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QUATERNARY GEOLOGY OF THE FRANCES LAKE MAP AREA, YUKON AND NORTHWEST TERRITORIES

Arthur S. Dyke 1990

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Alpine glaciers northeast of Tungston.

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Preface

This report presents the results of the first systematic surficial geological mapping to be undertaken in the Frances Lake map area, a part of the northern Cordillera that has been the site of much mineral prospecting. The investigations were undertaken at the request of the Department of Indian and Northern Affairs to provide data pertinent to resource assessment, environmental impact assessment, development of transportation corridors, identification of natural hazards, and general land use regulation. This memoir also presents interpretations of local and regional glacial history that will be of use in planning further exploration activity and more detailed environmental assessments of the region.

Elkanah A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

Préface

Le présent rapport contient les résultats des premiers travaux de cartographie sustématique de la géologie des formations en surface de la région de Frances Lake, dans la partie nord de la Cordillère, endroit qui a fait l'objet de nombreux travaux de prospection minière. Ces travaux ont été entrepris à la demande du ministère des Affaires indiennes et du Nord canadien aux fins de recueillir les données nécessaires à l'évaluation des ressources, a l'évaluation des répercussions environnementales, à la délimitation des corridors de transport, à la reconnaissance des dangers naturels et à la réglementation générale de l'utilisation des terres. Le présent mémoire contient également des interprétations de l'évolution glaciaire aux plans local et régional, lesquelles serviront à la planification des futurs travaux d'exploration et à une évaluation environnementale plus approfondie de la région.

Elkanah A. Babcock, sous-ministre adjoint,
Commission géologique du Canada

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Abstract

The Quaternary geology of the Frances Lake map area described herein is based on the first detailed mapping (1:100 000 scale) in the area. This part of the northeastern Cordillera was eroded by alpine cirque glaciers throughout much of the Quaternary. However, almost all surficial deposits and smaller landforms result from complete glaciation by ice flowing southward from the Logan Mountains during the Late Wisconsinan and from postglacial, alpine, slope processes. Till, the dominant surficial material, is subdivided into several lithic facies that differ widely in clast lithology and more subtly in grain size and geochemical composition. Glaciofluvial and alluvial deposits are thick and nearly continuous along most valleys and thick glaciolacustrine deposits occur in two eastern valleys. Alpine slope processes have produced extensive talus aprons and many rock glaciers derived from them as well as some rock and numerous snow avalanches. Widespread rock glacier development occurred about 4500 years ago with resurgences at several times since. Several glacial advances occurred during the last 400 years. Late Wisconsinan deglaciation was marked by large, lowland ice lobes that retreated northward accompanied by segregation from alpine glaciers. Both types of glaciers left an abundant geomorphological record but deglaciation remains undated.

Résumé

La géologie du Quaternaire de la région cartographique de Frances Lake décrite ci-dessous se base sur les premiers travaux cartographiques détaillés (échelle de 1/100 000) de la région. Cette partie du nord-est de la Cordillère a été érodée par des glaciers de cirque de type alpin pendant la plus grande partie du Quaternaire. Toutefois, presque toutes les formations en surface et les formes de relief plus petites résultent de la glaciation complète causée par l'écoulement des glaces vers le sud à partir des monts Logan pendant le Wisconsinien supérieur et de processus postglaciaires, alpins et de solifluxin. Le till, soit le matériau de surface prépondérant, se répartit en plusieurs lithofaciès qui différent de façon plus considérable au niveau de leur lithologie détritique et de façon plus subtile au niveau de leur composition granulométrique et géochimique. Les dépôts glaciofluviaux et alluviaux sont épais et presque continus le long de la plupart des vallées, et d'épais dépôts glacio-lacustres se manifestent dans deux vallées orientales. Les processus de versants alpins sont responsables de la formation de vastes cônes d'alluvions et de nombreux glaciers rocheux dérivent de ces processus, ainsi que quelques avalanches de pierres et de nombreuses avalanches de neige. De nombreux glaciers rocheux se sont formés il y a environ 4500 ans avec plusieurs résurgences ultérieures. Plusieurs avancées glaciaires ont en lieu au cours des 400 dernières années. La déglaciation au Wisconsinien supérieur a été marquée, dans les basses-terres, par de grands lobes glaciaires qui, au cours de leur recul vers le nord, se sont séparés des glaciers alpins. Les deux types de glaciers ont laissé de nombreuses traces géomorphologiques de leur passage, mais on ne peut dater la déglaciation.

SUMMARY

This report includes the first detailed maps of surficial materials and landforms of the Frances Lake map area, located in the Selwyn Mountains of the northeastern Canadian Cordillera. NNW-SSE trending mountain ranges are separated by two broad and several smaller river valleys and the ranges are crossed by many transection valleys which isolate individual massifs. Erosion of cirques by alpine glaciers must have continued during much of the Quaternary for cirques are eroded to mature forms, occur in optimum density, and are little restricted as to aspect. Only a

SOMMAIRE

Le présent rapport comprend les premières cartes des matériaux de surface et des formes de relief de la région cartographique de Frances Lake, située dans la chaîne Selwyn, dans le nord-est de la Cordillère canadienne. Les chaînes de montagnes orientées NNO-SSE sont séparées oar deux larges vallées fluviatiles et plusieurs vallées plus petites, et les chaînes sont traversées par de nombreuses vallées tranfluentes qui isolent des massifs individuels. L'érosion des cirques par les glaciers alpins a dû se poursuivre tout au long de la plus grande partie du Quaternaire car ell a atteint le stade de la maturité, et les cirques sa manifestent en grand small fraction of cirques are occupied now by glaciers. Cirque erosion, formation of the transection valleys by breaching of cols by ice streams, and overdeepening of stretches of the large valley floors to form fiord-like lakes and troughs set into broader Tertiary valleys constitute the largest physiographic alterations during the Quaternary. Preglacial surfaces are preserved on some upper alpine slopes that have survived oversteepening of rock walls by valley glaciers. These surfaces show that the Tertiary topography was already mountainous and that valleys of even higher order were already formed.

Almost all surficial materials and all smaller landforms in the area result from complete and intensive glaciation during Late Wisconsinan time (McConnell Glaciation) and from postglacial alpine slope processes. At the height of McConnell Glaciation, some time after 24 000 years ago, ice pored generally southward across the map area from the northeasternmost dome of the Cordilleran Ice Sheet (Logan Dome), in confluence with ice flowing southeastward into the Liard Lowland from a regional ice divide crossing the central Yukon (Yukon Ice Divide). It coalesced in the Liard Lowland with ice flowing eastward from the north-central part of the Cordilleran Ice Sheet. All peaks in the map area are thought to have been overtopped by ice at the McConnell maximum. Deglaciation is not dated but probably occurred about 13 000 to 10 000 years ago.

Despite the mountainous terrain, rock outcrops over only 15% or so of the area and is generally confined to steep alpine slopes and ridges, which are commonly buttressed by instable screes. McConnell till is thick and continuous along almost all valley floors and slopes. Thin till is restricted to steeper and higher slopes and to summits. Till surfaces are patterned by drumlin fields in the large valleys, by numerous morainal forms, including end, lateral, and medial moraines, and are incised by numerous meltwater channels, including an impressive maze of proglacial channels in the Frances River valley. The tills comprise several lithic facies, locally dominated by Devono-Mississippian black shale, Cambrian and older slate and phyllite, Hadrynian gneiss and schist, Cretaceous monzonite and granodiorite as well as other, less widespread lithologies. Despite the wide range of lithic composition and of resistance of parent bedrock, these till facies differ only subtly in grain size composition, perhaps reflecting a relative immaturity of the deposits. Some facies, however, have distinctive geochemical signatures; for instance, the black shale till facies has a remarkably high content of mercury and the monzonite till facies has a high concentration of uranium. Background and anomalous levels are established for each lithic till facies and location of anomalously high elemental occurrences are recorded on the maps and in an appendix. Many samples contain anomalous concentrations of lead and zinc. They comprise two sets; one set from the black shale till of Frances River valley, the other associated with the Cretaceous batholith and contacting metamorphic rocks.

nombre, et se présentent sous de nombreux aspects. Actuellement, seul un petit nombre de cirques abritent encore des glaciers. L'érosion des cirques, la formation de vallées transfluentes due à l'éroxion des cols par les langues glaciaires, et le surcreusement de certaines sections du fond des grandes vallées menant à la formation de lacs en forme de fiord et d'auges glaciaires dans des vallées tertiaires plus larges, constituent les altérations géomorphologiques les plus importantes du Quaternaire. Des surface préglaciaires ont été conservées sur quelques-uns des versants alpins supérieurs qui ont survécu au surraidissement des parois rocheuses par les glaciers de vallée. Ces surfaces montrent que la topographie tertiaire était déjà montagneuse et qu'il existait déjà des vallées d'un ordre plus élevé.

Presque tous les matériaux de surface et les formes de relief plus petites de la région résultent d'une glaciation complète et intensive à fin du Wisconsinien (glaciation de McConnell) et des processus post-glaciaires de versants alpins. À l'apogée de la glaciation de McConnell, il y a tout au plus 24 000 ans, la glace s'écoulait généralement vers le sud à travers la région cartographiée depuis le dôme gisant le plus au nord-est de l'inlandsis de la Cordillère (dôme de Logan), en confluant avec la glace s'écoulant vers le sud-est depuis des bassesterres de la Liard, à partir d'une ligne de partage glaciaire régionale traversant le centre du Yukon (ligne de partage glaciaire du Yukon). Elle fusionnait dans les basses-terres de la rivière Liard avec la glace s'écoulant vers l'est depuis la partie centre-nord de l'inlandsis de la Cordillère. Tous les pics de la région cartographiée auraient été recouverts par de la glace au plus fort de la glaciation de McConnell. La déglaciation a dû avoir lieu il y a probablement 13 000 à 10 000 ans, mais la date exacte demeure inconnue.

En dépit du terrain montagneux, les roches affleurent seulement sur 15 %, ou à peu près, de la région et se manifestent généralement sur les versants alpins raides et les crêtes qui servent souvent d'appui à des éboulis instables. Le till de McConnell est épais et continue le long de presque tous les fonds de vallée et des versants. Le till mince est restreint aux versants les plus raides et les plus élevés, et aux sommets. Les surfaces recouvertes de till sont réticulées par des champs de drumlins, particulièrement dans les grandes vallées, par de nombreuses formes morainiques, y compris des moraines frontales, latérales et médianes, et sont incisées par de nombreux chenaux proglaciaires dans la vallée de la rivière Frances. Les tills comprennent plusieurs lithofaciès, dominés par endroits par un schiste argilieux noir datant du Dévon-Mississippien, des ardoises et de la phyllite cambriennes et plus anciennes, du gneiss et du schiste hadryniens, de la monzonite et de la granodiorite crétacées ainsi que d'autres lithologies moins répaundues. En dépit de la vaste gamme de compositions lithologiques et de résistances de la roche-mère, ces faciès de tills n'accusent que de légérer différence de composition granulométrique, mettant peut-être ainsi en évidence l'immaturité relative des dépôts. Quelques faciès ont, toutefois, des signature géochimiques caractéristiques; par exemple, le faciès de till de schiste argileux noir a une teneur remarquablement élevée d'uranium. Pour chaque lithofaciès du till, on a établi les teneurs de base et les teneurs anormales; l'endroit où se situent les éléments anormalement élevés est inscrit sur les cartes et dans l'annexe. Beaucoup

Glaciofluvial sediments and postglacial alluvium, largely derived from them, are nearly continuous and as much as 30 m thick along the axes of all major valleys. These are predominantly gravels and constitute a major granular resource. Thick glaciolacustrine deposits occur in two eastern valleys.

Postglacial slope modification has been extensive throughout the alpine areas and has led to thick accumulations of talus, development of about 1000 rock glaciers and three, large, rock avalanches. Rock glaciers developed mostly about 4500 years ago, but several younger resurgences are recognized. Snow avalanching is a prevalent current process, likely resulting in tens of significant events per year. Renewed glaciation has occurred in the past 400 years or so and has lead to development of 168 small cirque glaciers which advanced and built moraines during six or so advances. There is no obvious area-wide correlation between ages of Neoglacial moraines and ages of rock glacier lobes.

McConnell ice marginal deposits and landforms occur in such profusion as to allow for detailed reconstruction of the pattern of ice retreat. Ice retreat is summarized on one map and on three paleogeographical maps which show early, middle, and late phases of deglaciation. Although complex in detail because of the interaction of lowland ice lobes and alpine glaciers, in general the pattern shows a northward retreat of large ice lobes that continues into the Nahanni map area to the north, accompanied by segregation of alpine ice masses. Final ice retreat involved a withdrawal of valley glaciers to massifs in the north-central part of the area.

d’échantillons contiennent des concentrations anormales de plomb et de zinc. Ils forment deux séries: une série provenant du till de schiste argileux noir de la vallée de la rivière Frances, l’autre, associée au batholithe crétacé et aux roches métamorphiques qui reposent en contact avec ce dernier.

Des sédiments glacio-gluviaux et des alluvions postglaciaires, provenant largement de ceux-ci, sont presque continus et peuvent atteindre 30 m d’épaisseur le long des axes de toutes les principales vallées. Il s’agit surtout de graviers, matériau qui constitute une ressource granulaire importante. Dans deux vallées situées à l’est, on trouve d’épais dépôts glacio-lacustres.

Les fortes modifications des versants à l’époque postglaciaire dans toutes les régions alpines ont entraîné la formation d’épaisses accumulations d’éboulis, la formation d’environ 1000 glaciers rocheux et ont causé trois importantes avalanches de pierres. La formation des glaciers rocheux date d’il y a environ 4500 ans, mais on a identifié plusieurs résurgences plus jeunes. L’avalanche de neige est un processus actuel et fort répardu qui se manifeste des dizaines de fois de mainère importance chaque année. La glaciation a repris au cours des 400 dernières années ou à peu près, et a mené à la formation de 168 petits glaciers de cirque qui ont avancé et construit des moraines au cours d’environ six avancées. Il n’y a aucune corrélation évidente à l’échelle de la région entre l’âge des moraines néoglaciaires et l’âge des lobes des glaciers rocheux.

Les dépôts proglaciaires de McConnell et les formes de relief sont si abandants qu’ils permettent la reconstruction détaillée du mode de retrait de la glace. Ce dernier est résumé sur une carte et sur trois cartes paléogéographiques qui montrent les phases initiale, moyenne et finale de la déglaciation. Bien que de détail complex à cause de l’interaction des lobes de glace dans les basses-terres et des glaciers alpins en général, il semble que le retrait des grandes lobess de glace se soit effectué vers le nord et qu’il se soit poursuivi plus au nord dans la région cartographique de Nahanni, la swparation des masses de glace alpines se produisant en même temps. Le retrait final de la glace a impliqué le recul des glaciers de vallée vers les massifs dans la partie centre-nord de la région.

INTRODUCTION

The Frances Lake map area (105 H) is situated in southeastern Yukon Territory and adjacent District of Mackenzie between 61° and 62°N, and 128° and 130°W (Fig. 1). Fieldwork was conducted in the area during 1981 and 1983 concurrent with other surficial geological mapping in adjacent areas by Klassen (1983a,b) and Klassen and Morison (1982) to the south and by Jackson (1982, 1986a,b) and Jackson and Morison (1984) to the west and north. A preliminary, unedited, surficial geology map of the study area was released on open file shortly after completion of the fieldwork (Dyke, 1983). The four maps that accompany this report were recompiled on recently published 1:50 000 topographic bases and photographically reduced to publication scale (1:100 000). Areas to the northeast and east remain unmapped except for portrayal of generalized ice flow features by Gabrielse et al. (1973) and for certain aspects of the geomorphology of the Nahanni National Park area by Ford (1976).

Canada’s only tungsten mine at the town of Tungsten is located near the northeast corner of the map area and is linked with the town of Watson Lake, the major regional population and service centre to the south, by Nahanni Range Road and Robert Campbell Highway. Robert Campbell Highway also provides access to Frances River valley and Frances Lake along the western side of the map area.

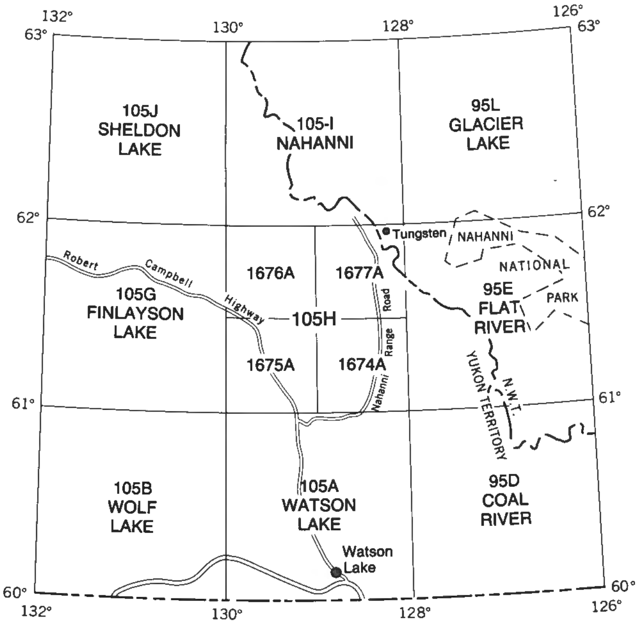


Figure 1. Location map showing study area covered by Maps 1674A-1677A, as well as areas and names of adjoining geological maps. Flat River and Glacier Lake areas are unmapped.

This report describes the surficial materials and landforms of the map area, which are the result predominantly of Late Wisconsinan (McConnell) glaciation and postglacial alpine slope processes. Field studies in 1983 concentrated on the ages and geomorphological and mechanical properties of rock glaciers and ages of Neoglacial moraines. These data are treated in a separate report (Dyke, in press) and only general conclusions are presented here.

Physiography

The Frances Lake area is in the Selwyn Mountains and Liard Lowland of the northeast Canadian Cordillera (Mathews, 1986). Liard Lowland extends northward into the map area as Frances River valley (Fig. 2), a broad Tertiary valley into which is set a narrower Quaternary valley occupied by Frances River and both east and west arms of Frances Lake (Fig. 3). Frances River valley separates the Simpson Ranges of the Selwyn Mountains on the west (previously known as Simpson Ranges of the Pelly Mountains) from the Logan Mountains, also a subdivision of the Selwyn Mountains, on the east (Fig. 2). The Logan Mountains are separated from the Ragged Range, a third subdivision of the Selwyn Mountains, by Flat River valley in the northeast. The Logan Mountains form two sets of ranges that trend NNW-SSE separated by Hyland River valley, which also drains southward to Liard Lowland.

The Simpson Ranges and Logan Mountains are divided into a block-like arrangement of massifs by valleys that transect the ranges and that descend toward either end from low passes. The massifs of the Logan Mountains and Ragged Range are higher than the massifs of the Simpson Ranges and consequently are much more sculpted by alpine glacial erosion. The intensity of cirque development and degree of alteration of preglacial topography is such that almost all massifs form fretted mountains. The northern massifs of the Logan Mountains and the Ragged Ranges support 168 small cirque glaciers, most of which are restricted to a narrow range of north-facing basins with elevations of 1900 m or more (Fig. 4). During much of the Quaternary, snowlines must have been much lower than they are today, and the resulting widespread alpine glaciation produced mature cirques that are little restricted as to aspect. The lower massifs of the Simpson Ranges are scalloped by cirques in places, but most of the surface, including the cirques, bears signs of areal scour by pervasively overriding ice sheets.

In all ranges small upland surfaces show little or no sign of erosion by either alpine glaciers or ice sheets. In these small areas of preserved preglacial (Tertiary) topography (unit R2, Maps 1674A, 1675A, 1676A, and 1677A) the slopes indicate that all the larger river valleys and many of, if not all, the smaller valleys had formed before the Quaternary. Tectonic disturbance of the preglacial surface has apparently been limited to uplift. The preglacial surface formed on rocks as young as Cretaceous and relict slopes indicate a mountainous terrain similar to the present except for the oversteepening of slopes by cirque and valley glaciers. Major uplift that occurred throughout the Yukon during the Late Tertiary, and likely during the Pliocene, produced a mountainous terrain by fluvial dissection of an older physiographic surface of low relief (Templeman-Kluit, 1980).

The transection valleys — those that transect mountain ranges - are striking physiographic features. They could have originated through a long sequence of stream erosion and capture during the Tertiary. More likely, however, they result from breaching of alpine headwalls by vigorously moving ice streams during the Quaternary. If so, the largest physiographic alteration during the Quaternary, barring sculpting of the mountains by cirque erosion, has been the subdivision of mountain ranges into a mosaic of massifs by formation of the transection valleys.

