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TERRAIN INVENTORY AND QUATERNARY HISTORY OF THE PELLY RIVER AREA, YUKON TERRITORY

Lionel E. Jackson, Jr.

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Preface

The upper Pelly River basin and contiguous areas are rich in both renewable and nonrenewable resources. The spectacular scenery and abundant wildlife of this region sustain local first nation peoples, non-native trappers, and guides and annually attract hunters, fishermen, and wilderness canoeists from around the world. It is a headwaters area of two of the largest rivers in Canada – the Yukon and Mackenzie. This region also contains two towns, the largest mine in Yukon, and other developed or potentially economic deposits of metals and coal. Several power dams have been proposed for the region.

Development of the nonrenewable resources of this region, while minimizing the impact to its renewable resources, will require careful planning. An understanding of the surficial materials of this region and the processes that act on them will be essential to planning in this region. Furthermore, because much of the bedrock is buried by surficial materials, an understanding of these sediments is also essential for mineral exploration.

This report contains a detailed description and explanation of the unconsolidated sedimentary materials and landforms in the upper Pelly River basin and an account of the geological process that have been active during the Quaternary Period which includes the present. The information is vital to the understanding of the nature of foundation conditions, the location of aggregate resouces, and the nature of natural hazards within this region.

E.A. Babcock
Assistant Deputy Minister
Geological Survey of Canada

Préface

Le bassin de la haute Pelly et ses environs sont riches en ressources renouvelables et non renouvelables. Ses paysages splendides et sa faune abondante assurent des moyens de subsistance aux résidents autochtones, aux trappeurs non autochtones et aux guides, et attirent chaque année des chasseurs, des pêcheurs et des adeptes de canot en région sauvage du monde entier. Des branches de tête de deux des plus grands cours d'eau du Canada, le Yukon et le Mackenzie, se trouvent dans le secteur à l'étude. Il y a aussi deux villes, la plus grosse mine du Yukon de même que des gîtes métallifères et des gisements de charbon d'importance économique, dont certains sont déjà exploités. Plusieurs projets de barrage électrique ont été envisagés dans la région.

La mise en valeur des ressources non renouvelables de ce secteur devra être planifiée soigneusement et viser à minimiser les répercussions sur les ressources renouvelables. Cet exercice de planification exigera une parfaite connaissance des matériaux meubles de la région et des processus qui les modifient. Ces sédiments doivent être d'autant mieux connus qu'ils recouvrent une bonne partie du substratum rocheux qui est la cible de l'exploration.

Ce rapport décrit dans le détail les sédiments non consolidés et les formes observés dans le bassin de la haute Pelly, en plus de faire le bilan des processus géologiques qui ont été actifs durant le Quaternaire, qui s'étend jusqu'à notre époque. Cette information est essentielle pour connaître les conditions des terrains, le lieu où se trouvent les granulats et la nature des risques naturels qui existent dans cette région.

E.A. Babcock
Sous-ministre adjoint
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Abstract

The study area, encompassing large tracts of land around the headwaters of Pelly, Liard, and Nisutlin rivers, was covered by the Cordilleran Ice Sheet during the (last) McConnell Glaciation between 26.5 and 10 ka. At its acme, the ice sheet in this area was a complex of anastomosed valley glaciers comprising four sectors, each flowing from mountainous source areas and separated by mountains or ice divides. Underlying topography always directed ice flow. The ice sheet disappeared by stagnation and downwasting with the uplands first to be ice free and major valleys last.Deposits of an older glaciation or an early stade of McConnell Glaciation are restricted to Tintina Trench.

Till is the most widespread glacial deposit, usually in blankets and veneers over bedrock. Tills have a low clay content and plasticity and a variable carbonate content. Till geochemistry shows the greatest diversity between tills derived from ophiolite and sedimentary suites.

Glaciofluvial deposits, predominantly gravels, are common in most valleys as kame, esker, and planar deposits. Glaciolacustrine silts and clays occur where glacial ice impeded drainage during deglaciation. These deposits commonly contain massive ground ice and, consequently, are subject to retrogressive thaw sliding.

Colluvial deposits and their landforms form the largest nonglacial category in the study area. Because they are formed by a continuous spectra of chiefly nonfluvial processes, they intergrade. For example, a continuous series of landforms exists among talus cones, rock glaciers, and colluvial fans and between felsenmeer and solifluction deposits.

Five large rock avalanches or sturzstoms (>10^6 m^3) have occurred in Pelly Mountains in postglacial time.However, smaller scale rockfalls (<10^6 m^3) are volumetrically the most significant and widespread form of rapid slope failure.

Fluvial deposits, predominantly gravels, form fans, floodplains, and terraces. Some floodplains contain significant fine lacustrine and overbank sediments - primarily silts and clays; these may contain clear ice lenses and develop thermokarst. Much material of the alluvial fans and terraced gravels was deposited during early postglacial time when rates of sediment transport were conditioned by glaciation rather than by the present erosional regime.

Organic deposits are present in floodplains, in paludifying lakes, and as blanket bog. These deposits usually contain clear ice lenses that are subject to growth, heave, and collapse; they are particularly sensitive to disturbance.

Résumé

La région à l'étude englobe de vastes étendues autour du cours supérieur des rivières Pelly, Liard et Nisutlin; elle a été recouverte par l'Inlandsis de la Cordillère durant la Glaciation de McConnell (dernière), entre 26,5 et 10 ka. À son apogée, l'inlandsis était un complexe de glaciers de vallée anastomosés comportant quatre secteurs, chacun s'écoulant à partir de régions montagneuses et étant séparé par des montagnes ou des lignes de partage glaciaire. La topographie sous-jacente a toujours contrôlé le sens d'écoulement des glaces. La nappe glaciaire a disparu par stagnation et par fusion sur place, d'abord dans les hautes terres et ensuite dans les grandes vallées. Ce n'est que dans le sillon de Tintina que sont observés des dépôts d'une glaciation antérieure ou d'une phase précoce de la Glaciation de McConnell.

Le dépôt glaciaire le plus répandu est le till, qui forme habituellement des nappes ou des placages sur le substratum rocheux. Les tills ont une basse teneur en argile et une faible plasticité; ils contiennent des quantités variables de carbonates. La plus grande diversité géochimique se présente entre les tills dérivés d'ophiolites et les tills provenant de séquences sédimentaires.

Les dépôts fluvioglaciaires, surtout des graviers, abondent dans la plupart des vallées où ils forment des kames, des eskers et des dépôts plans.

Des silts et des argiles glaciolacustres se rencontrent aux endroits où la glace de glacier a obstrué la vidange durant la déglaciation. Ces dépôts contiennent fréquemment de la glace de sol massive et, par conséquent, sont sujets aux glissements rétrogressifs dus au dégel.

