scars. In addition, small debris flows, which are a type of landslide, are shown on the maps by a different symbol. The largest landslides are in Nechako River (Fig. 22), Stuart

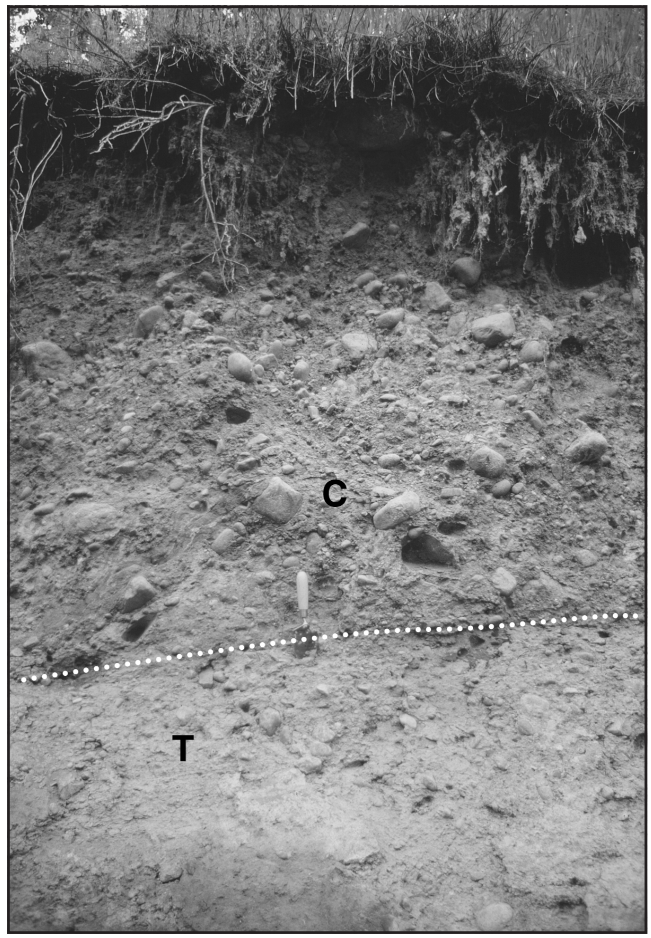

Figure 21. *Till (unit* T*) overlain by colluvium (unit* C*), approximately 10 km northwest of Burns Lake. Note the greater clast content of the colluvium. The trowel (20 cm long) at the contact provides scale. Photograph by A. Plouffe. GSC 1999-051H*

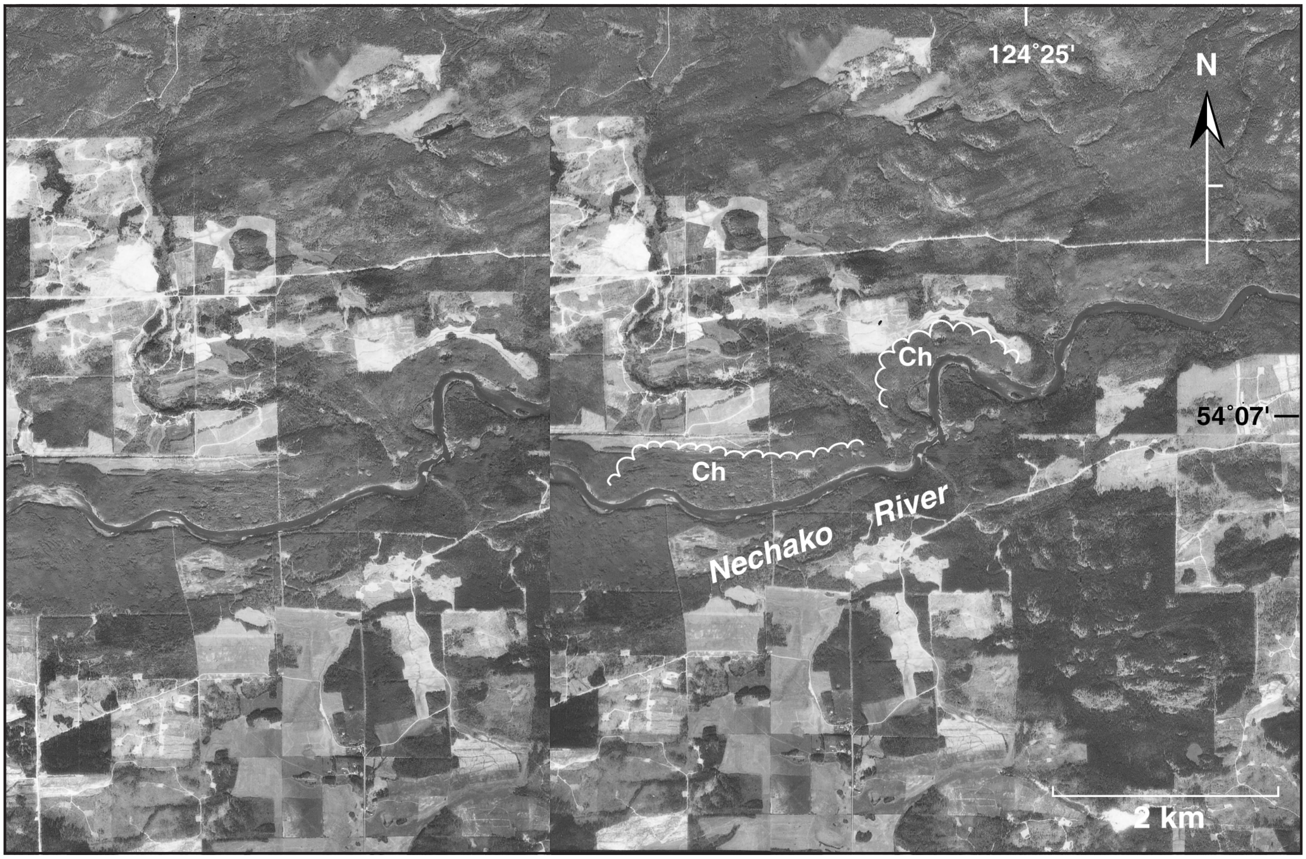

Figure 22. *Stereo pair showing landslides (unit* Ch*) in glaciolacustrine sediments of the Nechako River valley. Used with permission, Geographic Data BC, Ministry of Environment, Lands and Parks. British Columbia Government airphotos BC88074-251, -252*

River, Stuart Lake, Burns Lake, Babine Lake, and Middle River valleys (Map 1986A), in areas underlain by fine-grained glaciolacustrine sediments. A few slope failures were noticed in areas underlain by clayey till and glaciofluvial sediments (*see* 'Natural hazards' section, below). Some landslides, such as those in the Burns Lake and Babine Lake areas, may have resulted from undercutting of weak Tertiary volcaniclastic rocks beneath more resistant basalt lava or breccia (as described by Evans (1984)).

Slope colluvium (unit Cs*)*

Areas mapped as slope colluvium are underlain by an average of 1 to 5 m of rock fragments in a matrix of sand, silt, and clay. The sediment can be massive or thickly bedded, with beds oriented parallel or subparallel to the slope. Slope colluvium is commonly gullied.

Colluvium apron and talus (unit Ca*)*

Talus, in the form of aprons and cones and composed of locally derived, angular rock fragments, has accumulated at the bottom of some steep slopes (>40°). Sediment thickness averages 1 to 10 m and it generally increases toward the toe of the slopes. Talus is particularly abundant below cirque headwalls in the Omineca Mountains.

Alluvial (fluvial) deposits

Modern stream deposits are sediments transported and deposited from running water in postglacial time. Although glacier ice is not involved in their deposition, some of the sediments may have been laid down at the very end of the last glaciation, or in early-postglacial time when glacial sediments were readily available for erosion and transport by streams (paraglacial period; *see* Ryder (1971a, b), Church and Ryder (1972), Jackson et al. (1982)). The texture of alluvial sediments depends on flow regime, distance of transport, and sediment source. They generally consist of moderately to well sorted, stratified sand and gravel, except in alluvial fans (*see* below). The thickest accumulations of alluvium are found in the main valleys and in tributary valleys containing abundant glaciofluvial sediments.

Alluvial deposits have been grouped, on the basis of landforms, into the following four units.

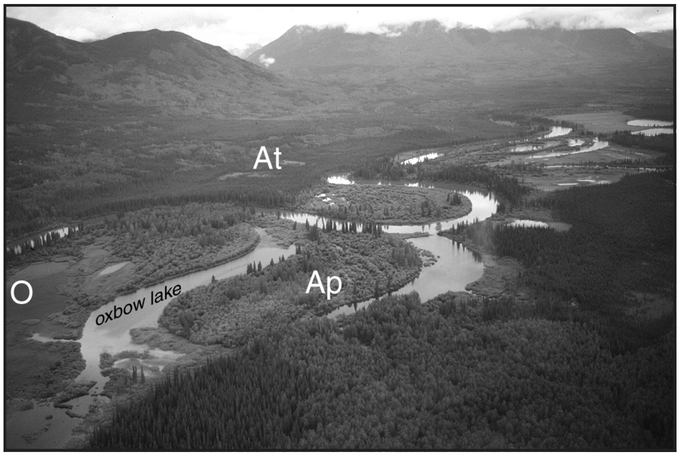

Figure 23. Alluvial terraces (unit At*) and floodplain (unit* Ap*) in the Omineca River valley. Note elongated oxbow lakes (abandoned channels of Omineca River) and large bogs (*O*) on the floodplain. Photograph by A. Plouffe. GSC 1999-051Y*

Floodplain sediments (unit Ap*)*

A floodplain is a flat to gently sloping surface that occurs at or near present-day stream level and is therefore flooded periodically (Fig. 14). Alluvial floodplains are underlain by well sorted sand and minor silt, which generally overlie coarser sand and gravel deposited during the migration of the main channel. Thin lenses of organic matter occur within floodplain sediments. Floodplain sediments are generally on the order of 1 to 3 m thick. It should be noted that the total sediment thickness beneath alluvial floodplains depends on valley size and glacial history. For example, large sediment accumulations are suspected in the Omineca River valley, where floodplain sediments overlie thick glaciolacustrine valley fills (Fig. 23; Map 1987A).

Because of the periodicity of flooding in the regions mapped as floodplain, they are not appropriate for the establishment of infrastructure.

Terrace sediments (unit At*)*

Following deglaciation, streams aggraded in response to the oversupply of sediment to the fluvial system. This period of aggradation was followed by one of degradation, when the sediment supply decreased and streams began to incise valley fills. Former floodplains were left as paired and unpaired terraces along valley walls, which mark an older and higher stream base level (Fig. 14). The terraces slope gently downvalley and are underlain by moderately to poorly sorted, horizontally bedded sand and gravel, commonly capped by a veneer (1 m or less) of sand. Terrace sediments are commonly horizontally bedded. Flat clasts may be imbricated, dipping in an up-flow direction. Alluvial terrace sediments average 2 to 10 m in thickness.

Deltaic sediments (unit Ad*)*

A delta is a depositional landform built at the mouth of a stream that enters a standing body of water (Fig. 15). It has a flat to gently sloping surface (delta top) that terminates as an abrupt scarp (delta foreslope). Deltas are composed of sand grading up into pebbly gravel. The pebbly gravel is capped by a veneer of fine sand and silt. The uppermost beds of a delta are horizontal (topsets), whereas underlying beds are inclined (foresets). Total sediment thickness in any single delta is difficult to estimate, but may range from 2 to 10 m. Active deltas were not mapped as unit Ad because they are subaqueous landforms that do not appear on the topographic bases. Following the practice of Clague (1984), the subaerial portion of active deltas was mapped as unit Ap. However, some deltas occur 1 to 5 m above present lake levels and formed when lakes were higher, before downcutting of their outlets. Downcutting accompanied a general lowering of base levels associated with the development of the modern drainage system.

Fan sediments (unit Af*)*

An alluvial fan is a constructional, fan-shaped landform built at the mouth of a tributary valley or gully where there is an abrupt change in slope (Fig. 24). Sediments are deposited in these settings because of the decrease in flow regime. The character of alluvial fan sediments depends on the source sediments. In the steeper regions of the Omineca Mountains, alluvial fans comprise a variety of material ranging from sorted sand and gravel to angular local bedrock fragments. In

***Figure 24.** Alluvial fan in the Swannell Ranges north of Omineca River. Photograph by A. Plouffe. GSC 1999-051Z*

the hilly parts of the Nechako Plateau, they are composed mainly of reworked till and sorted sand and gravel. Lenses of detrital organic matter are commonly present within alluvial fan sediments. Fan sediments average 2 to 15 m in thickness. The fans are vegetated, but many support immature forest, indicating that they have been recently active (Fig. 24). Most fans are not deeply incised by the streams that cross them, and sediment can be deposited on them during snowmelt season or periods of heavy rain.

Alluvial sediments, undivided (unit Au*)*

Most narrow valleys contain a mixture of alluvial fans, terraces, and floodplains that are too small to be mapped individually. The floors of these valleys were mapped as undivided alluvial sediments.

Organic deposits (unit O)

Organic deposits consist mainly of peat, with a lesser amount of marl (fine-grained organic sediment with abundant shells), in various stages of decomposition. These deposits are found in fens and bogs in poorly drained areas such as depressions in bedrock and till, valleys with underfit streams, and abandoned meltwater channels (Fig. 25). The deposits are generally 1 to 3 m thick, but a peat thickness of more than 5 m has been reported in the Omineca River valley (Alley and Young, 1978). Peat commonly overlies marl or well sorted clay; even in regions covered with till, peat is rarely found directly overlying till. At the bottom of bogs, peat can be interbedded with minor clay and silt. Therefore, peat accumulated in depressions that were initially small ponds and lakes. Occurrences of organic deposits that are too small to be mapped are widespread throughout the region.

Anthropogenic deposits (unit X)

The only anthropogenic deposit large enough to be mapped occurs near the Endako mine, west-southwest of Fraser Lake. It includes the mine tailings and settling-pond sediments.

Figure 25. *Bog in an abandoned meltwater channel southeast of Taltapin Lake. Photograph by A. Plouffe. GSC 1999-051AA*

Landforms

Glacial and nonglacial landforms are described below in the same sequence as in the symbol section of the legend on the surficial geology maps (*see* Maps 1986A, 1987A). Although there is some ambiguity regarding the age relationships of some glacial landforms (e.g. striations, drumlins, moraines), they are tentatively described from oldest to youngest.

Glacial landforms

Glacial landforms were formed by the direct or indirect action of glaciers.

Cirques and arêtes

Cirques and arêtes are glacial erosional landforms that are prevalent in mountainous parts of the study area (Fig. 26). Cirques are bowl-shaped bedrock depressions that open downslope and were carved by glaciers. Arêtes are sharp, narrow, bedrock ridges separating the headwalls of adjacent cirques. Cirques and arêtes are the cumulative product of lengthy erosion during many Pleistocene glaciations.

Cirques and arêtes range from fresh, with sharp profiles, to subdued, with more rounded profiles. Most of the subdued cirques and arêtes are at lower elevation than the fresh ones, possibly indicating that the subdued landforms suffered greater glacial erosion because they were covered by greater ice thicknesses.

Glacial striations

Glacial striations are linear abrasion marks formed as rock fragments embedded in the sole of a glacier were dragged across a rock surface (Fig. 27). Individual striations generally range from one to a few millimetres in width and from 10 cm to 2 m in length. Glacial striations occur in association with glacial grooves, which are similar to striations but larger in size. Miniature crag-and-tail features or ‘rat tails’ are also associated with striations. These were produced where glacial erosion was inhibited down-ice from a hard projecting element of the bedrock (e.g. quartz vein), thus creating a ‘tail’ on the lee side of the obstruction. Miniature crag-and-tail features, glacial striations, and grooves are denoted by a single symbol on the surficial geology maps (Maps 1986A, 1987A).

Orientations of these features have been measured at 130 sites (Fig. 28). Striated bedrock surfaces are not abundant because: 1) over large areas, thick deposits of unconsolidated sediments cover bedrock; and 2) some rock types are poorly indurated, deeply weathered, or jointed, so polished and striated bedrock surfaces are not well preserved. Particularly good glacial striations were found on fine-grained outcrops recently exposed by forestry road construction. Striations were found as high as 1800 m a.s.l. in the Hogem Ranges. These striations are associated with a small roche moutonnée (Fig. 29), which clearly indicates that ice was moving to the east.

Striations are generally parallel to the drumlins, flutings, and crag-and-tail features (*see* below). However, some striated outcrops record more than one ice-flow direction. The

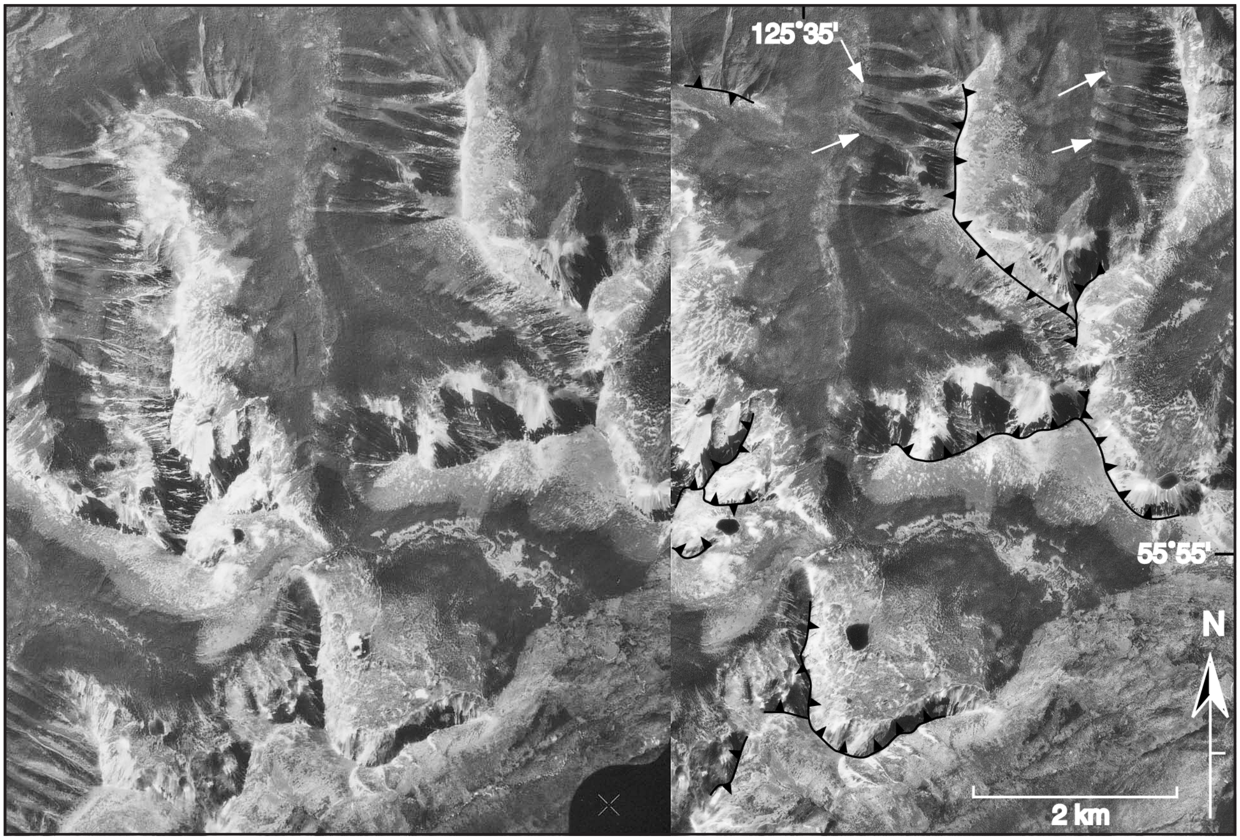

Figure 26. *Stereo pair showing cirques (indicated by symbol with teeth on one side) and arêtes (indicated by symbol with teeth on both sides) in the Swannell Ranges. Arrows point to avalanche tracks, which are common in the mountainous part of the study area. Used with permission, Geographic Data BC, Ministry of Environment, Lands and Parks. British Columbia Government airphotos BC87067-159, -160*