Bedrock geology

Frances Lake map area (Fig. 5) falls within the Selwyn Fold Belt and the Anvil Allochthon of the Cordilleran Orogen (Gabrielse et al., 1980). The Anvil Allochthon occupies much of the southwestern part of the map area and comprises chert, greenstone, serpentinite, and limestone of Mississippian to Permian age. The rocks were thrust into place from a source to the west; the northeast hanging wall of the thrust fault forms the boundary scarp between the Campbell Range (of Simpson Ranges) and Frances River valley. The Selwyn Fold Belt occupies the rest of the map area and contains rocks that range in age from Hadrynian (Proterozoic) to Cretaceous. The oldest rocks are Hadrynian schist and gneiss succeeded upward by shale, phyllite, and quartzite with minor marble. They outcrop along broad northwest-southeast belts through central and northeastern parts of the map area. Paleozoic

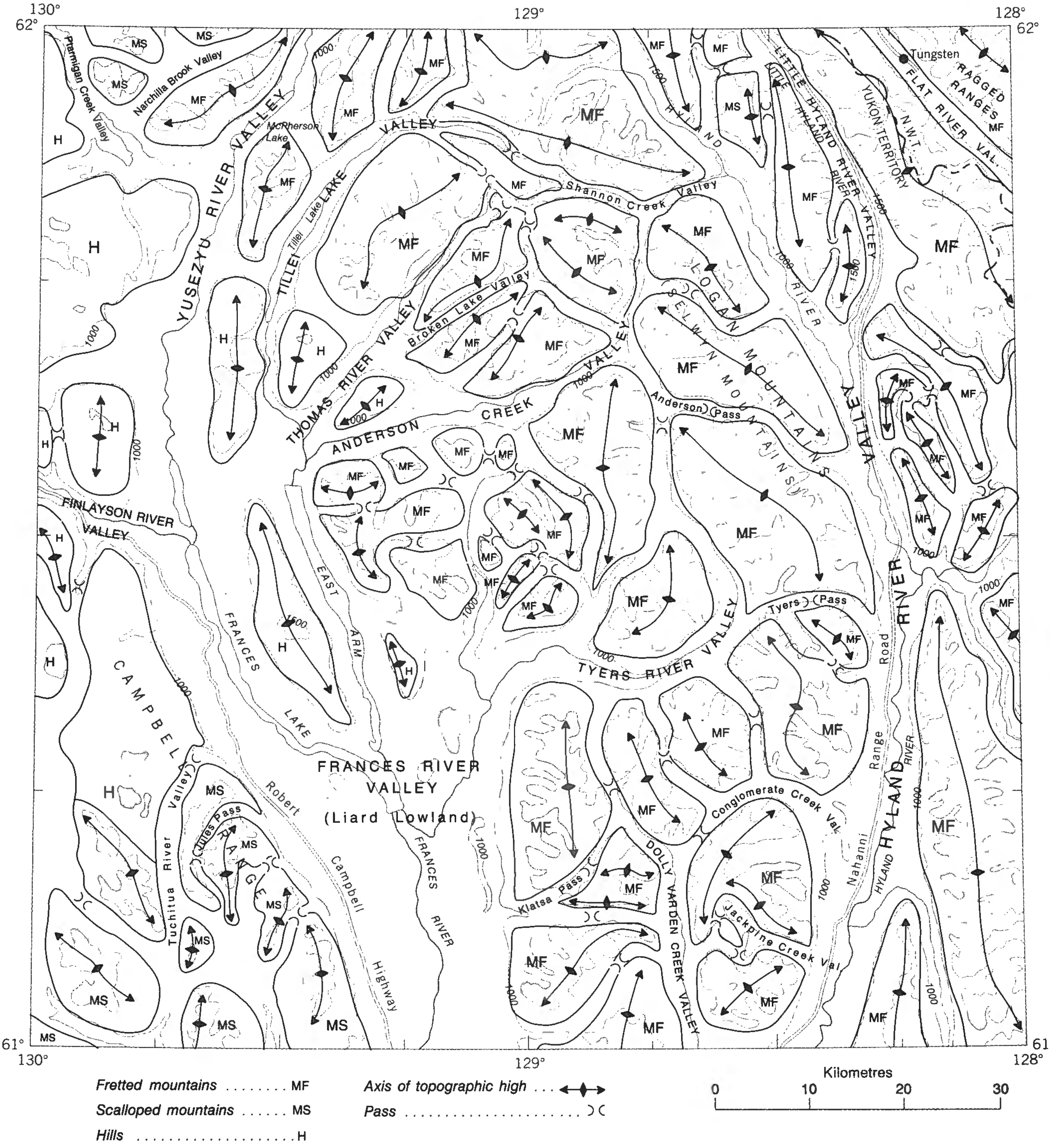


Figure 2. Physiography of the Frances Lake map area.

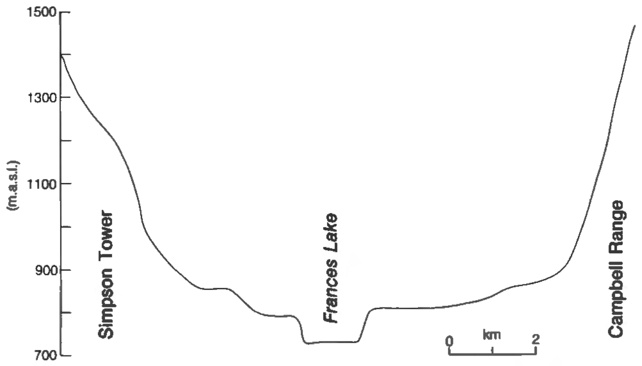
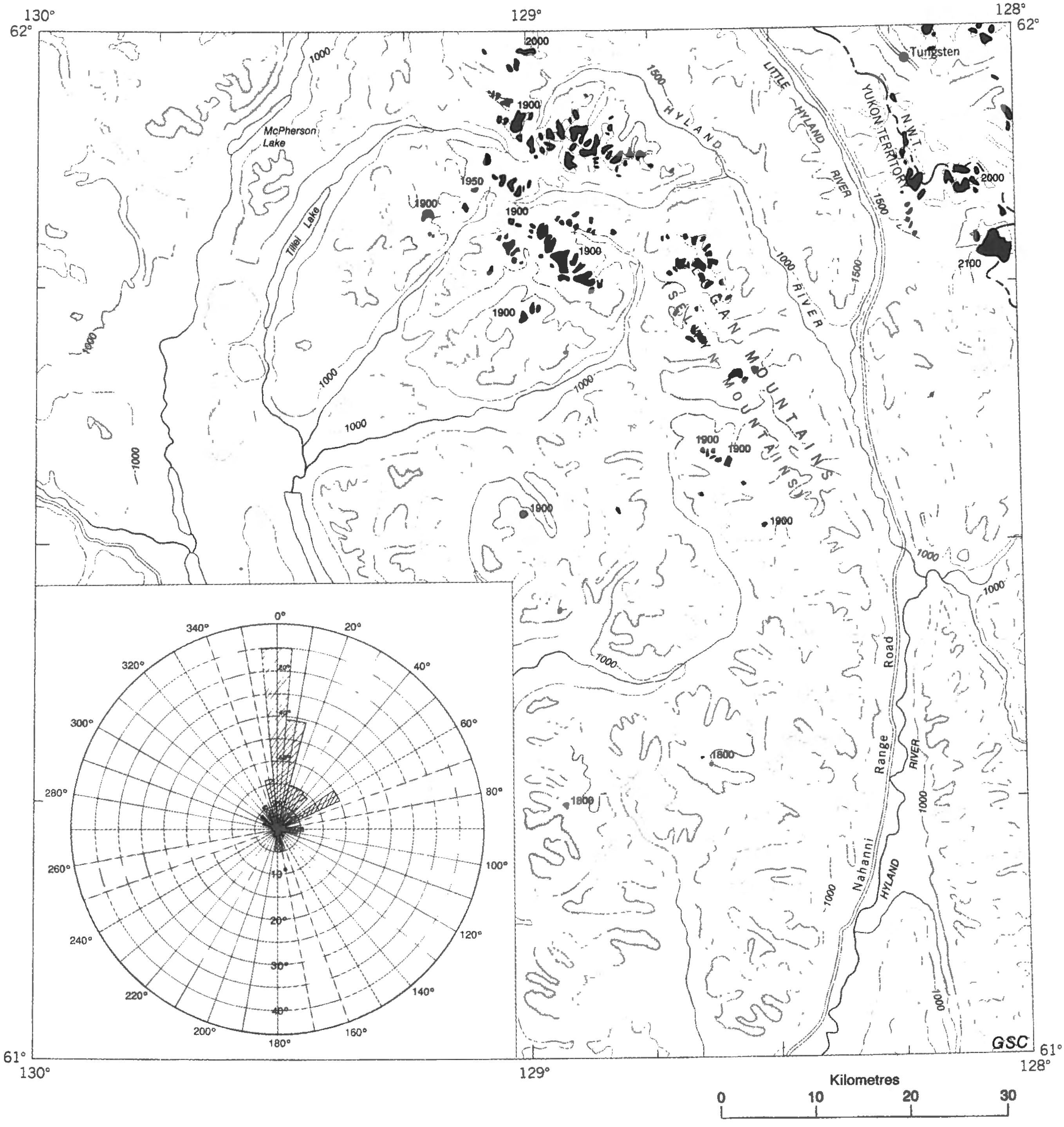


Figure 3. Topographic profile across Frances Lake showing the Quaternary valley set into the much broader Tertiary valley.

Figure 4. Distribution of active glaciers with rose diagram of glacier orientations (inset).



rocks are widespread to the northeast and to the southwest of the Hadrynian rocks and include much fine grained clastic sediment (siltstone and shale) as well as carbonates. Mississippian volcanic rocks (greenstone) outcrop on the eastern side of the floor of Frances River valley southeast of Frances Lake. Most of this large valley, however, is floored by Devono-Mississippian black shale. Lower Cambrian siltstone and shale and Cambro-Ordovician limestone and siltstone underlie Flat River valley, much of the Ragged Range and the easternmost range of the Logan Mountains. Little consistent relationship is found between lithological resistance and topography, perhaps because of the young age (Tertiary) of the last major tectonic event. The Paleozoic and Proterozoic sediments are intruded by several large Cretaceous batholiths, the largest being the Mount Billings batholith which occupies the central part of the map area. The batholiths are composed mostly of quartz monzonite and granodiorite.

The most detailed report on the bedrock geology of the map area is a 1:253 440 scale map with marginal notes (Green et al., 1966). Although some of the geology was reinterpreted in a regional context by Gabrielse et al. (1980), more detailed lithological information given by Green et al. provides the basis for the discussion of till composition in this report.

Regional Quaternary geological context

Generalized directions of ice flow in southeastern Yukon are shown on the Glacial Map of Canada (Prest et al., 1968) and on paleogeographic maps of northern North America, derived from the glacial map (Dyke and Prest, 1987). A portrayal (Fig. 6) based on recent surficial geological mapping (Klassen, 1983a,b; Klassen and Morison, 1982; Jackson, 1982, 1986a,b; Jackson and Morison, 1984; Maps 1674A-1677A) differs only in detail from earlier interpretations.

The Logan Mountains, from which ice flowing westward extended more than 350 km to its limit in west-central Yukon, must have been the major centre of accumulation on the northeastern Cordilleran Ice Sheet during the Late Wisconsinan glacial maximum. The eastward extent of ice from this source is not clear. Ford (1976) proposed that during the Late Wisconsinan only limited advances of local cirque glaciers occurred in the Ragged Range just east of Frances Lake map area and hence, by implication, that the Cordilleran Ice Sheet was limited to areas farther west. This situation would require a severe east-west asymmetry of that part of the Cordilleran Ice Sheet centred on the Logan Mountains by limiting its eastward advance to something less than 80 km. Ford recognized another limit of ice of Cordilleran origin much farther east. Although he proposed that this

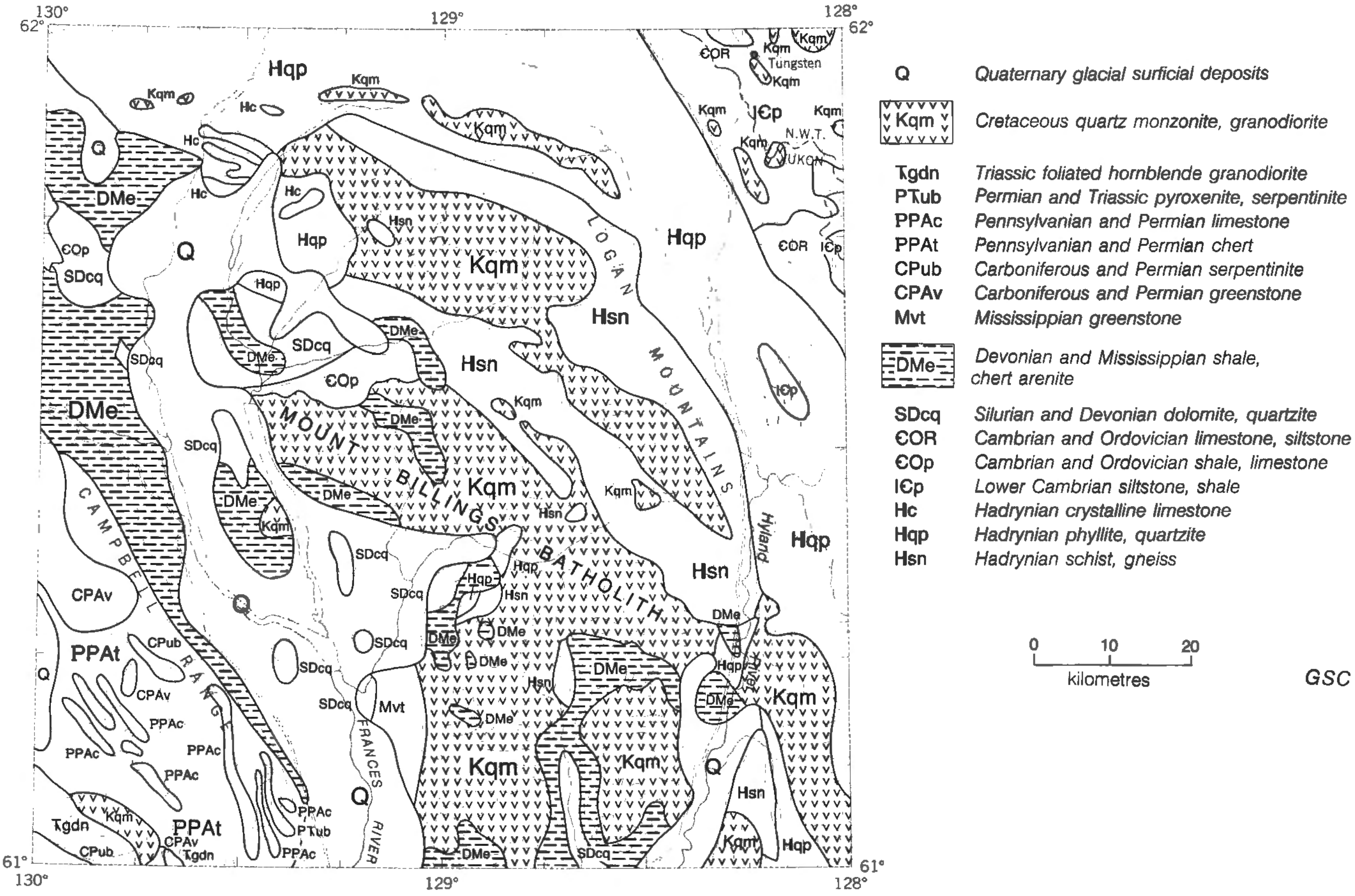


Figure 5. Bedrock geology of the Frances Lake map area.

limit is of Illinoian age, a Late Wisconsinan age is more compatible not only with the large westward extent of ice from the Logan Mountains but also with the fact that no limited Late Wisconsinan advance is recognized in Frances Lake map area.

A major regional ice divide must have extended from the Logan Mountains southwestward across south-central Yukon to the central divide of the northern Cordilleran Ice Sheet (Dyke and Prest, 1987) because flow is diametrically opposed toward the northwest and the southeast from that line. This Yukon Ice Divide crosses the northwest corner of Frances Lake map area; flow across that part of Frances Lake map area was toward the southeast whereas it was westward across the adjacent area to the west. Flow across Frances Lake map area emanated from the domal area of the northeastern Cordilleran Ice Sheet (the Logan Dome) and was influenced by a set of regional divides that branched from it. Ice flowed generally southward across Frances Lake map area. In Watson Lake area to the south, however, this flow was deflected eastward by the stronger flow of ice emanating from the central part of the Yukon Ice Divide and from the central divide of the Cordilleran Ice Sheet over northern British Columbia. This eastward flow fanned out toward the northeast around the southeastern flank of the Logan Mountains and Ragged Range and likely coalesced with ice flowing down Flat and Nahanni river valleys. Although Klassen (1987, p. 15) thought that the two ice masses stopped short of coalescing, evidence for this conclusion is not strong; more detailed mapping of Flat River map area is needed to clarify the interplay of Logan Ice and ice from the southwest.

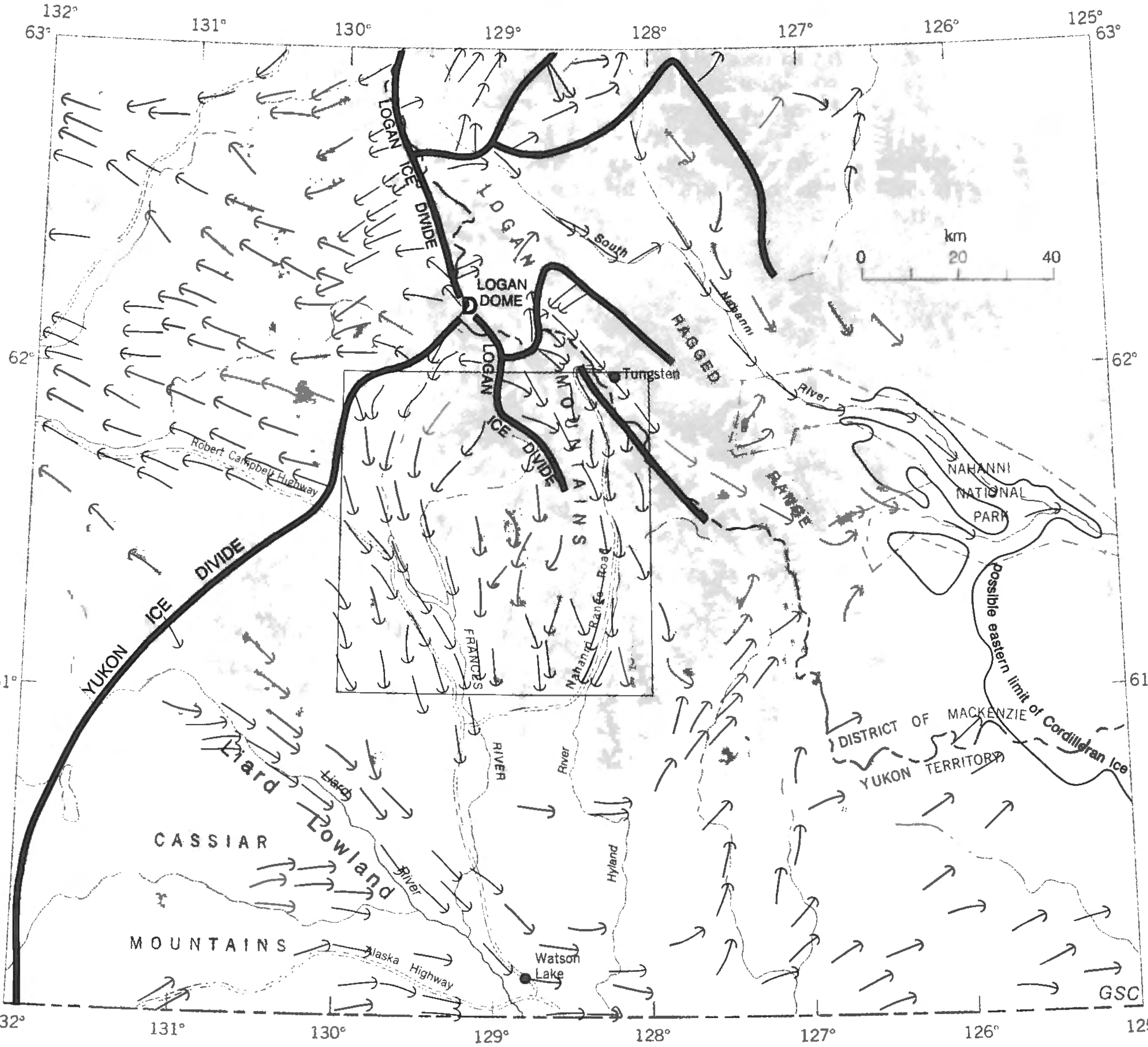


Figure 6. Late Wisconsinan ice flow directions and ice divides of southeastern Yukon and adjacent District of Mackenzie.

Although many features of ice flow in the region date from deglaciation, the generalized flow pattern (see Fig. 6), which excludes features displaying strong local topographic control and obviously young features, likely represents conditions at the last glacial maximum. The last glacial buildup in this region occurred after nonglacial conditions that ended about 24 000 years ago in Liard Lowland (Klassen, 1987). Deglaciation, although undated throughout the entire southeastern Yukon and only poorly dated elsewhere in the territory, may have occurred as early as 10 000 or even 12 000 years ago. Parts of Shakwak Valley, near active glaciers in the St. Elias Mountains in southwestern Yukon, were deglaciated by 12 000 years ago and the Cordilleran Ice Sheet had almost entirely disappeared by 10 000 years ago (Clague, in press). Furthermore, northwestern Canada appears to have been considerably warmer than present by 12 000 years ago with summer insolation peaking about 10 000 years ago (Delorme and Zoltai, 1984; Ritchie, 1987). Retreat of the northeastern Cordilleran Ice Sheet may have begun as early as 16 000 years ago, for the adjacent margin of the Laurentide Ice Sheet was withdrawing from its limit by that time (Hughes et al., 1981; Hughes, 1987).

SURFICIAL MATERIALS AND LANDFORMS

The distribution of surficial materials and landforms in the Frances Lake map area is shown on four 1:100 000 scale maps (Maps 1674A-1677A). General field checking and sampling throughout the area involved 35 hours of helicopter flying and 100 or so stops in alpine areas and along rivers. More concentrated work was done using a vehicle along the two major highways of the area, a boat along Frances Lake, and foot traverses around six alpine fly camps. Ground observations were recorded at more than 400 sites shown on the maps, and more than 200 till samples were analyzed for texture, carbonate content, granule lithology, and concentrations of base metals, silver, and uranium. Table 1.1 (Appendix 1) records these analyses; metal occurrences judged to be anomalously high for a given lithic facies of till are noted on the maps.

The maps were compiled on 1:50 000 scale topographic bases from interpretation of 1:30 000 scale vertical airphotos. A preliminary photogeological map was prepared prior to fieldwork and served as the basis for ground checking by a crew of two. Re-interpretation of airphotos after the field season involved about 25% correction to the preliminary mapping.

Photogeological interpretation is made easier by a close association between surficial materials and vegetation. Below treeline throughout most of the map area, till is covered with a spruce forest growing in a thin blanket of peat moss, except in recently burned areas where aspen and birch dominate. Near treeline and at lower altitudes in the northeastern part of the map area, spruce cover on till gives way to alpine fir, which reflects a tolerance of the fir for cooler and shorter growing seasons. Lodgepole pine stands growing in an understory of lichen (Fig. 7) dominate droughty sand and gravel substrates throughout most of the area below treeline. This pine gives way to stands of dwarf birch (Betula glandulosa) and lichen in the valleys of the northern part of the area and in higher valley floors, such as along upper Conglomerate Creek, in the south (Fig. 8). The rather abrupt northward transition from spruce to fir on till substrates and from pine to dwarf birch on sand and gravel substrates marks an important ecological boundary within the map area.

Frances Lake map area lies in the zone of discontinuous permafrost (Brown, 1967). Oddly, permafrost was encountered in the field only in the lowest parts of the area, along the bluffs of Frances Lake, where peat blankets steep slopes in open stands of stunted spruce and larch to depths of more than 30 cm (Fig. 9). Frost table was not encountered in shallow pits (< 1 m) dug in alpine areas, but the widespread distribution of rock glaciers presumably indicates numerous occurrences of permafrost at north-facing or otherwise shadowed sites

Figure 7. Lodgepole pine stand with understory of lichen on glaciofluvial gravel in Hyland River valley. Closed depressions are kettle holes. GSC-203603-M

Figure 8. Dwarf birch stands in lichen-covered glaciofluvial gravel, upper Little Hyland River. GSC-204510-C

above treeline. Stream cuts (thermokarst) through one rock glacier revealed much massive foliated ice with debris bands. Yet not all rock glaciers necessarily have ice in them today. Many rock glaciers exhibit no meltwater discharge at their sides or snouts and lichen cover in relict discharge channels indicate abandonment long ago.

Palsas are widespread and prominent features of peat bogs in the area of Macmillan Pass only 140 km north of Frances Lake map area (Kershaw and Gill, 1979). None were observed in the numerous small bogs of the study area so it appears that an important environmental threshold occurs between the two areas. Palsas of Macmillan Pass have been degrading since the 1940s.