Les dépôts colluviaux et les formes de relief qu'ils produisent constituent la plus importante catégorie de matériaux non glaciaires dans la région à l'étude. Ils passent progressivement l'un à l'autre, car ils sont le produit d'une gamme complète de processus principalement non fluviatiles. Par exemple, les cônes d'éboulis, les glaciers rocheux et les cônes colluviaux constituent une série continue de formes de relief, tout comme les felsenmeer et les dépôts de solifluxion.

Cinq avalanches de pierres ou sturzstrom de grande étendue (> 10^6 m^3*) ont eu lieu dans les monts Pelly au Postglaciaire. Cependant, le phénomène de moindre envergure des éboulements (<* 10^6 m^3*) est la forme de rupture rapide de talus la plus importante et la plus étendue du point de vue volumétrique.*

Des dépôts fluviatiles, surtout des graviers, forment des cônes, des plaines d'inondation et des terrasses. Certaines plaines d'inondation contiennent des quantités considérables de sédiments de débordement et de sédiments lacustres fins - principalement des silts et des argiles - qui peuvent contenir des lentilles de glace transparente et présenter une topographie de thermokarst. Une grande proportion des matières des cônes alluviaux et des graviers en terrasses s'est accumulée au Postglaciaire précoce, lorsque la vitesse de transport des sédiments était régie par la glaciation plutôt que par le régime d'érosion actuel.

Il existe des dépôts organiques dans les plaines d'inondation et les lacs en tourbification; on en trouve aussi sous la forme de tourbières oligotrophes en couverture. Ces matériaux contiennent habituellement des lentilles de glace transparente qui peuvent croître, se soulever ou s'effondrer; ils sont particulièrement sensibles aux perturbations.

SUMMARY

The study area was intensely glaciated during the last (McConnell) glaciation by three major components of the Cordilleran Ice Sheet – the Selwyn, Cassiar, and Liard lobes. Glaciation dramatically altered the drainage systems of this region. Northwest trending valleys and reversed drainage have been superimposed on the primarily south draining preglacial valleys. The resulting topographic pattern over much of the study area is that of anastomosed valleys surrounding island-like tablelands that are surmounted by small mountain ranges.

Cordilleran Ice in the study area came into being after ca. 26.5 ka and had disappeared by 10 ka. At its acme, the ice sheet was a complex of bifurcating and reuniting valley glaciers. The underlying topography always directed ice-flow. The ice sheet disappeared by stagnation and downwasting first from the uplands and finally from the major valleys. Deposits of an older glaciation or an early stade of McConnell Glaciation are restricted to Tintina Trench.

Upland areas, excluding former nunataks, are typically covered by morainal (till) blankets and veneers, whereas valley bottoms are filled with glaciofluvial and glaciolacustrine sediments. Tills have a low clay content and plasticity and a variable carbonate content. Till geochemistry shows the greatest diversity between tills derived from the allochthanous ophiolites and granites of Pelly Mountains and Tintina Trench and those derived from the

SOMMAIRE

La région à l'étude a été en grande partie englacée au cours de la Glaciation de McConnell (dernière); trois grandes composantes de l'Inlandsis de la Cordillère la recouvraient – les lobes de Selwyn, de Cassiar et de Liard. La glaciation a beaucoup modifié les réseaux hydrographiques de la région. Des vallées à orientation nord-ouest et des cours d'eau à direction d'écoule- ment renversée se sont superposés aux vallées préglaciaires, qui se vidaient principalement vers le sud. Dans une grande partie de la région à l'étude, la topographie résultante comporte des vallées anastomosées entourant des plateaux que surplombent de petites chaînes de montagnes.

Après environ 26,5 ka, l'Inlandsis de la Cordillère avait envahi la région à l'étude; il s'en était retiré à 10 ka. À son apogée, l'inlandsis comportait un complexe de glaciers de vallée anastomosés. La topographie sous-jacente a toujours contrôlé le sens d'écoulement des glaces. La nappe glaciaire a disparu par stagnation et par fusion sur place, d'abord dans les hautes terres et ensuite dans les grandes vallées. Ce n'est que dans le sillon de Tintina que sont observés des dépôts d'une glaciation antérieure ou d'une phase précoce de la Glaciation de McConnell.

À l'exception des anciens nunataks, les plateaux sont typiquement couverts de nappes et de placages de till, tandis que les fonds de vallées sont comblés de sédiments fluvioglaciaires et glaciolacustres. Les tills ont une basse teneur en argile et une faible plasticité; ils contiennent des quantités variables de carbonates. La plus grande diversité géochimique se présente entre, d'une part, les tills dérivés des ophiolites et des granites allochtones des monts Pelly et du sillon de Tintina et, d'autre part, les tills provenant des roches sédimentaires du bassin de Selwyn et sedimentary rocks of Selwyn Basin and correlative rocks in Pelly Mountains. The former tills are enriched in chromium, manganese, cobalt, and nickel relative to the latter.

Till blankets and veneers are usually stable. However, melting ground ice can cause large tracks of uplands to fail as flows.

Glaciofluvial deposits are common in most valleys either as planar deposits of outwash or as kames and eskers. The latter are commonly found as complexes of terrace, knob and kettle, and ridges, which mark former areas of stagnant ice.

Glaciolacustrine sediments are predominantly silts, clays, and fine sands. They were deposited in lakes dammed in valleys by the wasting Cordilleran Ice Sheet or by glacial damming and isostatic depression within Tintina Trench. They represent depositional environments as diverse as meltout from floating and grounded icebergs, debris flow from ice margins, deltaic and subaqueous fan deposition, settling of fines from suspension and subsequent deformation triggered by ice meltout and slumping. Glaciolacustrine deposits commonly contain massive ice lenses. Where they have been eroded, such as along the outside of river bends, the thawing fine sediments retreat rapidly as retrogressive thaw slides.

Rock glaciers span both the glacial and nonglacial genetic categories. Lobate rock glaciers in the study area can be in the order of several hundred metres in width, whereas tongue-shaped rock glaciers locally approach 1 km in length. Rock glaciers may grade up slope into non debris-covered glaciers, talus aprons, and debris cones. Construction or any long term activities on top or in the path of these features is unfeasible. Rock glaciers not only move horizontally and vertically but also rocks periodically topple from their advancing precipitous snouts.

Colluvium encompasses deposits originating by the in situ breakdown of bedrock and unconsolidated sediments followed by gravitational transportation and resedimentation. Where these movements are rapid, such as the avalanching of rocks on to talus aprons and cones, colluvial deposits are hazardous sites for human activities.