Figure 27. *Two sets of glacial striations on phyllite, west of Takatoot Lake. The dominant set is parallel to the pencil on the left. The second set, which is more faint, is parallel to the other pencil. The age relationship between the two movements is not evident at this site. Photograph by A. Plouffe. GSC 1999-051BB*

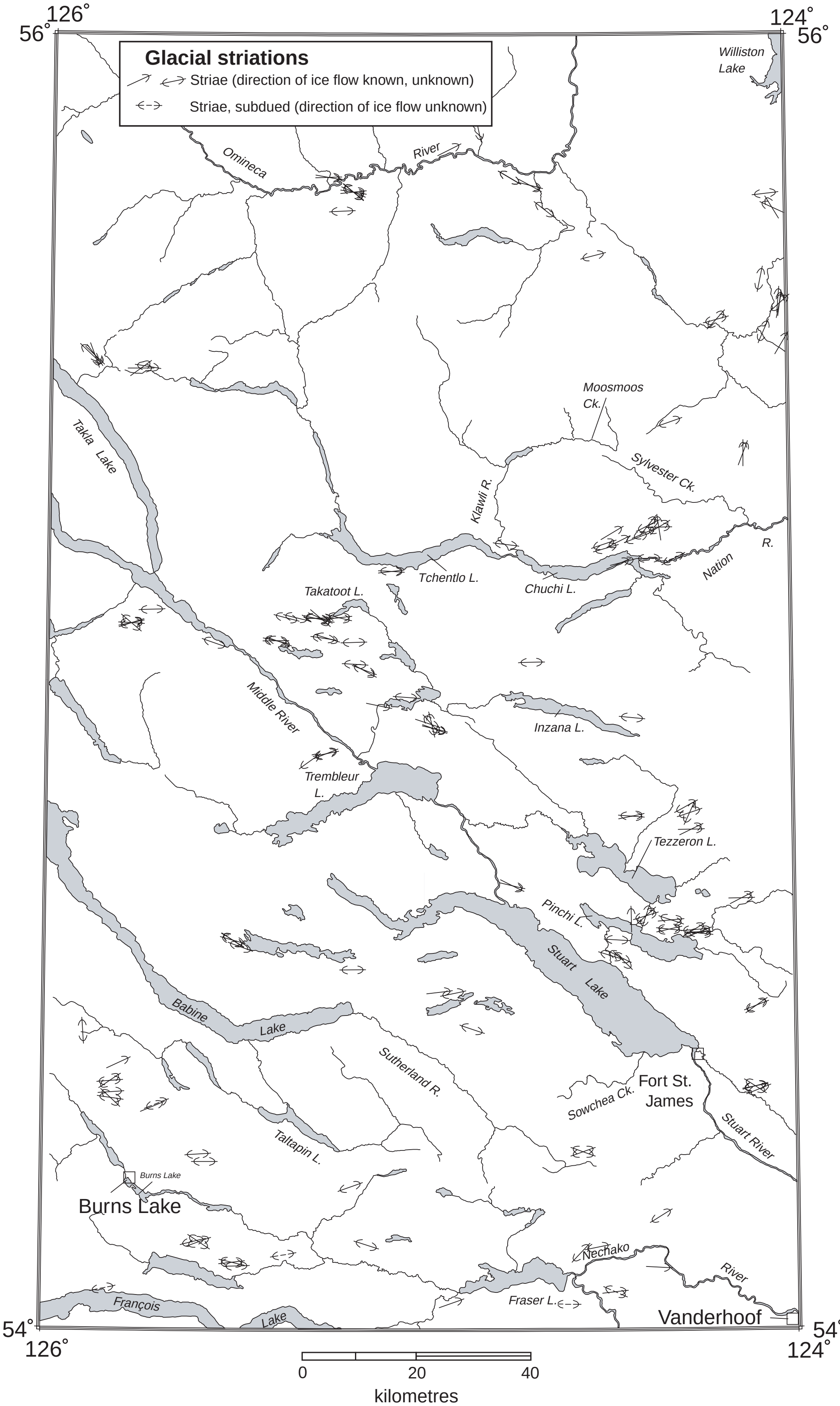

Figure 28. *Orientations of glacial striations measured in the study area (*modified from *Plouffe, 1997b).*

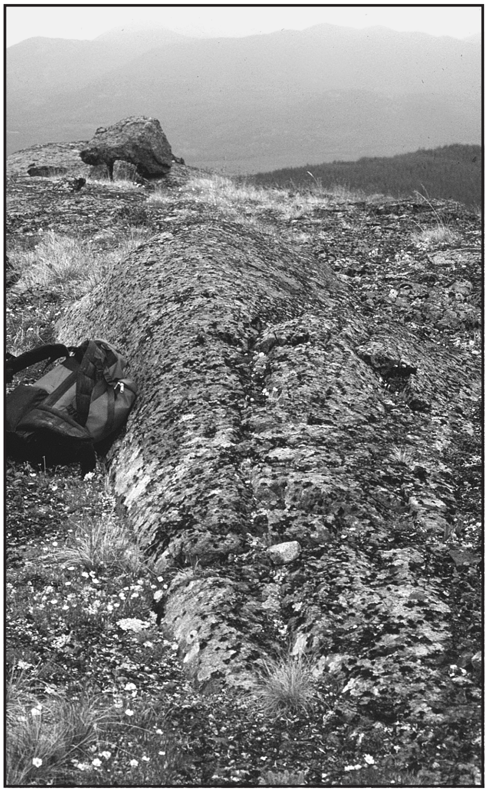

Figure 29. *Roche moutonnée at an elevation of 1800 m in the Hogem Ranges, looking down-ice. Photograph by A. Plouffe. GSC 1999-051A*

sequence of ice movements could be established from truncated surfaces or the presence of striations on the stoss side of bedrock outcrops or larger grooves. Shifts in ice-flow direction determined from striations with different orientations can be related to progressive ice buildup: as the glacier thickened it was able to flow over topographic obstacles rather than around them. However, at a few sites, the variation in ice-flow directions is thought to reflect differences in the timing of ice advances from different source areas. In the Pinchi Lake area, for instance, east-trending glacial grooves are cut by northeast-trending striations, suggesting that the easterly flowing ice from the Coast Mountains, which reached the area first, was subsequently deflected to the northeast by the Cariboo Mountain ice lobe (*see* 'Quaternary history' section, below).

Drumlins, flutings, and crag-and-tail features

Macro landforms that are oriented parallel to the direction of ice flow include drumlins, crag-and-tail features, and flutings (Fig. 30). Many drumlins have a steep stoss side and a more

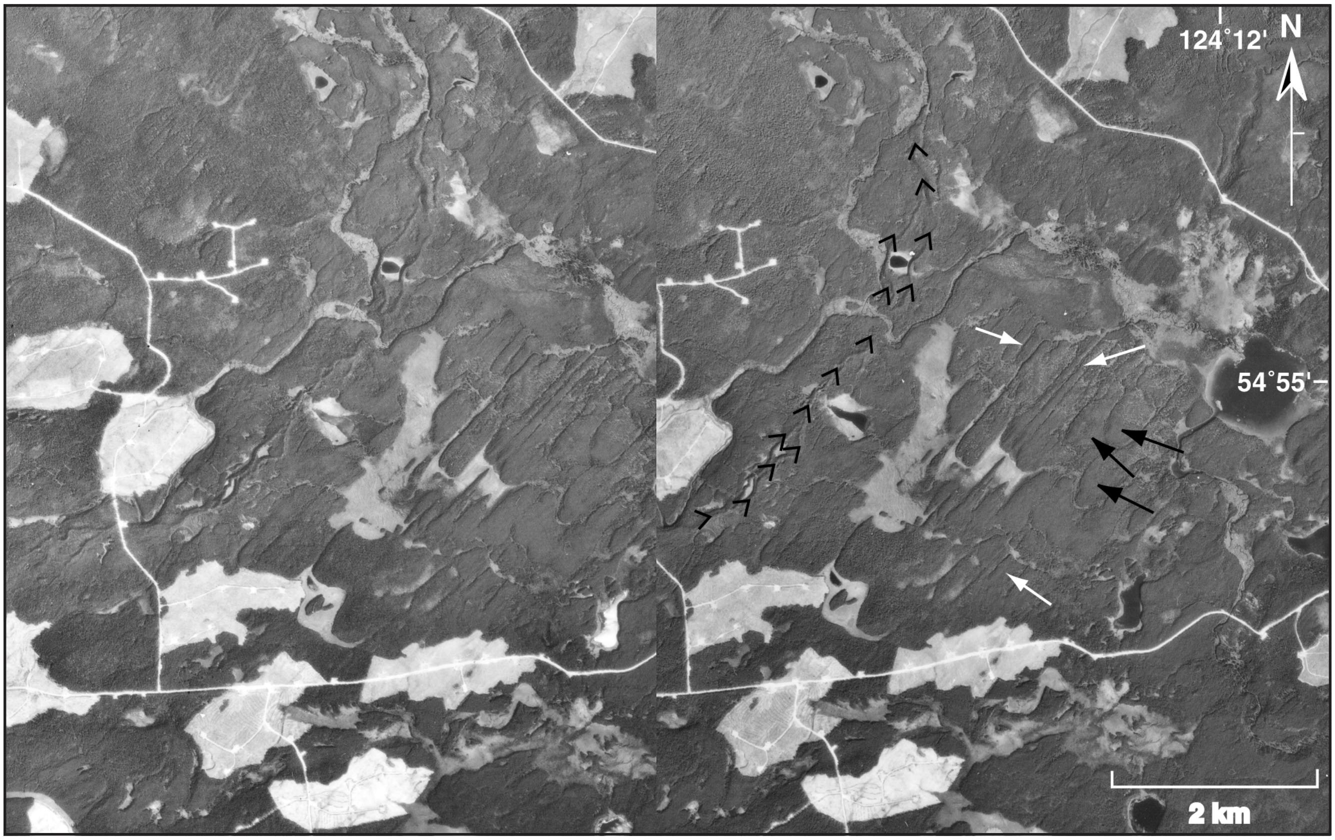

Figure 30. *Stereo pair showing drumlins, flutings, and an esker complex east of Inzana Lake. The esker complex is depicted with the same symbols as on the surficial geology maps. Black arrows indicate typical drumlins and white arrows indicate flutings. Used with permission, Geographic Data BC, Ministry of Environment, Lands and Parks. British Columbia Government airphotos BC87061-192, -193*

gentle lee side, thus providing the sense of the direction of ice flow (Fig. 31). Others show no distinction between their up- and down-ice profiles, and are therefore only bidirectional indicators. Drumlins average less than 30 m in height and range from 100 m to 2 km in length. Drumlins of the study area have the typical inverted spoon profile. All observed sections in drumlins reveal that they are composed of till. In their essay on the glaciation of north-central British Columbia, Armstrong and Tipper (1948a) gave a more thorough description of drumlins and other glacial landforms, which will not be repeated here.

Figure 31. Oblique aerial view to the east-northeast near Witch Lake. Drumlins are delineated by small creeks. Photograph by A. Plouffe. GSC 1999-051B

Flutings are low ridges oriented parallel to the direction of ice flow. They are typically at least as long as drumlins, but do not exceed 10 m in height (Fig. 30). These landforms are readily discernible on airphotos, but are barely visible on the ground except in deforested areas (Fig. 32). The orientation of small creeks is highly influenced by the orientation of flutings and drumlins. This relationship greatly facilitates the mapping of these landforms from airphotos, since the creeks appear as straight lines without trees (Fig. 30).

Crag-and-tail features are composed of a bedrock knob with a tail of till extending down-ice from it. They have been observed at all elevations throughout the study area, but are most common in areas of thin till (unit Tv). Their heights are controlled by the heights of the bedrock knobs, which is generally in the range 20 to 50 m. Lengths range from 100 to 500 m and are proportional to heights.

Orientations of drumlins, crag-and-tail features, and flutings show the dominant ice-flow directions during the Fraser Glaciation (Fig. 33). Ice generally flowed easterly, with some deflection parallel to valleys and around high ridges (e.g. ice-flow deflection around the Wolverine Range in the northeastern part of the study area). The general deflection of ice flow in the eastern part of the study area results from the coalescence of Coast Mountains glaciers with Cariboo Mountains glaciers.

No evidence of nunataks, such as moraines wrapping around mountain peaks or block fields (periglacial features), has been found within the mountainous parts of the study area (Plouffe, 1997b). Although ice flow was obviously deflected around peaks and high ridges, there is no altitudinal zoning of ice flow in the trunk valleys (Plouffe, 1997a). Drumlins close to mountain summits in the Hogem Ranges (Fig. 34) are parallel to drumlins at lower elevations in the adjacent Omineca River valley (Plouffe, 1997b). Drumlins, flutings, and crag-and-tail features delineate the regional ice-flow patterns

Figure 32.

Fluting (arrow) in a deforested block, southeast of Cripple Lake. The low profile of these landforms hinders identification in the field. Photograph by A. Plouffe. GSC 1999-051C

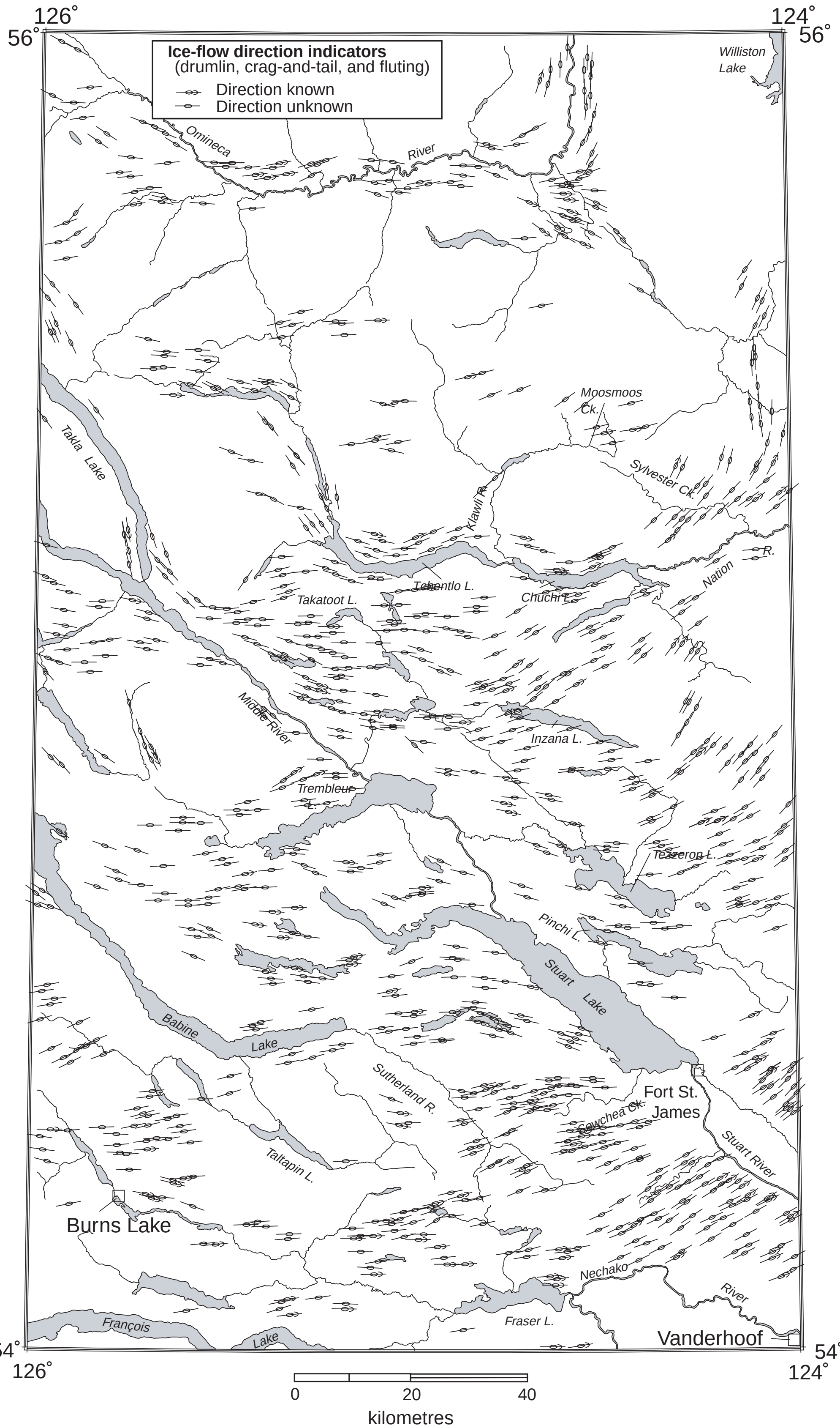

Figure 33. *Ice-flow directions in the study area, based on orientations of drumlins, crag-and-tail features, and flutings* (modified from *Plouffe, 1997b). Each symbol represents a group of landforms derived from the surficial geology maps (Maps 1986A, 1987A).*

at a moment in time during the last glaciation, but provide no information on shifts in ice flow during ice-sheet growth and decay. Their orientations could record ice-flow directions at the climax of the Fraser Glaciation, or later, when ice was still thick enough to flow over high ridges (Plouffe, 1997a, b).

Lateral moraines

Ridges on mountain slopes, often close to cirques, are interpreted as lateral moraines. Such ridges have been identified 1) in a small valley near Mount Sidney Williams, northwest of Trembleur Lake; 2) in a valley in the Swannell Ranges; and 3) in the Wolverine Range (Maps 1986A, 1987A). Other, more subdued moraines are undoubtedly present in the region, but their recognition is hindered by forest cover. For example, a 3 m high by 800 m long moraine south of Pinchi Lake was only identified in the field because it is located in a deforested block. In a detailed watershed study, Ryder (1994) identified several lateral moraines associated with cirques of the Pyramid Peak region, west of Middle River (*see* Fig. 2 for location).

Figure 34. *Till-cored drumlins near a roche moutonnée (*see *Fig. 29) at an elevation of 1800 m in the Hogem Ranges (*from *Plouffe, 1997a). Photograph by A. Plouffe. GSC 1999-051D*

Eskers

Eskers are ridges of stratified glaciofluvial sand and gravel deposited in tunnels at the base of, or within, glaciers (Fig. 16, 35). Two types of esker occur in the region: single-ridge eskers and multiple-ridge eskers or esker complexes. Eskers can evolve from a single ridge to multiple ridges and vice versa (e.g. east of Inzana Lake; Fig. 30). Single-ridge eskers are generally less than 10 m high and up to 4 km long (Fig. 35). Multiple-ridge eskers are generally larger: up to 30 m high and several kilometres long. Good examples of eskers are found 8 km south of Fort St. James, in the Sutherland River valley, east of Inzana Lake (Fig. 30), east of Burns Lake (Fig. 16), east of Witch Lake, and east of Germansen Lake (Maps 1986A, 1987A). Eskers commonly occur among other glaciofluvial sediments, especially ice-contact sediments, and in association with other glacial landforms, such as meltwater channels and kettles.