Snow avalanching is an important and widespread contemporary process. Invividual avalanche tracks and slopes with closely spaced avalance tracks are shown on the surficial geology maps. Tracks are mostly 1 to 2 km long and appear as deforested belts on and below steep to moderately steep slopes (Fig. 10). The runout zone is usually on the middle slopes of broader valleys such as that of Hyland River. In narrower valleys, for example around Tustles Lake, Broten Lakes, and Anderson Creek, the avalanches run out on the valley floor. Thousands of avalanche tracks can be seen on the 1950 airphotos. All occurred within an interval that was too brief to allow for reforestation, perhaps in the order of a century or so. Considering that many tracks are likely used repeatedly, because they are controlled largely by source area topography and funnelling of flow along ravines, tens of avalanches capable of denuding forested slopes over width of tens of metres and lengths of a kilometre or more must occur annually. The distribution of avalanche tracks and slopes provides initial guidance to land use planning and engineering design for roads and other features.

The surficial materials, other than bedrock, are grouped into six genetic categories: till, and sediments of glaciofluvial, glaciolacustrine, eolian, alluvial, and colluvial origin. Varves underlie till in a small section on Yusezyu River and are the only known sediments in the area that predate or correlate with the Late Wisconsinan (McConnell) ice advance. All other sediments, including more extensive glaciolacustrine sediments that date from deglaciation, are of Late Wisconsinan and Holocene age and were deposited during and after retreat of the McConnell Glaciation. Tills are subdivided on the basis of age into McConnell Glaciation and Neoglaciation. Other glacigenic sediments of Neoglacial age occur, particularly outwash, but are included with the much more extensive deposits of McConnell age because of the mapping scale.

Sand and gravel deposits, in the form of ice contact stratified drift, proglacial outwash, and postglacial alluvium are both widespread and voluminous in all the larger valleys. Substantial granular resources, in the form of alluvial fans, occur in most smaller and higher valleys. In addition, sandy till is loose enough to be used for road material on the major highways. Hence the area has granular resources that are likely surplus to any future need.

Figure 9. Typical vegetation at permafrost site along Frances Lake — open spruce stand in blanket bog on moderately steep till slope. Frost table is encountered within the peat blanket. GSC-203603-N

Figure 10. Snow avalanche tracks on the slopes of Hyland River valley. GSC-203603-0

Bedrock: Quaternary modification

As already described, a wide variety of ages and lithologies of bedrock occurs in the area: from Hadrynian to Cretaceous, from carbonate and shale to monzonite and serpentinite. Despite the mountainous relief, well exposed bedrock occupies only about 15% of the area and is restricted mostly to the crests of alpine ridges and the side and back walls of alpine valleys, which are difficult to access because of buttressing screes. The bedrock surface is modified by large-scale glacial erosion and, to a lesser degree, by periglacial and other alpine slope processes, over most of its outcrop area (R_1*). This erosion has three main expressions: in the form of alpine cirques and aretes in the Logan Mountains and Ragged Range; in the form of major glacial troughs resulting from selective linear erosion along the main north-south valleys and along transection valleys that cross mountain ranges, including formation of large fiordic lakes; and in the form of areal scour, nearly restricted to the broad Frances River valley and the lower reaches of its tributaries and to the lower Simpson Ranges. In the Simpson Ranges modification by areal scour appears to be superimposed on modification by scalloping of the ranges by cirque erosion earlier in the Quaternary. Only small patches of areal scour occur in the Logan Mountains where ice sheets apparently failed to reach sufficient height to degrade seriously the higher cols and ridges. Nevertheless, all peaks seem to have been overtopped by ice for no nunataks are recognized and erratics, patches of till, and glacial landforms (meltwater channels, small lateral moraines) occur at very high elevations.

Some rock surfaces show little or no signs of erosion by either alpine glaciers or ice sheets (R_2) and, hence, are considered remnants of the preglacial topography (see "physiography"). In places, these surfaces extend beneath a thin till mantle, as in the Tungsten area and adjacent to lower Hyland River valley. Elsewhere they are incised by small lateral meltwater channels, which demonstrates that they are not areas that escaped glaciation. The surfaces of unit R_2 are mantled with felsenmeer sprinkled with erratics.

McConnell till and till landforms

Distribution

Till deposited during the retreat of McConnell Glaciation covers about 70% of the study area and is continuous along most valleys. Generally it completely masks the local relief of the underlying bedrock. Till veneers, less than about 2 m thick and locally discontinuous, are restricted largely to high alpine slopes, spurs, and broad summits. Patches of thin till also occur within areas mapped as bedrock.

Landforms

Till-cored landforms, both ice moulded and morainal, are widespread. Most of the floor of Frances River valley consists of a drumlin field with closely spaced forms in the southern part (Fig. 11). The head of this drumlin field extends northward into Yusezyu River valley and its distal end extends 20 km south of the map area (Klassen and Morison, 1982), giving a total length of about 100 km. Four smaller drumlin fields, the largest about 20 km long, occupy reaches of Hyland River valley floor and midslope from its northern to its southern end. Most individual forms in these drumlin fields are roughly symmetrical, and hence nondirectional, but those that have asymmetrical longitudinal profiles all indicate southward flow, as do a few crag-and-tail features.

Most till-cored moraines in the map area are lateral moraines; medial and end moraines are less common. Hundreds of individual lateral moraine segments occur on middle and upper valley slopes throughout the area, the largest extending only 5 km between Dolly Varden Creek valley and Hyland River valley. Lateral moraine segments in many places occur as flights of features trending nearly parallel to the contours. The largest features form drift benches 10 m or so wide but most are small threads of drift, especially where they directly overlie bedrock (Fig. 12). Some such features are positioned near the very tops of steep, rocky alpine slopes and, where occurring as nested sets, illustrate the initial appearance and progressive enlargement of nunataks during deglaciation. Lateral moraines commonly occur in association with lateral meltwater channels. In many places, channels and moraine segments can be reasonably correlated on airphotos based on their downvalley gradients, and in this manner quasi-continuous ice frontal positions can be reconstructed.

Medial moraines are common features in alpine areas where they extend as one or more mid-valley ridges down-ice from spurs that separate cirques or groups of cirques. Most features are less than 2 km long and are only a few metres high. Large, sharp-crested medial moraines project down-ice from confluences of larger lower valleys, as in a valley north of Tyers Creek and in several valleys of the Anderson Lake — Tellei Lake region (Fig. 13). These features are sharp crested and contain several metres of drift accumulation. Many alpine medial moraines indicate late stages of flow by cirque glaciers during deglaciation which otherwise have left no morphological record of this event.

End moraines composed of till are relatively rare, minor features. The largest, about 1 km wide and 4 km long with 30 to 40 m of relief, forms a ridge across the mouth of Narchilla Brook valley. It was built by ice retreating northward. Small end moraine ridges in lower Hyland River valley, just south of Moose and Jackpine creeks, were also built by a northward-retreating ice lobe. The most prominent end moraines are those that were built at the mouths of alpine valleys by alpine glaciers after their separation from the main trunk glaciers. Moraines of this sort occur in the valley draining westward from Mount Billings and, more spectacular ones, at the mouths of four valleys perched above Little Hyland River and Nahanni Range Road (Fig. 14). However, most alpine valley mouths are devoid of end moraines, which

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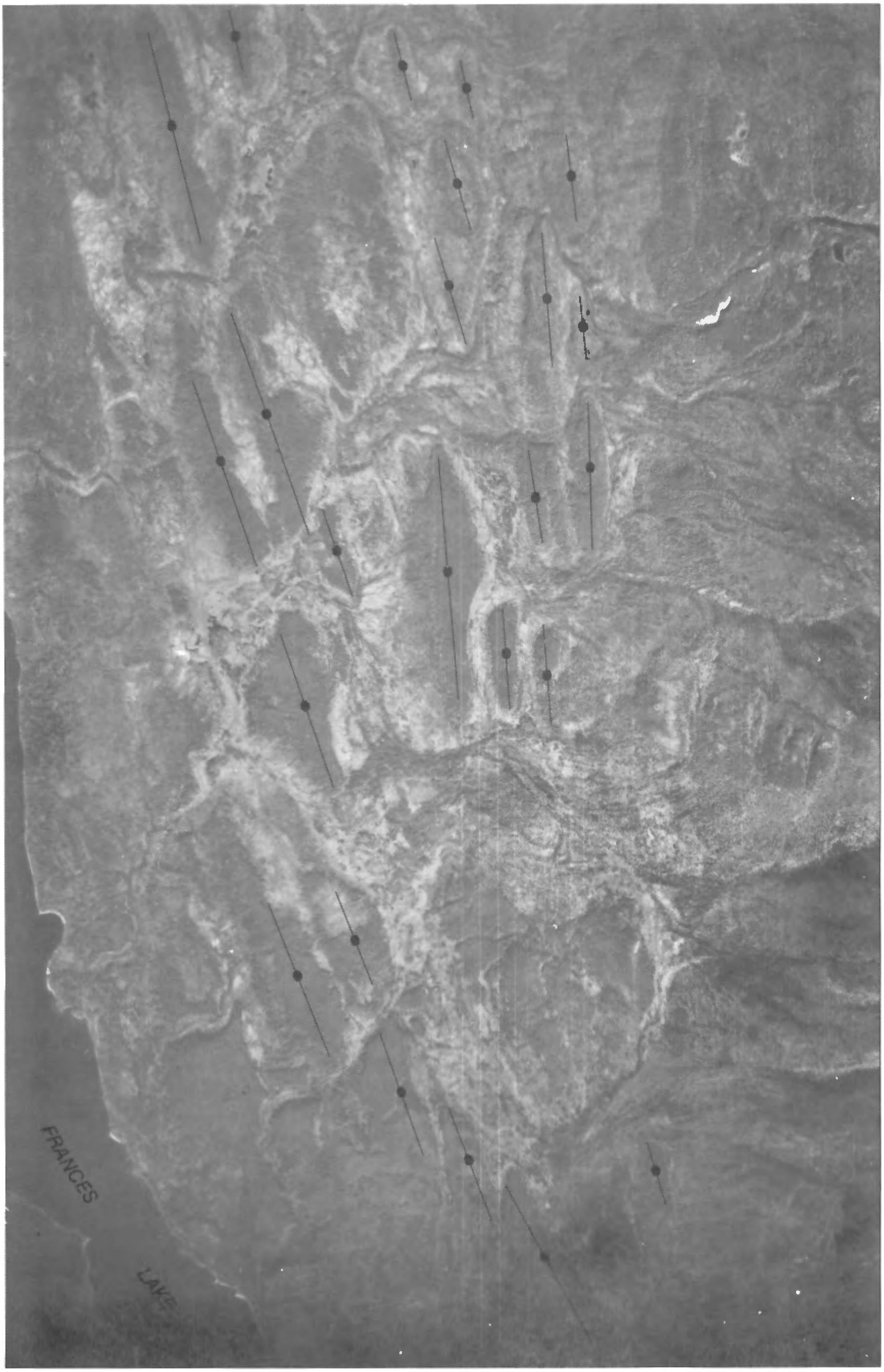
*Map unit designator on Maps 1674A-1677A.



GSC

Figure 11. Part of Frances River valley drumlin field on the east side of Frances Lake across from the Territorial Campground. Drumlins are forested "islands" rising above broad, flat, meltwater channels occupied by bogs that appear light-toned. NAPL A12281-161; approximate scale 1:30 000

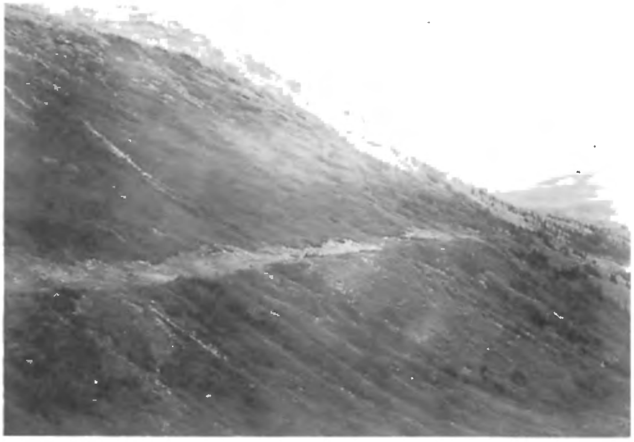


Figure 12. Lateral moraine bench on alpine valley wall. GSC-204511-E

Figure 13. Large medial moraine at junction of two transection valleys north of Tyers River, northwest part of Dolly Varden Creek map area (Map 1674A). GSC-203603-Y

Figure 14. Large end moraine at cirque mouth, as seen from Nahanni Range Road along Little Hyland River, northeastern part of Little Hyland River map area (Map 1677A). Crest of moraine forms skyline to left of arrow. GSC-203603-W

indicates that in most cases deglaciation proceeded without halt following separation of alpine and lowland ice. Small end moraines occur farther up a few alpine valleys but most appear to have been deglaciated all the way to the cirque heads without interruption.

A distinctive, thick hummocky till, composed almost entirely of black shale and including large, tabular erratics, covers the valley floor and lower slopes just west and north of Frances Lake. It forms belts along, rather than across, the direction of ice flow and so is not considered an end moraine. It interrupts the drumlin field in Frances River valley and, hence, likely is younger than the drumlin field. Possibly a heavy, basal debris load in the ice caused disorganized flow or stagnation during deglaciation.

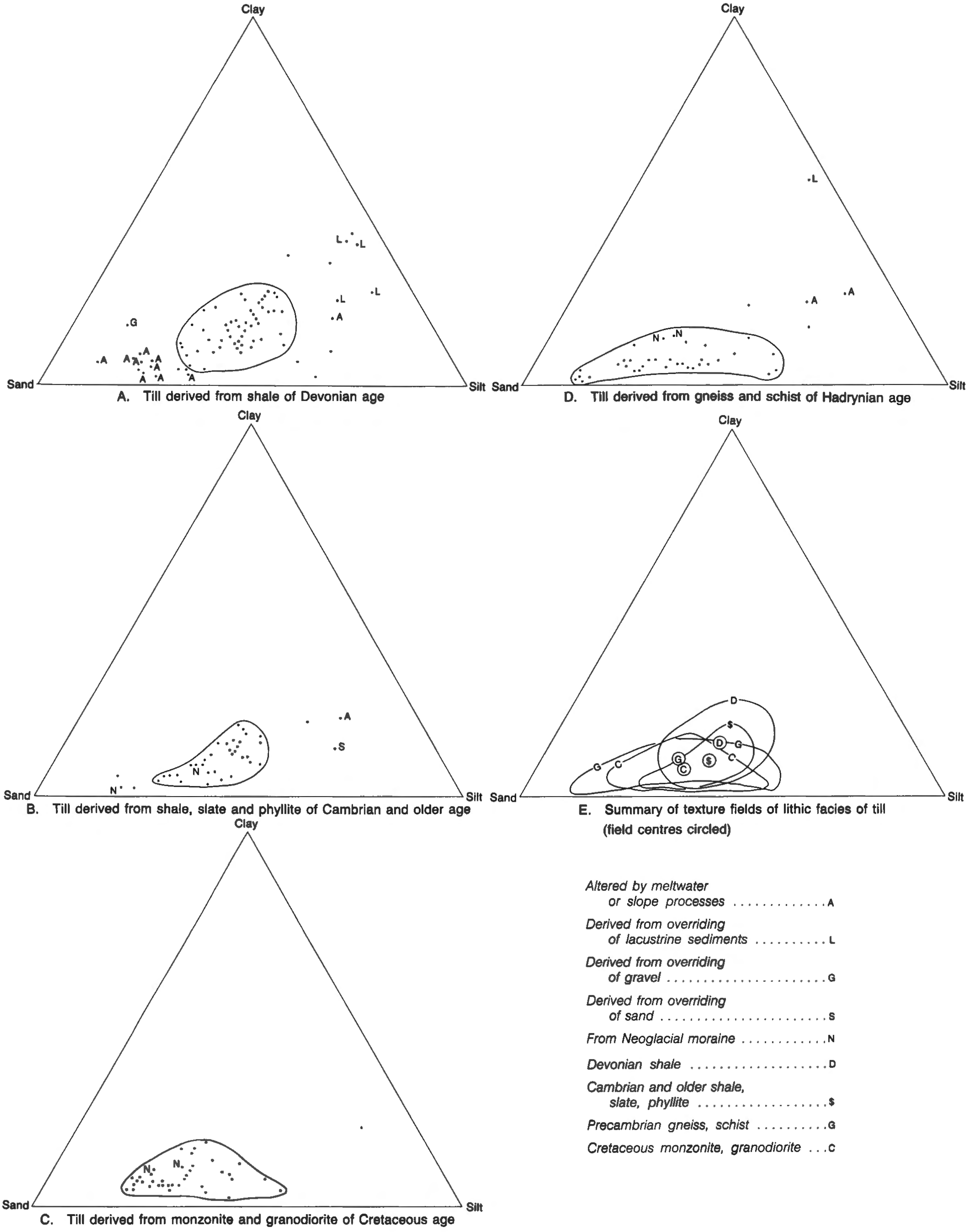
Lithic composition

The till of Frances Lake map area is as varied in lithic composition as is the bedrock and more varied in the sense that various source rocks are mixed as clasts and matrix material in the till. Nevertheless, in most places the till composition strongly reflects the lithology of the underlying bedrock; for example, in the central crystalline terrane tills have mostly granitic clasts (derived from gneiss, granodiorite, and monzonite) and along Frances River valley till has been derived mostly from black shale (Table 1.1 in Appendix 1). Elsewhere the tills are derived almost entirely from phyllite, serpentine, limestone, red shale.

Data from about 200 till samples are inadequate to address the question of direction and distance of debris dispersal but form an initial data set that can be augmented by future sampling. Over most areas covered by Laurentide ice that sample density would be adequate (e.g., Dyke, 1984), but the complexity of bedrock and topography in the map area requires a sample density some tenfold greater.

Grain size

The grain size composition of the till is but a poor indicator of the lithic composition or source of the till, for it varies only within narrow limits (Fig. 15). Representative textural fields for each lithic till facies are drawn to exclude samples that were either judged in the field to have been altered by meltwater or by postglacial slope processes or appeared to have been derived from overriding of preexisting Quaternary sediments. Tills derived primarily from bedrock sources as widely different as shale and monzonite have texture fields that overlap by a much as 50%. Field centres show a slight fining as provenance shifts from gneiss and schist to slate and phyllite to shale but these centres are separated by only a 7% difference in silt and clay content and only a 12% difference in sand content (Fig. 15E). Local alteration by postglacial slope processes of till derived from shale has led to much larger shifts in grain size, primarily by depletion of fines (Fig. 15A). The facies most varied in grain size is that derived primarily from gneiss and schist, which



A. Till derived from shale of Devonian age

B. Till derived from shale, slate and phyllite of Cambrian and older age

C. Till derived from monzonite and granodiorite of Cretaceous age

D. Till derived from gneiss and schist of Hadrynian age

E. Summary of texture fields of lithic facies of till (field centres circled)

Figure 15. Ternary diagrams of till texture for various lithic facies in the Frances Lake area.

has the widest range of silt and sand content (Fig. 15D). This variability likely reflects the local variability in the proportion of gneissic versus schistose bands in the source rock, with the more micaceous schists yielding more silt. Tills derived primarily from Devonian shale have much less variability and a more uniform scatter about the field centre (Fig. 5A), perhaps reflecting a greater uniformity in the properties of the source rocks.

Carbonate content

At the available sample density the regional variation in till matrix (<63 μm) carbonate content is difficult to interpret in terms meaningful to glacial history or processes. Carbonate content is as high as 53% in till overlying limestone (Fig. 16). However, it is commonly 1 to 10% in the four major lithological groups that are

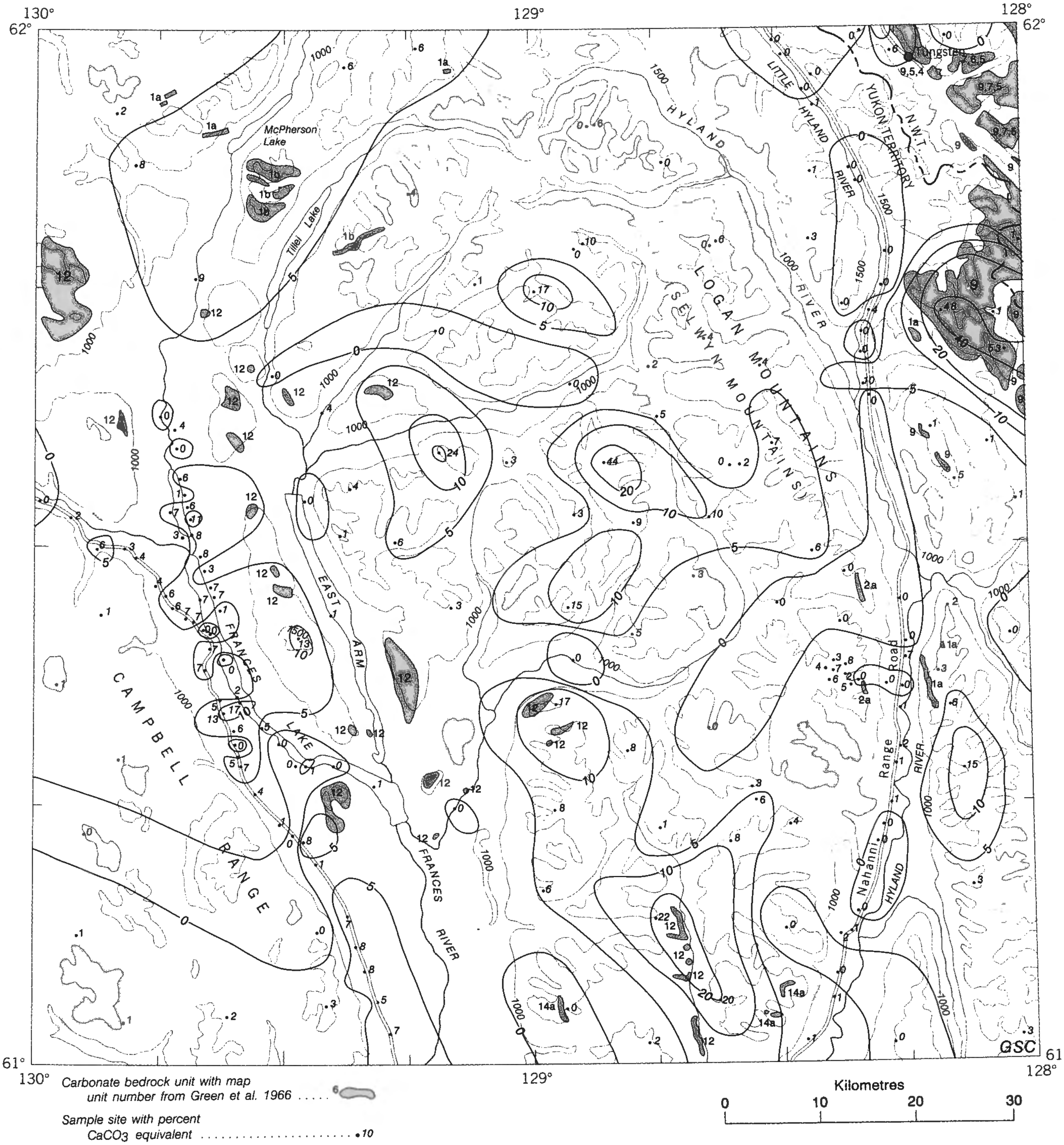


Figure 16. Carbonate content (%) of till matrix (<63 μm fraction).

predominantly noncalcareous (Fig. 16 and 17). It reaches levels well in excess of 10% (e.g., isolated highs of 17, 24, and 44%, Fig. 16) on local marble bands in the Precambrian gneiss and schist.