Landslides occur within bedrock and unconsolidated deposits within the study area. Five large rock avalanches or sturzstroms have occurred in Pelly Mountains in postglacial time. However, rockfalls are the most significant form of slope failure both in frequency and cumulative volume. Snow avalanching is common in all alpine areas of the study and is an important agent in shaping talus aprons and colluvial fans.

Fluvial deposits are Holocene gravels and sands commonly overlain by or grading laterally into lacustrine or organic sediments in poorly drained areas of floodplains.

d'équivalents des monts Pelly. Les premiers sont riches en chrome, en manganèse, en cobalt et en nickel par rapport aux seconds.

Les nappes et les placages de till sont normalement stables. Cependant, la fonte de la glace de sol peut faire glisser de vastes étendues de hautes terres.

Les dépôts fluvioglaciaires abondent dans la plupart des vallées sous la forme de dépôts plans d'épandage proglaciaire ou de kames et d'eskers. Ces derniers se présentent fréquemment en complexes de terrasses, de bosses et creux ou encore de crêtes, qui marquent les anciennes zones de glace stagnante.

Les sédiments glaciolacustres se composent principalement de silts, d'argiles et de sables fins. Ils se sont accumulés au fond des lacs de barrage glaciaire formés dans les vallées par la fonte de l'Inlandsis de la Cordillère ou par l'emprisonnement de glace et la dépression isostatique dans le sillon de Tintina. Ils témoignent de divers types de sédimentation, notamment de la fusion d'icebergs flottants et ancrés, de coulées de débris en provenance de marges glaciaires, de l'accumulation sous forme de cônes deltaïques et subaquatiques, ainsi que du dépôt de matériaux fins en suspension et de la déformation subséquente provoquée par la fonte des glaces et les phénomènes de décrochement. Les dépôts glaciolacustres contiennent fréquemment des lentilles de glace massive. Aux endroits où il y a eu érosion des sédiments fins en dégel, par exemple sur la rive concave des cours d'eau, ces sédiments reculent rapidement par glissement rétrogressif.

Les glaciers rocheux sont dits à la fois glaciaires et non glaciaires. Dans la région à l'étude, ceux qui sont lobés peuvent atteindre plusieurs centaines de mètres de largeur, tandis que ceux en forme de langue, observés par endroits, ont presque 1 km de longueur. Les glaciers rocheux peuvent passer vers le haut de la pente à des glaciers sans couverture de débris, à des tabliers d'éboulis et à des cônes de débris. Il est impossible d'entreprendre des travaux de construction ou toute autre activité à long terme sur ou devant les glaciers rocheux; en effet, ceux-ci se déplacent horizontalement et verticalement, et des roches tombent périodiquement du haut de leur front abrupt en avancée.

Les colluvions englobent les dépôts produits par la fragmentation sur place du substratum rocheux et des sédiments meubles, suivie d'un transport gravitationnel et d'une resédimentation. Lorsque ces mouvements sont rapides, par exemple dans le cas des avalanches de roches sur des tabliers et cônes d'éboulis, les dépôts colluviaux constituent un site dangereux pour toute activité humaine.

Dans la région à l'étude, les glissements de terrain se produisent au sein du substratum rocheux et des dépôts meubles. Cinq avalanches de pierres ou sturzstrom de grande étendue ont eu lieu dans les monts Pelly au Postglaciaire. Cependant, du point de vue de la fréquence et du volume cumulatif, les ruptures de talus les plus importantes sont les éboulements. Les avalanches de neige sont fréquentes dans toutes les zones alpines de la région à l'étude; elles contribuent largement à façonner les tabliers d'éboulis et les cônes colluviaux.

Les dépôts fluviatiles sont des graviers et des sables holocènes; dans les régions mal drainées des plaines d'inondation, ils sont fréquemment recouverts de sédiments lacustres ou

Stream terraces are good sources of sand and gravel. They are suitable for most permanent activities because their nearly level surfaces are free of threat from geological hazards. Alluvial fans include landforms ranging from fans formed only of fluvial sediments to those composed of much debris flow and avalanche-borne sediment. Meanders characterize most of the larger streams. Extensive oxbow and thermokarst lakes and organic deposits occur on the floodplains of Pelly, South Macmillan, Tay, Ross, Finlayson, Nisutlin, Big Salmon, and Liard rivers and their larger tributaries.

Organic deposits are found in areas of poor drainage or high water table conditions such as floodplains, shallow paludifying lakes, and low areas in hummocky moraine. They also cover slopes as blanket bog. The low bearing strength of organic deposits coupled with their contents of ice lenses makes them sensitive to disturbance and totally unsatisfactory as foundation substrates.

Earthquakes originating along seismically active belts in the southwestern Yukon and Alaska panhandle and in Mackenzie and Richardson mountains have not caused damage within the study area. The period of record is too brief to properly evaluate the potential for damaging earthquakes posed by the Tintina Fault system.

organiques ou passent latéralement à ces lithologies. Les terrasses fluviatiles sont de bonnes sources de sable et de gravier. Elles conviennent à la plupart des activités permanentes, car leurs surfaces à peu près planes ne présentent presque aucun danger géologique. Les cônes alluviaux comprennent toute une gamme de formes de relief; ils peuvent, à un extrême, être constitués uniquement de sédiments fluviatiles et, à l'autre, présenter une importante proportion de sédiments de coulées de débris et d'avalanches. La plupart des grands cours d'eau ont des méandres. De vastes lacs en croissant et lacs thermokarstiques de même que des dépôts organiques se rencontrent sur les plaines d'inondation des rivières Pelly, MacMillan Sud, Tay, Ross, Finlayson, Nisutlin, Big Salmon et Liard, ainsi que de leurs grands tributaires.

Les dépôts organiques s'observent dans les régions mal drainées ou à nappe phréatique élevée comme les plaines d'inondation, les lacs peu profonds en tourbification et les creux dans les secteurs de moraines bosselées. En outre, ils forment des tourbières oligotrophes en couverture sur les pentes. En raison de leur faible portance et de la présence de lentilles de glace, les dépôts organiques sont fragiles aux perturbations; ils ne conviennent donc pas du tout à l'établissement de fondations.

Les séismes se produisant le long des zones actives délimitées dans le sud-ouest du Yukon et l'enclave de l'Alaska ainsi que dans les monts Mackenzie et Richardson n'ont pas causé de dommages dans la région. La période sur laquelle s'échelonnent les observations est trop courte pour permettre d'évaluer la possibilité qu'il se produise des séismes destructeurs associés au système de failles de Tintina.

INTRODUCTION

The Pelly River area is rich in mineral resources including both base and precious metals. This study area is also rich in water, wildlife, forest, recreational, and scenic resources of the upper Pelly, Teslin, and Liard River systems. Future land use conflicts are likely unless careful planning is employed.