Kettles

A kettle is a depression resulting from the melting of a buried ice block (Fig. 14, 15, 36). Kettles occur mainly in glaciolacustrine sediments (e.g. Kuzkwa River valley and Nation River valley east of Chuchi Lake) and glaciofluvial sediments (e.g. south of Fort St. James). They are tens to hundreds of metres in diameter and 10 to 30 m deep, the largest occurring in ice-contact glaciofluvial sediments.

Meltwater channels

Meltwater channels are defined as channels eroded into sediments and bedrock by glacial meltwater. Following Derbyshire's (1962) classification, abandoned meltwater channels in the study area are of two types: direct overflow and lateral meltwater channels. Direct overflow channels were eroded by meltwater flowing away from the ice front. They include outlet channels of glacial lakes. Direct overflow

Figure 35.

Single-ridge esker east of Inzana Lake. Person in left centre of photograph provides scale. Photograph by A. Plouffe. GSC 1999-051I channels, like nonglacial streams, are oriented perpendicular to topographic contour lines. In contrast, lateral meltwater channels are subparallel to contour lines, indicating that they formed at or near the margins of glaciers filling valleys (Fig. 37). Because of hydrostatic pressure within the ice, it is unlikely that these meltwater channels were carved far beneath the glacier margin. Therefore, meltwater channel positions represent a good approximation of ice-front positions during glacier retreat. Meltwater channels range widely in size, from tens of metres to 0.5 km in width and from hundreds of metres to 10 km in length (e.g. east-northeast of Fraser Lake). Localized sand and gravel accumulations occur near

Figure 36.

Kettle in glaciofluvial sediments, approximately 12 km south-southeast of Fort St. James. Person (arrow) provides scale. Photograph by A. Plouffe. GSC 1999-051J

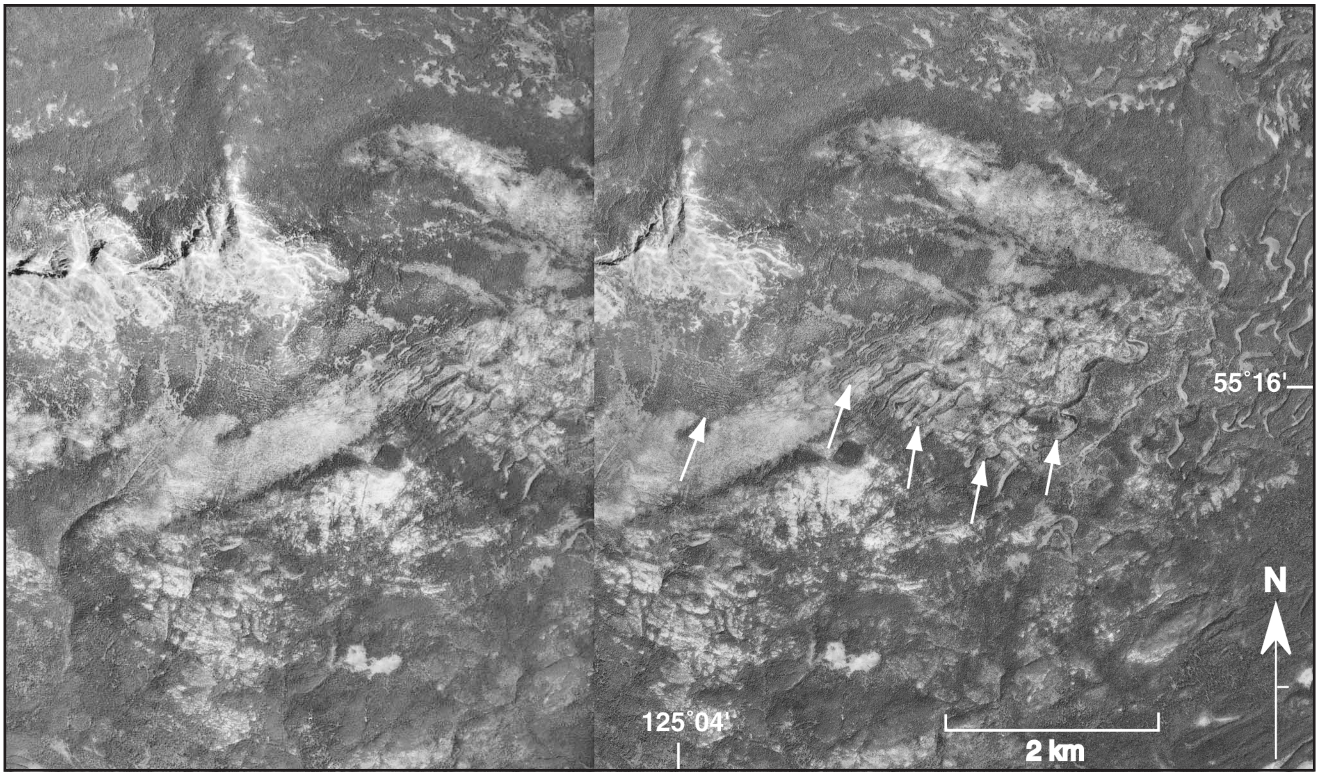

Figure 37. *Stereo pair showing ice-marginal meltwater channels (arrows) on the southeastern flank of Nation Mountain, north of Tchentlo Lake. At this site, the channels occur up to 1600 m a.s.l. Used with permission, Geographic Data BC, Ministry of Environment, Lands and Parks. British Columbia Government airphotos BC87067-203, -204*

the banks and mouths of meltwater channels. Little glaciofluvial sediment is found on the floors of meltwater channels, except the larger ones. This may indicate that the channels were eroded rapidly and then quickly abandoned for other, lower meltwater routes.

Meltwater channels can be distinguished from Holocene valleys because 1) they are underfit for modern streams; 2) they cut across drainage divides; 3) they may have associated glaciofluvial sediments; and 4) in the case of lateral meltwater channels, they are subparallel to contour lines. Paleocurrent directions in meltwater channels were determined in the field from clast imbrication and crossbedding, and on airphotos from their general pattern (i.e. channels join in a downstream direction). The distribution of abandoned meltwater channels reveals the mode of deglaciation of the study area (*see* 'Quaternary history' section, below).

Beaches

Discontinuous, well sorted deposits of sand and pebbly sand, slightly above the upper limit of glacial-lake sediments, were interpreted as beach sediments. These deposits are not continuous and cannot be followed for great distances. Two areas of sandy beach deposits, 6 km apart, occur at an elevation of about 780 m north of Vanderhoof, at the northern limit of the glacial-lake sediments that occupy the Nechako valley.

No glacial-lake shorelines were identified in the region, probably because 1) the glacial lakes were short lived; 2) till, the main sediment available for erosion by waves, is not easily eroded; 3) lake levels may have fluctuated during the life of the glacial lakes; and 4) the forest cover hampered identification of shorelines (Plouffe, 1997b).

Although most beaches shown on the surficial geology maps (Maps 1986A, 1987A) developed around glacial lakes, some of them occur less than 50 m above modern lake level and formed in postglacial time, before the downcutting of lake outlets (e.g. east end of Babine, Stuart, and Tezzeron lakes, and west end of Trembleur Lake). Therefore, beaches represent a combination of glacial and nonglacial landforms.

Nonglacial landforms

Nonglacial landforms are indicative of geomorphological processes that took place in postglacial time.

Avalanche and debris-flow tracks

Snow avalanches are ubiquitous on the slopes of steep and high ridges of the Omineca Mountains. Below the treeline, their paths are marked by deforested tracks (Fig. 26, 38).

Debris flows result from failures of water-saturated till and colluvium, and typically follow steep stream courses on mountainsides. Their tracks are generally narrower than avalanche tracks.

Landslide scars

Landslide scars were described in the 'Landslide material' section.

Dunes

Sand dunes occur in association with fluvial and glaciofluvial sediments east of Chuchi Lake (Map 1987A) and at two sites in Nechako River valley (Map 1986A). Rolling topography characterizes the sand-dune areas. All dunes are now stabilized by vegetation. They likely formed during and after deglaciation, before the forest became established on the sandy fluvial and glaciofluvial sediments. Sand dunes were only identified in the field, because the tree cover hampers their identification on airphotos.

Figure 38.

Avalanche tracks in the Omineca Mountains, north of Omineca River. Photograph by A. Plouffe. GSC 1999-051K

QUATERNARY STRATIGRAPHY

British Columbia was glaciated several times during the Pleistocene (Flint, 1971; Fulton, 1984; Ryder and Clague, 1989). Most of the exposed sediments in the central part of the province are products of the last (Fraser) glaciation. Older deposits are rare because they were eroded by Fraser glaciers and are covered by Fraser Glaciation drift. Subsurface sediments are exposed in natural bluffs in valleys and in placer mines near Germansen Landing and Manson Creek. A total of 315 sections was logged during this project, but only the most significant and representative exposures are described in this report (Fig. 39, in pocket).

All units identified in exposures were placed in the Quaternary stratigraphic framework previously described. Stratigraphic units that predate the last glaciation outcrop only in sections and are therefore not depicted on the surficial geology maps (Maps 1986A, 1987A).

Old sediments of unknown age

Placer gold recovered from the Manson Creek and Germansen Landing areas comes from sand and gravel deposits of unknown age lying on bedrock and overlain by Fraser Glaciation drift (e.g. Fig. 39, section 92-087; Kerr, 1933; Lay, 1936). These old sediments consist of clast-supported sandy gravel, locally grading upward into well sorted sand. The gravel is pebbly to bouldery, moderately to poorly sorted, and stratified to massive. At several exposures, it has a yellowish colour resulting from oxidation. Exposures of these sediments are limited to bedrock depressions and are therefore interpreted as erosional remnants. No organic material was found in these sediments.

These old sediments were deposited in channels of aggrading streams. Aggradation may have taken place in response to the onset of a glaciation, but an entirely nonglacial origin is also possible. Although Armstrong (1949) tentatively assigned a late Tertiary age to these deposits, they are undated and could be of Pleistocene age.

Sediments of a pre-Fraser glaciation

Few sections expose more than one till, and only one within the study area provides evidence for a pre-Fraser Glaciation till. Two diamictons separated by nonglacial sediments in section 91-094 on Necoslie River (Fig. 39) are interpreted as tills (Plouffe and Jetté, 1997). The lower diamicton is massive, compact, and matrix supported. It contains Cache Creek Group and felsic intrusive clasts, some of which are striated. Clasts are predominantly pebble size and constitute less than 15% of the unit. The fabric of the diamicton was not measured because of the limited exposure and low clast content. The diamicton is unconformably overlain by well sorted, fine to medium sand containing dispersed organic matter. This diamicton is interpreted as a till, because it is massive, compact, and contains striated clasts, including intrusive rocks derived from a source to the west (Plouffe and Jetté, 1997). The till may be Early Wisconsinan or older.

Two diamictons separated by sand and minor gravel have been reported from the Nation River valley (Fig. 39, section 91-266) and were originally interpreted as tills of pre-Fraser and Fraser glaciations (Plouffe, 1992). This interpretation has been revised following more detailed fieldwork, and only one till is now thought to be present in section 91-266. The lower diamicton is compact and contains abundant striated clasts. Elongated clasts plunge preferentially to the west and southwest, which is the up-ice direction of Fraser Glaciation in this area. The compaction, abundance of striated clasts, and strong fabric indicate that the lower diamicton is till (Fraser Glaciation). The till is overlain by well sorted, crossbedded sand that grades laterally into gravel. This sandy unit was likely deposited in a deltaic or prodeltaic environment within the glacial lake that occupied Nation River valley at the close of Fraser Glaciation (Plouffe, 1992). The upper diamicton is discontinuous and contains several sand and gravel lenses. Its elongated clasts trend preferentially west-northwest. The upper diamicton drapes the eroded surface of the underlying sandy unit. It is now interpreted as a glaciogenic debris flow (flowtill). Its fabric reflects the direction in which the debris flow moved. This upper diamicton is overlain by well sorted, horizontally laminated silt and clay, interpreted as glaciolacustrine sediments.

Sediments of the Olympia Nonglacial Interval

Olympia Nonglacial Interval sediments were found at three new sites during this project. The stratigraphy of these sites, described previously by Harington et al. (1996) and Plouffe and Jetté (1997), is briefly reviewed here. In addition, new radiocarbon age determinations, diatom flora analyses, and interpretation are presented for the Chuchi Lake site.

Chuchi Lake site

A unit of rhythmically laminated silt and clay is overlain by Fraser Glaciation sediments and postglacial, fluvial sand and gravel (Harington et al., 1996) in a natural bluff along Nation River, 1 km downstream from Chuchi Lake (Fig. 39, section 91-264). The silt and clay unit contains shell fragments, twigs, and bison bones. The collagen fraction of two of the bison bones yielded accelerator mass spectrometry (AMS) and conventional radiocarbon ages (Harington et al., 1996) of 30 740 ± 220 BP (TO–3653; AMS), 34 800 ± 420 BP (Beta-78573, CAMS-17566; AMS), and 35 480 ± 1080 BP (Beta-78574; conventional). A small twig fragment, found 0.5 m below the dated bison bones but too poorly preserved to be identified, yielded an AMS radiocarbon age of 55 260 ± 2960 BP (TO-4785; Table 1). A sample of Tertiary wood from the Beaufort Formation on Meighen Island (Thorsteinsson, 1961) was submitted with the Nation River twig to test the reliability of the radiocarbon age of the latter. The Tertiary wood sample yielded an AMS radiocarbon age of 45 110 ± 470 BP (TO-4786). The same piece of Tertiary wood had been previously dated in the GSC conventional radiocarbon laboratory and yielded a nonfinite age of greater than 48 000 BP (GSC 1923; Table 1). Because the radiocarbon age of the Tertiary wood sample is younger than that of the twig from Nation River, the age of the twig should be

Table 1. Radiocarbon ages on a twig from the Chuchi Lake bison site and Tertiary wood from Meighen Island (*modified from* Plouffe, 1997a).

Sample	Laboratory number	Date (years BP)	Latitude	Longitude	Technique	Sample weight analyzed
Twig, Chuchi Lake	TO-4785	55 260 ± 2960	55°11′26″	124°22′39″	AMS ^{14}C	546 mg
Wood, Meighen Island	TO-4786	45 110 ± 470	79°55′10″	99°23′30″	AMS ^{14}C	265 mg
Wood, Meighen Island	GSC-1923	>48 000	79°55′10″	99°23′30″	High pressure conventional ^{14}C	50 g

viewed as a minimum for the true age of the sediments. Nevertheless, the radiocarbon age on the twig is problematic because there is no apparent unconformity within the silt and clay unit and no reason to suspect a minimum of 15 740 radiocarbon years of sedimentation between the level of the twig and that of the bison bones. The twig probably represents older reworked organic debris. Alternatively, the collagen radiocarbon ages could be spurious and would therefore represent minimal ages of the sediments, in which case the entire silt and clay unit would be greater than 48 000 radiocarbon years old.

A sample of the silt and clay unit at station 91-264 was submitted for diatom analysis for paleoecological reconstruction. The sample was found to be barren of diatoms (GSC Diatom Report 95-10), possibly due to a combination of cold water, high turbidity, high sedimentation rate, and lack of nutrients.

Necoslie River and Nautley River sites

A section at Nautley River (Fig. 39, section 90-032) exposes a sandy unit with dispersed plant fragments overlain by Fraser Glaciation sediments (Plouffe, 1991; Plouffe and Jetté, 1997). Twigs collected from the sandy unit yielded radiocarbon ages of 38 230 ± 410 BP (Beta-88557) and 42 460 ± 670 BP (Beta-88558; Plouffe and Jetté (1997)). Section 91-094 at Necoslie River (Fig. 39) shows similar stratigraphy: sand, silt, and minor clay with dispersed organic matter, overlain by Fraser Glaciation drift (Plouffe and Jetté, 1997). The organic matter content of the sediment at Necoslie River was too low to allow for reliable radiocarbon dating. Pollen assemblages of the sandy units at Nautley and Necoslie rivers both indicate tundra-type vegetation, which is very different from the modern subalpine to montane forest of the region (Plouffe and Jetté, 1997). The sandy units at Nautley and Necoslie rivers are interpreted as fluvial (overbank) deposits of the Olympia Nonglacial Interval (Plouffe and Jetté, 1997).

Sediments of the Fraser Glaciation

Three phases of the Fraser Glaciation are recognized: advance phase, glacial phase, and recessional phase. Sediments of the advance phase were deposited before the development of a full glacier-ice cover. Till and associated minor subglacial sand and gravel deposits are ascribed to the glacial phase. These sediments were deposited in subglacial environments. Recessional-phase sediments were deposited during ice retreat and, as with the advance-phase sediments, the influence of ice on sedimentation is discernible. Advance-phase sediments are exposed only in sections and are therefore not shown on the surficial geology maps (Maps 1986A, 1987A). Only the sediments of the glacial and retreat phases are extensive enough to be depicted on the maps.

Advance-phase sediments

Advance-phase sediments were eroded by overriding ice and covered by younger deposits, and have consequently been found at only a few sites. Stratified deposits beneath the till of the Fraser Glaciation are thought to date to the early part of that glaciation because of their stratigraphic position and lack of weathering; however, the possibility that these deposits predate the onset of Fraser Glaciation cannot be ruled out.

Advance-phase sediments are subdivided into advance-phase glaciofluvial and advance-phase glaciolacustrine lithofacies.

Glaciofluvial lithofacies

The advance-phase glaciofluvial lithofacies comprises stratified sand and gravel with sand interbeds (Fig. 40). The gravel is clast supported and has a sandy matrix. It is massive to well bedded, poorly to moderately sorted, and generally coarsens upward. Clasts are dominantly rounded to well rounded, although subangular rock fragments are locally abundant. Lenses of diamicton occur within the gravel beds. Paleocurrent directions are indicated by cross-stratification in sandy interbeds, clast imbrication in gravel, and clast rock types. For example, in section 90-073 north of Vanderhoof, clast imbrication and clasts of intrusive rocks suggest flow to the southeast (Fig. 39). Advance-phase glaciofluvial sediments are locally folded and faulted (Fig. 40).

This lithofacies is thought to have been deposited in confined streams or on outwash plains during glacier advance. The presence of diamicton interbeds suggests that debris flows occurred from nearby ice (flowtill) or from adjacent slopes as the sand and gravel accumulated. Folding and faulting are most likely the result of deformation by overriding ice.

Glaciolacustrine lithofacies

Well sorted, stratified sand and silt with minor clay also underlie till of the Fraser Glaciation. The sand is horizontally to crossplanar laminated, and locally contains clay intraclasts (rip-ups) and beds and lenses of massive to crudely bedded, clast-supported gravel and diamicton up to 2 m thick. Diamicton lenses commonly increase in abundance and thickness toward the top of the unit. Continuous clay interbeds occur within the sand and diamicton beds (Fig. 41). The upper part of this unit, near the contact with the overlying Fraser Glaciation till, is locally faulted and folded.