The till is entirely noncalcareous in only small parts of the area; levels range from 1 to 5 per cent in most places. The moderately calcareous nature of the till derived from Devonian black shale perhaps is explained by the lime content of the shales, but the moderate to low carbonate content of till overlying the Cretaceous batholiths is less easy to explain. Perhaps it indicates widespread, weak dispersion resulting from several glaciations or the more widespread distribution of small, carbonate bedrock units than is known at present.

Except locally, the surficial deposits and bedrock have only a low capacity to buffer the effect of acid precipitation. The coarse grained character of much of the till enhances permeability, decreases buffering capacity of soils, and enhances the potential for mobilization of toxic elements by acidified soil water.

Trace element contents

The clay fractions (<2 μm) of till samples were analyzed for concentrations of copper, lead, zinc, cobalt, nickel, silver, chromium, molybdenum, manganese, iron, cadmium, uranium, arsenic, and mercury (Table 1.1 in Appendix 1) as part of a national collection program for till geochemistry data. Prospecting was not an objective of the fieldwork, yet the general results may be of value to mineral exploration. The lithic till facies have distinct geochemical signatures, in that background levels of various elements differ from facies to facies. Because of this, samples with anomalously high elemental levels are separated from those with background levels at the facies level, which is done simply through interpretation of histogram plots (Fig. 18). All measured concentrations are listed in Table 1.1 (Appendix 1) and sample numbers and anomalous elements, keyed to the table, are plotted on the surficial geology maps.

Geochemically, the most distinctive till facies are those derived from Devonian shale and those derived from granitic rocks. The shale-rich till is distinctive particularly because of its high background levels of mercury (Fig. 18A); background levels approach 1000 ppb compared to 200 ppb in the other facies. Till derived primarily or entirely from Cretaceous monzonite and granodiorite and till derived from Precambrian gneiss (Fig. 18C,D) have much higher background concentrations of uranium than do other facies. Background levels approach 20 ppm, which is much higher than in most till derived from similar rocks in the Canadian Shield (Dyke, 1984). Background levels of uranium in the other facies are less than 6 ppm, and, in most areas, less than 4 ppm. Till derived from Cambrian and older shale (Fig. 18B) is less easy to distinguish geochemically from other facies. But it does have uniformly low levels of cadmium, molybdenum, and silver in comparison to other till, including that derived from Devonian shale, as well as slightly higher background levels of arsenic. All facies exhibit much broader ranges of background concentrations of zinc and manganese than of other elements, a common feature of tills on the Precambrian Shield (Dyke, 1984).

Many samples contain anomalous concentrations of one or more elements, although a much higher sample density might reveal these "anomalies" to represent simply areas of enhanced background levels. More than half of the samples with anomalous concentrations have

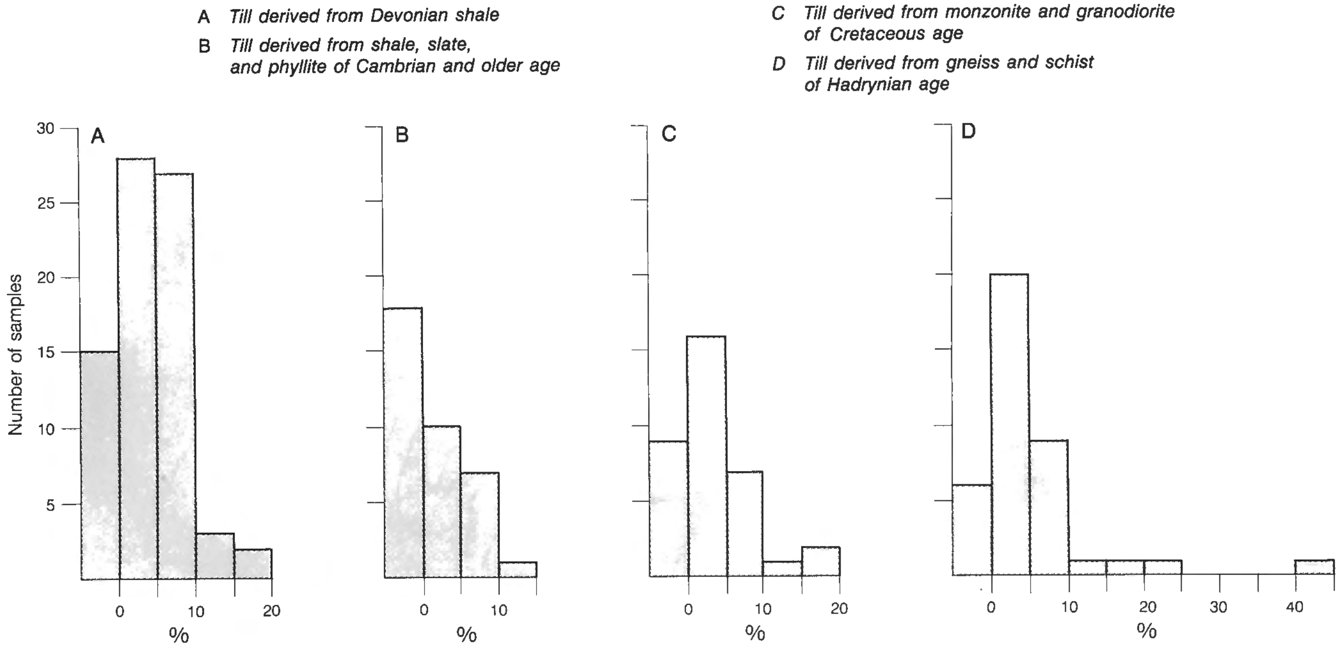


Figure 17. Histograms of carbonate content of till matrix for tills derived primarily from four, noncalcareous rock sources.

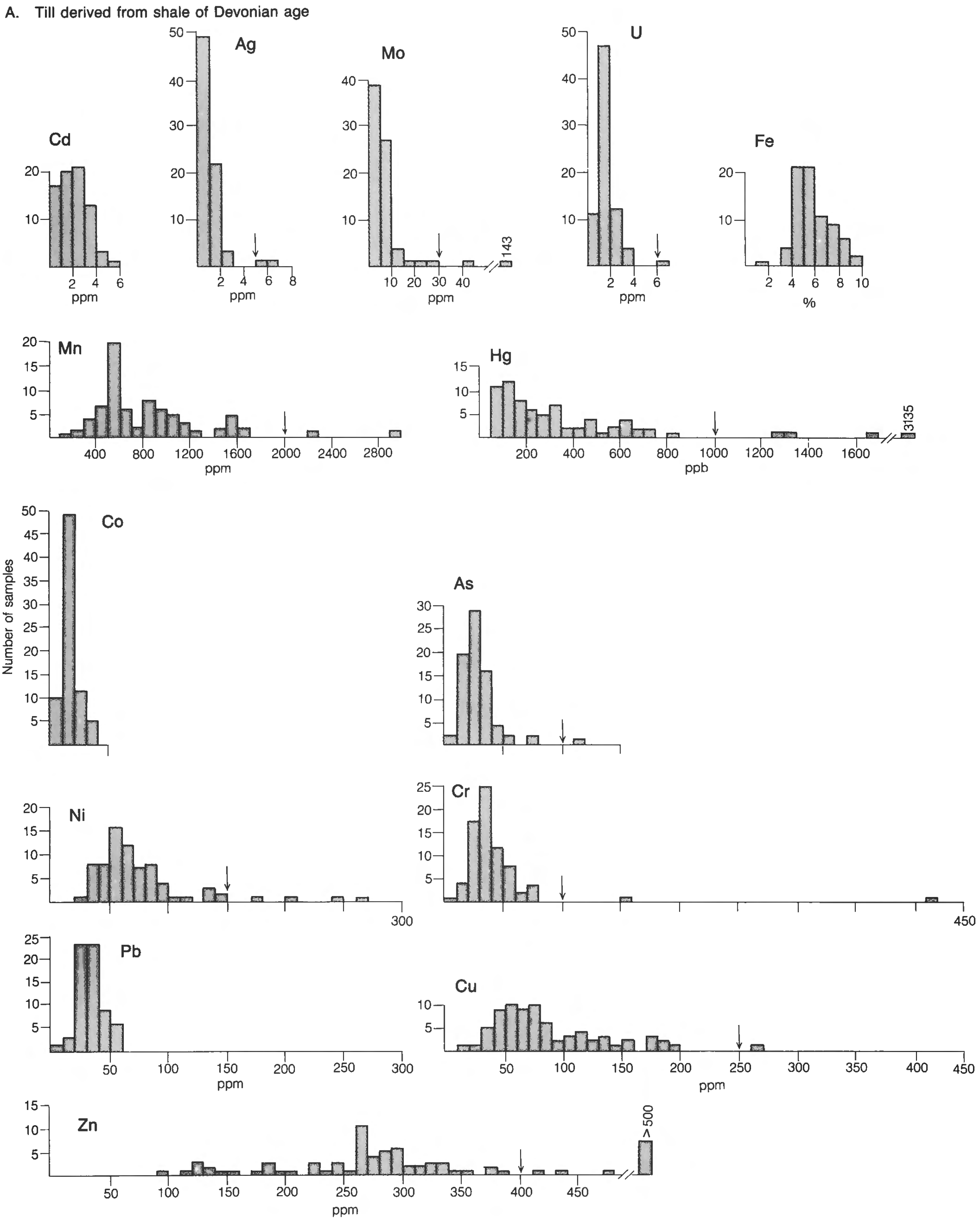

A. Till derived from shale of Devonian age

Figure 18. Histograms of trace element concentrations in the clay fractions of the various lithic facies of till.

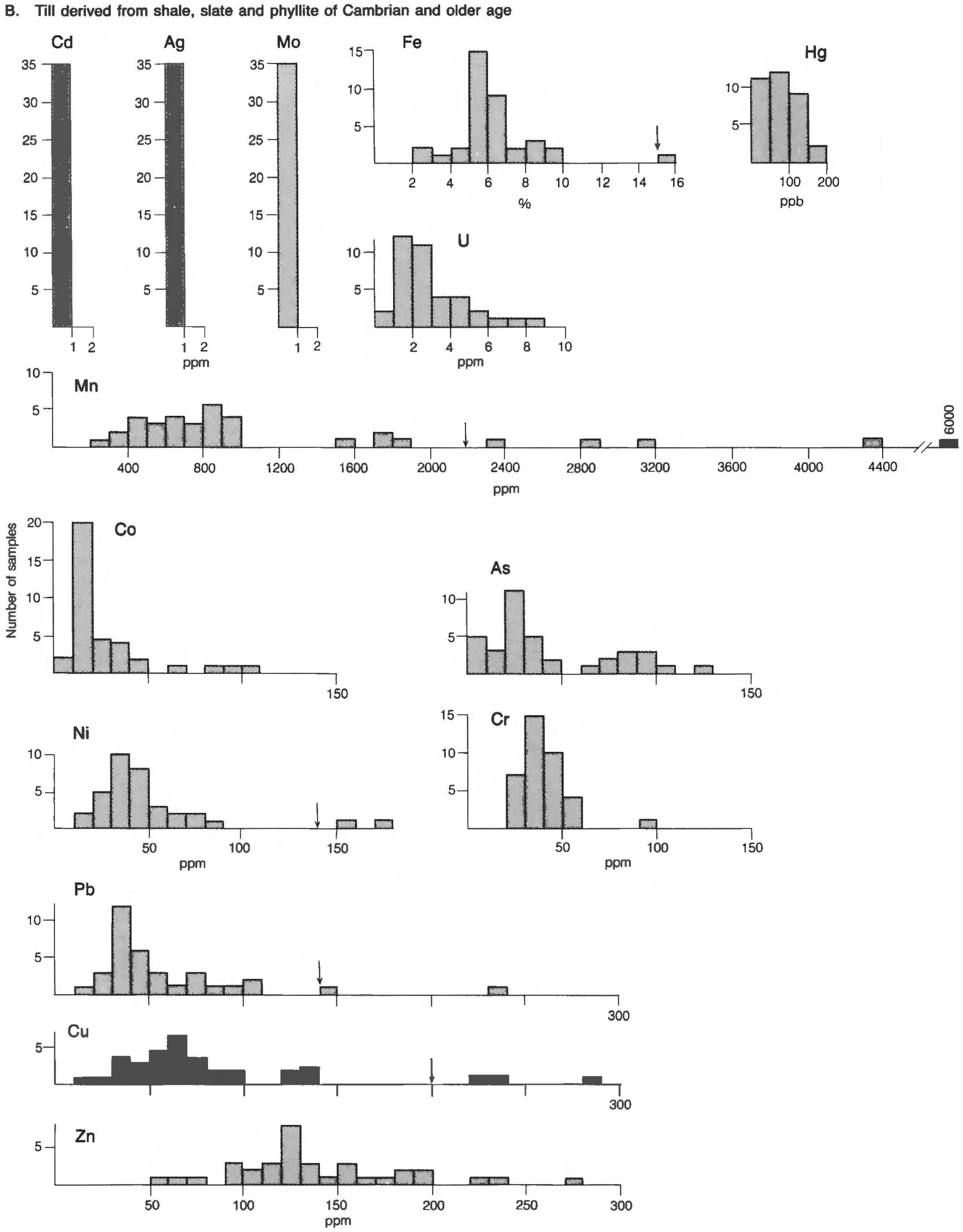

B. Till derived from shale, slate and phyllite of Cambrian and older age

Figure 18. (cont'd)

C. Till derived from monzonite and granodiorite of Cretaceous age

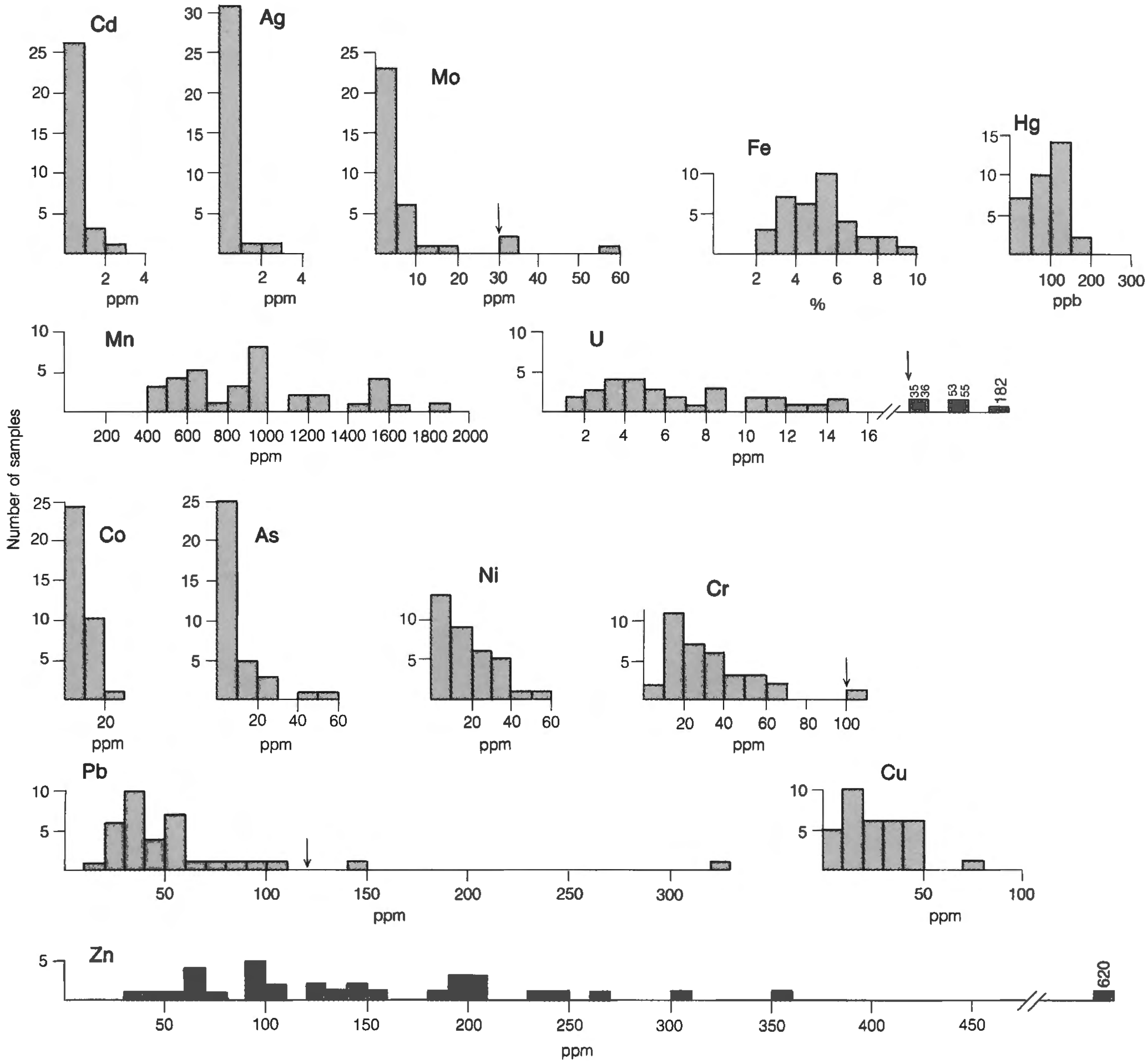


Figure 18. (cont'd)

D. Till derived from gneiss and schist of Hadrynian age

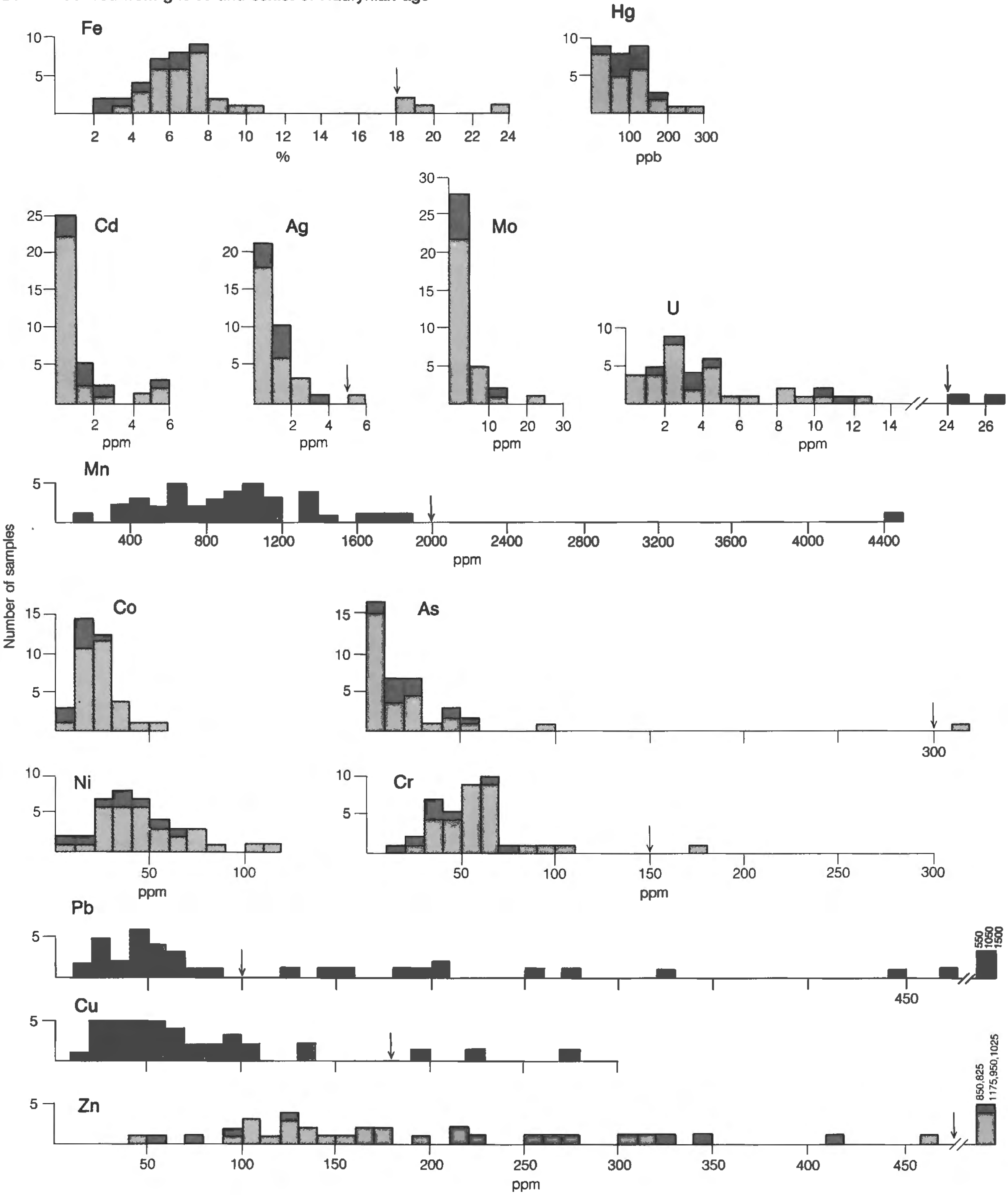


Figure 18. (cont'd)

high levels of lead or zinc, or both. These occur mostly in two groups (Fig. 19). One group forms a NNW-SSE cluster of samples along the eastern side of the Cretaceous batholith and contacting bands of Precambrian gneiss and schist. Several of these samples are from three known areas of mineralization that have been prospected by exploration companies. The other group is in Frances River valley along Robert Campbell Highway and the shore of Frances Lake and these samples are of till derived almost entirely from Devonian shale. Two samples with anomalous mercury levels occur in the same area. No mineralization of this rock has been reported from this area.