Knowledge of its surficial geology will be essential in planning whether the Pelly River area is used to find materials for road construction, to select the least hazardous routes through landslide-prone terrain, or to evaluate the sensitivity of the landscape to various human activities. A detailed knowledge of the Quaternary history of an area is also useful in the exploration for undiscovered mineral deposits. For example, determination of ice flow directions during the last glaciation expedites the tracing of mineralized float in drift or the pinpointing of the sources of geochemical anomalies.

The author provides an inventory of surficial deposits of the Pelly River area, describes the processes that modify them, and details the Quaternary history of this area. This report enlarges upon the accompanying Geological Survey of Canada maps 1790A-1793A (105F), 1794A-1797A 105G), 1819A-1822A (105K), and 1832A-1835A (105J). They supercede maps in open files 1379, 1380, 1536, (Jackson et al., 1984; Jackson 1986a,b, 1987a).

The information on which this report is based was gathered between 1981 and 1987. It was part of a larger surficial geology mapping project encompassing NTS map areas 105 F,G,I,J,K,L, and 115 I. Map units were first delinated on air photographs and then field-checked using foot, boat, and helicopter traverses. The stratigraphy of the deposits was investigated at that time where natural or artificial exposures existed.

Physiography

The region covered by map areas 105 F,G,J,and K is bounded by latitudes 61° and 63° N and longitudes 130° and 134° W (Fig. 1). The area includes the mountainous headwaters of Pelly and Macmillan rivers and smaller Yukon tributaries such as Little and Big Salmon rivers; Nisutlin River drains its southwestern margin, flowing into Teslin River, which is a major tributary of Yukon River. The extreme southeastern corner of the area includes the headwaters of Liard River, a major tributary to the Arctic-flowing Mackenzie River. Major physiographic subdivisions of this area of the Cordillera were first standardized by Bostock (1948) and have recently been revised under the direction of Mathews (1986). This report uses the latter's terminology and hierarchy of physiographic subdivisions.

The study area spans three major phsiographic subdivisions: Yukon Plateaus, the northern extension of the northwest- trending Kasca Mountains, and the western margin of Selwyn Mountains. The summits of these uplands, whether included in mountains or plateaus, are remnants of an elevated surface of formerly low relief (Tempelman-Kluit, 1980).

Yukon Plateaus occupy much of southern and central Yukon, where this complex of rolling uplands is cut by steep-sided valleys. MacMillan Highland, a subdivision of Yukon Plateaus in the study area, comprises Anvil and South Fork ranges, Selous Mountains, and Ross Lowland. Ross Lowland is a relatively low lying area including the wide, drift-filled valleys of Ross and the upper Pelly and MacMillan rivers. Valley bottoms range in elevation from 640 to 760 m, the general plateau surface from 1070 to 1370 m. Some mountain summits above the general plateau surface have an additional relief with elevations of 600 m up to about 2130 m.

The rugged Pelly Mountains and Simpson Ranges, marked by classic alpine arête and horn peaks and the more subdued Nisutlin and Dease plateaus, are the major subdivisions of Kaska Mountains. Elevations range from major valley floors at 700 m to summits exceeding 2100 m in Pelly Mountains. Logan Mountains including the glacier-clad Itsi Range are subdivisions of Selwyn Mountains. Elevations and relief within Logan Mountains compare to those in Pelly Mountains.

Pelly Mountains are separated from MacMillan Highland, Ross Lowland, and Simpson Ranges by Tintina Trench, a major northeast-trending valley controlled by Tintina and related faults (Roddick, 1967). Tintina Trench is abruptly bounded by scarps where it abuts Ross Lowland, MacMillan Highland, and Pelly Mountains northwest of Simpson Ranges. These scarps range in relief from 100 to 1200 m. Tintina Trench becomes a deep, narrow, linear valley between Pelly Mountains and Simpson Ranges.

The major upland elements within the study area are incised by broad, southwest-trending preglacial valleys, such as the valleys followed by Ross and Nisutlin rivers and and Blind and Anvil creeks, and by narrower, northwest-trending valleys (Fig. 2, 3). Ross Lowland, which contains the headwaters of Pelly River including Ross River, probably owes its