These sediments are thought to have been deposited in glacial lakes that formed when drainage was blocked by advancing glaciers. The clay, silt, and sand were deposited by overflows, interflows, and underflows. Gravel lenses are attributed to deposition in subaqueous channels near the ice front. The diamicton lenses probably record subaqueous debris flows.

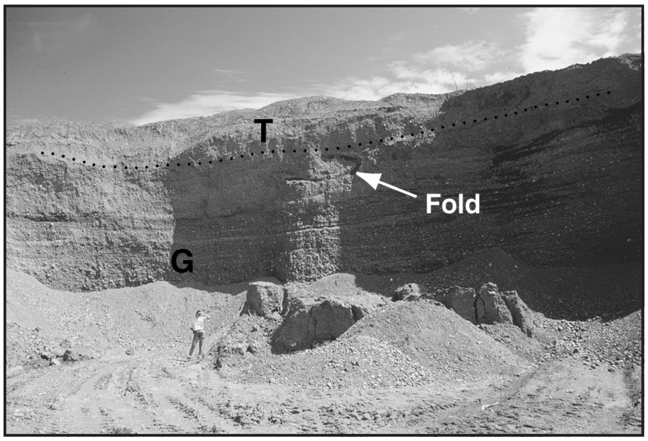

Figure 40. *Glaciofluvial sand and gravel (unit G) overlain by till (unit T), section 90-073, Nechako River valley. Note fold in the glaciofluvial sediments. Person provides scale. Photograph by A. Plouffe. GSC 1999-051L*

Figure 41. *Continuous clay interbeds (black arrow) in a diamicton, part of the advance-phase glaciolacustrine sediments in section 94-047, northwest of Tchesinkut Lake. Pick (white arrow) is 65 cm long. Photograph by A. Plouffe. GSC 1999-051CC*

The stratigraphic relationship between the advance-phase glaciofluvial and glaciolacustrine lithofacies was seldom observed. However, at sites where both lithofacies are present, the advance-phase glaciolacustrine sediments conformably overlie the glaciofluvial sediments (e.g. Fig. 39, sites 93-145, 93-211, and 91-314).

Glacial sediment (Fraser Glaciation till)

The typical sediment of the glacial phase of the Fraser Glaciation is the till described in the 'Description and genesis of map units and landforms' section. Some local features of Fraser Glaciation till are described below.

Multiple tills of the Germansen River valley

In most exposures, the Fraser Glaciation is represented by a single till sheet. However, four diamictons, interpreted as tills, are present in section 92-104 (Fig. 39) in the Germansen River valley. The diamictons are matrix supported and compact, and have a sandy, silty matrix and abundant striated clasts. The four diamictons are similar in rock type, their pebbles being a mixture of intrusive (8%), volcanic (45%), and sedimentary (47%) rocks. Clast fabrics are bimodal and unimodal, with a-axes plunging preferentially to the northwest, north, east, and southeast (Fig. 39). The diamictons extend across the width of the exposure and are separated by units of sand and gravel, and sand and silt. The sand-gravel units are clast supported, pebbly to bouldery, and massive to well bedded. The sand-silt units are laminated and coarsen upward; the lowest one contains dropstones. None of the sediments interbedded with the diamictons contain organic matter or show evidence of paleosol development. Oriented samples collected from silty sediments, including two samples from the matrix of the lower diamicton, are normally magnetized (R. Enkin, pers. comm., 1993). The fine-grained sediments at the Germansen River site were likely deposited in glacial lakes dammed by advancing or retreating ice. The sand and gravel units are thought to have been deposited by meltwater streams near an ice front.

Two compact diamictons with abundant faceted and striated clasts occur at a nearby site (Fig. 39, section 93-178) and at a site west of Babine Lake (Fig. 39, section 94-067). These diamictons are separated by glaciofluvial sediments.

All four diamictons at the Germansen River site (Fig. 39, section 92-104) could be till. Their fabrics are oriented either parallel or transverse to ice flow, in a region where the general eastward flow may have been affected by topography. The diamictons in sections 93-178 and 94-067 are interpreted as till because they are poorly sorted, compact, and contain striated clasts. However, one or more of these diamictons could have been deposited by debris flows. More detailed sedimentological analyses would have to be conducted at these sites to confirm the genesis of the diamictons. Because no numerical ages are currently available for any of these sites, the multiple tills could reflect 1) local fluctuations of the ice front during Fraser Glaciation ice advance and/or retreat, or 2) one or more pre-Fraser glaciations of unknown age. The first possibility is favoured because there are no major differences in the degree of weathering of diamictons at the various sites.

Pinchi Creek lens

As mentioned earlier, the Pinchi Creek lens is a lithostratigraphic unit of limited extent located northeast of Stuart Lake. At its type section along Pinchi Creek (Fig. 39, section 92-004), the lens is 20 m thick and consists of a clayey diamicton with a low clast content (10–15%). No boulders were observed in the lens at this site. Slickensides on fracture planes in the lower portion of the unit trend northwest (Fig. 42). Two oriented samples from the Pinchi Creek lens are magnetically anisotropic, with poles of flat magnetic particles plunging dominantly to the southeast (R. Enkin, pers. comm., 1997). Elongated clasts in the lens plunge preferentially to the south and east (Fig. 39, section 92-004, upper diamicton).

The Pinchi Creek lens at the type section is underlain successively by 1) up to 2 m of horizontally and crosslaminated sand, 2) 5 m of diamicton containing discontinuous sand lenses 3 to 5 cm thick, and 3) 1 m of more compact massive diamicton. Elongated clasts in the two diamicton units below the Pinchi Creek lens plunge mainly to the west-southwest and southwest. The contact between these two diamicton units is unconformable. The Pinchi Creek lens is sharply overlain by rhythmically and horizontally laminated, fine sand, silt, and clay.

Figure 42. *Slickensides trending northwest on a fracture plane in the lower portion of the Pinchi Creek lens. Photograph by A. Plouffe. GSC 1999-051DD*

The Pinchi Creek lens occurs within an altitudinal range of 55 m, from Stuart Lake up to approximately 730 m a.s.l. The highest occurrence of the unit is below the maximum level of the glacial lake that occupied the Stuart Lake valley at the end of the last glaciation (Plouffe 1997b).

Based on regional relationships, the two diamictons below the Pinchi Creek lens are interpreted as two different facies of Fraser Glaciation till. The lower one could be lodgment till and the upper one melt-out till, because the lower one does not contain sand lenses and is more compacted than the upper one. The overlying Pinchi Creek lens is also interpreted as till, because it is massive and poorly sorted, and contains striated clasts. Slickensides are attributed to shearing due to glacier flow during a readvance into a glacial lake. Reworking of fine-grained glacial-lake sediments by the glacier may explain the high clay and low clast content of the Pinchi Creek lens. Clast fabric and magnetic data suggest that the ice may have readvanced toward the southeast, parallel to Stuart Lake valley. The cause of the readvance, whether climatic or dynamic (e.g. local ice profile readjustment during ice retreat), is uncertain.

Correlative units could be present elsewhere within the study area, but were not recognized in the field. If ice was to readvance over till instead of lake sediments, two identical and indistinguishable allostratigraphic units would be produced. Furthermore, at any site where the readvance took place in a glacial lake, evidence of a clayey diamicton similar to the Pinchi Creek lens might be concealed beneath thick glacial-lake deposits.

Recessional-phase sediments

Recessional-phase sediments are abundantly exposed in the study area because they occur right at surface, except in larger valleys near modern base level where recent alluvium predominates, or in poorly drained depressions where they are covered with thick deposits of organic matter. Recessional-phase sediments, like advance-phase deposits, are subdivided into glaciofluvial and glaciolacustrine lithofacies.

Glaciofluvial lithofacies

Sand and gravel, interpreted as glaciofluvial in origin and found stratigraphically above Fraser Glaciation till, were deposited during glacier recession. All glaciofluvial units (unit G) shown on the surficial geology maps (Maps 1986A, 1987A) are recessional-phase glaciofluvial deposits. In exposures, these sediments generally fine upward, but sandy beds locally are abruptly overlain by pebbly and cobbly gravel. Rare diamicton interbeds of limited extent occur within gravel in the lower part of the recessional sequence.

The overall fining-upward trend of these sediments results from the retreat of glaciers from the area. Abrupt changes in grain size at the bed scale may be due to shifts in the position of channels during sedimentation. The diamicton interbeds are interpreted as debris flows derived from nearby ice (flowtill) or higher ground.

Glaciolacustrine lithofacies

Thick accumulations of sand, silt, and clay overlie Fraser Glaciation till in several valleys in the study area. The succession typically fines upward from medium sand, through fine sand, to silt and clay. Planar laminations, crossplanar laminations, trough crossplanar laminations, and dropstones are common in the lower, sandy part of these deposits. The upper, finer part is rhythmically bedded and laminated (Fig. 43). The rhythmites consist of a bed of sand and silt abruptly overlain by a thinner bed or lamina of clay or silty clay. Horizontal laminations, crossplanar laminations, and fining- and coarsening-upward cycles are the dominant sedimentary structures within the coarser layer of the couplet; horizontal laminations characterize the overlying, finer, clayey layer. *Lebensspuren* (biogenic structures) were observed in both the coarser and finer layers. Couplets become thinner upsection, ranging from 1.5 m near the base of exposures (Fig. 43b) to 2 to 3 cm near the top. Lenses and interbeds of diamicton and sand and gravel occur within the fine-grained sediments and generally decrease in number and thickness upward.

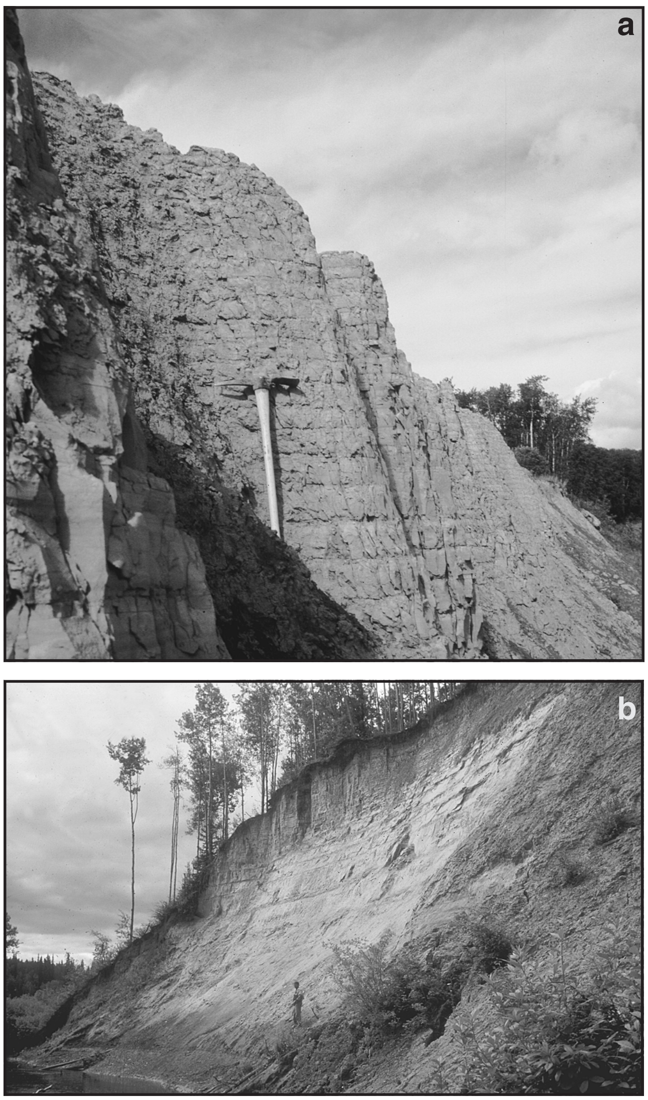

Figure 43. *Glaciolacustrine rhythmites exposed along:* ***a****) the railroad track south of Fraser Lake (GSC 1999-051EE), and* ***b****) Kuzkwa River (GSC 1999-051FF). Photographs by A. Plouffe.*

The maximum number of couplets in the rhythmically bedded part of the glaciolacustrine sequence is 45 in Kuzkwa River valley. Only 25 have been counted in Nechako River valley, and 32 in Takla Lake valley; however, the upper parts of these sections are bioturbated, this precluding an exact count of the couplets.

As was the case with the advance-phase sequence, the relationship between retreat-phase glaciofluvial and glaciolacustrine sediments has seldom been observed. The retreat-phase glaciofluvial sediments unconformably overlie the glaciolacustrine sediments at sites where both lithofacies are present (e.g. sections 93-171 in Klawli River valley, 90-202 in Sowchea Creek valley, and 93-257 in Sutherland River valley, Fig. 39).

The laminated, fine-grained sediments were deposited in ice-dammed lakes during deglaciation. The rhythmites are interpreted as varves, based on the criteria of Smith and Ashley (1985): individual beds within the coarser ‘summer’ layers have normal and reverse grading or no trend; *lebensspuren* occur within the rhythmites; and a sharp contact separates ‘summer’ and ‘winter’ layers. Similar sediments occurring in the same stratigraphic position in Fraser River valley have also been interpreted as varves (Clague, 1988). The upward fining and thinning of couplets probably reflects retreat of the ice and an associated decrease in the influx of sediment into the glacial lake (Plouffe, 1991). The blanket of sand and gravel capping glaciolacustrine sediments in the valleys of Klawli River, Sutherland River, and Sowchea Creek was deposited by streams after the glacial lakes had drained (*see* Fig. 39 for the stratigraphy of these valleys).

Accumulations of glaciolacustrine sediments extensive enough to be mapped occur in several of the valleys in the study area (Fig. 44). Maximum elevations of these sediments differ from valley to valley.

Inclined beds of sand and gravel, overlain in places by horizontally laminated sand, occur near the upper limit of the fine-grained glaciolacustrine sediments (Fig. 45). The upper surface of the deposits slopes gently out into the valleys. These deposits are interpreted as deltas with typical foresets and topsets. Thirteen deltas have been identified in the study area, of which six are large enough to be shown on the maps (Fig. 44; Maps 1986A, 1987A). With few exceptions, deposits identified as deltas generally occur near the local highest occurrences of glacial-lake sediments (Fig. 44). At most sites, the contact between foresets and topsets was not preserved, so the maximum elevation of the foresets represents a minimum value for the level reached by the glacial lake. These values are shown with the “>” symbol on Figure 44, indicating that the water level of the glacial lake was greater than the elevation of the foresets. Elevations of glacial-lake sediments, deltas, and potential outlets have been used to reconstruct the glacial-lake history of the region (*see* ‘Fraser deglaciation and glacial-lake history’ section).

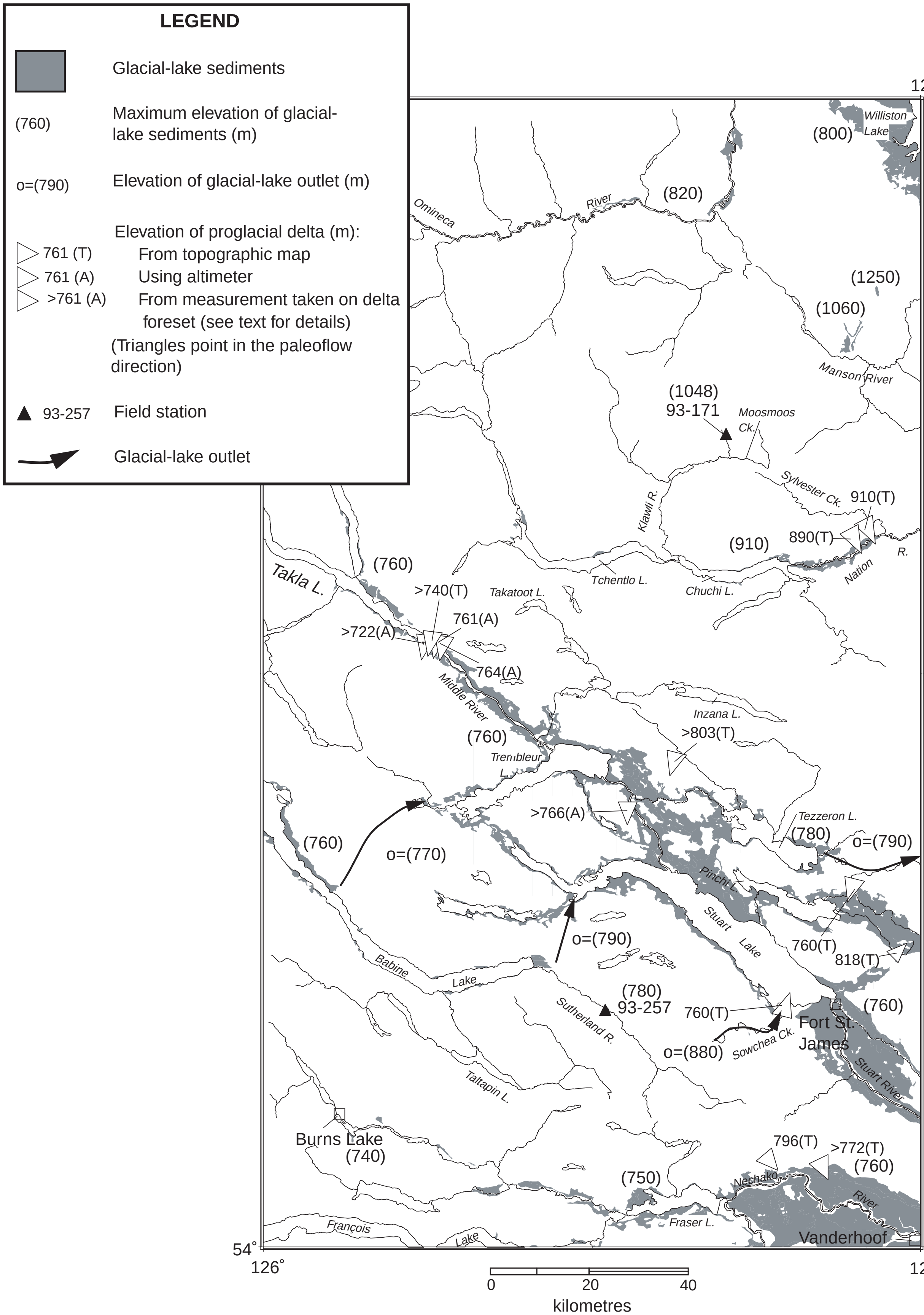

Figure 44. *Distribution of glacial-lake sediments, glacial-lake outlets, and proglacial deltas in the study area.*

Figure 45. Inclined beds of sand and pebbly gravel, interpreted as delta foresets: ***a****) east of Pinchi Lake (GSC 1999-051 U), and* ***b****) at the southeastern end of Takla Lake (GSC 1999-051V). Photographs by A. Plouffe.*

Postglacial sediments

Lake sediments

A 3 m section, consisting of crudely bedded, clast-supported sand and gravel, abruptly overlain by laminated silt and clay, was exposed in 1990 in a gravel pit on the northeastern shore of Stuart Lake, approximately 5 km northwest of Fort St. James and 14 m above present lake level (Fig. 39, section 90-205). The silt and clay contain the gastropods *Valvata sincera*, *Succinea* sp., *Stagnicola elodes*, and *Fossaria modicella*; several specimens were in growth position. These gastropods are common in modern lakes with muddy substrates in Canada (Clarke, 1981). The shells were not submitted for radiocarbon dating because of a high risk of contamination with radiogenically dead carbon derived from nearby Cache Creek Group limestone. Gravel extraction has ceased at this locality and section 90-205 is now buried.