Two other groups of anomalous samples are recognized. Three samples with high concentrations of uranium are of till overlying the Cretaceous batholith and contacting gneiss at widely separate sites. Five samples of till overlying or near serpentinite and greenstone have high levels of nickel and chromium, although there are too few

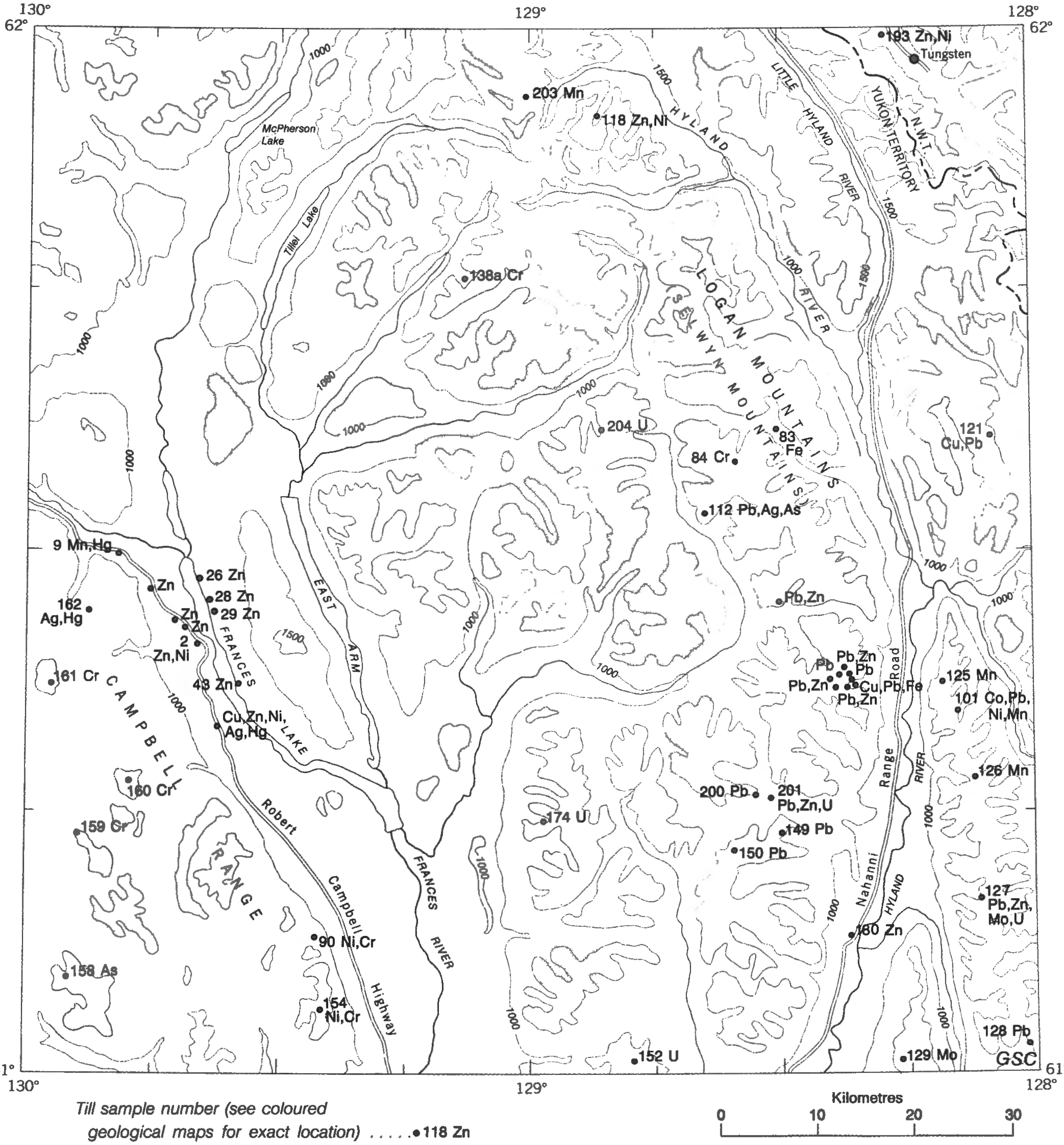


Figure 19. Till samples exhibiting anomalously high concentrations of trace elements.

samples of till derived from these rock types to separate background properly from anomalous levels.

Nothing in the sample data indicates long-distance glacial transport of elements at the sites of anomalous samples, so sample geochemistry is thought to reflect properties of the local bedrock. However, some appreciable displacement from source may have occurred along Frances River valley for rate of glacier flow was likely higher in ice streams occupying the large valleys than in ice crossing the mountains.

Glaciofluvial deposits and landforms

Distribution and classification

Glaciofluvial deposits form trains of sediment along the axes of most of the lower valleys. They are nearly continuous, or interrupted only by fluvial deposits derived from them, along the valleys of Flat, Little Hyland, Hyland, Dolly Varden, Tyers, Frances, Thomas, Yusezyu, Tuchitua, and several other rivers, where they are as much as 30 m thick. In places they are reworked by modern streams. They also occur well away from the major rivers, such as along the lower east wall of Frances River valley, where they were isolated from source upon deglaciation, and as patches here and there through the alpine massifs.

Glaciofluvial deposits are divided into ice contact stratified drift and proglacial outwash. Both consist of gravel and sand, but the ice contact sediments generally are much coarser than proglacial outwash, with maximum clast size of about 100 cm in the former compared to about 20 cm in the latter. They were deposited by high-energy, dominantly braided, streams but bedding is much more chaotic and disturbed by faulting and slumping in the ice contact sediments than in the proglacial sediments due to removal of supporting ice masses.

Landforms

Ice contact and proglacial sediments are separated from each other and are further subdivided on the basis of morphology. Ice contact stratified drift is of two main types reflecting environment of deposition. The most widespread type exhibits pronounced hummocks, ridges, or both and was formed by deposition in moulins, crevasses, and tunnels just behind the retreating ice margin. Eskers, crevasse fillings, and moulin kames occur together in many deposits. In places, such as along lower Frances River, multiple, parallel, anastamosing eskers trend at right angles to crevasse fillings or thread through hummocky kame fields, which indicates deposition in locally stagnant, ice marginal zones. The longest esker is about 5 km long and most are only 1 to 2 km long. Crevasse fillings are more numerous than, and almost as large as, eskers. Large fields of crevasse fillings occur within ice contact stratified drift deposits at the south end of a lake just east of Tuchitua River, along upper Tyers River and in several deposits along Hyland and Little Hyland rivers, where some are crossed by Nahanni Range Road (Fig. 20). Crevasse fillings also occur in isolation from other glaciofluvial sediments and directly overlie till along lower Dolly Varden Creek valley, along valley slopes on both sides of the east arm of Frances Lake, and east of the main arm of Frances Lake. In places they trend directly up and down moderately steep slopes and are spaced some 100 to a few hundred metres apart. Some connect farther downslope with subglacial meltwater channels also oriented transverse to the direction of former ice flow. Crevasse fillings east of the main arm of Frances Lake overlie drumlins in places and trend along, across, and oblique to former ice flow direction, forming a reticulate network overall. These fields indicate that, locally, valley glacier snouts were stagnant and crevassed through to their bases during deglaciation. The width of the stagnant zone at any time, judging from these assemblages of landforms, was probably not more than 10 km and rarely more than 5 km.

Another category of ice contact stratified drift either forms terraces with distinct ice contact escarpments, where it was deposited as ice marginal deltas or fans in small ice dammed lakes and as lateral kame terraces, or forms end moraines. Frontal ice contact escarpments occur at both south and north ends of Tuchitua River valley, one formed by the margin of a lobe retreating westward, the other along the margin of a lobe retreating northward. Other frontal terraces were formed in Hyland River valley, near the headwaters of Tyers River, and just west of the East Arm of Frances Lake, all by northward-retreating ice. Lateral kame terraces occur along the main arm of Frances Lake, along the lower east wall of Frances River, and along upper Hyland River. End moraines comprised of stratified drift outline collectively a dozen or so successive northward-retreating ice front positions along both arms of Frances Lake (Fig. 21) and along an adjacent stretch of Tyers River valley.

Figure 20. Borrow pit face across a crevasse filling on the west side of Nahanni Range Road, northeast part of the Dolly Varden Creek map area (Map 1674A). Top of feature flattened by bulldozer. GSC-203603-Q

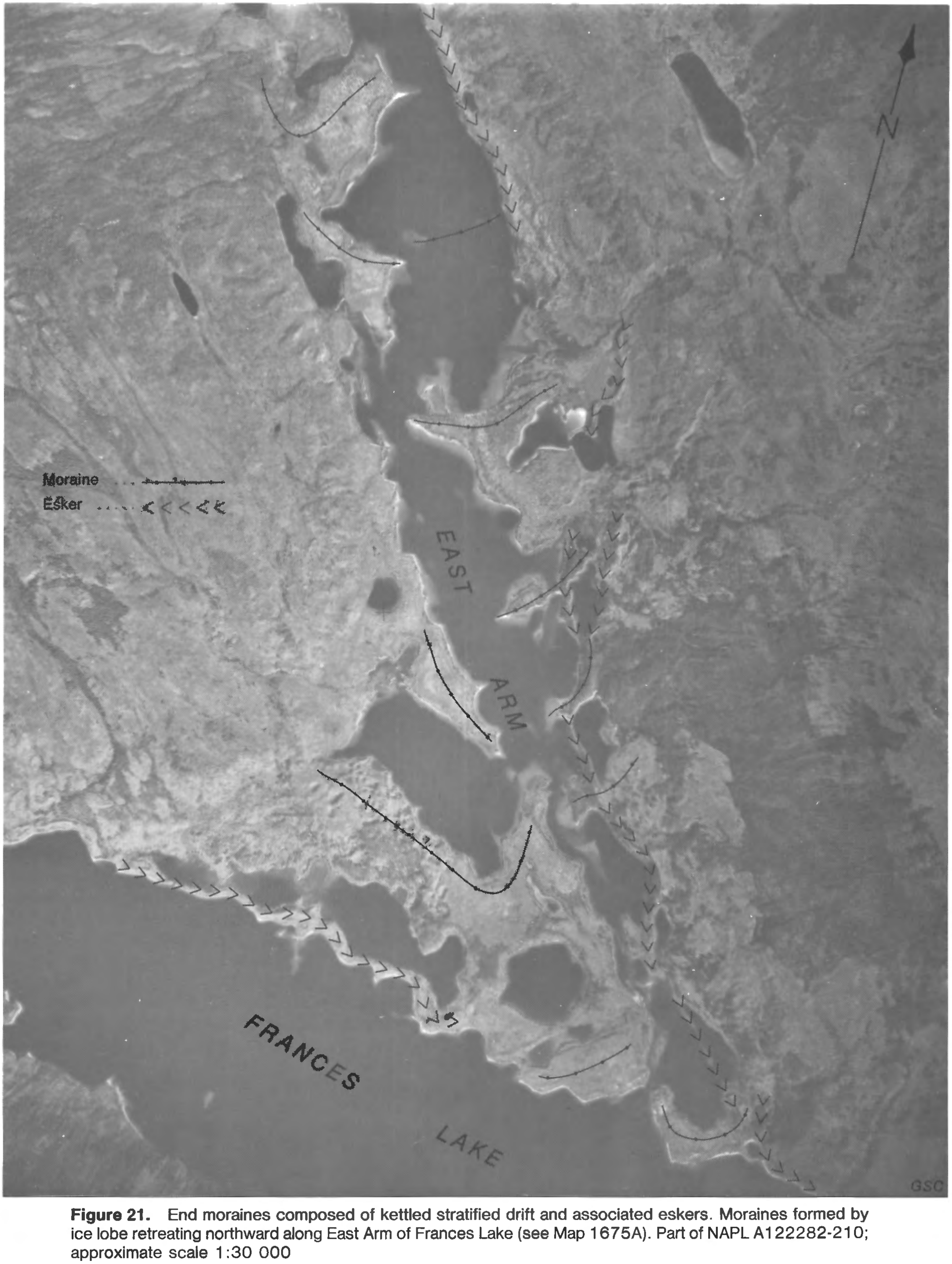


Figure 21. End moraines composed of kettled stratified drift and associated eskers. Moraines formed by ice lobe retreating northward along East Arm of Frances Lake (see Map 1675A). Part of NAPL A122282-210; approximate scale 1:30 000

Proglacial outwash underlies abandoned terraces that commonly display well preserved braided channel patterns. It is subdivided into proximal outwash where the terraces are kettled and distal outwash where they are not. Where one contacts the other, the distal outwash forms lower terraces or plains. Kettled proximal outwash, incised by deep meltwater channels, forms two trains of sediment, connected by a pair of deep meltwater channels incised in till, that extend for 32 km along the lower east wall of Frances River valley. The terracing of these sediments along with orientations of meltwater channels indicate that these sediments were laid down by meltwater coursing along the side of a large lobe of ice retreating up Frances River valley after separation from alpine glaciers to the east. Although the ice did not occupy a single position during deposition of all of this sediment, the sediment outlines by far the longest quasi-stable ice front position in the region.

Another large deposit of proximal outwash has a form similar to a terraced delta perched on the west wall of lower Hyland River valley. The shape of the deposit along with orientations of eskers and meltwater channels indicate that the source of sediment was ice in Conglomerate Creek valley. The resemblance to a delta suggests that the lower Hyland River valley was occupied by a lake at time of deposition. Although there are no typical glaciolacustrine sediments at the surface of this part of the valley, a lake likely existed there prior to a readvance of the Hyland Valley ice lobe: till in this part of the valley is exceptionally fine grained, as if derived from overriding of lacustrine sediment (Fig. 15), and a thin lacustrine sediment, proximal varves, is exposed between two tills in a borrow pit along the highway just south of the delta (Fig. 22).


Figure 22. Two tills with intervening lacustrine sediment formed during a readvance along lower Hyland River. Person's left foot is at contact of lower till and lacustrine sediment, which is 61 cm thick and extends up to about knee-level. The upper till extends up to the level of the person's left hand, where it is overlain by surficial lacustrine sediment (site of till samples 180 and 181 on Map 1674A). GSC-204510-A

Distal outwash differs from proximal outwash in its lack of kettles. It also differs from postglacial alluvium in two important respects: first, it is devoid of organic detritus, whereas postglacial alluvium includes organic material in many places; and secondly, it invariably exhibits a relict braided channel pattern on its terraces, whereas postglacial alluvium exhibits meander scroll patterns. Large distal outwash trains occur along Jules Creek in Frances River valley, along Tyers Creek, and along lower Hyland River. The two large and several small deltas that were built into Frances Lake following deglaciation indicate that the lake was then only 1-2 m higher than at present. The Territorial Campground is on the large delta at the mouth of Money Creek.

Glaciofluvial landforms are not restricted to glaciofluvial deposits. A subglacial meltwater channel cut about 100 m into bedrock crosses the interfluve between Yusezyu River and Thomas Creek. Other large rock-cut channels cross interfluves at several places in the Simpson Ranges. All indicate southeastward discharge of meltwater. Broad, shallow, flat-floored, proglacial meltwater channels cut in till form a confusing labyrinth of features in Frances River valley. The flat-floored channels are occupied by shallow bogs and only drumlins stand as forested "islands" above the lower areas that were ubiquitously scoured by meltwater (Fig. 11). Material eroded from these channels was deposited along Jules Creek and as thin sheets of gravel just east of the lowermost Frances River. Lateral meltwater channels a few metres wide and about 1 m deep occur singly and in profusion on many hillslopes (Fig. 23). Many channels are associated with lateral moraines and together they are the most useful indicators of the detailed pattern of ice retreat.

Glaciolacustrine deposits and landforms

Two large glacial lakes were dammed along northward-flowing tributaries to Hyland River because ice lobes in these valleys retreated downstream. Lacustrine silts and sands that accumulated in the more southerly of these lakes extend as heavily dissected terraces along both sides of the modern alluvial plain. Gulleying of these sediments has occurred to depths of 120 m, which is about the total depth of sediment. Most gulleys appear to have stabilized as they are heavily forested. The sediments extend south into the Watson Lake map area where the lake must have discharged into a headwater tributary of Coal River via a low, wide pass (Klassen and Morison, 1982; Klassen, 1983a, 1987). Less remains of the sediment deposited in the other large lake, probably because it has been largely removed by postglacial stream erosion. Dissected lacustrine terraces occur along part of the lower reach of the valley, the largest occurs on its eastern side. The lake, however, must have extended into the Flat River map area and spilled southward into West Coal River. Meltwater from these two lakes either entered other lakes in Coal River valley dammed by ice splaying northward from the Liard basin (Klassen, 1983a), or drained freely down Coal River. Careful mapping of the Flat River map area is necessary to explain the interaction of ice from the Logan Mountains and ice from the Liard basin during deglaciation. Glacial lakes were dammed by both ice masses and the interrelationships of the two sets of lakes could provide clues to the relative chronology of deglaciation.

An ice-dammed lake, in which only a veneer of sediment accumulated, existed briefly during deglaciation in a small basin east of upper Frances River. The lake and end moraines just to the north indicate a northward-retreating ice lobe.

As already mentioned, lower Hyland River valley was occupied by a lake of considerable size prior to a readvance. Lake sediments, comprising 1.5 proximal varves, are exposed between tills in a borrow pit face and the readvance till is excessively silty, but no lacustrine sediments are recognized at the surface.

Eolian deposits and landforms

Eolian deposits in the form of loess and dune sand are widespread in the drier central and western Yukon (Hughes et al., 1972) but, with the exception of White River Ash (see below), are rare in the wetter eastern ranges. No accumulations of loess were noted in the Frances Lake map area and dune sand occurs as a mappable unit at only one locality, on the north side of Tyers River. These dunes, now stable and forested, indicate a former wind direction westward, downvalley. Oddly, they occur on, and adjacent to, till rather than sandy glaciofluvial sediments. They likely date from early in the postglacial period, before establishment of forest cover on the till.

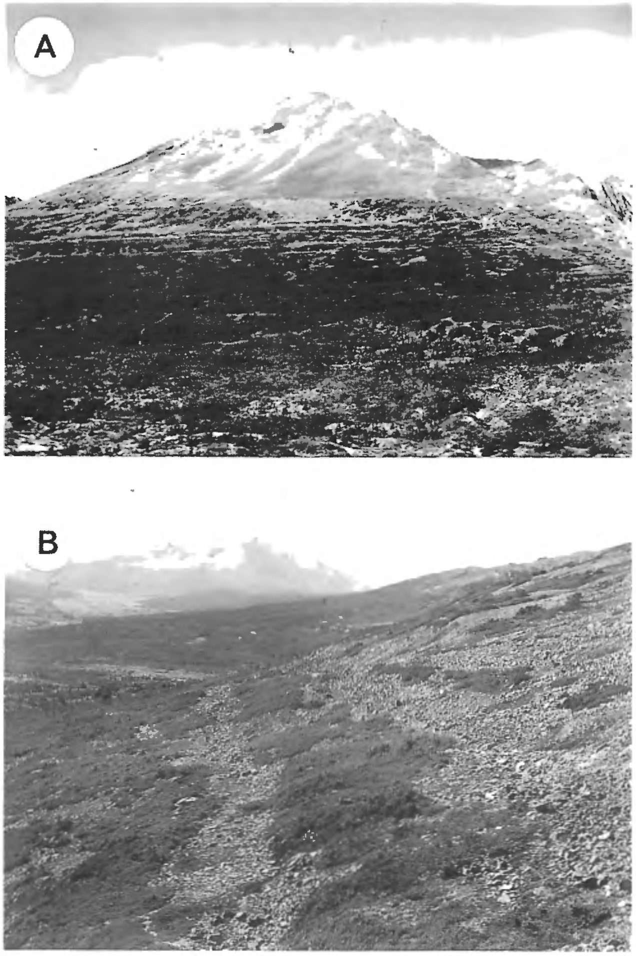


Figure 23. Aerial (**A**) and ground view (**B**) of a nested, parallel set of lateral meltwater channels eroded in till on the west side of Tyers River Pass, southwestern part of Little Hyland River map area (Map 1677A). Ice flowed toward left. GSC-204511-G, F

Alluvial deposits and landorms

Postglacial alluvium forms long, wide, meander-scrolled floodplains and low terraces along Hyland, Little Hyland (Fig. 24), Frances, Tyers, Anderson, and Yusezyu rivers. Smaller alluvial deposits occur along other streams, as well as in hundreds of alluvial fans, formed both where tributary streams debouch onto alluvial plains and at the mouths of alpine torrents. The alluvial plains are largest where the main rivers have eroded into glaciofluvial sediments. There they have formed graded reaches with meandering channels. Between these reaches, river channels are less sinuous and have either clast-armoured or bedrock beds characterized by rapids. Channel positions in the alluvial reaches change frequently as meander cutoffs occur, particularly where currents are deflected by natural log jams.

Sediments underlying alluvial plains and terraces are well sorted gravels and sands deposited in channel and point bar environments, fine organic detritus and mud deposited as overbank sediments, and coarse organic detritus — logs, many with rootballs — deposited on point bars, on channel sides, and on deltas (Fig. 25). In addition, much autochthonous organic material has accumulated in bogs occupying arcuate depressions between abandoned meander scrolls and in oxbow lakes.

Alluvial fans are of both lowland and alpine types. Lowland fans occur on middle to lower valley walls, either where tributary streams have encountered declivities, as among the drumlins of lower Hyland River valley, or where streams meet the alluvial plains of the main rivers. Most lowland fans are derived from stream erosion

Figure 24. Meander-scrolled alluvial plain along lower reach of Hyland River, southern part of Dolly Varden Creek map area (Map 1674A). GSC-203603-U

of till. They are larger and have gentler slopes than alpine fans, and are now forested. Alpine fans are mostly only a few hundred metres wide at the toe and occur on steeper slopes, largely above treeline, below chutes in glacially oversteepened rock walls. Individually, they are smaller than lowland fans but, commonly, have coalesced laterally with other fans to line lower valley walls. Less commonly, they have coalesced across valleys from opposite sides.

Alpine fans include material eroded from till by streams and remobilized till in the form of debris flows, but also include rockfall material as well as organic and other debris brought down by snow avalanches. They also include autochthonous organic material in the form of buried soils. Debris flow levees are conspicuous forms on many above treeline. Alluvial fans occur only rarely in the Simpson Ranges but they are common in other mountains of the map area on all rock types.

Colluvial deposits and landforms

Colluvium in the map area includes talus (scree), rock glaciers, and landslide debris found mostly in the alpine zone above treeline. It is common in all mountains but the Simpson Ranges. Colluviated till is undoubtedly widespread on steeper slopes where it has undergone downslope creep, cryoturbation, frost heaving, and solifluction. However, preservation of rather delicate landforms, such as small lateral moraines and meltwater channels on steep slopes, indicates that such processes have not led to appreciable morphological degradation, so colluvium of this sort is not distinguishable at the scale of mapping from the original till.