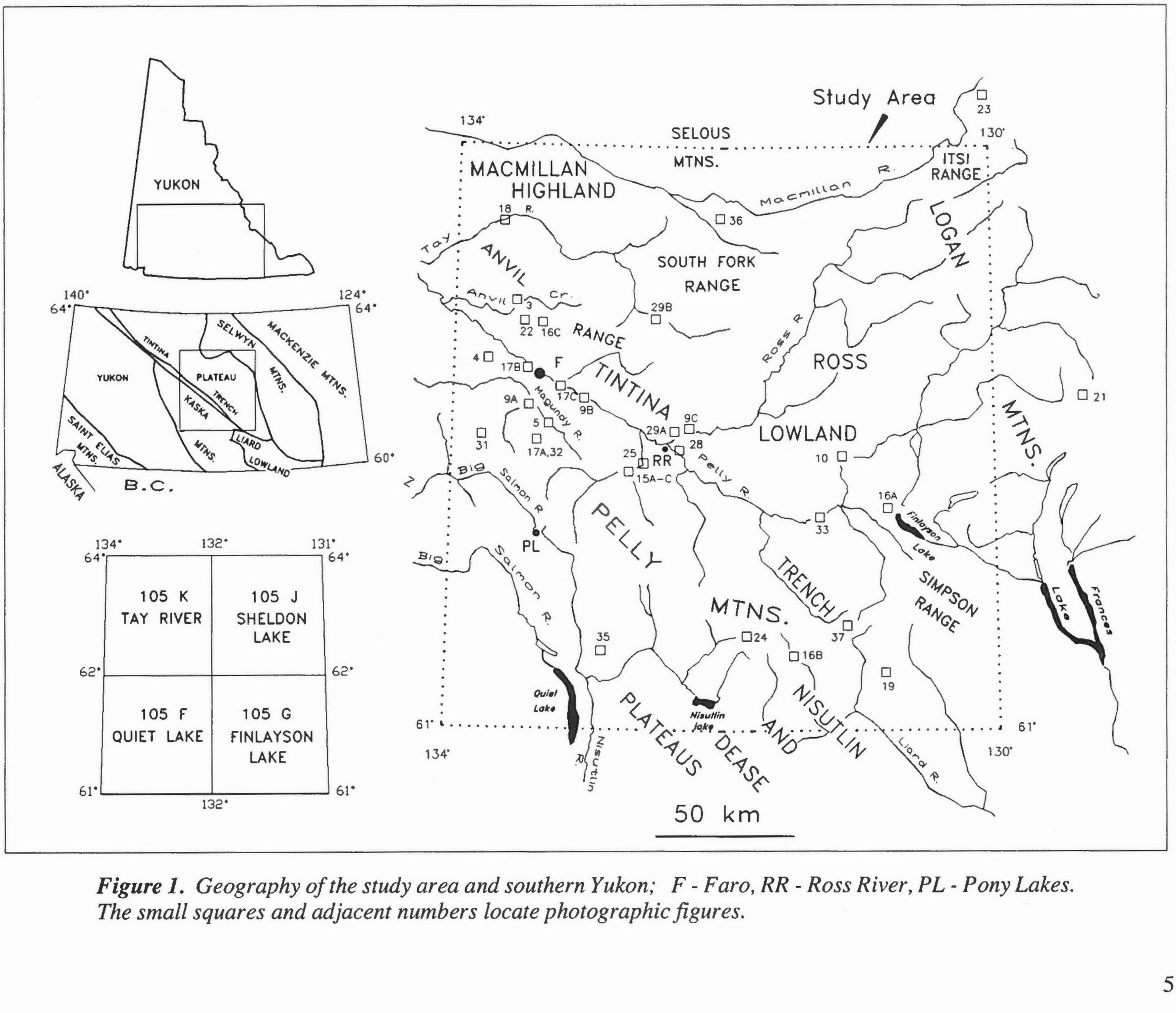

Figure 1. Geography of the study area and southern Yukon; F - Faro, RR - Ross River, PL - Pony Lakes. The small squares and adjacent numbers locate photographic figures.

comparatively low relief to its persistence as a conduit for south-flowing streams since preglacial times. With the exception of the Ross River valley, these southwest-trending preglacial valleys are occupied by underfit streams or by short reaches of contemporary major streams. These valleys mark the courses of trunk streams during preglacial times. The generally narrower northwest-trending valleys were cut during the Pleistocene by ice that diverted drainage to the northwest. The South Macmillan valley is an exception. It has likely followed a northwesterly course since preglacial times. In the case of Big Salmon River and parts of the upper Nisutlin and Liard rivers, the direction of flow has been reversed by the deposition of thick glacial drift and by the breaching of divides, presumably by glacial and glaciofluvial erosion (Fig. 2). The resulting topographic pattern over much of the study area shows anastomosed valleys surrounding islandlike tablelands that are surmounted by small mountain ranges.

Evidence of past glaciation, in addition to the anastomosing of valleys, is ubiquitous. Summits above 1 800 m typically feature arête ridges, cirques, and horn peaks. Lower plateaus and the sides of larger valleys are marked by whaleback ridges and crag-and-tails, which indicate past ice flow directions (Fig. 4). Valley bottoms contain complexes of glaciofluvial deposits or thick fills of glaciolacustrine sediments. Flights of gravelly benches are common on mountain sides and locally are nearly continuous from valley floor to mountain summit (Fig. 5). The gravelly benches are the beds of former ice-walled channels.

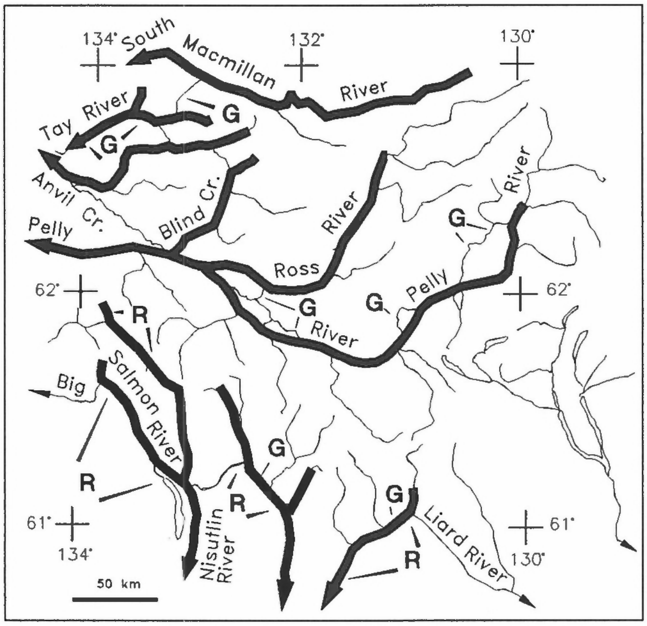

Figure 2. Major preglacial drainage systems. The stream names refer to the preglacial course of the stream. G - gorges or rapids along contemporary streams created by glacial diversion from the preglacial course. R - reaches of streams now reversed from the preglacial direction of flow by glacial sedimentation and diversion.

Table 1. Climatic summary for Tungsten and Ross River weather stations.

	Temperature (°C) Jan	 July	Mean annual precipitation (mm)
Tungsten[1], Northwest Territories (61°57 'N, 128°15 'W), elevation, 1143			
Daily max	-19.5	16.6	Total 644.7
Daily min	-29.3	5.3	Snow 316.7
Annual mean	-5.7		Rain 333.6
Extremes			
Max	27.8		
Min	-50.0		
Ross River[2], Yukon Territory (61°59 'N, 132°27 'W), elevation 698 m			
Daily max	-23.6	21.8	Total 263.5
Daily min	-36.1	5.3	Snow 105.8
Annual mean	-5.7		Rain 152.2
Extremes			
Max	33.3		
Min	-59.4		

[1] Record period is 10-14 years depending upon the parameter measured and the month of measurement.

[2] Record period is 9-14 years depending upon the parameter measured and month of measurement.

Climate and vegetation

The map area lies within the zone of discontinuous permafrost (Brown, 1967), and its climate is marked by long cold winters and short mild summers. The Tungsten and Ross River climatic records (Table 1) reasonably represent comparable elevations in the study area. Precipitation falls almost entirely as snow from October through April and predominantly as rain from May through September at low elevations. However, snow may fall during any month at higher elevations.

Permafrost is nearly continuous in the area except on south-facing slopes and along stream courses.

Vegetation is determined by elevation, topography, and microclimate. The forest is mainly black spruce (*Picea mariana*) and white spruce (*Picea glauca*). The former dominates under poorly drained conditions and commonly indicates the presence of underlying permafrost. Above timberline (at about 1220 m). (*Betula glandulosa*) blankets the plateaus. At yet higher elevations reindeer moss (*Cladonia* spp.) is widespread, and at the highest elevations or on steep, unstable or highly exposed areas, only crustose lichens and scattered herbaceous plants survive. Wet areas are dominated by sphagnum (*Sphagnum* spp.) and sedge (*Carex* spp.) bogs.

Soils are classified mainly as regosols in steep areas and above treeline and gleysols and organics in poorly drained locations. Cryosols are present where permafrost is within 1 m of the surface. Brunisols dominate under well drained forest conditions (Tarnocai, 1987).