The lower sand and gravel unit at this site is probably part of a delta or fan that prograded into Stuart Lake during late-glacial or early-postglacial time. The overlying fine sediments are thought to reflect shallow-water lacustrine conditions similar to those of present-day Stuart Lake. Freshwater gastropods would not survive in the cold, turbid waters of a glacial lake. These postglacial sediments indicate that Stuart Lake was higher than at present for some time after deglaciation. Lake level dropped as the outlet was lowered through erosion. Raised beaches on the south shore of Stuart Lake and deltas located slightly above the present-day lake are also indicative of higher lake levels (Fig. 15). The presence of alluvial deltas slightly above present-day lake levels throughout the study area (Maps 1986A, 1987A) has also been inferred to reflect higher lake levels in early-postglacial time.

Alluvium

Sections in alluvium generally reveal little stratigraphic information because they commonly consist of loose sand and gravel with little obvious bedding and few sedimentary structures. Exceptions to this general rule are active gravel pits and some recent natural exposures. One such natural exposure (Fig. 39, section 91-22) is located 10 km east of Chuchi Lake, at an unnamed creek that flows into Nation River. The section, beneath a fluvial terrace, exposes 1.5 m of interbedded, clast-supported, pebbly gravel and sand, overlain by 0.5 m of fine sand (Fig. 46). Charcoal (*Pinus* sp.), at a depth of 0.8 m below the surface, yielded a radiocarbon age of

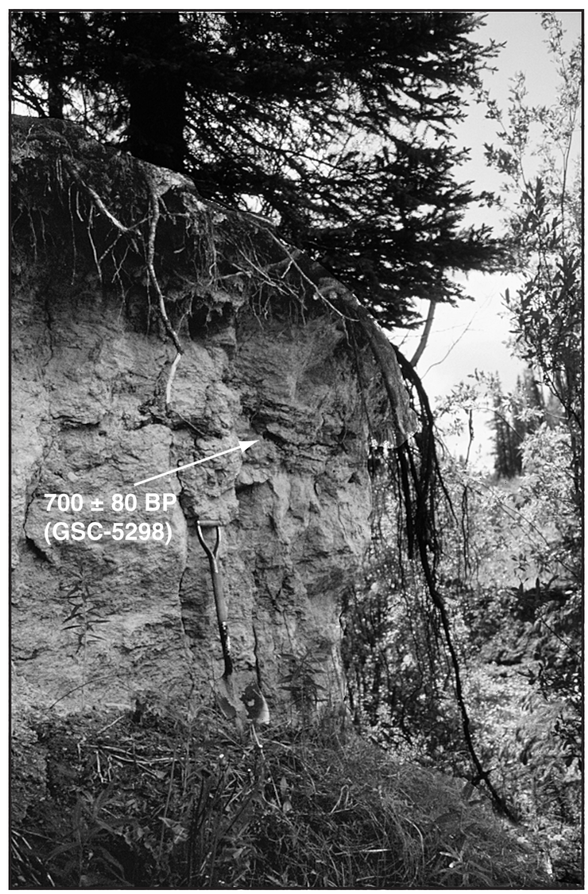

Figure 46. *Alluvial sand and gravel, overlain by sand, in an unnamed valley 10 km east of Chuchi Lake (Fig. 39, section 91-222). Charcoal wood (Pinus sp.) from a depth of 0.8 m was dated at 700 ± 80 BP (GSC-5298), which indicates that sediment aggradation has taken place since 700 radiocarbon years ago. Photograph by A. Plouffe. GSC 1999-051W*

700 ± 80 BP (GSC-5298). This radiocarbon age indicates that 0.8 m of sediment aggradation occurred after 700 BP in this small valley. The sediment may have been deposited during one or more floods. Aggradation appears to coincide with the Little Ice Age (Ryder and Thomson, 1986).

Organic deposits

Fulton (1971) stated that bog-bottom radiocarbon ages in the southern interior of British Columbia generally become younger toward the west, perhaps reflecting differences in the time of deglaciation (Clague, 1981). To establish a possible link between the time of deglaciation and the onset of peat accumulation (paludification) in the study area, bulk samples of basal peat were collected from ten bogs along east-west and north-south transects, and dated by conventional methods at the GSC Radiocarbon Laboratory (Fig. 47; Table 2). The samples comprised the lowest 3 cm of peat directly above clay or till. Special care was taken to avoid bogs in meltwater channels, areas of ice stagnation characterized by abundant kettles, and stream valleys, because the onset of paludification in such areas may have been delayed until well after deglaciation. Furthermore, no samples of peat directly overlying marl were dated. One marl and peat sample from Omineca Valley, collected by Alley and Young (1978), was added to the database.

The distribution of basal-peat radiocarbon ages (Fig. 47) does not show a north-south or east-west trend through the area, as was found in the southern interior by Fulton (1971). Six of the eleven radiocarbon ages on peat are older than 8000 BP; the others range from 3700 to 7520 BP.

Pollen assemblages of the basal peat samples bear several similarities to modern assemblages from local lakes. They are dominated by arboreal pollen, mainly *Pinus* with lesser amounts of *Picea*, *Betul*a, *Alnus*, and *Salix*. When compared with pollen spectra from MacDonald and Ritchie (1986), this assemblage is typical of modern lakes in the subalpine forest region of British Columbia. Sample GSC-5891, which yielded a radiocarbon age of 9830 ± 130 BP, is an exception, as its pollen spectrum is dominated by shrubs and herbs, with little *Pinus*. Because pine trees are prolific pollen producers and pine pollen can be transported long distances (cf. Ritchie, 1974), the small amount of *Pinus* pollen in sample GSC-5891 could well be derived from a distant source. Therefore, the pollen assemblage in this sample suggests that the local vegetation about 10 000 BP was dominated by shrubs and herbs with few trees. This vegetation was replaced by forest similar to the modern one as early as 8400 BP in the southern part of the study area and about 9400 BP in the northeast. The rate of change, duration, and evolution of this paleovegetation are unknown. No pollen count was reported by Alley and Young (1978) or Blake (1986) for GSC-2036 (10 000 ± 140 BP).

Basal peat samples yielded radiocarbon ages that are much younger than deglaciation. There are three possible reasons for this discrepancy: 1) accumulation of organic matter may have been delayed by buried ice in sediments (i.e. the depression in which the peat accumulated formed sometime after the ice melted; cf. Richard et al. (1989)); 2) the peat samples, which were 3 cm thick, encompassed too much time; and 3) a dry and/or warm climate may have retarded paludification in early Holocene time. Based on palynological evidence, Hebda (1995) suggested that the climate was warmer and drier than today from 10 000 to 7000 BP (xerothermic climate phase) in central British Columbia. Similar conclusions were reached by Hebda (1982), Mathewes (1985), and Clague and Mathewes (1989) for sites in southern British Columbia.

QUATERNARY HISTORY

Limited exposure of the old gravel deposits in the Manson Creek and Germansen Landing areas hinders paleogeographic and sedimentological interpretation of these deposits. Likewise, no data are currently available from the study area on the ice-flow pattern and chronology of the pre-Fraser glaciation.

Table 2. Radiocarbon ages on basal peat and basal marl from the study area (*modified from* Plouffe, 1997a).

Site	Laboratory number	Date (years BP)	Material	Latitude	Longitude	Depth below surface (m)	Reference
Omineca Valley	GSC-2036	10 100 ± 90	marl	55°47′	125°05′	5.6–5.7	1, 2
Omineca Valley	GSC-2036-2	10 000 ± 140	peat	55°47′	125°05′	5.6–5.7	2
93-PMA-267	GSC-5692	5450 ± 80	peat	54°20′	124°16′	3.94–4.12	this study
94-PMA-003	GSC-6003	6240 ± 140	peat	54°25′	124°37′	1.15–1.12	this study
94-PMA-026	GSC-5932	8320 ± 90	peat	55°07′	124°13′	1.64–1.67	this study
94-PMA-030	GSC-5912	7520 ± 90	peat	55°42′	124°33′	2.27–2.30	this study
94-PMA-031	GSC-5869	9440 ± 110	peat	55°25′	124°06′	3.13–3.16	this study
94-PMA-032	GSC-5995	6220 ± 80	peat	54°55′	124°09′	1.12–1.15	this study
94-PMA-061	GSC-5993	8150 ± 100	peat	54°02′	125°26′	1.62–1.65	this study
94-PMA-071	GSC-6002	3700 ± 90	peat	54°08′	125°43′	1.42–1.45	this study
94-PMA-073	GSC-5989	8410 ± 80	peat	54°02′	125°02′	1.70–1.73	this study
94-PMA-075	GSC-5891	9830 ± 130	peat	54°08′	124°35′	2.87–2.90	this study

References: 1, Alley and Young (1978); 2, Blake (1986).

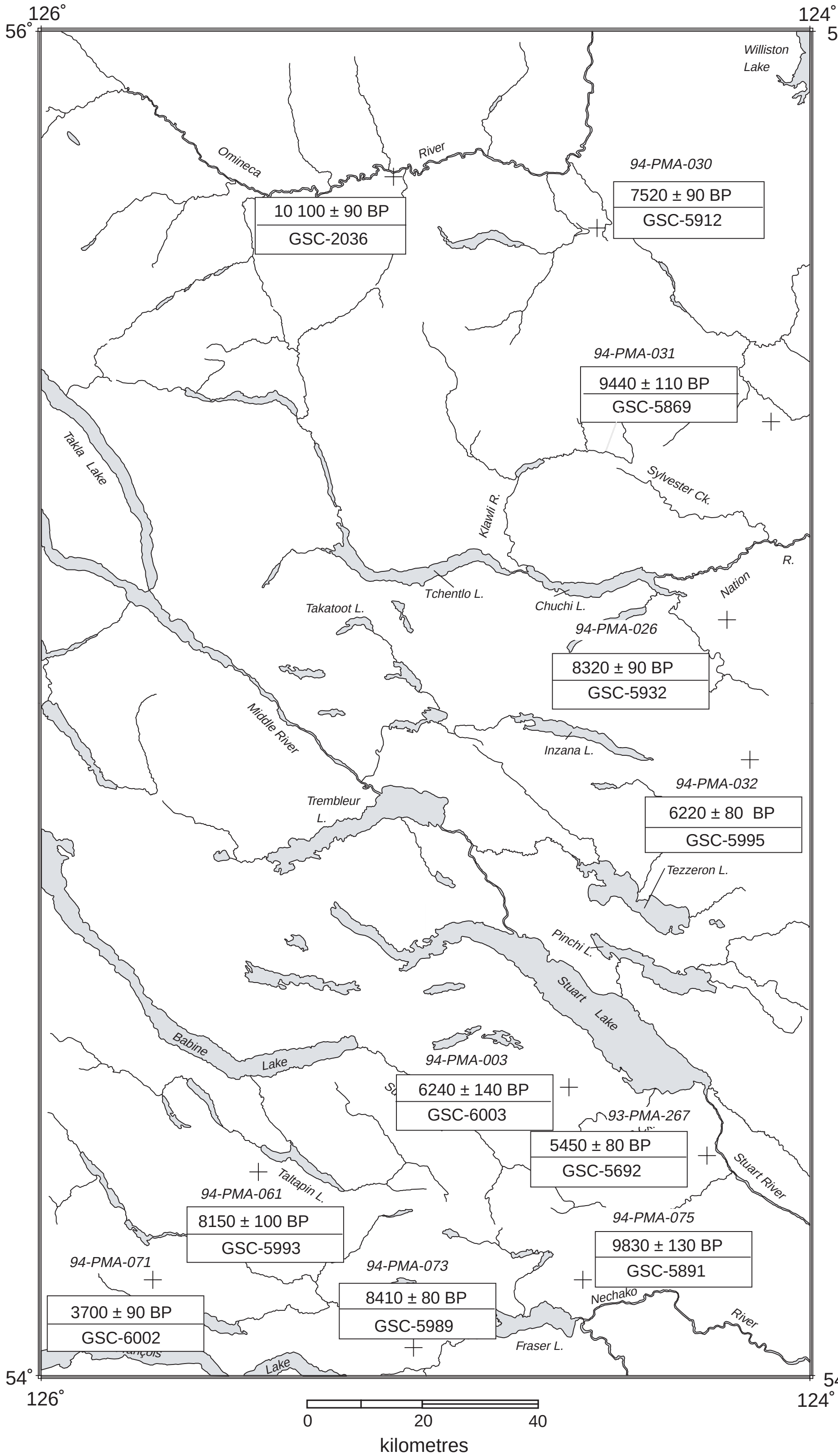

Figure 47. *Radiocarbon ages on basal peat collected in bogs. A date on marl beneath peat in Omineca valley (GSC-2036; Alley and Young (1978)) is included for comparison.*

Olympia Nonglacial Interval

Interpretation of the Olympia Nonglacial Interval is based on radiocarbon age determinations and palynology of Middle Wisconsinan sediments from sites at Chuchi Lake, Nautley River, and Necoslie River. These sediments are described in detail in two papers (Harington et al., 1996; Plouffe and Jetté, 1997), so their paleoecological interpretation is only briefly summarized here. At all three sites, pollen assemblages from the Middle Wisconsinan sediments are dominated by herb pollen, with a lesser amount of tree and shrub pollen, indicating a tundra to open forest environment. The climate was cooler than at present. Giant bison and Columbian mammoths lived in central British Columbia at the close of the Middle Wisconsinan (Harington et al., 1974, 1996).

Fraser Glaciation: onset to glacial maximum

The first glaciers to form in the study area at the beginning of the Fraser Glaciation were located in cirques in the highest mountains (Fig. 48). West (1997) found abundant schist clasts (the bedrock type underlying cirques in the Wolverine Range) in advance-phase glaciofluvial deposits in Manson River valley. She suggested that cirque and valley glaciers in the Wolverine Range were the source of these glaciofluvial sediments. Alternatively, till or sediments deposited by local valley glaciers at the onset of the Fraser Glaciation were eroded by the trunk glacier in Omineca valley (Mouton, 1994).

Figure 48 depicts a hypothetical configuration of valley glaciers during the early part of the Fraser Glaciation. The distribution of cirques indicates that the vast majority of valley glaciers were in north-, northeast-, and northwest-facing valleys, which received less heat from the sun. At this stage of glaciation, ice flow was completely controlled by topography. Small glacial lakes probably developed in some valleys as the drainage was progressively blocked by ice (Fig. 48).

Ice from major accumulation centres in the Coast and Skeena mountains later reached central British Columbia and coalesced with local valley and piedmont glaciers. The trunk valleys and low areas were invaded first, and glacial lakes developed in several tributary valleys as their drainage was blocked by ice. Glacial lakes also formed in valleys where ice advanced upslope (e.g. Necoslie River valley). Hypothetical ice-front positions and advance-phase glacial lakes inferred from the stratigraphic record are depicted on Figure 49. Ice-front positions are not connected to one another from valley to valley because their exact ages are unknown. Although no subtill stratigraphy was observed in Sutherland River valley, a glacial lake is assumed to have formed in this westerly draining valley during ice advance. The glacial lakes likely drained along glacier margins, under ice, or across drainage divides. As glaciers expanded, the glacial lakes became smaller and were eventually overridden. Little is known about the history of these glacial lakes because the sediments deposited in them were eroded by ice and covered by glacial sediments.

As suggested by Clague (1989), glacier growth during the last glaciation may have been interrupted by stillstands and possibly retreat. The multiple tills in Germansen River valley, Manson Creek area, and Babine Lake valley (Fig. 39, sections 92-104, 94-067, and 93-178, respectively) may have been deposited during such fluctuations of the glaciers. At the climax of the last glaciation, mountain summits of the study area were completely covered by ice (Plouffe, 1997b). Drumlins and striations occur up to 1800 m a.s.l. in the Hogem Ranges and there is no evidence of nunataks (e.g. moraine ridges skirting peaks) in the mountains, as was observed in the Selwyn Lobe sector of the Cordilleran Ice Sheet in the Yukon Territory by Duk-Rodkin et al. (1986) and Jackson (1989). The sharpness of mountain peaks and arêtes at 2000 m a.s.l., however, suggests that ice had little erosive effect in these high areas and that the maximum elevation of the ice surface probably was about 2100 m a.s.l., just above the highest mountain summits.

The orientation of drumlins, flutings, and crag-and-tail features shows that ice flow during the Fraser Glaciation was strongly influenced by accumulation in the Coast and Skeena mountains. Only in the eastern part of the study area was flow deflected to the northeast and north by ice derived from the Cariboo Mountains (Fig. 28, 33). Shifts in ice flow determined from crosscutting glacial striae indicate that easterly flowing ice was the first to invade the area and was subsequently deflected to the northeast by the Cariboo Mountain ice lobe (e.g. striations near Pinchi Lake, Fig. 28). This sequence is supported by the stratigraphy at a site north of Vanderhoof (Fig. 39, section 90-073), where till overlies advance-phase glaciofluvial sand and gravel. The glaciofluvial deposits suggest that the drainage in this area was not obstructed during glacier advance and that any ice derived from the Cariboo Mountains had not yet blocked the easterly drainage; however, the possibility that any glacial-lake sediments may have been eroded by the overriding glacier cannot be refuted.