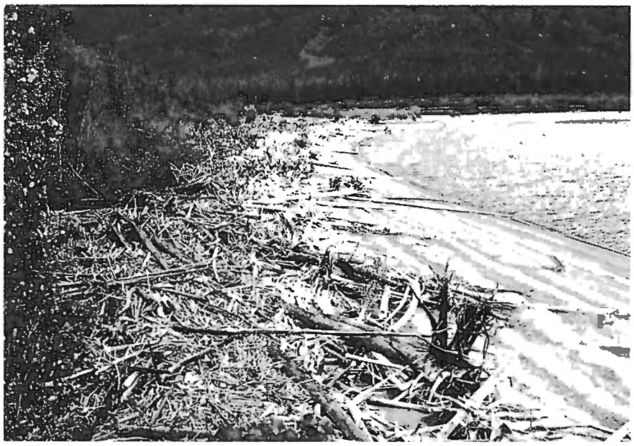


Figure 25. Accumulation of logs on delta at the head of East Arm, Frances Lake, Yusezyu River map area (Map 1676A). GSC-204510

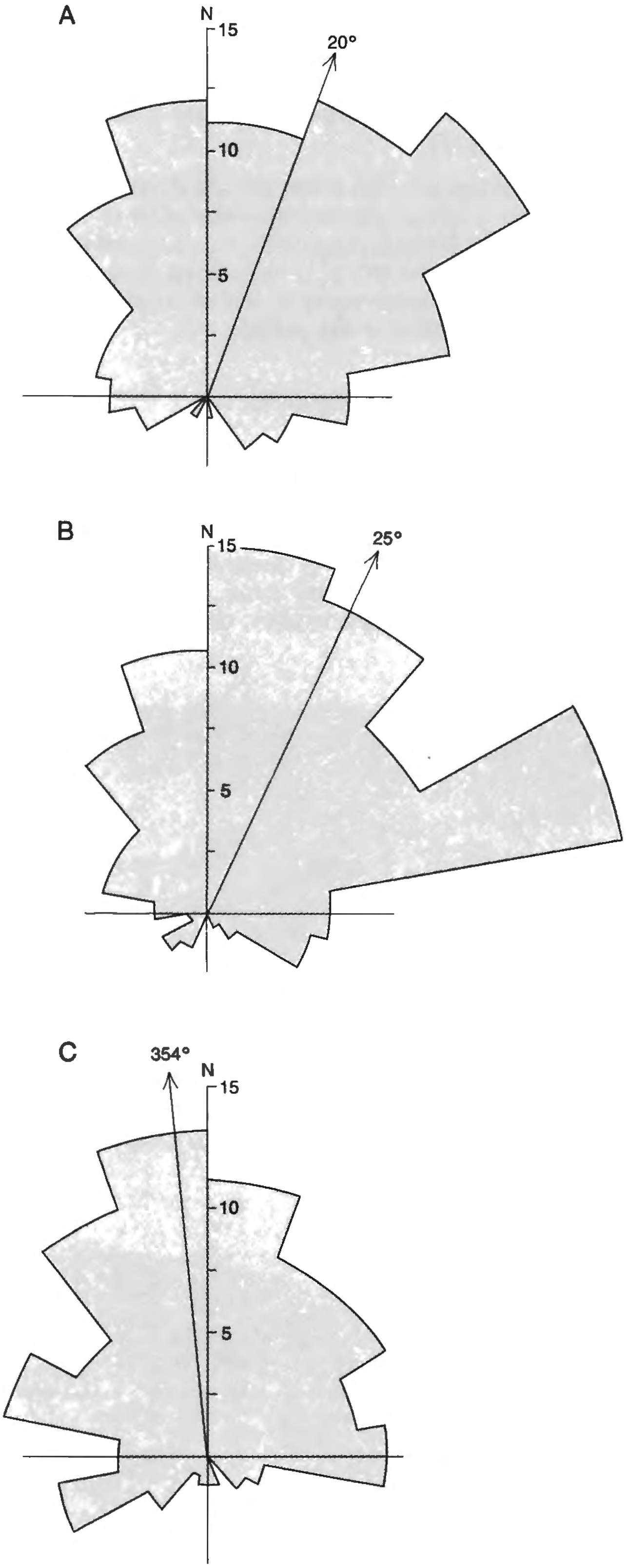


Figure 26. Rose diagrams of orientations of rock glaciers developed on Hadrynian gneiss and schist (**A**); Cambrian and older shale, slate, and phyllite (**B**); and Cretaceous monzonite and granodiorite (**C**) (from Peters, 1987, p. 38).

Talus (scree)

Talus aprons line most alpine rock walls above treeline in the map area. They represent the results of substantial postglacial rock wall retreat as a result of frost riving of the higher rock slopes. The talus is formed of block accumulations, with some interstitial fines. Individual blocks commonly exceed 3 m across where composed of monzonite, but are smaller where composed of limestone, shale, and phyllite. The rectilinear talus slopes are interrupted by numerous alluvial fans and rock glaciers, but otherwise are nearly continuous along most cirque headwalls and sidewalls. In some valleys, particularly in the eastern ranges of the Logan Mountains south of Tungsten and in the Ragged Ranges, the toes of talus slopes have coalesced across valley floors. Only in a few places do talus slopes extend to the arêtes above. They have formed on all major bedrock lithologies and on slopes of all orientations, although there are more on generally north-facing slopes. Talus slopes exhibit various degrees of current activity, judging from the maturity of crustose lichen covers. But only a few appear to be relict from earlier in postglacial time and most appear very active.

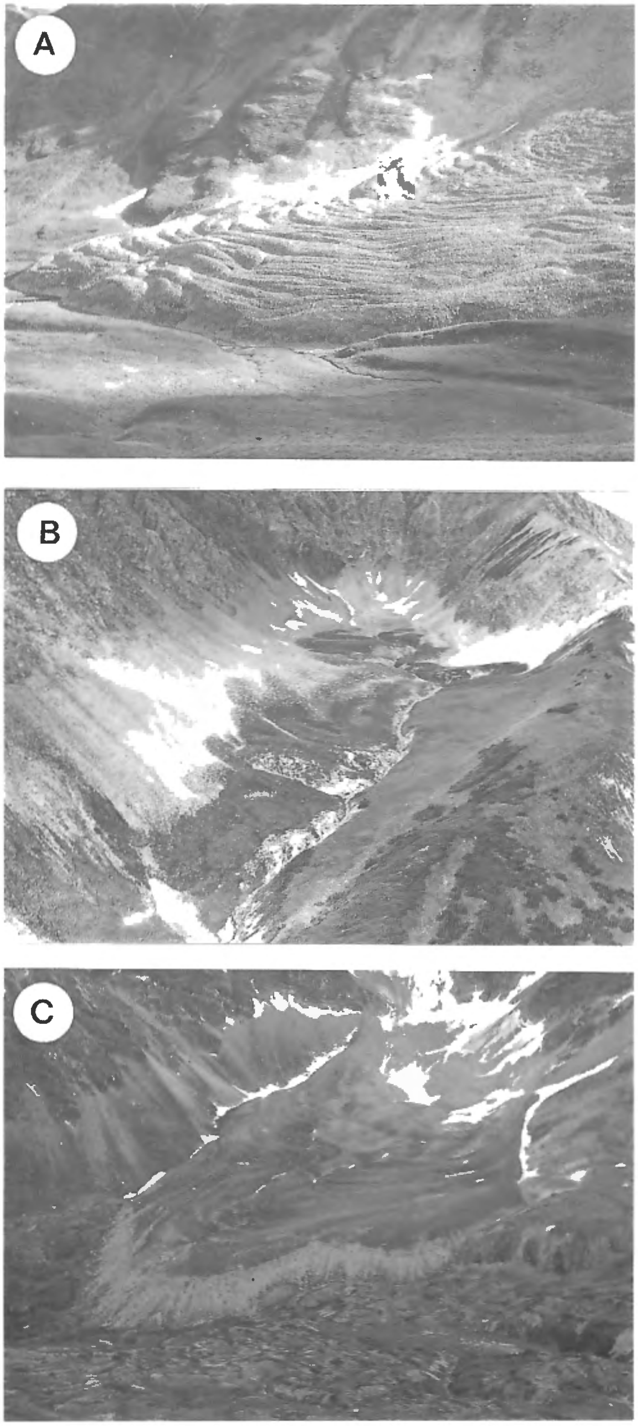


Figure 27. Rock glaciers exhibiting multiple transverse ridges and furrows (**A**); stable, sod-covered snouts (**B**); and active, lichen-free, steep side and front slopes (**C**). GSC-204511-D, 203603-X, 203603-Y

Rock glaciers

About 1000 rock glaciers occur in the Frances Lake map area, many of which represent two or more coalescent forms. Most or all these features are thought to be "talus glaciers" (i.e., formed through flow of talus off the valley walls by plastic deformation of ground ice). Possibly some of those emanating from cirque heads are rubble-covered glaciers, although this has not been shown to be the case for any single feature. Furthermore, rock glaciers are much more widespread than active glaciers and occupy a much less restricted range of topoclimatic environments. Although they have formed predominantly on generally north-facing slopes, they occur in all orientations from 270° to 90° (Fig. 26; Peters, 1987). No obvious lithology controls their development, for they occur on widely diverse rock types from limestone and shale to gneiss and monzonite although they differ in texture according to lithology of the source debris.

Many sizes and shapes of rock glaciers occur below a maximum length of about 3 km (downflow) and width of about 4 km. A subdivision into the various morphological classes that have been proposed (e.g., lobate, tongue-shaped, spatulate, and complex) reveals little regarding lithological or other environmental controls on their formation or likely mechanisms of movement (Peters, 1987). Most rock glaciers, like those elsewhere, have multiple, transverse, arcuate ridges and furrows and some, especially the tongue-shaped ones, have lateral ridges (Fig. 27). Some features have frontal and lateral slopes that are well covered with crustose lichens, sod or even trees, giving the impression that they have been stable for some time, and a few blockfields on lower valley slopes resemble collapsed rock glaciers. But most features have nearly lichen-free and oversteepened sides and snouts, surmounted by carapaces with mature lichen covers, apparently indicating active flow.

Rock glaciers in the study area are of a wide range of Holocene ages. Some sod-covered features contain White River Ash within the sod and are clearly older than the ash, which dates about 1200 BP; others are younger than the ash. Lichenometric studies conducted at 36 rock glacier sites reveal several groups of features older than White River Ash and groups younger than the ash

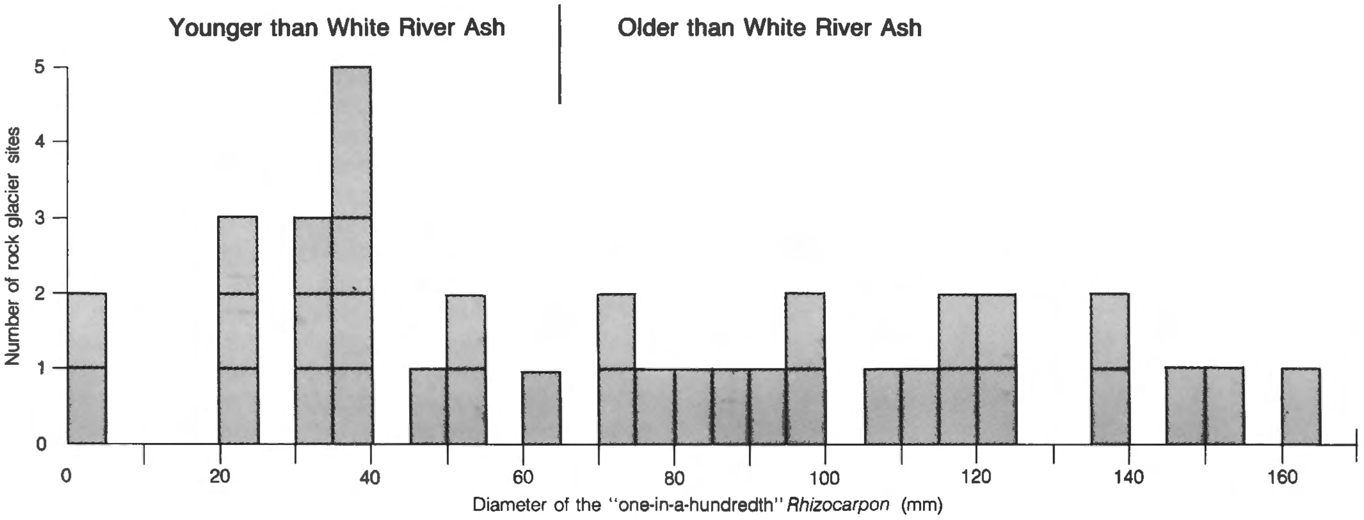


Figure 28. Histogram of lichen (*Rhizocarpon* spp.) diameters on 35 rock glaciers. Diameter used is that of the "one-in-a-hundredth" lichen; only 1% of all lichens on the deposit have larger diameters. (Convert to approximate age by using Fig. 29).

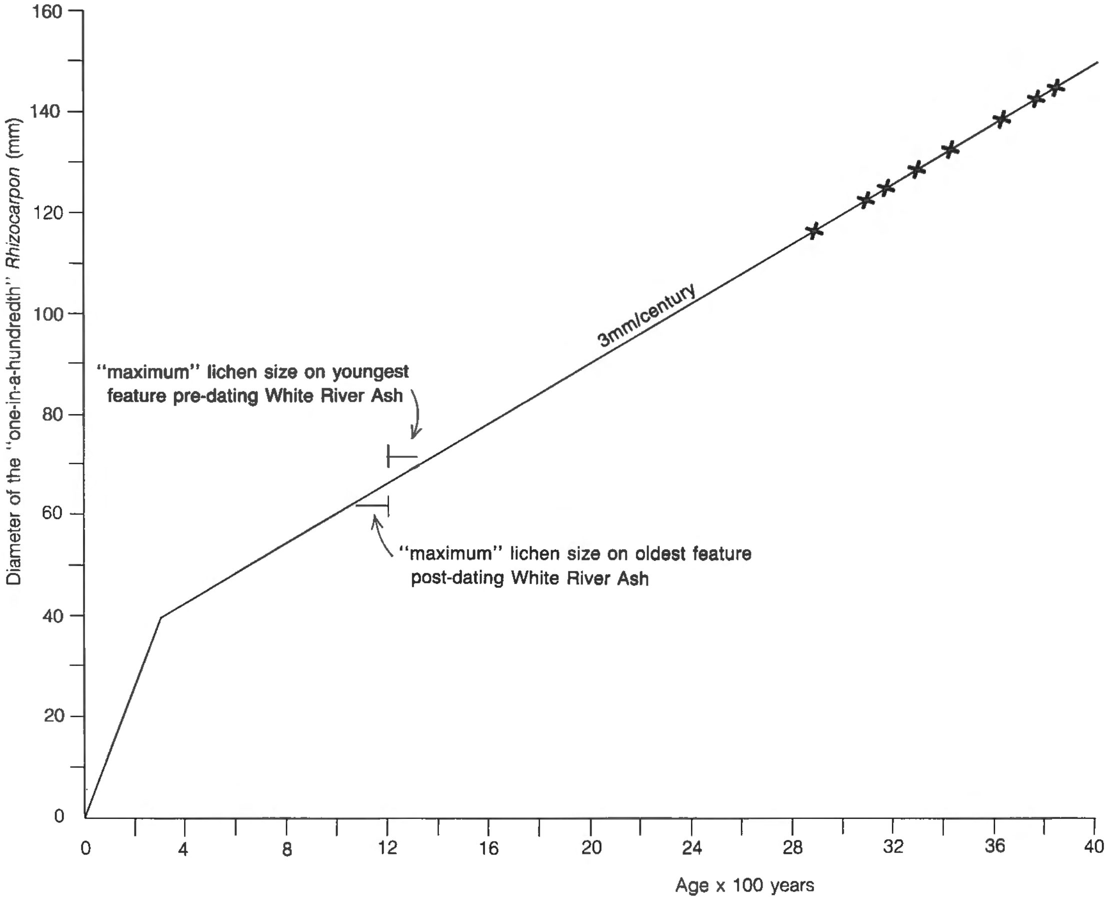


Figure 29. Approximate growth curve for *Rhizocarpon* spp. based on lichen sizes on the youngest features older than White River Ash, on the oldest features younger than White River Ash and on an assumed growth rate of 3 mm per century during the linear phase.

(Fig. 28). Using a growth rate of 3 mm per century for Rhizocarpon lichens during their linar phase (Locke et al., 1979), and the size of lichens on features just older and just younger than White River Ash, the oldest rock glaciers formed about 4500 years ago (Fig. 29). Other age groups centre on 3500, 3000, 2000, 1400, 700, 250, 200 and 50 years ago. It is likely that features of all ages younger than about 4500 years are present, with groupings of features around certain ages representing climatic events conducive to rock glacierization of talus (Dyke in press). Although rock glaciers have a range of ages, an estimated 90 per cent or so of all features are older than White River Ash and most of these are close to 4000 years old.

An initially enigmatic aspect of these features is that many apparently active features, with steep, unstable snouts and sides, have mature lichen communities, including large individuals (*Rhizocarpon* spp.) indicative of an age older than White River Ash, or have the ash itself on their innermost treads all the way up to the active talus toe. The absence of an inner tread younger than White River Ash seems to indicate a lack of rock glacier motion off the talus slope during the last 1200 years, which belies the active appearance of the snout. More likely though, these are sites where the rate of accretion at the talus toe has exceeded the rate of movement of the rock glacier and has led to overriding of the inner rock glacier tread by talus.

Figure 30. Large rock avalanche in cirque between Hyland River and Little Hyland River valleys (Map 1677A). Individual blocks easily distinguishable on surface. Part of NAPL A12797-60; approximate scale 1:30 000

In 25 rock glaciers of various lithological source and form, precisely surveyed arrays of metal pins were installed in 1983 to detect present rates of movement and hopefully to correlate rates and perhaps mechanisms of movement with morphological and textural attributes. This study is the first large sampling of rock glaciers in the northern Cordillera for this purpose. Previous studies include work by H. Gabrielse of the GSC during 1963 Operation Nahanni. He painted lines of boulders on the long tongue-shaped Tungsten rock glacier and surveyed the position of its snout. This rock glacier was resurveyed in July 1980, which thus provided a 17 year record of movement (Jackson and MacDonald, 1980). The rock glacier consists of rubble derived from Cambrian argillites and argillaceous carbonates and descends from about 1980 m to 1070 m elevation over a distance of about 2.7 km. During the period of record it exhibited a surface flow pattern similar to that of a typical glacier, as would be expected from its tongue shape and valley floor position. Surface boulders near the axis of the feature moved as much as 45 m, or at an average annual rate of 2.65 m, whereas boulders on the lateral ridges moved little at all; the snout advanced about 10 m. Jackson and MacDonald (1980) concluded that the Tungsten rock glacier is a rubble-covered glacier (ice-cored rock glacier). Because most rock glaciers in the map area are thought to be talus glaciers (ice-cemented rock glaciers) and because few have the ideal tongue shape of the Tungsten rock glacier, movement of the Tungsten rock glacier may not be typical of the movement of most rock glaciers in the region.

Landslide debris

Accumulations of coarse, blocky material appear to have resulted from rock avalanches at three localities; two in the Campbell Range (Simpson Ranges), the other between Hyland and Little Hyland rivers in the Logan Mountains. Those in the Campbell Range both occur in rocks mapped as Devono-Mississippian black shale by Green et al. (1966), a unit reinterpreted as Pennsylvanian and Permian chert of the Anvil Allochthon by Gabrielse et al. (1980). They occur on west- and northwest-facing valley walls below distinct source areas in rocks that strike north-south and dip westward at 44° to 55°. They are about 400 m wide and about 700 m long. The Hyland slide (Fig. 30) occurs below a west-facing cirque sidewall cut in Hadrynian phyllite that dips northeast at about 60°. It extends about 1200 m along the wall and entirely across the 400 m width of the valley, where its toe partly ascends the opposite wall and lies higher than its central part. The surface of the feature has considerable relief and what appear to be individual blocks of rock are readily recognizable (Fig. 30).

Small landslide scars in till and associated landslide debris accumulations occur along the steep bluffs of Frances Lake (Fig. 31) and on a steep, north-facing slope just south of Anderson Creek. Both may be associated with local permafrost degradation. The debris foot of the Anderson Creek slide has been reworked into an alluvial fan by water, perhaps produced by melting ground ice, issuing from the scar area.

Neoglacial till

Neoglacial advances of the 168 active glaciers of the map area, and of two or three glaciers that have since melted entirely, laid down till, mostly in the form of end and lateral moraine deposits, as much as 1800 m beyond glacier front positions shown on airphotos taken in 1950. The glaciers commonly are fronted by one or two, rarely more, distinct end moraines that are distinguishable from moraines of McConnell age by their incomplete vegetation, sod, and lichen covers (Fig. 32). In addition, at least one sod-covered moraine contains blebs and deformed lenses of White River Ash, incorporated during the Neoglacial advance.

Lichenometric studies were made on 20 Neoglacial moraines (Fig. 33) and on three substrates recovering from lichen-kill by former perennial snow banks (Fig. 34). These measurements indicate that at least six ages of moraines are present, all younger than 1200 years.

Figure 31. Small landslide and associate debris flow in till on east bank of upper Frances Lake, Yusezyu River map area (Map 1676A). GSC-204511-A

Figure 32. Fluted, bouldery Neoglacial till and associated end moraine ridge in front of small glacier, southern part of Little Hyland River map area (Map 1677A). GSC-204511-I

Lichenometric ages of moraines refer to times of their initial stabilization following glacial advance and their deposition. The oldest Neoglacial moraines have maximum diameters for Rhizocarpon spp. of 42 mm, whereas younger moraines exhibit maxima of about 35 mm, 29 mm, 18-24 mm, 15 mm, and less than 2 mm. These measurements fall within the range of sizes usually attained during the so called "great period" — the period of maximum growth rate following substrate colonization. The great period is thought to last two to four centuries and to involve growth rates of about 10 mm per century or more. Hence, six periods of glacial advance followed by moraine stabilization occurred in the Frances Lake map area during the last four centuries or so. Two of these intervals were also characterized by persistence of perennial snow banks at sites where complete ablation occurs today.

There is no convincing correlation between lichenometric ages of Neoglacial moraines and of rock glaciers, even for the post-White River Ash interval. At the coarser scale, the two are negatively correlated, for most rock glaciers are more than 1200 years old, whereas no Holocene moraines of that age were identified. Whatever conditions triggered the development of hundreds of rock

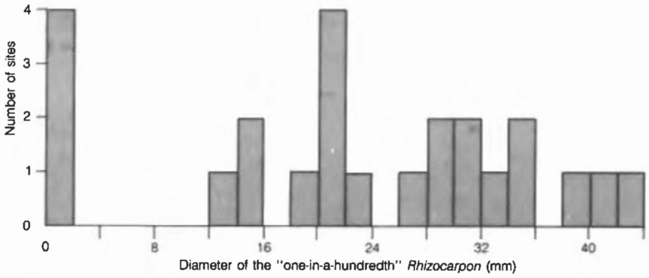


Figure 33. Histogram of lichen (*Rhizocarpon* spp.) diameters on 20 Neoglacial moraines and 3 former snowbank sites. Diameter used is the "one-in-a-hundredth" lichen; only 1% of all *Rhizocarpon* on a feature have larger diameters. All sites younger than White River Ash.

Figure 34. Areas of lichen kill by former perennial snowbanks (Little Ice Age), southern part of Little Hyland River map area (Map 1677A). GSC-203603-S

glaciers during the middle Holocene were insufficient to trigger renewed glaciation. Possibly the critical geomorphological threshold for rock glacier formation was the accumulation of the minimum thickness of talus necessary to harbour permafrost on aspect-favoured slopes. This accumulation apparently occurred under climatic conditions still too warm for glacier formation.