Previous work

Geological investigations of the study area began in 1887 when G.M. Dawson traversed it via Pelly River during his exploration of the southern Yukon. He encountered placer miners working gravel bars along Pelly River. He described the bedrock and surficial geology of the region (Dawson, 1888). An exploration of the Macmillan River basin by R.G. McConnell in 1902 included South Macmillan River up to the Confluence of Riddell River in the northwest corner of the study area (McConnell, 1903). He noted the upper limits of drift and observed that parts of Selwyn Mountains had projected above the former ice sheet (p. 58). During the summer of 1907 Keele (1909) followed Pelly River upstream from Ross River to Wolf Canyon and traversed the Ross River basin during his crossing of Selwyn and Mackenzie Mountains in the winter and spring, 1907-1908. He commented on the distribution of surficial deposits and the general flow patterns of an ice sheet that he estimated to have been 900 m thick over Selwyn Mountains. Adventurous explorations by Pike in 1893 (Pike, 1896) contributed further geographical knowledge of the study area.

Systematic reconnaissance geological mapping of the bedrock of the area was initiated in 1960's at a scale of 1:250 000 (Roddick and Green 1961a,b; Wheeler et al., 1960 a,b). The discovery of large lead-zinc deposits in the

Figure 3. The sediment-filled preglacial valley of Anvil Creek. Underfit streams such as Anvil Creek typify many preglacial valleys in the study area (view looking north). A former nunatak is flanked by well developed moraines (dashed lines) marking the upper limits of ice during McConnell Glaciation. The former direction of ice flow was south around the nunatak with a major ice-stream flowing down the valley of Anvil Creek toward the viewer. The 30 m elevation difference between moraine levels on the north and south sides of the nunatak has resulted largely from compressive flow against that side of the nunatak (Duk-Rodkin et al., 1986). Distinctive dendritic drainage patterns on the floor of Anvil Creek have developed on thick glaciolacustrine sediments. Valley floor is approximately 1 km wide at centre of view. (NAPL T10-140)

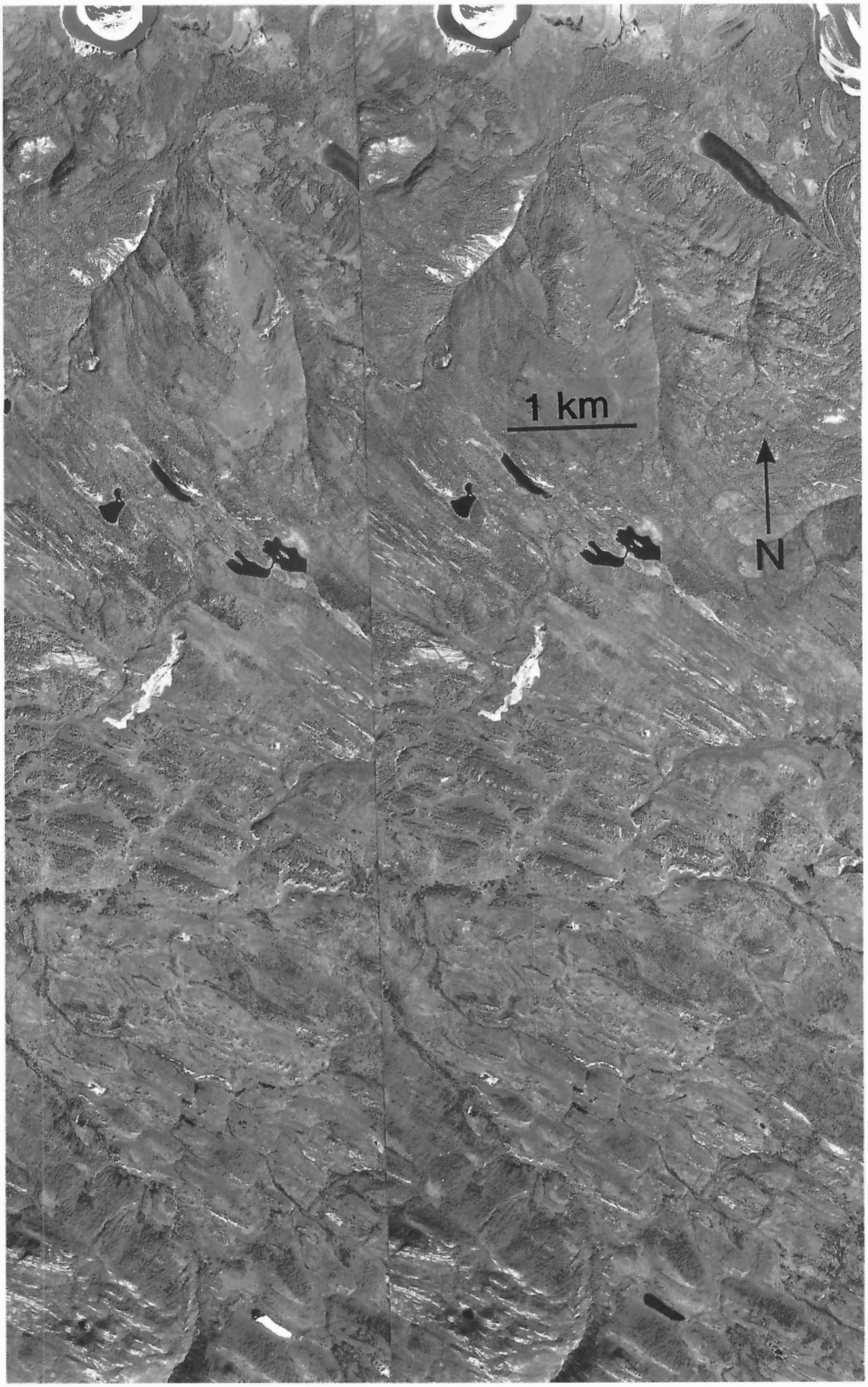

Figure 4. *Streamlined topography underlain by morainal (till) blankets in areas of low relief and veneers in high relief areas – former ice flow was from southeast (lower right) to northwest (upper left). The small landslides are debris flows triggered by the meltout of ground ice within till. (NAPL A20112 32-33)*

Paleozoic metasediments in Anvil Range in the early 1960s and lode gold associated with Tertiary volcanics in Tintina Trench in the 1980s stimulated new phases of more detailed bedrock mapping and related site specific investigations (Duke and Godwin, 1966; Tempelman-Kluit, 1972, 1977, 1979; Wood and Armstrong, 1982; Gordey, 1983, 1987; Pigage and Anderson, 1985; Jackson et al., 1986; Gordey and Irwin, 1988; Pride, 1988; Smith and Erdmer, 1990; Hughes and Long (1980) investigated Eocene coal deposits in Tintina Trench.