A few authors have suggested that an ice dome with outward radial flow formed over central British Columbia at the last glacial maximum (Dawson, 1881; Kerr, 1934; Fulton, 1967; Flint, 1971). For such an ice dome to form, the ice divide over the Coast and Skeena mountains would have to have shifted to the east toward central British Columbia. In theory, areas over which the ice divide migrated would experience a shift from easterly to westerly ice flow. Westerly-directed ice-flow indicators have been found in the southern Babine Mountains west of the study area and as far east as Pendleton Bay on Babine Lake (see Fig. 2 for location; Tipper (1994), Levson et al. (1997b, 1998, 1999), Stumpf et al. (1997)). Three explanations have been offered for this westward ice flow: 1) an ice dome developed east of the Coast Mountains during the Fraser Glaciation (Stumpf et al., 1997; Levson et al., 1998, 1999); 2) an ice dome formed during an older glaciation (Tipper, 1994); and 3) rapid calving of glaciers at the end of the Fraser Glaciation, west of the Coast Mountains, caused a drawdown of the ice surface over the Coast Mountains and a reversal of ice flow (Levson, et al., 1997b). Data presented here from the Fort Fraser and Manson

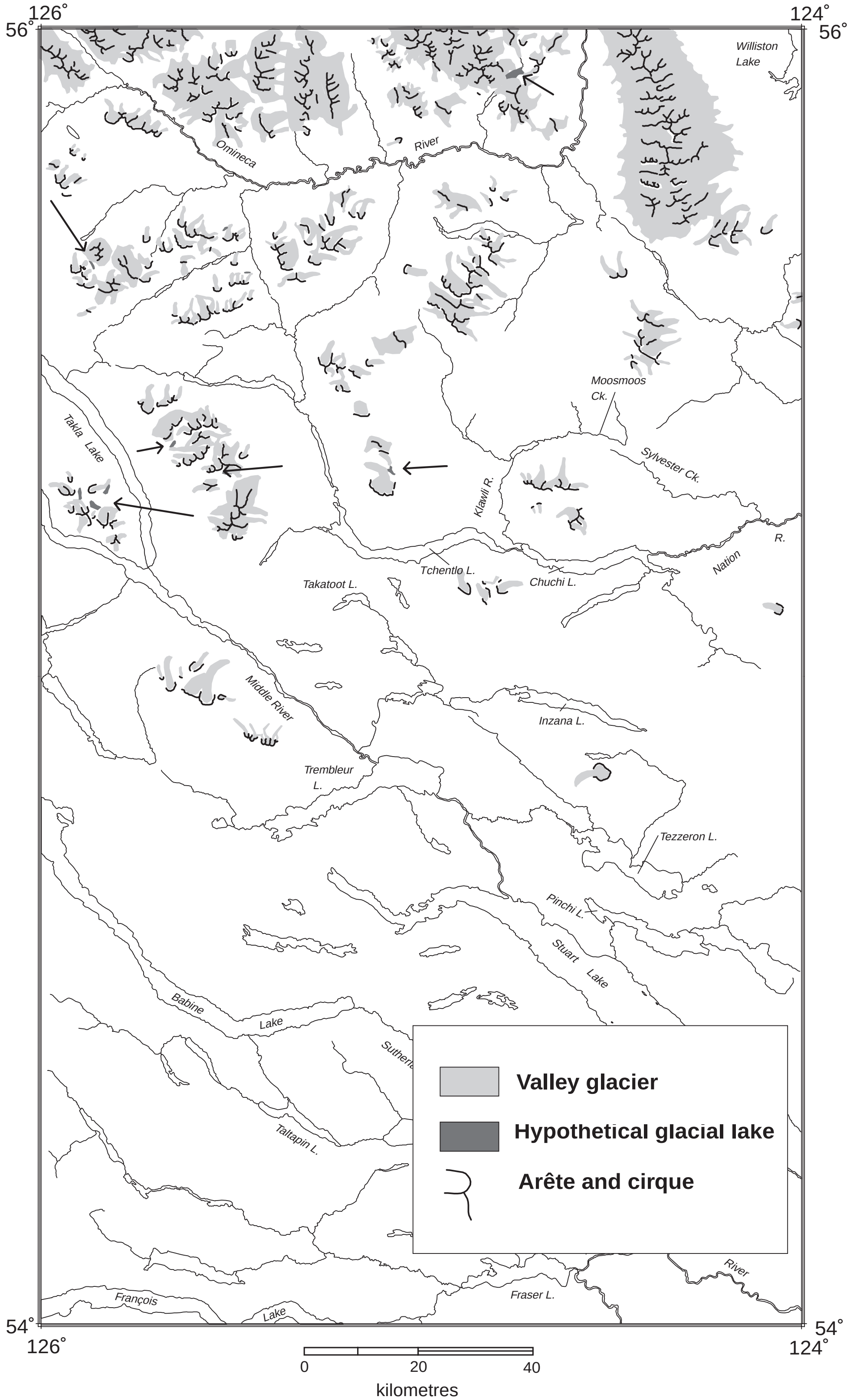

Figure 48. *Distribution of valley glaciers in mountains of the study area at the onset of the Fraser Glaciation. Hypothetical glacial lakes (arrows) are shown at sites where there may have been a blockage of the drainage by advancing glaciers. The extent of valley glaciers is assumed to be proportional to the size of the accumulation centres.*

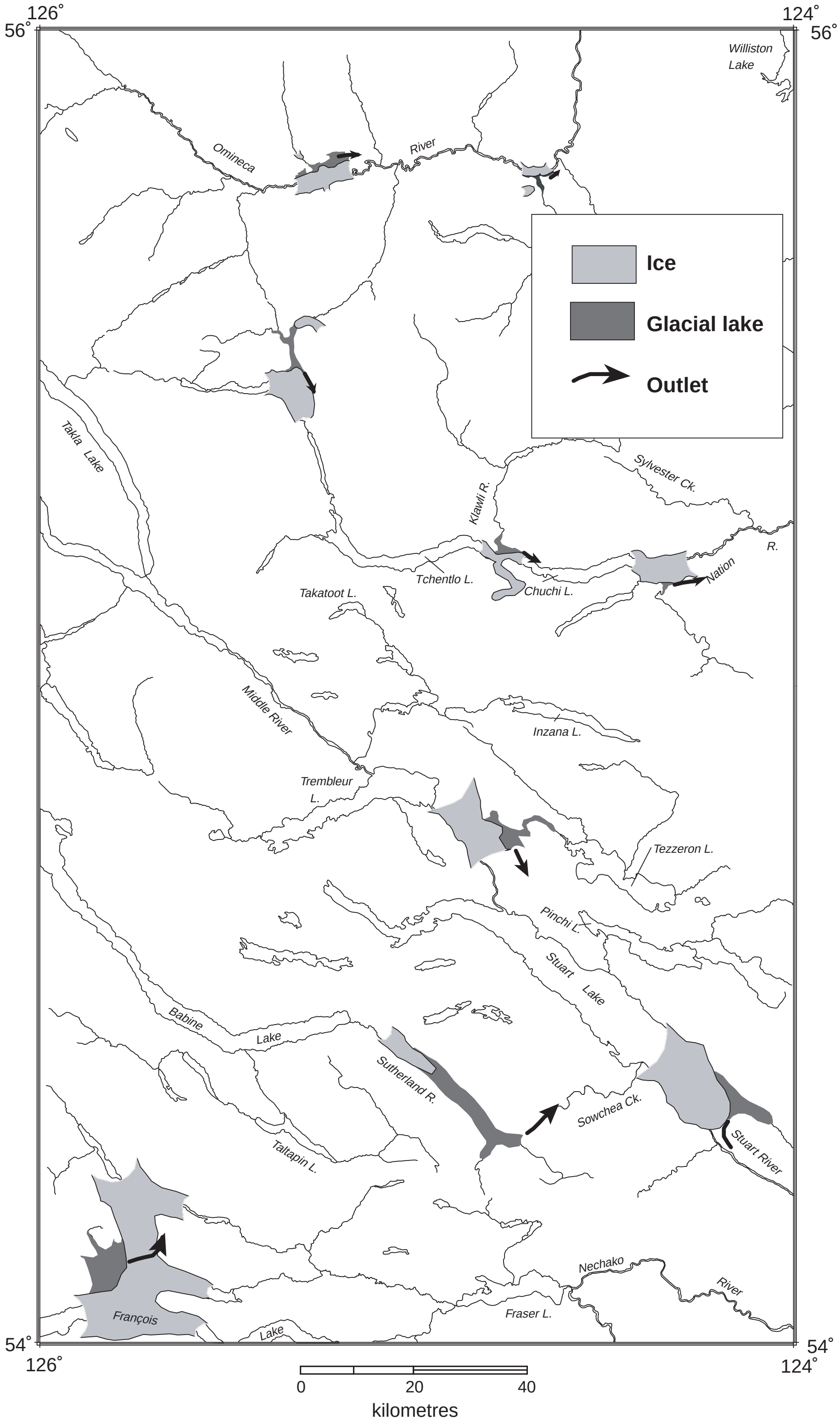

Figure 49. *Advance-phase glacial lakes of the Fraser Glaciation, inferred from the stratigraphic record in the study area.*

River areas are inadequate to favour any one of these hypotheses. Based on one westward ice-flow indicator in the Pendleton Bay region, however, Levson et al. (1999) suggested that the ice divide during the last glacial maximum migrated as far east as longitude 125°30′W.

A growth model for the Cordilleran Ice Sheet was developed by Kerr (1934) and later slightly modified by Davis and Mathews (1944). Both models involve four phases for the development of the Cordilleran Ice Sheet. During the first phase, glaciers were confined to mountains and mountain valleys, and local relief greatly exceeded ice thickness. During the second phase, most areas were covered by ice, but relief slightly exceeded ice thickness and topography therefore influenced ice-flow patterns. In this phase, valley and mountain glaciers united to form branching glacier systems. During the third phase, ice thickness exceeded relief and mountain summits were covered by ice. However, because the topography beneath the ice was rugged, ice flow was parallel to major valleys. During the fourth and final phase, ice thickness greatly exceeded relief, and ice flow was controlled by the location of major accumulation centres. Evidence presented here indicates that the Cordilleran Ice Sheet in central British Columbia during the Fraser Glaciation reached the third phase. With the increasing amount of evidence for the formation of an ice dome (Levson et al., 1997b, 1998, 1999; Stumpf et al., 1997), it is likely that stage four was also attained.

Chronology

The youngest radiocarbon age obtained from sediments underlying Fraser Glaciation till within the study area (30 740 ± 220 BP (TO-3653) on bison bones from Chuchi Lake; Harington et al. (1996)) is a maximum age for the beginning of the last glaciation. This age, however, probably does not closely delimit the time of glaciation of the study area. Radiocarbon ages from southern and southwestern British Columbia and northern Washington indicate that the Fraser Glaciation began approximately 29 000 to 25 000 BP and peaked at 15 000 to 14 500 BP (Fulton, 1971; Clague, 1981; Ryder and Clague, 1989). Glacier growth in these regions was slow, and some areas were still ice free as late as 17 000 BP (Clague et al., 1980; Clague, 1981). Bobrowsky (1989) reported a radiocarbon age of 15 180 ± 100 BP (TO-708) on wood recovered from sediments beneath Fraser Glaciation till in Finlay River valley, about 130 km north of the study area. This radiocarbon age suggests that some parts of central British Columbia remained nonglaciated until 15 000 BP.

Fraser deglaciation and glacial-lake history

Principles and assumptions

The pattern and style of deglaciation of the area were determined using several principles and assumptions outlined below; this approach has been used to document deglaciation by other authors, including Dyke (1990) for the Frances Lake map area in east-central Yukon Territory and Fulton (1967) for the Kamloops region in south-central British Columbia.

1. The position of lateral meltwater channels delineates ice margins during retreat: Since lateral meltwater channels formed in contact with ice, a series of channels at different positions on valley walls defines successive ice-margin positions during retreat. Upper channels were abandoned and new ones eroded at lower levels as ice downwasted and retreated. Slower ice retreat and abundant meltwater discharge on an unconsolidated sediment substrate favoured the formation of larger meltwater channels.
2. Glaciolacustrine sediments in tributary valleys were deposited in lakes impounded by ice in the trunk valley: These sediments are another indication that ice disappeared from some tributary valleys before trunk valleys were deglaciated.
3. During deglaciation, the glacier surface in narrow valleys parallel to ice flow was roughly symmetrical transverse to the valley axis: If an indication of an ice level was found on one valley wall (e.g. a lateral meltwater channel), the glacier surface was assumed to be at the same level on the opposite valley wall. In flatter areas and regions less confined than narrow valleys, such as the Nechako Plateau and Fraser Basin, ice margin positions were not extrapolated in this manner; instead, they were only drawn on slopes where meltwater channels and glaciofluvial deposits clearly delineated the edge of the glacier.
4. Sedimentation took place on ice in areas of hummocky topography with abundant kettles: Exposures in hummocky terrain reveal folds, faults, and tilted beds (Fig. 19) related to the melting of supporting ice blocks. These ice masses were detached from the retreating ice front.

Fraser deglaciation

The configuration of glaciers during retreat was reconstructed using these principles plus information extracted from the surficial geology maps (Maps 1986A, 1987A), specifically the distribution of glaciofluvial and glaciolacustrine sediments, meltwater channels, and lateral moraines (Fig. 50a, in pocket). Over most of the area, ice-margin positions in adjacent drainage basins were not joined, because the landforms are not continuous from one drainage basin to the next and there is no chronological control. Ice fronts were drawn across the lower portion of some valleys assuming an average ice-surface gradient ranging from 14 to 25 m/km (derived from the gradient of lateral meltwater channels). A similar ice-surface profile was assumed in a deglaciation study of southern British Columbia (14 m/km; Fulton (1967)), but a gentler profile was measured for the outer 50 km of the Selwyn Lobe of the Cordilleran Ice Sheet in east-central Yukon Territory (9 m/km; Duk-Rodkin et al. (1986), Jackson (1989)). Although such differences in gradient would affect slightly the configuration of ice fronts depicted in Figure 50b (in pocket), they would not alter the pattern and sequence of deglaciation envisaged for the area.

Ice retreated generally from east to west along an irregular front, the location of which was controlled by topography. The first areas to be deglaciated were the high summits of the northern mountainous region. Few ice-marginal landforms, such as lateral and end moraines, are known from these high sites. Those that have been identified are short, low, and tree covered, characteristics which hinder their identification on airphotos. The presence of lateral moraines within a few valleys near summit areas suggests that local glaciers occupied cirques during deglaciation. For example, lateral moraines occur downslope from cirques near Pyramid Peak and Mount Sidney Williams (Ryder, 1994; Map 1986A). The one on the northeast slope of Mount Sidney Williams extends from 1400 to 1200 m in elevation. Two scenarios can be envisaged for the formation of these lateral moraines. They may have formed during deglaciation, before the equilibrium line rose above the level of the cirques. Alternatively, they may have been built during a Holocene (Neoglacial) glacial advance. It is unlikely that these moraines formed at the onset of the Fraser Glaciation, because some of them are located in areas that would have been unprotected from erosion at glacial maximum.

Glacial-lake history

During deglaciation, numerous glacial lakes formed behind retreating glaciers. The glacial-lake history of the study area was reconstructed from the distribution of the maximum elevation of glacial-lake sediments, which represents a minimum water level reached by a glacial lake. The elevation of delta topsets represents a more precise evaluation of the level reached by a glacial lake. Any outlet that controlled the level of a glacial lake has to be located at or above the maximum elevation of the glaciolacustrine deposits or very close to the elevation of delta topsets. This relationship works best if the outlet and the evidence of the glacial-lake level are in close proximity, thus limiting the potential effect of isostatic rebound.

Early during deglaciation, when ice occupied Manson River valley, two glacial lakes formed at different times in a tributary valley (Fig. 44). The levels of these lakes (1250 and 1060 m a.s.l.) were probably controlled by a combination of subglacial and ice-marginal drainage. At that time, two separate ice lobes surrounded the Wolverine Range and spilled into Omineca and Manson valleys. A northwesterly-retreating ice lobe in Manson valley became detached from a lobe retreating southwesterly toward the valley of Tchentlo and Chuchi lakes (Fig. 50b). The northwesterly-retreating lobe then separated into two more lobes, a larger one that retreated parallel to Omineca River valley and a smaller one occupying Germansen Lake valley.

A glacial lake inundated Omineca River valley to about 820 m a.s.l. during deglaciation (Fig. 44). It may have been connected to one in Williston Lake valley that had shorelines at 855, 820, and 710 m a.s.l. (Rutter, 1977), although this has not been proven. Lake levels in Williston Lake valley, and possibly Omineca River valley, were controlled by ice and/or sediment damming of Peace River (Rutter, 1977; Mathews, 1980; Bobrowsky, 1989).

As ice retreated toward the valley of Chuchi and Tchentlo lakes, a glacial lake of unknown extent formed in upper Klawli valley, as evidenced by glacial-lake sediments at station 93-171 (Fig. 39, 44). This glacial lake drained to the northeast through meltwater channels. A subsequent, lower glacial lake formed in Tchentlo Lake, Chuchi Lake, and Nation River valleys due to damming of Nation River by a combination of ice and sediments (Fig. 44; Plouffe, 1992, 1997b).

Further south, southwesterly-retreating ice formed a lake by damming Tezzeron Lake valley; this lake overflowed to the east at 780 m a.s.l. through meltwater channels at its eastern end (glacial lake Tezzeron; Plouffe (1997b)). While deglaciation proceeded southwesterly, ice readvanced in the Pinchi Creek region, depositing the Pinchi Creek lens. Similar readvances have been documented in other areas of British Columbia, for example in the Fraser Lowland (Armstrong, 1981; Clague et al., 1997), the Rocky Mountain Trench (Clague, 1975), and the central Interior Plateau south of the study area (Tipper, 1971a, b). This suggests that Fraser deglaciation was marked throughout by stillstands and local readvances (Clague, 1981, 1989). According to Clague (1989), these readvances were asynchronous from one region to another and were probably controlled by local rather than global climatic factors. The lack of chronological control on the readvance in the Pinchi Creek region precludes any correlation with events elsewhere in the province.

Three separate ice lobes occupied Nechako River, Taltapin Lake, and Babine Lake valleys during deglaciation. As ice occupied lower Sutherland River valley, a glacial lake was pounded in the upper valley and drained through a meltwater channel at 880 m a.s.l. at the drainage divide between Sutherland River and Sowchea Creek (Fig. 44; Plouffe, 1997b). A subsequent, lower glacial lake formed in Sutherland River valley and overflowed at 790 m a.s.l. (Fig. 44) at the divide between the east end of Babine Lake and north arm of Stuart Lake (glacial lake Sutherland; Plouffe (1997b)).

Glaciolacustrine sediments in Babine Lake valley, at a maximum elevation of 760 m a.s.l., were deposited in glacial lake Babine (Huntley et al., 1996b), which was dammed by ice to the west. A channel from Babine Lake to Trembleur Lake, at an elevation of 770 m a.s.l., was the outlet of glacial lake Babine, as revealed by detailed elevation measurements and paleocurrent direction indicators in the channel region (Fig. 44).

When the southern part of the study area was partly deglaciated, a glacial lake inundated all valleys tributary to Fraser River. This glacial lake was possibly connected to glacial lake Fraser to the east (Clague, 1987, 1988; Eyles and Clague, 1991). Most of the valleys that were inundated contain glaciolacustrine sediments up to a maximum elevation of 760 m, with deltas at a slightly higher elevation (Fig. 44). The exceptions include areas in the southwestern part, such as Burns Lake and Fraser Lake, where glaciolacustrine sediments occur up to 740 m and 750 m, respectively. The lower maximum elevation of glaciolacustrine sediments in the southwestern part of the study area could be due to: 1) differential isostatic uplift, with greater uplift in the east and north than in the southwest (compare data from Burns Lake, west end of Fraser Lake, Nechako River area, and Takla Lake valley *in* Fig. 44) and, 2) asynchronous glacier retreat (i.e. during a higher stage of glacial lake Fraser, the Burns Lake and Fraser Lake valleys were occupied by ice; by the time these areas were free of ice, glacial lake Fraser had fallen, draining through lower outlets; Plouffe, 1997b).

Anomalous glacial-lake features include deltas at 772 and 796 m a.s.l. northeast of Fraser Lake, a delta at 818 m a.s.l. southeast of Pinchi Lake, and sandy deposits, interpreted as beaches, at 780 m a.s.l. north of Vanderhoof. These features may be related to local glacial lakes that developed early during deglaciation. Such localized ice damming has also been inferred by Levson et al. (1997b) for the Babine Lake area, west of the study area. Another possibility is that these higher deposits may record the true maximum level of the regional glacial lake, in which case fine glaciolacustrine sediments accumulated in water depths no shallower than 20 m. As a comparison, Veillette (1983) noted that a water depth of 50 m was necessary for sedimentation of varves in glacial Lake Barlow–Ojibway in Quebec.

Deglaciation model

Fulton (1967) envisaged the deglaciation of an area of moderate relief in southern British Columbia as proceeding through four phases. During the first (active-ice) phase, ice was thicker than relief and the ice-flow patterns were not strongly influenced by topography. In the second (transitional-uplands) phase, uplands appeared through the ice, but active flow was maintained in valleys as glaciers remained connected to source areas. Ice tongues in valleys retained a gradient and minor movement during the third (stagnant-ice) phase. In the last (dead-ice) phase, only dead-ice masses were present in the area. Some of this ice was buried beneath sediments. Fulton's (1967) deglaciation model is applicable to the study area with minor modifications. Because of the proximity of the region to the mountain accumulation centres, ice movement in the stagnant-ice phase may have been more significant than in the moderate-relief region to the south in which Fulton worked. Ice tongues in valleys remained connected to their sources, and active ice flow was likely maintained throughout deglaciation.