All glaciers in the area today appear to be in active retreat. The surficial geology maps show the extent of glacier ice as it appears on the 1950 airphotos whereas the 1:50 000 scale topographic base maps show the glacier margins as of 1984. Most glaciers have retreated 10s to 100s of metres since 1950, some have separated into two or more smaller glaciers and a few have disappeared completely.

White River Ash

White River Ash resulted from two eruptions of a volcano in the St. Elias Mountains near the headwaters of White River (Hughes et al., 1972). The eruptions resulted in two plumes of ash. One plume is oriented northward along the Yukon-Alaska boundary and a younger, much larger plume extends eastward across much of central and southern Yukon and into District of Mackenzie. Radiocarbon dates on organic material in soil just below the northward plume place deposition between 1850 and 1900 years ago, whereas dates on peat and charcoal underlying the eastward ash plume indicate that it was deposited about 1200 years ago. The Frances Lake map area lies just within the distal margin of the eastward plume as sketched by Hughes et al. (1972, p. 19; Fig. 35). The ash forms an invaluable stratigraphic marker of known age for studies of Holocene deposits and features in the Yukon.

White River Ash was observed at more than 100 sites in the Frances Lake map area. It generally occurs as a parting from less than 1 cm to more than 7 cm thick within the surface organic layer but is locally disrupted in alpine areas by cryoturbation. It is conspicuous along forested valleys in the upturned root balls of windfallen trees and can be found easily in most places by parting the surface organic layer at zeric sites or by making shallow holes (20-30 cm) in peats. The ash is about 4 cm thick in the western part of the map area and about 1 cm thick in the east (Fig. 36). Locally it is 5 to 7 cm thick in the west and possibly local plumes of thicker ash can be recognized trending eastward along the valleys of Tyers River and Anderson Creek, although a higher sample density would make this more convincing.

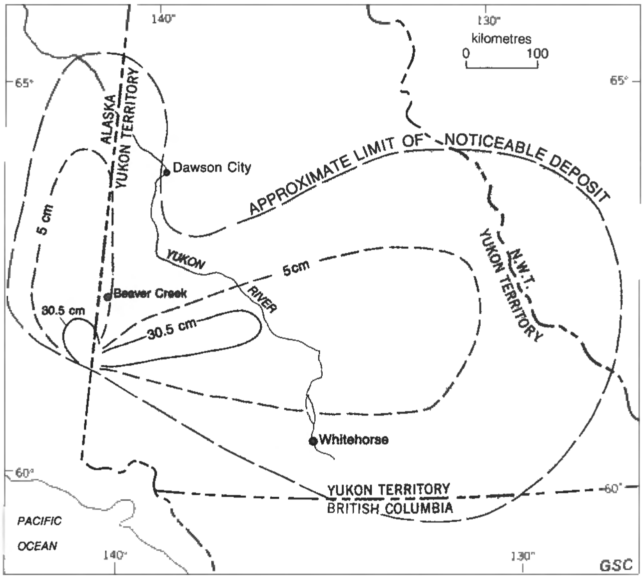


Figure 35. White River Ash plumes (from Hughes et al.).

PATTERN OF DEGLACIATION

Hundreds of ice marginal and submarginal features are identified in the Frances Lake map area as already described. These include end moraines, lateral moraines, lateral meltwater channels, crevasse fillings, and medial moraines.

Ice marginal features were correlated locally on the basis of gradient and orientation during stereoscopic interpretation of airphotos to produce quasi-continuous sets of ice margin outlines along most smaller valleys and along each slope of the wider valleys. These outlines were plotted on a 1:250 000 scale topographic base and pairs of margins were correlated across valleys based on an assumption of rough symmetry of valley glacier lobes to yield a more coherent pattern of ice retreat (Fig. 37A). The pattern is highly complex in detail because of the interaction of lowland ice lobes and alpine glaciers and the emergence of numerous nunataks as the ice surface lowered during retreat. In general, however, the pattern shows a northward retreat of the large ice lobes of the Frances, Hyland, Flat, and other valleys across the entire map area, continuing into the Nahanni map area, accompanied by segregation of alpine ice masses and retreat of massif-centred icefields in the Selwyn Mountains. Final local centres of alpine ice correspond to areas of active current glaciation.

A further level of extrapolation is necessary to reconstruct ice margins across the entire map area. The discontinuity of ice marginal features and the characteristic complexity of ice margins in the alpine areas between the large valleys allows for many interpretations. Possible correlations (Fig. 37B,C,D), based entirely on the general ice retreat pattern on Figure 37A, combined with topographic continuity, display an early, middle, and late phase in deglaciation of the area.

During an early phase (Fig. 37B) ice spilled southward into the valleys and across the lower summits of the Simpson Ranges and the Frances lobe pushed well south of Frances Lake overtopping Simpson Tower. The smaller Hyland lobe had withdrawn farther north; the initial separation of the Hyland lobe from a lobe splaying eastward from Dolly Varden Creek valley was followed by a separation of the Dolly Varden lobe into two, one retreating northward, the other westward into the Frances lobe (Fig. 37A). Local alpine glaciers, some coalescent

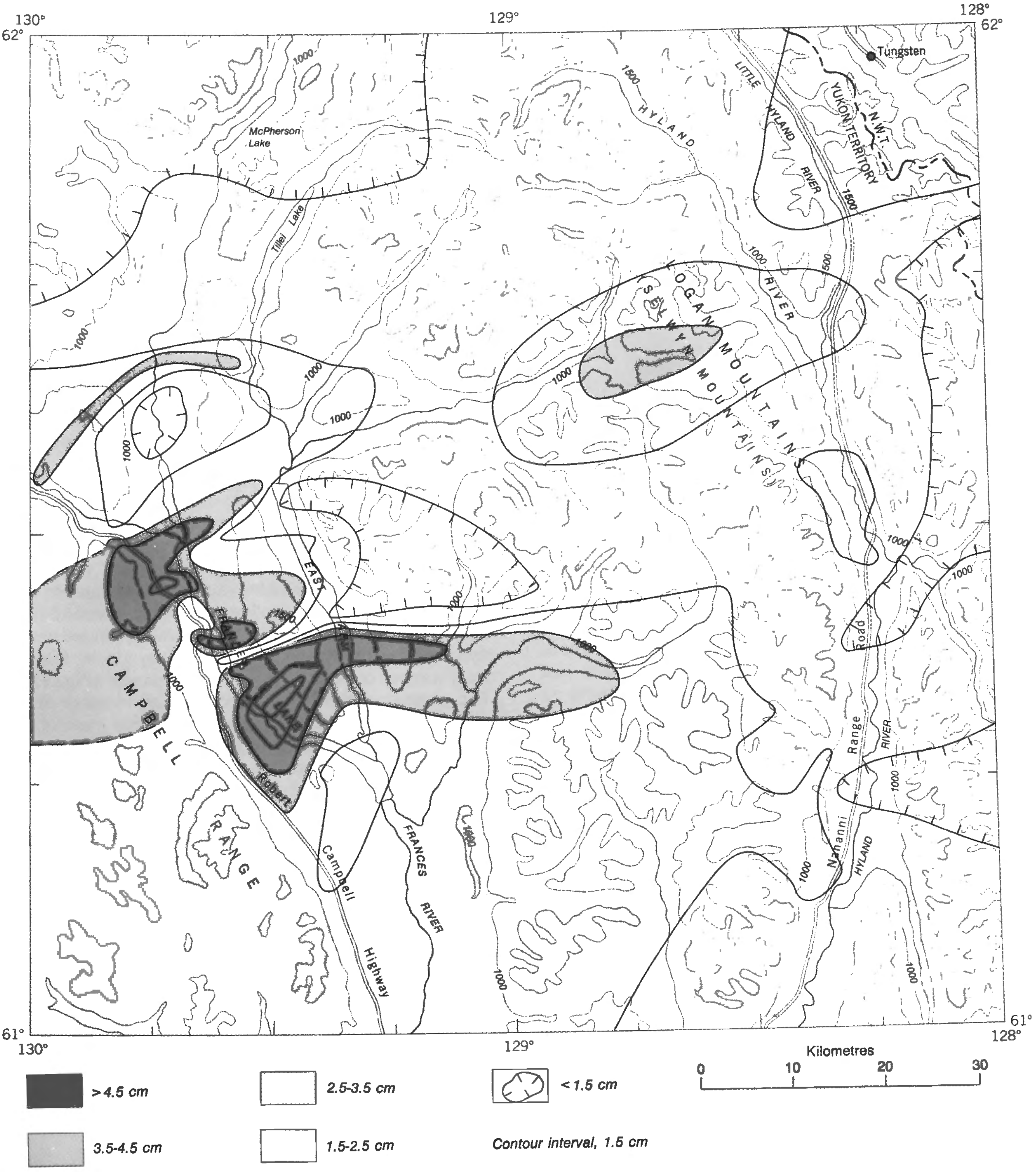


Figure 36. Isopleth map of White River Ash thickness in the Frances Lake area.

with the main ice sheet, some autonomous, occupied the Logan Mountains south of the ice sheet. Drainage was as at present except for an ice-dammed lake which drained southward from a valley in the east. The ice flow pattern at this time likely was controlled primarily by the larger north-south valleys of Frances, Hyland, and Flat rivers, with a slight departure of flow from a local ice divide over the central Logan Mountains.

During a middle phase of deglaciation (Fig. 36C) the Frances lobe was divided into two, one retreating along East Arm, the other along the Main Arm of Frances Lake, each leaving abundant evidence in the form of end moraines, meltwater channels, and crevasse fillings. Ice flowed into the Main Arm lobe from Macpherson Lake trough to the north and from Finlayson River valley to the northwest and pushed slightly into the Campbell Range on the west. The East Arm lobe was supplied by flow from Tellei Lake trough to the north, from Tustles Lake and Broken Lakes troughs to the northeast and from Anderson Creek valley to the east. Much ice also spilled southward from Anderson Creek valley along north-south transection valleys where it was joined by flow from local alpine glaciers. This confluent ice formed the large Tyers lobe. The Tyers lobe also received ice from confluent cirque glaciers on the south and issued smaller distributory tongues along passes to the south and east. The Hyland lobe must have retreated north of Flood Creek at this time for it had separated from the distributory tongue flowing east along Flood Creek from Tyers glacier. The Hyland lobe received its main flow from Hyland and Little Hyland river valleys but also received strong flow from Anderson Pass Creek to the northwest. A local ice divide still persisted in the Logan Mountains and separated flow into the East Arm lobe from flow into the Hyland lobe.

During a late phase of deglaciation (Fig. 37D) a considerable supply of ice continued to flow from a dispersal area north of the map area. Large outlet glaciers extend southward along Ptarmigan Creek, Narchilla Brook, Macpherson Lake, Tillei Lake, and Hyland, Little Hyland, and Flat rivers. Adjacent parts of the Logan Mountains and Ragged Ranges were covered heavily with alpine ice fields which coalesced with the main south-flowing lobes and generated large outlet glaciers of their own along Tustles Lake, Broten Lakes, and Anderson Creek. Some local cirque and valley glaciers, the largest north-facing, persisted in the massifs south of Anderson Creek and southeast of the Little Hyland lobe.

Final ice retreat in the map area involved a withdrawal of valley glaciers to the massifs between the upper Hyland River and Tillei Lake and to the narrow ranges east of Little Hyland River, where bulky end moraines were built by local cirque glaciers following their separation from the Little Hyland lobe. Outlet glaciers in the Flat, Little Hyland, and Hyland river valleys and in the Macpherson Lake valley withdrew northward into the Nahanni map area.

FUTURE RESEARCH

This investigation of the Quaternary geology of the Frances Lake map area suggests several directions for future research within this and adjacent areas. The first two of these represent direct extensions of this project; the other are open suggestions:

1. Detailed statistical analyses of alpine landforms should be undertaken to determine environmental and lithological controls on formation of cirques, glaciers, rock glaciers, talus slopes, alluvial fans, and avalanche tracks. This examination can be done directly from the surficial geology maps but may lead to a design for future field research.
2. Long-term monitoring of the 25 surveyed rock glaciers should be implemented to determine flow rates and mechanisms as well as the influence of lithological and various geomorphological controls.
3. Mapping of the Flat River map area to the east is necessary to determine the eastward extent of Late Wisconsinan ice from the Logan Mountains and to interpret the interaction of this ice with apparently more powerful ice flow that splayed northward from the Liard Lowland.
4. A lake or bog coring program is probably the only way that chronological control can be provided for the deglaciation sequence.
5. A regional synthesis of the pattern of deglaciation based on mapping of all adjacent sheets should be undertaken to outline the retreat pattern for much of the northeastern Cordilleran Ice Sheet.

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APPENDIX

Textural, petrological, and geochemical composition of till samples from the Frances Lake map area

Sample localities and numbers (Table 1.1) are given on Maps 1674A-1677A. Silt-clay boundary used is 2 μm; carbonate content by LECO method on the < 63 μm fraction; granule lithology done on the 2-5.6 mm fraction; trace element geochemistry on the clay fraction. Geochemical values in bold type indicate concentrations in excess of apparent background (see text and Fig. 18).

Table 1.1. Textural, petrological, and geochemical composition of till samples from the Frances Lake map area

Sample	Sand %	Silt %	Clay %	$CaCO_3$ equiv. %	Granule Lithologies %																			
					Granitoids	Shale/phyllite	Limestone/marble	Clastic sediments	Quartz	Chert	Serpentine/ greenstone	Cu ppm	Pb ppm	Zn ppm	Co ppm	Ni ppm	Ag ppm	Cr ppm	Mo ppm	Mn ppm	Fe %	Cd ppm	U ppm	As ppm	Hg ppb
1	32	44	24	7	25	63	0	2	5	5	0	54	22	300	8	40	0.3	29	3	510	4.0	5.1	2.3	20	140
2	63	33	4	7	11	72	0	0	15	0	1	173	41	***600***	33	***175***	1.0	46	18	1500	7.0	2.0	1.5	49	605
3	48	42	11	0	47	43	0	0	10	0	1	87	28	250	14	70	0.6	41	6	470	6.7	0.5	2.5	28	285
4	45	39	16	7	20	69	4	0	6	1	0	72	32	290	16	63	0.3	30	4	820	5.2	2.5	1.7	27	205
5	65	31	3	7	3	78	0	3	14	2	0	179	56	***480***	31	145	1.2	38	11	1600	7.4	2.9	1.8	***119***	595
6	48	41	12	6	0	97	0	0	3	T	0	126	27	***550***	22	***210***	1.6	17	***42***	520	6.4	1.4	***6.1***	53	485
7	48	39	14	6	0	82	0	0	18	0	0	182	30	280	28	84	1.0	34	9	750	6.2	1.2	3.1	26	310
8	74	23	2	4	2	85	0	0	13	0	0	192	54	***570***	28	85	1.1	26	12	***2300***	8.7	4.4	1.9	36	615
9	45	45	9	4	17	81	0	0	0	2	0	114	40	265	32	138	0.9	8	28	***3000***	9.3	1.0	1.0	39	***1300***
10	62	33	5	3	6	92	0	0	2	0	0	94	34	270	25	90	0.4	22	22	1600	7.6	1.5	1.4	34	660
11	59	37	4	6	0	95	0	0	5	0	0	90	46	345	16	51	0.4	30	5	1650	5.9	1.4	1.2	29	330
12	40	40	20	2	12	53	0	0	16	19	0	86	40	340	17	74	0.8	34	8	620	6.1	2.3	2.7	28	250
13	48	36	16	0	25	68	0	0	7	0	0	76	34	360	12	70	1.0	28	10	560	5.3	2.5	2.2	27	310
14	32	43	26	7	4	59	0	23	14	0	0	49	28	230	14	55	0.7	31	4	660	4.0	2.3	2.5	16	180
15	71	27	2	7	22	57	0	T	21	T	0	160	52	***570***	28	136	112	78	9	1675	8.4	3.0	1.7	51	720
16	47	42	11	5	50	40	0	T	10	0	0	136	34	340	18	100	1.0	53	5	1100	8.7	1.6	1.0	36	560
17	61	31	8	13	1	98	0	0	1	0	0	***265***	29	***590***	40	***250***	***6.5***	40	9	1600	5.2	1.8	1.1	19	***1345***
18	40	43	16	5	6	82	0	2	9	1	0	74	29	270	14	57	1.1	34	8	820	5.3	2.2	1.6	21	320
19	61	28	11	7	3	67	0	T	12	18	0	92	28	295	16	75	0.6	58	8	1100	5.6	3.0	0.6	25	465
20	54	37	9	4	7	77	0	T	7	10	0	136	40	335	21	92	1.4	58	8	1300	6.2	2.3	0.6	30	710
21	47	42	12	0	0	83	0	0	15	2	0	119	40	280	16	119	1.7	71	8	860	7.3	1.5	0.9	30	430
22	33	47	20	6	0	86	0	0	14	0	0	80	30	270	14	71	0.7	43	7	920	4.8	3.0	0.8	23	255
23	52	38	9	0	0	88	0	0	9	3	0	46	32	184	14	82	0.8	56	2	1060	3.6	2.0	1.2	14	IS
24	54	34	11	7	3	60	0	4	17	15	0	81	28	320	11	57	1.0	33	6	540	5.1	4.2	1.2	31	280
25	53	31	16	8	12	63	0	5	8	12	0	59	27	245	11	46	0.4	26	4	570	4.5	3.3	1.7	24	170
26	71	13	16	3	5	59	0	5	13	18	0	104	41	***510***	16	79	1.6	31	7	540	5.6	3.0	1.2	33	465
27	36	50	14	7	4	66	0	7	10	13	0	64	29	285	14	57	0.2	25	6	770	4.4	2.1	1.5	35	120
28	36	58	6	7	17	58	0	0	14	11	0	105	56	***440***	30	93	1.2	36	6	1600	7.6	2.5	1.0	48	360
29	71	24	4	1	12	46	0	25	17	0	0	62	44	***420***	20	64	1.4	34	8	940	5.4	2.8	1.5	32	215
30	46	37	17	3	8	47	0	25	18	2	0	56	36	280	18	55	0.4	30	6	560	5.2	1.4	1.0	27	120
31	35	41	24	7	9	48	0	12	14	17	0	61	29	270	16	56	0.6	26	5	580	4.6	2.5	1.7	22	150
32	36	44	20	6	29	77	0	1	14	1	0	69	34	330	19	64	0.8	29	6	410	5.4	2.0	2.0	39	205
33	37	41	22	0.7	14	36	0	15	23	13	0	52	36	280	19	57	0.8	31	4	320	4.6	1.4	1.2	21	135
34	40	40	20	6	34	50	0	0	13	3	0	35	36	270	14	46	0.4	28	3	530	4.2	2.0	1.0	18	120
35	73	21	6	11	5	42	34	0	19	0	0	76	38	310	17	63	0.2	28	4	820	4.5	1.9	1.9	36	150
36	42	42	16	8	1	55	14	19	11	0	0	71	29	300	15	64	0.5	28	4	690	4.9	2.5	1.0	28	235
37	51	29	21	0	0	100	0	0	0	0	0	151	30	230	33	138	0.6	12	***143***	250	8.5	2.9	2.2	18	***3135***
38	83	11	5	2	3	57	0	30	10	0	0	176	48	250	28	146	1.6	76	4	1500	5.8	1.8	0.6	30	650
39	74	22	4	17	5	88	0	0	8	0	0	74	28	320	18	77	1.3	34	5	960	3.4	3.1	1.5	22	370
40	36	41	23	5	9	70	0	12	9	T	0	60	20	270	10	57	0.6	42	4	580	4.0	2.5	1.5	22	265
41	74	19	7	0	3	62	3	19	13	0	0	104	34	300	21	96	1.4	67	4	510	5.4	0.8	0.7	80	690
42	45	39	16	0	1	48	0	30	21	0	0	54	32	270	15	55	1.0	46	3	510	3.9	3.0	1.3	16	135
43	63	34	3	6	5	51	16	13	14	0	0	158	58	***600***	23	107	2.4	40	8	1200	7.8	3.5	1.1	77	650
44	22	60	18	1	0	100	0	0	0	0	0	36	32	290	19	62	0.6	38	3	1200	4.4	1.6	1.5	20	125
45	44	41	15	0	0	65	0	24	12	0	0	58	30	300	14	64	0.8	40	6	500	4.6	1.4	1.3	28	180
46	6	56	38	1	Missing							64	30	240	15	68	0.3	52	4	620	4.8	1.7	1.1	22	155
47	51	37	12	0.6	0	92	0	0	7	1	0	150	23	260	12	79	1.8	57	4	480	6.6	0.5	1.1	32	820
48	48	43	10	0	14	74	0	0	7	4	0	119	26	330	12	77	1.7	53	4	465	6.6	1.3	1.3	26	515
49	43	40	16	8	1	75	6	T	16	1	0	84	26	285	12	64	0.8	46	6	700	4.6	3.0	1.2	26	340

Table 1.1 (cont'd.)