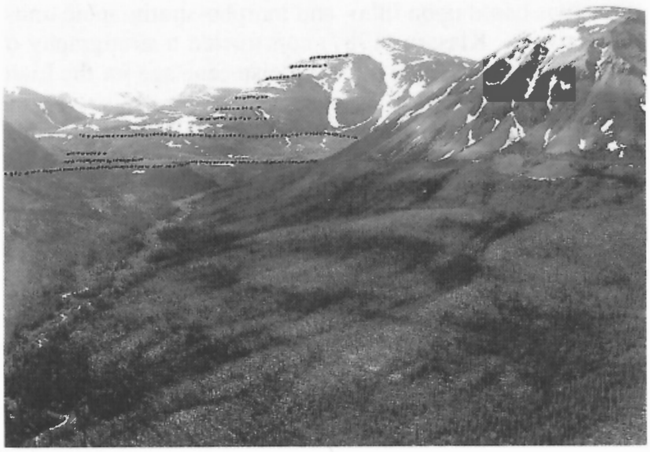

Figure 5. Flights of kame terraces, Magundy River headwaters. (Terraces have been accentuated with dotted lines.) Vertical relief between upper and lower terraces is about 450 m. (GSC 1992-113E)

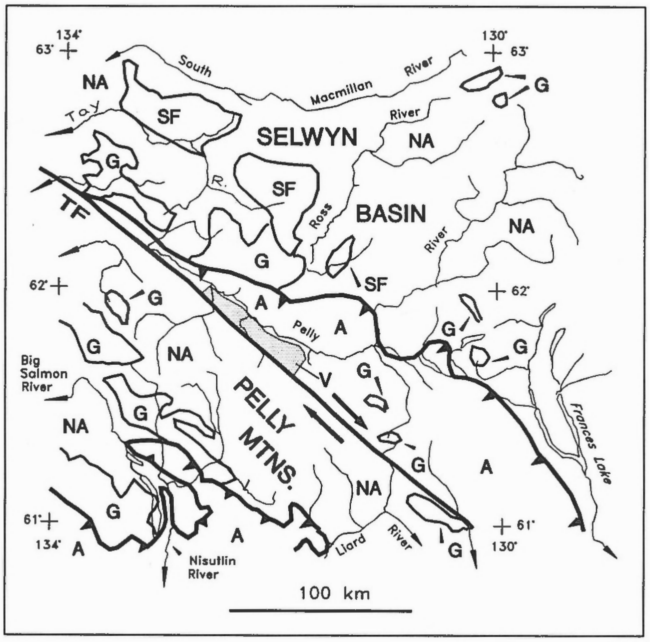

Figure 6. Bedrock geology of the study area (generalized from Gabrielse et al., 1980): A - obducted allochthons of mylonite, ophiolite, and granite of Mesozoic and older age, NA - folded and thrusted late Precambrian to Triassic miogeoclinal basinal and platform sedimentary rocks deposited along the North American margin, TF - Tintina Fault, G - late Mesozoic granitic intrusives, SF - middle Cretaceous crystal and lithic tuff caldera fill, V - (stipple pattern) Eocene bimodal volcanics and coal-bearing clastics.

Surficial geology mapping and stratigraphic investigations have been carried out within and adjacent to the study area out by Campbell (1966: 105 L), Jackson (1982, 1986a,b, 1987a,b, 1989), Klassen (1982: 105 B), Klassen and Morison (1982: 105 D; 1987: 105 E), Hughes (1983a,b: 105 M southeast and southwest), Jackson et al. (1984), and Dyke (1990a: 105 H). Other published studies of Quaternary deposits within and adjacent to the study area have dealt with drift prospecting (Plouffe, 1989; Plouffe and Jackson, in press) and specific phenomena such as palsas (Kershaw and Gill, 1979), rock glaciers (Kershaw, 1978; Jackson and MacDonald, 1980; Dyke 1990b), debris avalanches (Jackson and Isobe, 1990), Holocene palynology (MacDonald, 1983), and Holocene ore deposition (Jonasson et al., 1983).

Bedrock geology

The study area straddles three distinct geological provinces (Fig. 6), each of which is briefly summarized below.

Pelly Mountains suture zone

Southwest of Tintina Fault, Pelly Mountains mark a Jura-Cretaceous suture zone (Tempelman-Kluit, 1979). Within this suture, carbonates, arenites, argillites, and cherts (deposited along the western margin of North America between the late Precambrian and Triassic) were thrusted and folded to the northeast along with obducted allochthons of mylonite, ophiolite, and granite (derived from a former island arc). Slices of this same suture terrane are found discontinuously north of and along Tintina Fault and in Campbell Ranges. At least 450 km of right lateral movement occurred along Tintina Fault since late Cretaceous time (Roddick, 1967).

Selwyn Basin

With the exception of scattered allochthon remnants, bedrock northeast of Tintina Fault is dominated by northeast thrusted and folded autochthanous dark cherts, organic rich cherty shales, and chert pebble conglomerates, which are deposited along the North American margin between the late Precambrian and Triassic. This assemblage and region of deposition was named Selwyn Basin by Gabriesle (1967).

Syenites, quartz monzonites, and granodiorites, thought to have been created by crustal melting (Gordey and Irwin, 1987), intruded rocks throughout Pelly Mountains and Selwyn Basin during the Cretaceous. Contact metamorphism around these intrusions is confined to narrow aureoles north of Tintina Fault, whereas parts of Pelly Mountains have been regionally metamorphosed. The massive crystal and lithic tuffs of South Fork Volcanics were erupted on a grand scale in the northwest quarter of the study area in mid-Cretaceous time. South Fork Range and nearby ranges mark the locations of former caldera fills (Gordey, 1988).

Table 2. Glacial stratigraphy of southern Yukon Territory.

Age	Yukon Plateau (Bostock, 1966; Hughes et al., 1989; Jackson et al., 1990; Jackson and Harington, 1991)	Snag-Klutlan Area (Rampton, 1971)	Shakwak Trench (Silver Creek) (Denton and Stuiver, 1967)	Southern Ogilvie Mountains (Vernon and Hughes, 1966)	Liard Lowland (Klassen, 1987)
HOLOCENE	Postglacial (Stewart soil)	Neoglaciation Slims Nonglacial Interval	Neoglaciation		
		13.7 ka[2]	12.5 ka[2]		
PLEISTOCENE	McConnell Glaciation	Macauley Glaciation	Kluane Glaciation	Last glaciation	Glaciation
	Diversion Creek soil		Boutellier		
	Sheep Creek Tephra (ca. 80 ka)	Old Crow Tephra (80-130 ka)	Nonglacial interval		Nonglacial
	Reid Glaciation	Mirror Creek Glaciation	Icefield Glaciation	Intermediate glaciation	Glaciation
	Wounded		Silver		Nonglacial
					232 ± 21 BP
	Moose		nonglacial		Glaciation
					546 ± 46 BP
	soil		interval		Glaciation
	790 ka				
	Klaza Glaciation		Shakwak Glaciation?		
	Nonglacial (Fort Selkirk Tephra ca. 1 Ma)				
	Nansen Glaciation		Shakwak Glaciation?		