Chronology

The chronology of deglaciation and glacial-lake evolution is poorly known because of the lack of datable organic matter in late-glacial sediments. However, a radiocarbon age of 10 100 ± 90 BP (Table 2, GSC 2036) on basal marl in Omineca River valley (Alley and Young, 1978) indicates deglaciation of that area before 10 000 BP. The oldest radiocarbon age relevant to deglaciation in the southern part of the study area is 9830 ± 130 BP (Table 2, GSC-5891); the pollen assemblage of this sample indicates nonarboreal vegetation dominated by shrubs and herbs. These radiocarbon ages are in accord with the findings of Clague (1981), who suggested that valleys and plateaus of the British Columbia interior were ice free by 10 000 to 9 500 BP.

Postglacial (Holocene)

Immediately after deglaciation, nonvegetated glacial debris on steep slopes was transferred by streams, slope wash, and landslides to valley floors. Sediment transfer was fast at that time due to the abundance of meltwater and the large volume of glacial sediments readily available for erosion. Valleys were occupied by braided streams that were choked with sediments and had a rising base level. Some streams established their courses on the floors of former glacial lakes. Alluvial fans developed at the foot of steep slopes, and deltas formed where sediment-laden streams entered lakes. In early-postglacial time, most lakes were higher than at present prior to the entrenchment of valley fill. Once slopes stabilized and vegetation became established, sediment supply to streams decreased and valley fills and alluvial fans were incised. Stream patterns evolved from braided to meandering. Alluvial terraces formed during this period of falling base level.

Eolian sedimentation occurred in early-postglacial time before the establishment of vegetation. Dunes were constructed where sand was abundant, such as near certain glaciofluvial deposits and on floodplains. Dunes rapidly stabilized when vegetation became established.

Organic sediments began to accumulate in poorly drained depressions and lakes some 10 000 radiocarbon years ago. Accumulation of peat in fens and bogs was retarded in the early Holocene, probably because of a combination of dry and warm climate. Organic sediment accumulation has continued essentially uninterrupted since this warm and dry period.

Colluvium, produced from glacial sediments and weathered bedrock, has been transported by gravity to the bottom of steep slopes to form aprons and fans. Landslides occurred mainly in areas underlain by glacial-lake sediments.

ENVIRONMENTAL AND ECONOMIC GEOLOGY

Till geochemistry and mineral exploration

Results of all geochemical analyses completed during the course of this project are presented in Plouffe and Ballantyne (1993) and Plouffe (1995a).

Regional till geochemistry reflects the bedrock composition up-ice from the sample sites. For example, high chromium and nickel concentrations occur in till near and down-ice from ultramafic rocks of the Cache Creek Group on the south shore of Stuart Lake, north of Pinchi Lake, northwest of Trembleur Lake, at the west end of Tchentlo Lake, and along the Manson fault (Fig. 6, 51, 52). In the northeastern part of the study area, at the contact between the Slide Mountain and Cassiar terranes, high concentrations of La, Rb, Sm, Ta, Tb, Th, and U in till were derived from carbonatite and pegmatite dykes of that region. The extent of the geochemical anomalies suggests glacial transport of at least 1 to 5 km (West, 1997).

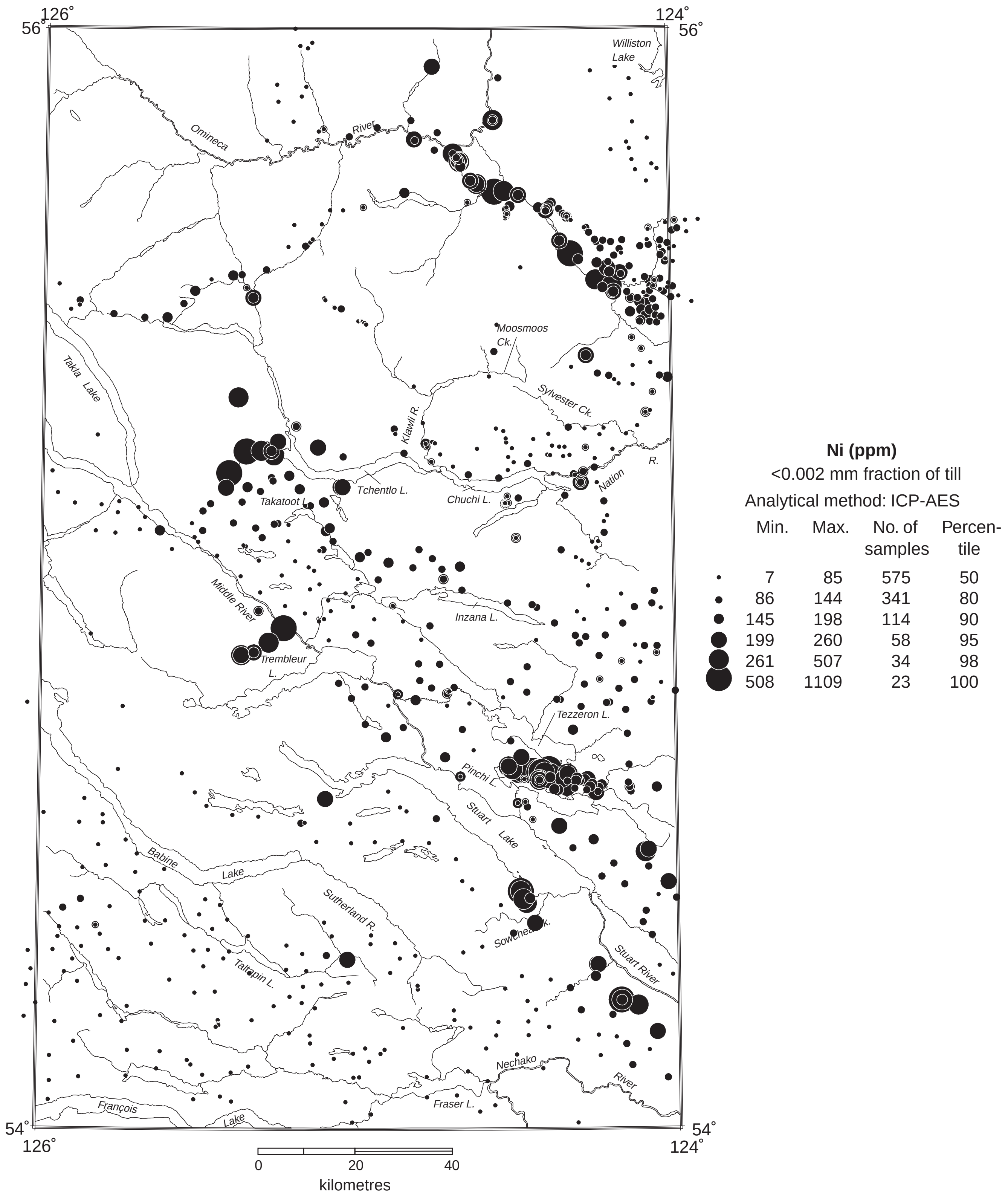

Figure 51. *Nickel content of the clay fraction of till in the study area.*

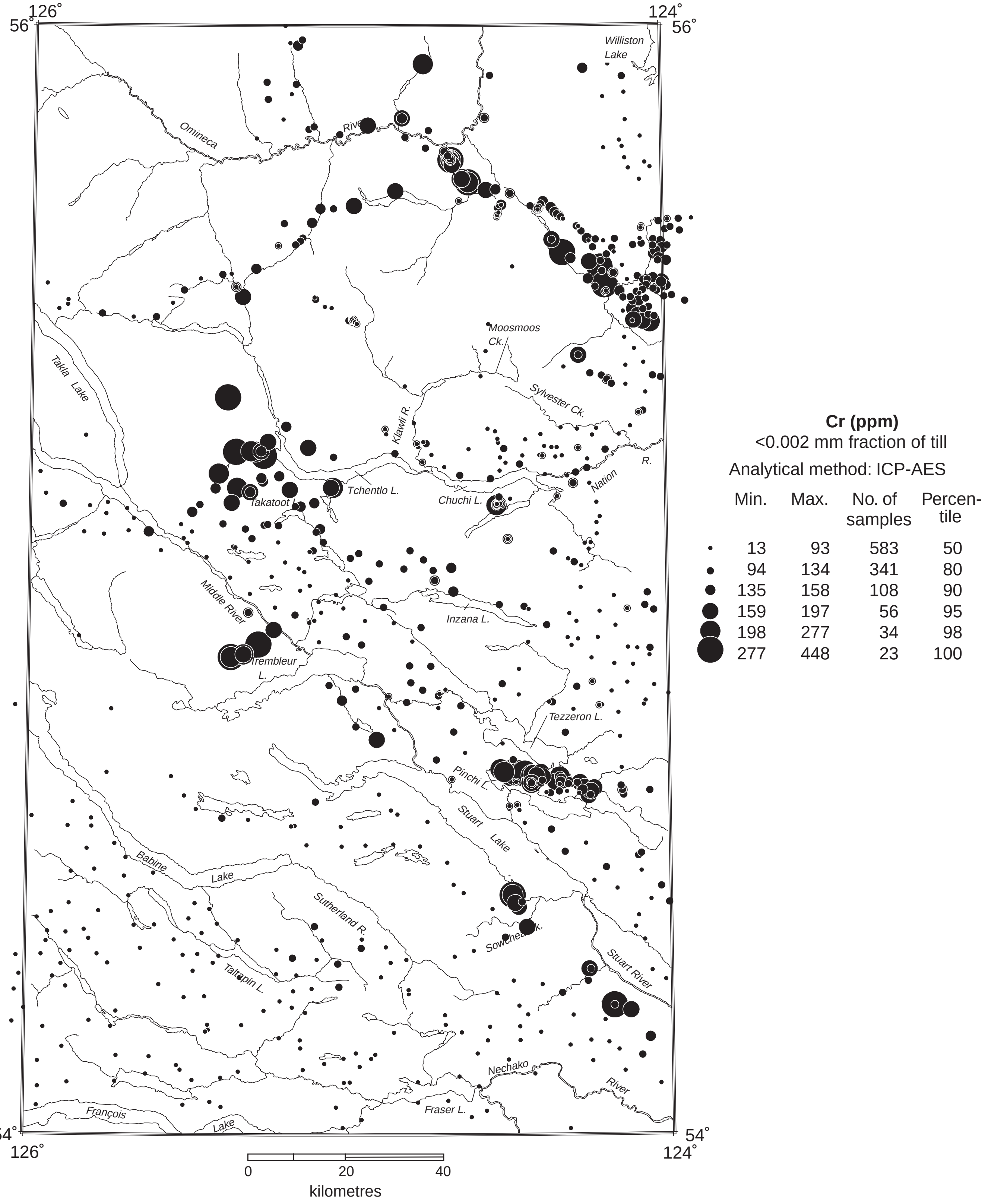

Figure 52. *Chromium content of the clay fraction of till in the study area.*

Other high metal concentrations of local extent in till could be related to bedrock mineralization. Elevated copper concentrations north of Chuchi Lake, north of Witch Lake, 30 km north of Tchentlo Lake, and 35 km west-northwest of Germansen Landing are all related to the presence of mineral showings (Fig. 53). A multi-element anomaly (Zn-As-Pb) south of Cunningham Lake could be derived from the Cunningham Lake showing (Plouffe, 1995a).

Gold in till

The highest gold concentrations in till in the study area were obtained from samples collected near known mineralized zones northwest of Valleau Creek and north and south of Chuchi Lake (Fig. 54). Other sites with high gold concentrations occur along Klawli River and Valleau Creek. These sites are located near areas of high potassium concentrations (> 2%), as determined by airborne gamma-ray spectrometry (Shives and Carson, 1994). The association of high gold levels in till with geophysical potassium anomalies is important, because porphyry mineralization within the Takla Group was found to be surrounded by potassic alteration halos (S.B. Ballantyne, D.C. Harris, R.B.K. Shives, K.L. Ford, P.B. Holman, A. Plouffe, A.S. Judge, and J.A. Pilon, abstract presented at Geological Survey of Canada, Minerals Colloquium, Ottawa, Ontario, 1992).

A few samples that yielded high gold levels cannot be directly linked to known mineral occurrences. One sample south of Takatoot Lake contains 47 ppb gold, abundant epidote grains, and traces of rutile. The epidote could indicate secondary alteration associated with mineralization. Williams and Cesbron (1977) have shown circumstantial evidence that links copper-rich rutile with porphyry copper mineralization. More sampling could be done in this area to determine the geological significance of the high gold content of till. South of Fort St. James, six till samples returned gold values ranging from 20 to 39 ppb. There is no known bedrock mineralization from which this gold in till could have been derived. In addition, placer gold in Sowchea and Dog creeks (Armstrong, 1949), and mineral showings at the southeastern end of Stuart Lake and southeast of Dog Creek, are evidence of the good mineral potential of this region (Plouffe, 1995a).

Placer deposits

Armstrong (1946) presented a comprehensive overview of placer mining in central and northern British Columbia, a very brief summary of which is given here. Placer gold was originally discovered in 1857 on the lower Thompson and Fraser rivers. By 1861, the rich placers of the Cariboo district were being exploited. As miners kept moving north in their continuous search for gold, placer gold was discovered in the Germansen Landing–Manson Creek area in 1868. The original gold discovery was apparently made on Silver Creek. Placer mining has continued until the present (Fig. 55), although at a much lower level of activity compared with the last few decades of the nineteenth century.

Most of the gold has been recovered from near the base of sand and gravel deposits that lie on bedrock; these deposits are unconformably overlain by Fraser Glaciation drift. Some of the gold found in modern alluvium is probably reworked from old sand and gravel deposits (Armstrong, 1949). Armstrong (1949) concluded that the sources of the placer gold are 1) quartz veins and mineralized shear zones within what he originally mapped as Cache Creek Terrane, but which has been reinterpreted as part of Slide Mountain Terrane (Ferri and Melville, 1994); and 2) mineral deposits along the Pinchi and Manson fault zones. Other, less important placer deposits occur along Sowchea and Dog creeks south of Fort St. James and Klawli River northwest of Chuchi Lake.

Till may be a useful prospecting medium for buried placer deposits. High gold concentrations in till in the Germansen Landing and Manson Creek areas (Fig. 54) are likely derived from the glacial erosion of placer deposits. A combination of geochemical analysis and gold grain counts may provide clues as to the proximity of additional gold placers. The main problem is that gold in till can be derived from either buried placer deposits or mineralized bedrock; geochemistry alone would probably not allow one to distinguish these two sources. A detailed analysis of the morphology of gold grains, on the other hand, could point to the source. A dominance of pristine gold grains in till might suggest a bedrock source, whereas reshaped and rounded grains would be more indicative of a placer source.

Armstrong (1949) noted that most placer deposits in the Manson Creek area are in valleys oriented transverse to the ice-flow direction of the Fraser Glaciation. Deposits in these valleys were protected from glacial erosion. Meltwater channels oriented northeast-southwest (transverse to ice flow) and located south of the former village of Manson Creek are incised in sediments and bedrock, and are therefore good exploration targets. Exploration work, including one underground placer mine, has been taking place in these valleys.

Environmental geochemistry

As noted in the ‘Bedrock geology’ section, cinnabar occurs in numerous places along the Pinchi fault zone. Mercury derived from this mineralization was transported down-ice and deposited in till (Plouffe, 1995b, 1998). Mercury concentrations in till are above the regional background level as much as 12 to 24 km down-ice from the source, depending on the size fraction analyzed (Plouffe, 1998). The mercury dispersal train defined by heavy mineral concentrates is longer than that in the clay fraction of till because heavy minerals yield a greater anomalous:background concentration ratio than does the clay fraction (Plouffe, 1998). Near the Pinchi fault, most of the mercury in till occurs in the sand fraction, reflecting the presence of sand-sized cinnabar grains. With increasing distance of glacial transport, peak mercury concentrations shift to finer size fractions. This shift is attributed to glacial comminution and the presence of mercury in mineral phases that have terminal grades in the clay fraction (Plouffe, 1997c). The area around the Manson fault also has high mercury levels in till, although not as high as near the

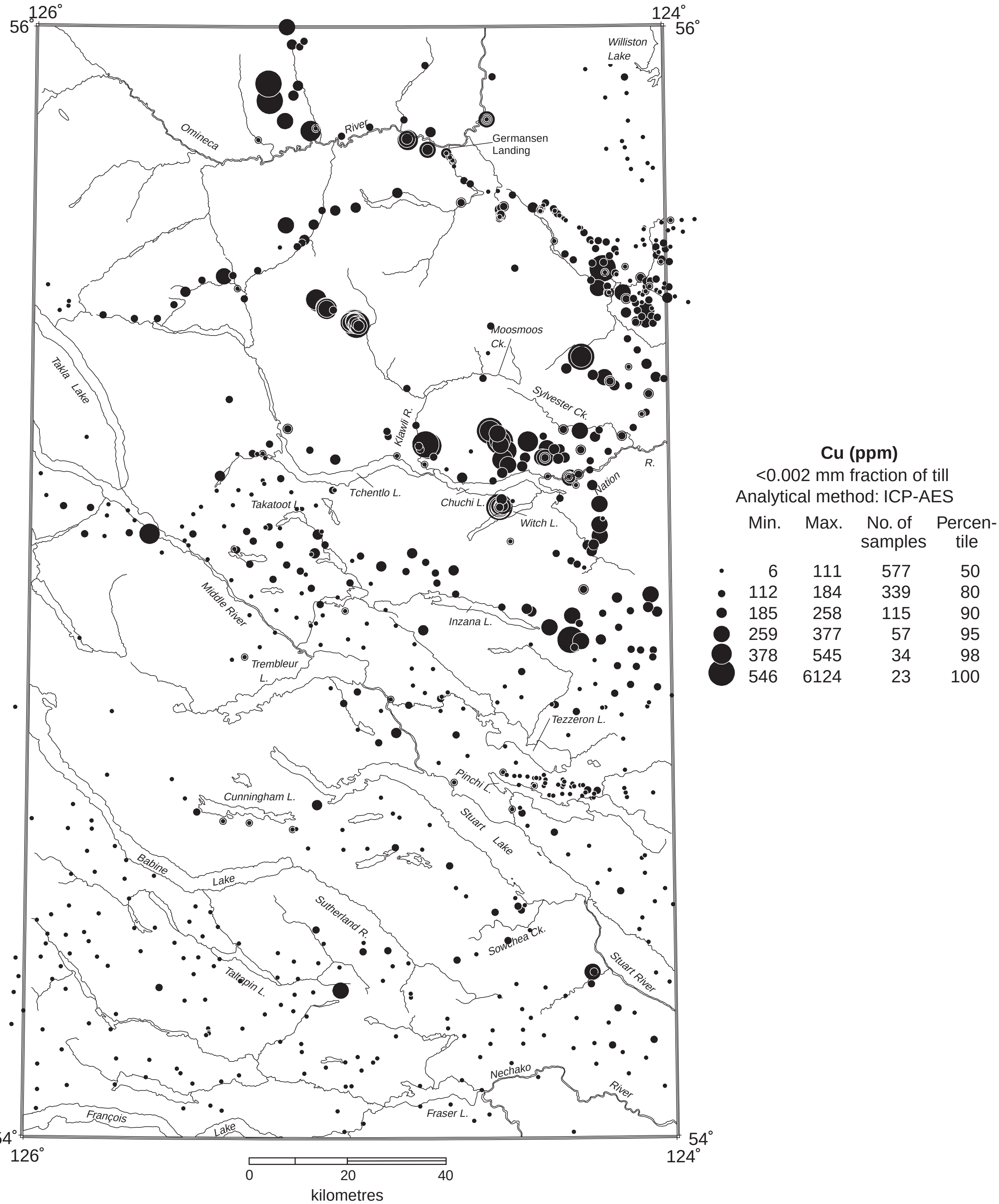

Figure 53. *Copper content of the clay fraction of till in the study area (*from *Plouffe, 1995a).*