					Granule Lithologies %																				
Sample	Sand %	Silt %	Clay %	$CaCO_3$ equiv. %	Granitoids	Shale/phyllite	Limestone/marble	Clastic sediments	Quartz	Chert	Serpentine/greenstone	Cu ppm	Pb ppm	Zn ppm	Co ppm	Ni ppm	Ag ppm	Cr ppm	Mo ppm	Mn ppm	Fe %	Cd ppm	U ppm	As ppm	Hg ppb
50	43	45	12	0.5	T	88	0	0	11	T	0	121	30	380	14	84	1.4	63	6	560	7.4	2.3	1.2	30	490
51	40	42	19	7			Missing					60	40	290	10	58	0.4	40	6	540	4.0	3.3	2.1	38	170
52	46	37	15	5	3	72	0	0	15	10	0	78	38	310	10	60	0.4	40	6	450	5.0	2.5	3.1	32	240
53	37	42	21	8	0	86	0	0	14	0	0	83	24	270	18	86	0.6	49	7	1050	4.6	3.2	1.0	22	340
54	34	41	25	8	1	78	0	0	7	13	0	63	20	210	10	53	0.6	44	6	620	3.9	3.0	1.2	18	315
55	35	45	19	7	0	90	0	0	10	0	0	72	20	230	8	50	0.4	44	5	550	4.3	3.1	1.5	17	300
56	11	64	25	1			Missing					23	16	79	12	29	0.2	12	1	135	2.2	0.6	1.0	21	20
57	39	41	20	0	49	47	0	0	0	4	0	49	38	270	16	53	0.6	67	4	570	5.1	1.3	1.0	29	150
58	72	20	7	0	0	97	0	0	3	0	0	70	44	375	18	58	2.0	12	4	360	6.3	1.8	1.3	17	120
59	70	24	5	4	4	92	0	0	4	0	0	78	34	295	15	64	2.2	16	3	330	4.6	1.0	0.8	22	435
60	58	33	9	0	0	61	0	22	17	0	0	60	42	270	20	54	0.8	26	4	1200	4.6	2.0	0.7	26	175
61	57	35	8	0	0	92	0	0	8	0	0	73	73	195	16	46	0.4	30	2	330	6.4	0.5	2.3	73	110
62	45	41	14	10	22	53	0	14	9	2	0	61	32	121	18	46	<.1	30	2	820	5.3	0.4	1.2	65	85
63	47	41	12	6	1	40	0	22	37	0	0	57	35	139	16	42	<.1	36	3	820	5.6	0.4	1.6	95	50
64	55	39	6	0	35	52	0	0	13	0	0	43	40	100	16	40	<.1	42	1	540	6.8	0.3	1.7	95	80
65	50	36	14	0	64	36	0	0	0	0	0	61	46	124	18	40	<.1	34	2	900	5.2	0.3	2.6	36	65
66	53	36	11	4	43	57	0	0	0	0	0	67	37	160	19	49	<.1	38	2	890	5.8	0.5	1.7	33	45
67	23	64	12	0	81	19	0	0	0	0	0	63	40	118	18	38	<.1	34	2	730	6.2	<.2	3.5	44	50
68	56	38	5	0	62	30	0	0	8	0	0	92	89	134	25	47	0.4	42	3	430	8.6	0.4	4.8	101	65
69	18	61	21	0	9	83	0	0	8	0	0	46	29	118	12	36	<.1	42	3	480	5.6	<.2	2.3	26	40
70	39	45	17	0	57	33	0	0	10	0	0	57	35	127	16	46	<.1	50	2	640	6.4	<.2	1.2	23	50
71	48	41	11	7	21	40	0	23	17	0	0	55	28	124	14	42	<.1	40	3	990	5.4	<.2	1.0	27	40
72	83	15	2	2	100	0	0	0	0	0	0	***200***	***160***	230	25	64	0.6	70	5	460	***18.5***	0.4	2.2	37	IS
73	86	12	2	5	100	0	0	0	0	0	0	***230***	***1050***	164	14	22	1.8	60	6	310	***24***	0.5	2.6	99	IS
74	85	13	2	0	96	0	0	0	4	0	0	***280***	***475***	310	43	68	0.2	67	4	700	***18.5***	0.5	4.2	50	IS
75	40	47	12	0	91	0	0	1	8	0	0	47	48	166	18	48	<.1	45	2	760	6.2	0.4	2.3	28	40
76	36	42	22	0	49	34	0	0	17	0	0	59	28	134	15	49	<.1	45	2	830	5.4	<.2	0.7	28	45
77	55	39	6	1	37	50	0	0	13	0	0	106	44	265	24	73	<.1	58	2	730	8.4	0.4	1.0	28	35
78	58	37	5	2	55	37	0	0	8	0	0	100	46	280	24	77	<.1	66	2	920	8.0	0.5	1.1	43	35
79	4	40	56	1			Missing					40	42	180	16	40	0.1	34	3	960	5.4	0.5	0.8	17	35
80	7	55	38	0.5	52	46	0	0	2	0	0	40	30	164	13	40	0.2	37	3	575	5.4	0.4	1.0	16	40
81	4	46	50	0			Missing					44	46	168	16	40	0.2	35	2	660	5.2	0.5	0.8	24	35
82	58	32	10	0.3	48	47	0	0	5	0	0	89	45	225	23	69	0.1	60	3	1200	7.2	0.5	1.5	53	65
83	72	21	7	7	96	0	0	0	4	0	0	135	74	107	12	30	0.6	94	13	830	***19.5***	<.2	3.3	5	65
84	57	29	14	0	100	0	0	0	0	0	0	48	20	139	32	119	<.1	***171***	2	1100	7.6	<.2	1.7	<2	20
85	65	28	7	2	100	0	0	0	0	0	0	61	44	144	28	44	<.1	45	2	1200	7.9	<.2	2.3	3	40
86	68	26	6	5	100	0	0	0	0	0	0	42	69	124	15	32	0.2	54	2	560	4.2	<.2	2.6	3	60
87	56	30	14	2	100	0	0	0	0	0	0	34	60	305	18	40	0.2	70	3	1300	6.5	1.0	3.8	3	20
88	52	36	12	0	87	13	0	0	0	0	0	37	35	145	10	19	0.2	37	2	650	5.1	0.3	4.8	4	20
89	45	46	10	13	73	27	0	0	0	0	0	98	24	136	12	45	1.0	38	5	660	3.0	5.5	11.5	58	145
90	24	69	6	0	0	0	0	0	T	0	100	35	24	131	26	***600***	0.4	***835***	2	580	5.3	0.4	0.3	15	130
90A	93	6	1	2	0	0	0	0	0	0	100	22	8	46	85	***2375***	<.1	***1750***	2	1500	2.9	0.2	<.1	3	IS
90B	25	68	8	0	0	0	0	0	0	0	100	40	31	160	28	***775***	<.1	***1150***	4	860	6.4	0.5	<.1	20	55
90C	90	8	1	0	0	0	0	0	0	0	100	26	17	71	100	1550	<.1	1100	1	2000	4.5	0.5	<.1	6	IS
91	58	28	14	0	26	63	0	2	9	T	0	59	27	145	18	41	0.2	34	2	500	5.7	0.5	1.5	29	40
92	48	38	15	0	70	30	0	0	0	0	0	28	34	140	18	36	<.1	40	3	920	5.6	0.5	5.5	7	25
93	65	30	6	0	99	0	0	0	1	0	0	81	***357***	***545***	21	49	0.8	91	3	1300	8.2	2.7	6.1	6	45
94	46	39	15	0	10	80	0	0	10	0	0	60	35	56	9	22	0.2	24	2	225	2.9	<.2	1.7	24	55
95	46	41	13	3	13	84	0	0	3	0	0	92	60	92	17	25	0.2	32	2	460	5.1	<.2	3	30	65
96	58	39	3	1	17	79	0	0	4	0	0	57	56	103	20	35	0.2	38	2	980	4.8	<.2	5	20	70
97	54	42	4	0	2	92	0	0	6	0	0	126	67	164	34	35	0.2	40	2	960	5.6	0.3	7.4	125	45
98	72	23	5	0	T	41	0	58	1	0	0	31	56	285	19	40	0.3	46	4	2000	8.1	<.2	1.5	57	90
99	58	34	8	0	29	71	0	0	0	0	0	51	32	124	20	29	0.2	38	2	540	7.8	<.2	8.7	96	20
100	48	40	12	2	3	96	0	1	0	0	0	38	50	95	28	39	0.1	42	3	650	6.8	<.2	0.9	22	120
101	67	28	5	6	5	95	0	0	0	0	0	***236***	***240***	196	92	***190***	0.6	56	4	***3200***	9.6	<.4	2.4	19	145
102	42	41	17	0	1	99	0	0	0	0	0	36	25	105	16	30	0.1	41	3	810	5.3	<.2	1.1	7	110

Table 1.1 (cont'd.)

					Granule Lithologies %																			
Sample	Sand %	Silt %	Clay %	$CaCO_3$ equiv. %	Granitoids	Shale/phyllite	Limestone/marble	Clastic sediments	Quartz	Chert	Serpentine/ greenstone	Cu ppm	Pb ppm	Zn ppm	Co ppm	Ni ppm	Ag ppm	Cr ppm	Mo ppm	Mn ppm	Fe %	Cd ppm	U ppm	As ppm	Hg ppb
103	45	46	9	1	24	72	0	0	4	0	0	48	50	125	18	44	0.2	29	2	770	5.6	<.2	2.1	27	120
104	70	26	4	4	100	0	0	0	0	0	0	138	30	220	34	110	0.6	64	4	1350	7.1	<.2	10.8	2	75
105	60	27	13	4	100	0	0	0	0	0	0	57	***280***	***1175***	17	26	2.2	36	3	1500	5.8	5.2	1.5	3	60
106	36	55	9	5	100	0	0	0	0	0	0	83	70	200	30	43	0.3	33	7	1400	7.0	<.2	8.1	9	125
107	78	20	2	0	4	95	0	0	1	0	0	***290***	74	275	109	***167***	0.7	100	5	***4350***	***15.5***	0.9	2.6	9	90
108	64	31	5	6	0	97	0	0	3	0	0	131	54	225	39	83	0.1	56	4	1850	8.2	<.2	2.6	8	145
109	60	30	10	0	100	0	0	0	0	0	0	3	40	210	8	2	<.1	6	2	1550	7.6	<.2	8.2	<2	65
110	66	30	5	1	100	0	0	0	0	0	0	8	52	50	14	12	<.2	14	4	820	2.6	<.4	11	9	95
111	61	32	8	6	100	0	0	0	0	0	0	10	42	195	9	10	0.2	15	3	920	4.5	0.4	4.2	6	95
112	72	22	6	10	91	0	0	0	9	0	0	75	***1500***	315	34	31	***5.4***	62	3	1100	9.5	0.7	0.9	***315***	IS
113	57	38	5	9	100	0	0	0	0	0	0	40	56	122	18	44	0.8	56	4	640	5.6	<.4	4.7	6	210
114	84	12	4	44	100	0	0	0	0	0	0	30	40	50	30	35	1.0	70	10	1750	5.5	<1.0	2.4	2	280
115	68	24	8	0	100	0	0	0	0	0	0	33	52	200	8	7	0.2	17	17	1700	5.2	0.7	5.1	<2	55
116	73	20	7	10	100	0	0	0	0	0	0	15	100	95	7	8	0.5	20	5	1200	4.7	0.5	12	3	130
117	46	43	10	0	98	2	0	0	0	0	0	8	21	107	12	10	<.1	20	2	1400	5.7	<.2	3	4	50
118	84	84	13	6	60	40	0	0	0	0	0	177	50	***600***	90	***235***	1.0	47	17	1000	11	3.8	27	39	140
119	67	67	24				Missing					49	60	165	29	40	0.3	48	5	1000	6	1	1	19	100
120	64	64	32	5	100	0	0	0	T	0	0	225	160	182	69	60	0.3	35	2	1800	6.1	0.3	4.7	21	190
121	64	32	4	1	0	100	0	0	0	0	0	***225***	***160***	182	69	60	0.3	35	2	1800	6.1	0.3	4.7	21	190
122	37	43	20	53	0	0	94	0	6	0	0	16	13	71	10	24	<.1	16	4	330	2	0.3	0.6	67	75
123	57	35	8	1	0	100	0	0	0	0	0	74	86	410	18	68	1.8	40	27	530	7.2	2.7	5.4	53	105
124	28	59	13	48	0	0	94	0	6	0	0	34	30	195	16	49	0.1	32	2	310	4.9	<.2	0.9	29	125
125	46	44	10	3	15	85	0	0	0	0	0	87	100	237	50	62	0.2	55	5	***2875***	9.5	<.5	2.4	38	105
126	69	27	3	15	96	4	0	0	0	0	0	40	50	157	30	30	<.2	45	7	***2375***	5.2	<.5	6.6	12	140
127	13	66	21	2	100	0	0	0	0	0	0	28	***330***	***620***	8	8	2.6	14	***57***	1500	6.7	1.3	***53***	7	165
128	50	43	7	3	98	2	0	0	0	0	0	44	***145***	250	20	33	0.3	33	3	1000	5.2	0.7	4.2	20	105
129	50	42	9	0	100	0	0	0	T	0	0	50	60	190	10	30	<.1	45	***35***	1300	5.0	1	8	15	140
130	42	51	7	0	100	0	0	0	0	0	0	15	90	70	10	20	0.5	20	10	1875	2.5	1	7	7	155
131	63	32	5	1	100	0	0	0	0	0	0	32	90	110	15	10	2	67	9	410	3.5	0.8	4.7	3	103
132	40	46	14	0.6	0	100	0	0	0	0	0	11	16	63	5	16	0.2	24	2	100	2	0.3	1	6	75
133	17	60	23	0.7	0	100	0	0	0	0	0	14	15	98	8	22	<.1	27	2	450	3.3	<.2	1.7	10	70
134	51	38	11	0	94	0	0	0	6	0	0	76	56	255	25	55	<.1	58	3	990	7.8	0.4	9.2	18	60
135	21	56	23	1	100	0	0	0	0	0	0	33	24	124	16	27	1.2	39	6	570	5.6	0.4	12.7	6	130
136	66	27	7	0	93	0	0	0	7	0	0	66	***127***	118	14	26	<.1	84	4	500	7	<.2	0.6	11	25
137	65	30	6	0	98	0	0	0	2	0	0	33	80	360	8	5	1.4	12	10	1600	3.9	2	14.4	4	80
138	76	20	4	17	95	0	0	0	5	0	0	17	23	125	7	9	<.1	21	4	620	3.6	0.5	5.1	2	80
138A	58	32	10	1	100	0	0	0	0	0	0	8	40	200	17	38	<.1	***106***	3	620	8.0	<.2	5.2	2	35
139	55	30	15	0	100	0	0	0	0	0	0	16	30	205	7	9	<.1	20	2	600	4.0	0.2	2.6	<2	20
140	42	46	12	4	29	52	0	15	3	0	0	67	57	390	13	48	0.8	39	6	545	5.6	1.9	3.7	14	195
141	9	66	25	0	7	27	0	41	25	0	0	69	47	265	15	44	0.4	39	4	570	7.0	1	2.1	32	135
142	24	41	34	9	0	38	0	39	23	0	0	42	30	134	18	40	0.2	30	2	840	4.2	0.7	1.3	17	75
143	40	37	23	8	16	24	0	60	0	0	0	42	28	131	14	36	0.2	30	2	900	5	0.5	1.1	16	80
144	42	40	18	2	14	51	0	35	0	0	0	67	40	185	13	36	0.4	28	3	480	4.6	0.5	1.2	21	170
145	43	38	18	6	2	74	0	24	0	0	0	63	72	127	24	40	0.2	29	2	750	6.2	0.2	1.5	25	50
146	43	49	8	6	0	100	0	0	0	0	0	35	47	72	12	15	0.5	40	5	700	8.3	0.2	0.9	25	60
147	51	40	9	4	100	0	0	0	0	0	0	30	105	40	5	10	0.5	22	***35***	1525	3.8	1.3	***182***	2	100
149	55	33	12	4	60	40	0	0	0	0	0	52	***198***	330	18	40	1	37	2	1100	6.6	0.6	3.3	29	60
150	85	14	1	8	100	0	0	0	0	0	0	17	***150***	95	10	12	1.3	27	5	625	2.7	1.3	4.9	12	120
151	69	25	6	20	100	0	0	0	0	0	0	45	35	65	10	10	0.5	30	5	910	3.7	<.5	13.1	7	150
152	67	27	6	2	100	0	0	0	0	0	0	14	36	110	12	10	0.2	16	2	1200	6	<.2	***55***	60	70
153	67	28	5	0	100	0	0	0	0	0	0	25	38	235	8	16	0.3	16	2	970	6.2	0.6	14.1	10	35
154	27	64	9	3	0	100	0	0	0	0	0	137	36	125	22	85	0.4	***160***	4	1100	9.1	<.2	0.9	4	185
155	48	31	22	0	0	0	0	0	0	0	100	12	3	115	16	***270***	<.1	***415***	<1	160	1.4	<.2	<.1	<2	55
156	37	53	10	2	16	81	0	0	3	0	0	24	36	121	18	28	0.2	56	2	890	6.8	<.2	3.1	20	100
157	38	58	5	1	93	3	0	0	4	0	0	63	56	160	10	79	0.2	102	2	1100	7.4	0.4	2.8	26	135
158	29	63	8	1	0	98	0	0	2	0	0	144	80	390	18	84	11	77	10	310	9	1.4	2.8	***284***	265

Table 1.1 (cont'd.)

					Granule Lithologies %																				
Sample	Sand %	Silt %	Clay %	$CaCO_3$ equiv. %	Granitoids	Shale/phyllite	Limestone/marble	Clastic sediments	Quartz	Chert	Serpentine/ greenstone	Cu ppm	Pb ppm	Zn ppm	Co ppm	Ni ppm	Ag ppm	Cr ppm	Mo ppm	Mn ppm	Fe %	Cd ppm	U ppm	As ppm	Hg ppb
159	20	72	9	0.3	0	0	0	0	2	T	98	34	20	108	39	975	0.4	***415***	2	680	6.3	0.3	<.1	11	130
160	45	48	8	0.8	0	89	0	0	2	1	8	340	12	133	58	155	0.5	***340***	3	1750	10	<.2	<.1	18	65
161	42	54	4	1	0	0	0	0	8	0	92	100	26	134	33	52	0.3	***171***	4	1500	8.6	0.3	1.3	26	140
162	34	64	2	1	0	100	0	0	T	0	0	185	50	100	10	60	***5.0***	80	15	250	8	<1	2.4	48	***1660***
163	53	45	2	1	100	0	0	0	0	0	0	20	55	100	15	30	<.5	35	5	850	5	<1	3	11	95
164	51	32	16	3	96	0	0	0	4	0	0	48	38	147	16	35	0.3	38	2	425	5.3	<.2	1.4	<2	40
165	58	39	3	5	100	0	0	0	0	0	0	30	50	105	15	40	<.5	45	5	950	4	<1	10.2	14	105
166	72	22	6	15	96	0	0	0	4	0	0	20	60	70	10	20	1	30	10	550	5	<1	8.2	9	45
167	72	21	8	3	13	87	0	0	0	0	0	24	46	58	8	10	0.2	23	2	1000	2.5	0.2	2.1	<2	110
168	40	57	3	3	16	83	0	0	1	0	0	53	66	350	17	66	0.4	80	11	880	7.7	1.8	10.5	41	150
169	58	39	5	24	0	100	0	0	0	0	0	20	15	69	11	27	0.4	43	4	450	2.4	0.5	1.1	11	105
170	74	21	5	4	100	T	0	0	0	0	0	15	70	76	8	12	0.8	20	7	1600	3.8	0.5	***35***	22	120
171	58	37	5	6	100	0	0	0	0	0	0	18	28	94	10	14	0.2	25	7	960	3.5	0.5	11.5	6	125
172	40	56	4	3	69	31	0	0	0	0	0	32	14	66	26	47	0.2	52	4	680	8.4	0.3	2.8	25	145
173	61	28	11	17	1	99	0	0	0	0	0	54	34	330	17	36	0.4	46	2	580	8.7	1	0.9	15	130
174	46	43	11	8	100	0	0	0	0	0	0	38	33	121	9	24	0.6	51	4	480	7.2	0.5	***36***	14	140
175	75	21	4	6	91	9	0	0	0	0	0	20	26	157	10	23	0.1	38	2	620	5.1	0.3	3.5	8	150
176	61	32	7	22	100	0	0	0	0	0	0	23	28	58	4	10	0.6	34	2	380	4.5	0.4	2.8	4	75
177	58	27	5	1	100	0	0	0	0	0	0	48	54	210	10	27	0.2	57	2	560	5.3	0.5	6.7	2	105
178	68	27	5	8	100	T	0	0	0	0	0	5	30	135	7	8	0.2	10	4	860	4	0.4	4	3	105
179	6	58	36	0	73	27	0	0	0	0	0	33	26	157	10	32	0.6	40	3	450	5.4	0.3	1.8	17	55
180	46	41	13	1	39	61	0	0	0	0	0	115	38	***710***	19	90	0.2	47	11	980	7.4	4.4	2.1	46	265
181	18	59	23	3	36	38	0	26	0	0	0	52	40	190	16	42	0.2	36	3	950	6.4	0.9	1.2	28	80
182	8	53	40	11	23	77	0	0	0	0	0	34	24	147	9	32	0.2	39	3	360	5.4	0.3	2	15	70
183	40	35	25	2	53	39	0	0	8	0	0	44	38	185	18	40	0.2	37	3	900	5.7	0.6	1.4	23	70
184	33	42	25	0	25	42	0	21	11	0	0	57	36	200	18	46	0.3	41	2	940	6.2	0.5	1.5	33	75
185	15	52	33	1	25	36	0	34	4	1	0	44	30	175	12	41	0.3	40	2	570	5.8	0.5	1.3	23	75
186	56	28	16	1	48	38	0	2	13	0	0	36	32	128	10	34	<.1	35	4	550	5.2	<.1	1.6	19	80
187	59	33	8	0	10	79	0	11	0	0	0	76	39	126	21	44	<.1	36	<1	540	5.6	<.2	1.1	35	90
188	76	22	2	0	9	48	0	39	4	0	0	140	78	156	38	66	0.2	42	2	1750	6.9	<.2	4.9	74	70
189	64	31	5	1	8	63	0	26	3	0	0	80	44	95	15	28	0.3	45	7	750	9.8	<.2	6.8	47	90
190	51	44	5	0	0	66	0	31	3	0	0	137	108	149	45	60	0.2	38	2	900	6.2	<.2	2.7	83	105
191	26	54	20	0	0	61	0	37	2	0	0	74	38	180	16	77	0.2	48	2	400	3.7	<.2	3.4	36	50
192	55	35	10	0	5	55	0	38	2	0	0	79	48	118	20	51	<.1	59	1	670	5.8	<.2	3.8	84	60
193	55	37	8	12	0	98	0	T	2	0	0	106	29	***2000***	24	***285***	2.2	48	52	540	5.6	14.7	3.4	63	45
194	72	22	6	6	1	59	2	35	4	0	0	129	86	310	34	71	0.6	42	4	1250	7.4	1.2	1.8	105	115
195	74	20	6	8	94	0	0	0	6	0	0	108	***206***	220	37	51	0.2	65	4	1040	10	0.4	2.3	29	130
196	71	25	4	3	98	0	0	0	2	0	0	52	***208***	***850***	28	52	1.2	58	3	1400	6.8	1.6	4.3	5	140
197	54	39	7	7	98	0	0	0	2	0	0	47	***185***	465	24	40	1.2	58	3	1200	7.4	1.8	3.6	10	155
198	53	41	6	6	99	0	0	0	1	0	0	50	***330***	***950***	26	36	2.3	51	4	1400	4.9	5.9	5.2	5	IS
199	50	43	7	4	97	0	0	0	3	0	0	70	***446***	***825***	30	49	1.2	58	4	1700	6.5	2.5	4.5	17	160
200	60	34	6	3	13	87	0	0	0	0	0	83	***260***	420	23	51	1	61	4	690	5.8	1.3	3.4	15	90
201	59	35	5	6	74	25	0	0	1	0	0	39	***550***	***1025***	23	32	3	46	28	1175	6.6	2.5	***25***	20	160
202	45	45	10									83	36	182	40	78		48		1600	5.4		2.8	48	
203	66	29	5									125	105	204	88	61		34		***6000***	7.4		2.8	85	
204	24	60	16									28	43	97	15	17		25		910	4.0		***27.0***	10	
205	72	22	6									30	32	104	21	29		41		1800	6.7		6.2	4	
206	69	26	5									93	54	174	60	86		60		***4500***	6.6		8.4	55	
207	70	25	5									12	39	91	5	11		24		950	3.8		10.7	6	
208	59	32	9									24	25	93	5	14		35		415	4.2		3.2	4	