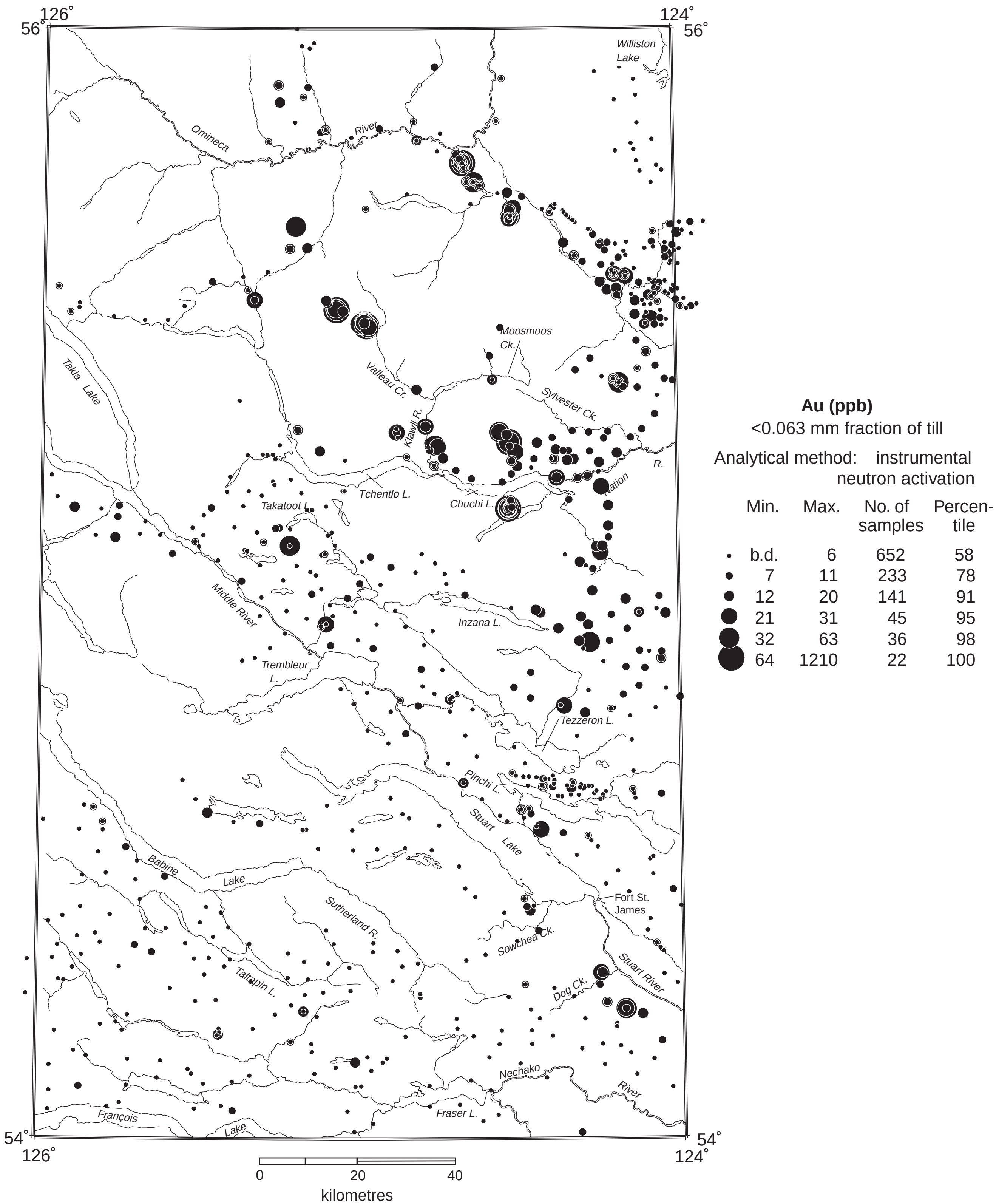

Figure 54. *Gold content of the silt+clay fraction of till in the study area (*from *Plouffe, 1995a).*

Figure 55. *Gold nuggets recovered from the Germansen Landing pit. Photograph by A. Plouffe. GSC 1999-051X*

Figure 56. *Gravel pit in glaciofluvial ice-contact deposits south of Fort St. James. Photograph by A. Plouffe. GSC 1999-051Q*

Pinchi fault zone (Plouffe, 1995a, b). Potential sources of mercury near the Manson fault include zones of hydrothermal alteration (Armstrong, 1949) or argillite units (Ferri and Melville, 1988) next to the fault zone (Plouffe, 1998). Argillite is known to contain high mercury levels because of the high absorption capacity of clay minerals for mercury (Jonasson and Boyle, 1971).

High mercury levels in till and bedrock in the Pinchi fault region account for the high mercury concentrations in lake sediments (Cook et al., 1997). Fish (Reid and Morley, 1975; unpub. report, Triton Environmental Consultants Ltd., Richmond, British Columbia, 1992), birds (Fimreite et al., 1971), and trees (Warren et al., 1983, 1984) around the Pinchi fault have elevated mercury levels. The transfer of this potentially toxic metal from bedrock to organisms is a concern (Plouffe, 1997a).

Aggregate resources

Aggregate resources are generally plentiful in the region, except in areas underlain by thick glaciolacustrine sediments. The principal source of aggregate is glaciofluvial sand and gravel.

Till

Till can be used for fill where an impermeable base or core is required (e.g. in dam construction). It is not suitable as a source of aggregate because its matrix is too silty and clayey. However, down-ice from intrusive rocks, till is sandy and could locally be used for road beds.

Glaciofluvial sediments

Map units and one landform with the greatest aggregate potential are glaciofluvial terrace sediments (unit Gt), glaciofluvial blanket (unit Gb), proglacial deltaic sediments (unit Gd), ice-contact deposits (unit Gh), and eskers (Fig. 56). Most active and abandoned gravel pits are located in recessional-phase glaciofluvial sediments, but gravel at one site is being extracted from advance-phase glaciofluvial sediments (site 90-073; Fig. 39, 40). Glaciofluvial deposits differ in quality, in terms of sediment sorting and content of well indurated rock types. In addition, the composition and texture of the deposits commonly vary vertically and laterally.

Small occurrences of sand and gravel are not shown on the surficial geology maps (Maps 1986A, 1987A) as individual glaciofluvial polygons because of the scale of mapping. However, these small deposits are associated with eskers, meltwater channels, and glacial-lake beaches. A gravel-pit symbol is used on the maps to locate significant aggregate deposits encountered in the field.

Alluvial sediments

Some alluvial deposits are potential aggregate resources, but environmental concerns, such as stream siltation or contamination by heavy machinery caused by gravel extraction, limit their exploitation. For example, gravel extraction near a stream could destroy fish habitat. The high water table in these alluvial sediments could hinder extraction.

Colluvium

Colluvium is mined where more suitable aggregate resources cannot be found. However, their poorly sorted nature and the content of abundant angular bedrock fragments can make these sediments unsuitable for road-base material.

Glaciolacustrine sediments

Glaciolacustrine sediments can be used as low-permeability fill material. They were used, for example, in the construction of the Kenney Dam, approximately 60 km southwest of Vanderhoof.

Groundwater

Surface water and groundwater quality can be affected by carbonate content. What is well known as 'hard water' represents groundwater with a high carbonate content. The Cache Creek and Cassiar terranes (Fig. 6) contain calcareous rocks, the main source of carbonate in surface water and groundwater. Because of glacial and glaciofluvial transport, the carbonate content of glacial sediments is high, not only close to carbonate-rich bedrock but also some distance down-ice from it (Fig. 10). Therefore, glacial sediments with a high carbonate content could also affect surface water and groundwater quality.

In areas outside the main valleys, Quaternary sediments are generally thin, consisting mainly of till with a patchy gravel veneer in places. In these areas, any groundwater that is present will reside in fractured bedrock. In valleys, groundwater may occur in buried sand and gravel deposited during the advance phase of the Fraser Glaciation. Any valleys where the drainage was unobstructed during glacier advance potentially contain water-bearing, buried, advance-phase glaciofluvial sediments. In such settings, aquifers are confined. In addition, recessional-phase glaciofluvial sediments and floodplains may have high groundwater potential, but aquifers here would most likely be unconfined.

Natural hazards

The three types of natural processes discussed below occur mainly in unpopulated areas, but should be taken into consideration as an area is developed, because their threat to people may increase.

Flooding

Flooding can occur in the spring as the snowpack melts or after a heavy rainfall in the summer or fall. At risk are areas mapped as alluvial floodplains (unit Ap), deltas (unit Ad), undivided alluvial sediments (unit Au), and, to a lesser extent, along the shorelines of lakes. Permanent infrastructure should not be installed in these areas because of their high flooding potential. Alluvial fans (unit Af) can also be flooded, but the biggest threat on some fans is debris flows. Alluvial terraces are generally high enough above stream level that the risk of flooding is minimal. However, terraces might be located in unstable positions and could be prone to bank erosion.

Landslides and debris flows

Steep slopes in thick glaciolacustrine deposits are vulnerable to landslides, especially where landslide scars are present. Past landslides in these materials have been in the form of rotational slumps and complex slides (i.e. a combination of rotational slumping and flow). Large landslides have occurred along Nechako River east of Fraser Lake, and on the northeast shore of Stuart Lake, where wave or stream bank erosion has undercut sediments, causing unstable slope profiles.

A series of landslides southeast of the town of Burns Lake and along the northeastern shore of Babine Lake originated either in sediments, due to slumping of recessional-phase glaciolacustrine sediments, or in bedrock, from the erosion of Tertiary volcaniclastic sediments beneath basaltic lava flows. Evans (1984) has described this latter type of landslide in southern British Columbia and suggested that they are dominantly postglacial.

In 1992, a landslide involving 423 000 m^3 of glaciofluvial and glaciolacustrine sand, silt, and gravel occurred at Donna creek in the northeastern part of the study area (Fig. 57). The failure resulted from disruption of the natural surface-water runoff due to construction of a forestry road without proper installation of cross drainage (Donna Creek Technical Investigative Team, unpublished report for Ministry of Environment, Lands and Parks and Ministry of Forests, Victoria, British Columbia, 1992). Landslides in till are generally small (Fig. 58). Nevertheless, proper mitigation measures must be taken when new roads are built in sloping terrain, because most of the recent landslides have been triggered by road construction.

Figure 57. *Donna creek landslide (debris flow). The length of the landslide, from the head scarp to the creek, is approximately 600 m. Photograph by A. Plouffe. GSC 1999-051R*

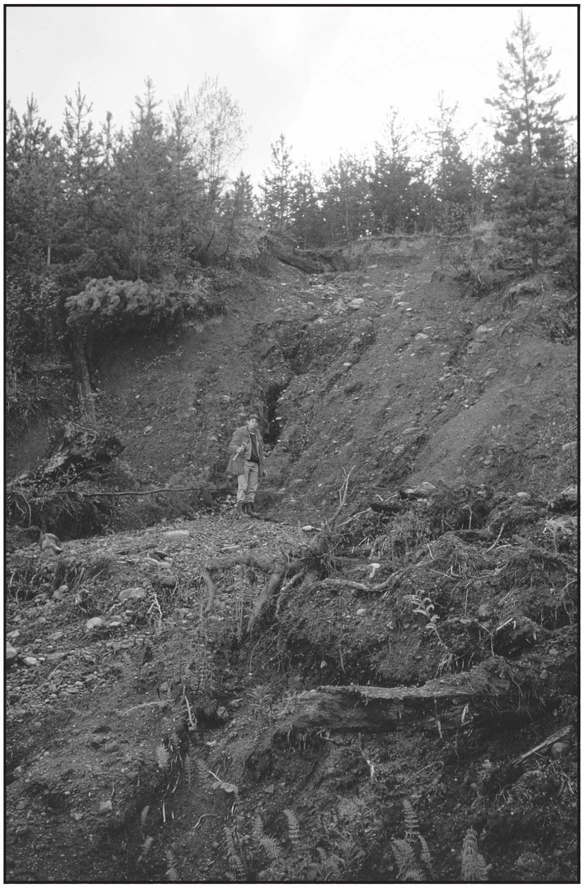

Figure 58. *Landslide (debris flow) in till, upper Pitka Creek valley. Note person in centre of photograph for scale. Photograph by A. Plouffe. GSC 1999-051S*

Rock avalanches and debris flows are restricted to steep mountainous terrain. Debris-flow scars, indicated by a symbol on the surficial geology maps (Maps 1986A, 1987A), and some alluvial fans are potentially hazardous terrain for debris flows. Temporary and permanent infrastructure should be located with caution in these areas. Debris flows can be triggered by an intense rainstorm, or during the snowmelt period in spring and early summer.

Snow avalanches

Snow avalanches are common in the Omineca Mountains and have left prominent tracks on steep slopes. Avalanches can be extremely destructive, because they can travel at high velocities, snap and unroot trees and displace them downslope, and transport large boulders (Luckman, 1978). They commonly recur in the same areas. The snow avalanche hazard is highest on steep terrain above the treeline, on slopes below the treeline where tracks are present, and on some alluvial fans at the foot of steep slopes. Permanent or temporary infrastructure, such as roads and winter camps, should not be located in areas prone to avalanches.

FUTURE RESEARCH

To help focus future research on the Quaternary geology of the region, unresolved questions relating to two topics are presented here:

1. Chronological and palynological data on basal peat collected from bogs are preliminary. More detailed research is required to determine more precisely the chronology of deglaciation and the history of early Holocene vegetation in the study area. Radiocarbon dating and palynological analyses of gyttja in lakes might provide this information.
2. A more intense search should be made for moraines near cirques, to provide additional data on deglaciation of the region. Such a search might also show whether small glaciers re-formed in the cirques during Neoglaciation.

Metals in the Environment (MITE)

As part of the GSC Metals in the Environment (MITE) initiative, research is being conducted near the two past-producing mercury mines in the region. The objectives of this research are to 1) determine if there is mercury derived from the mining activity and if it can be differentiated from mercury derived from the bedrock and sediments; 2) establish the extent of natural and anthropogenic enrichments; and 3) evaluate the mobility of metals in soils and their potential transfer into the food chain.

CONCLUSIONS

Quaternary deposits in the study area include, in chronological order: 1) old sediments of unknown age, 2) till predating the last glaciation, 3) nonglacial sediments of Middle Wisconsinan age, 4) deposits of the Late Wisconsinan Fraser Glaciation, and 5) postglacial sediments. Sediments predating the Middle Wisconsinan Olympia Nonglacial Interval are rare. Such sediments have been found in placer workings near Germansen Landing and Manson Creek, and consist of oxidized sand and gravel that locally contain high concentrations of gold. The exact age of these sediments is unknown. An Early Wisconsinan or older till was found at a single site along the Necoslie River southeast of Fort St. James.

Middle Wisconsinan sediments were found at three new sites during this study. Pollen spectra from these sediments are characterized by high percentages of herb pollen and smaller amounts of tree pollen, suggesting tundra to open-forest vegetation. The Middle Wisconsinan climate was colder than at present, at least for some time, because the region presently supports a forest dominated by spruce, subalpine fir, and lodgepole pine. Fossil evidence reveals that giant bison (at Chuchi Lake) and mammoth (at Babine Lake) lived in this region for at least part of the Olympia Nonglacial Interval.

Deposits of the Fraser Glaciation can be assigned to three phases: advance phase, glacial phase, and recessional phase. Advance- and recessional-phase sediments comprise glaciolacustrine and glaciofluvial lithofacies. At the onset of the Fraser Glaciation, cirque and valley glaciers developed in the mountainous parts of the study area. Ice advanced in a generally easterly direction. In westerly draining valleys and in several tributary valleys, the drainage was blocked by these advancing glaciers, impounding lakes in which silt and clay accumulated. In contrast, drainage in easterly draining valleys remained unobstructed, and sand and gravel were deposited in outwash fans and river channels. The main ice-accumulation centres were the Coast, Skeena, and Cariboo mountains. Ice-flow reconstruction suggests that glaciers flowing eastward from the Coast Mountains were deflected to the northeast and north as they coalesced with glaciers from the Cariboo Mountains. Ice advance and retreat were punctuated locally by fluctuations in the ice front. The Pinchi Creek lens is an informal lithostratigraphic unit consisting of clayey till deposited in a glacial lake during a local readvance in the Stuart Lake region at the end of the Fraser Glaciation. The cause of this readvance is unknown, but was likely controlled by local factors.

Lateral meltwater channels and recessional-phase glaciolacustrine and glaciofluvial sediments indicate that an irregular ice front, controlled by topography, generally retreated toward the west. In any one area, higher regions were generally deglaciated before adjacent valley bottoms. During deglaciation, glacial lakes developed in several valleys because drainage was blocked by retreating ice. The largest glacial lake occupied the valleys drained by tributaries of Fraser River when that river was blocked by decaying ice east of the study area.

The maximum elevation of fine-grained glaciolacustrine sediments in Endako and Nechako river valleys decreases to the southwest. This decrease might be the result of differential isostatic rebound or differences in the time of deglaciation of Endako and Nechako valleys, with attendant lowering of the glacial lake that occupied these valleys.

Radiocarbon dating of basal peat in bogs in the study area has shown that the onset of peat accumulation was delayed until long after deglaciation by a combination of warm and dry climatic conditions in early Holocene time.

Gold placer deposits of the Manson Creek–Germansen Landing area are overlain by Fraser Glaciation drift. The use of till geochemistry and the counting and characterization of gold grains are promising tools for placer gold exploration. Potential target areas include meltwater channels oriented transverse to the ice-flow direction. Old pay gravel at the bottom of these channels may have been preserved from glacial erosion.

Till close to and down-ice from cinnabar occurrences in bedrock along the Pinchi fault has relatively high concentrations of mercury. The transfer of this potentially toxic metal from bedrock to organisms is a concern and the subject of one component of the GSC Metals in the Environment Initiative (MITE).

The main source of aggregate is glaciofluvial deposits. There is generally no shortage of gravel in the study area, except in areas underlain by glaciolacustrine sediments. In these areas, gravel can be found at the mouths of meltwater channels near the former glacial-lake shoreline.

Carbonate-rich groundwater occurs in areas of calcareous bedrock within the Cache Creek and Cassiar terranes. The high carbonate content of glacial sediments down-ice from these bedrock units also contributes to the high carbonate content of groundwater.

Three types of natural hazards have been identified in the study area: floods, landslides, and snow avalanches. Some of these processes occur only in unpopulated areas, but should be taken into consideration prior to future development.

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