[1] Modified from Hughes et al., 1989.
[2] Radiocarbon years before present.

Tintina Trench Tertiary volcanics

The youngest series of rocks in the study area are bimodal volcanics (basalts and rhyolites) and locally interstratified coal-bearing clastics. They lie northeast of Tintina Fault, principally within Tintina Trench. These rocks were erupted and deposited within small but deep basins created by right lateral faulting along Tintina Fault during the Eocene (Jackson et al., 1986). Rocks in some of these basins were subsequently folded and faulted to varying degrees (Hughes and Long, 1980).

The bedrock geology of the study area has important implications for the composition of drift. Because of the widespread sedimentary rocks, particularly cherty siltstones and cherts, only a few distinctive lithologies exist. These include the fresh biomodal volcanics of Tintina Trench, South Fork Volcanics, and ultramafic rocks associated with ophiolites in Pelly Mountains. The latter (as noted under *Applications*) also inparts a distinctive geochemical signature.

Quaternary context

Central and southern Yukon has been glaciated at least seven times since the late Pliocene (Jackson et al., 1991). Bostock (1966) found evidence of four glaciations of central and southern Yukon, based upon morphostratigraphic, stratigraphic, and geomorphological evidence (Table 2). He named these glaciations Nansen (oldest), Klaza, Reid, and McConnell (youngest). Deposits of the two oldest and most extensive glaciations have been largely removed by erosion or buried by colluvium. Consequently, to discriminate between them is not usually possible in central and southern Yukon where their distributions are combined together as pre-Reid glaciations (Fig. 7).

For southwestern and west-central Yukon, Denton and Stuiver (1967) and Rampton (1971) constructed glacial stratigraphies based upon litho- and morpho-stratigraphic units, respectively. Klassen (1987) constructed a stratigraphy of multiple tills of early to middle Pleistocene age for the Liard Plain near the town of Watson Lake. These tills, with the exception of the youngest McConnell age till, were deposited during regional glaciations that occurred between Reid and the pre-Reid glaciations (Table 2). The extent of glacial ice cover during these glaciations as compared to that of the McConnell Glaciation in the Liard Plain region is not known.

Hughes et al. (1969) assigned names to semi-autonomous sectors of the last (McConnell) Cordilleran ice sheet in southern Yukon. These sectors (Selwyn, Cassiar and Liard lobes) are defined in Figure 8. The Selwyn Lobe flowed west from Selwyn Mountains and shared a common ice divide with the Liard Lobe in the area of Finlayson Lake. The Cassiar Lobe flowed west and northwest from Cassiar Mountains; it was separated from the Selwyn Lobe by Pelly Mountains. The Liard lobe flowed south from Selwyn Mountains and southeast and east from Pelly and Cassiar mountains, respectively. Pelly Mountains supported complexes of ice caps that shed ice to the Cassiar and Selwyn lobes as well. The Eastern Coast Mountain Lobe, which flowed northwestward from the summits of Eastern Coast Mountains in northwestern British Columbia, lay between the piedmont lobe complex originating in Saint Elias Mountains and the Cassiar Lobe. Parts of three of these sectors (Selwyn, Cassiar, and Liard lobes) are included within the study area.

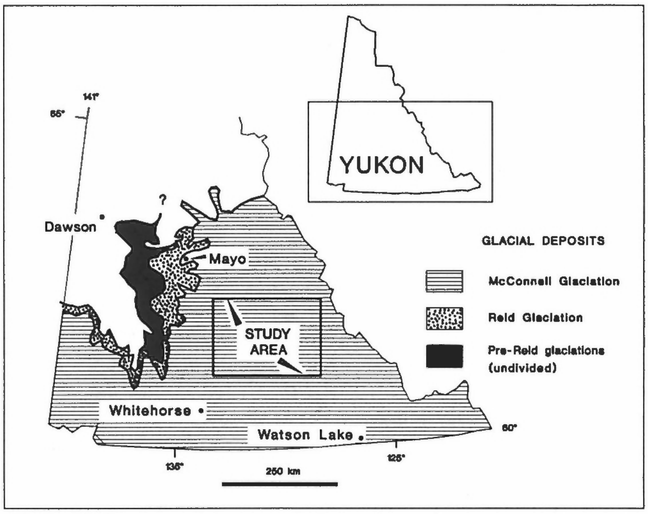

Figure 7. Generalized glacial limits in Yukon.

QUATERNARY DEPOSITS

Classification of landforms and surficial materials

The surficial materials portrayed in the accompanying Maps 1790A-1797A, 1819A-1822A, and 1832A-1835A and discussed here are broadly divided into two categories: (1) bedrock comprising consolidated materials of pre-Quaternary age and (2) unconsolidated or poorly consolidated sediments of Quaternary age. These categories have been subdivided using a simplified version of the British Columbia Terrain Classification System (BCTCS) (British Columbia Ministry of the Environment, 1988). In this system, surficial materials are initially subdivided according to genesis and then further sudivided on the basis of morphology and modifying surficial processes; the latter are usually indicated with a symbol. Other properties such as texture and stratification are implicit within these subdivisions. It has also proven to be easier and more useful to represent units including landslides, rock glaciers, and thin eolian and organic coverings as symbols rather than the BCTCS letter designators.

Quaternary deposits in the report area formed almost entirely during the last (McConnell) glaciation and the Holocene. Older Quaternary deposits, predating or from an early stade of McConnell Glaciation, have been recognized only in scattered exposures along river valleys. These deposits are described in detail under *Stratigraphy* later in this report. Because these deposits crop out only along near vertical sections, they do not appear on accompanying surficial geology maps except in idealized stratigraphic column which are displayed along the map margins. They are almost indistinguishable from their McConnell equivalents.

Genesis

R – Bedrock

Includes completely exposed bedrock or rock with a thin, patchy covering of colluvium or till. In alpine areas, the bedrock surface may be fractured and cryoturbated into blockfields, sorted stone polygons, and solifluction lobes.

M – Morainal deposits

Usually referred to as till, these sediments are directly deposited by glacier ice. Till is a diamicton, that is, an unsorted, matrix-supported, massively bedded to poorly stratified sediment ranging from clay to boulders in texture (Fig. 9). Till has been the most widely used term in North

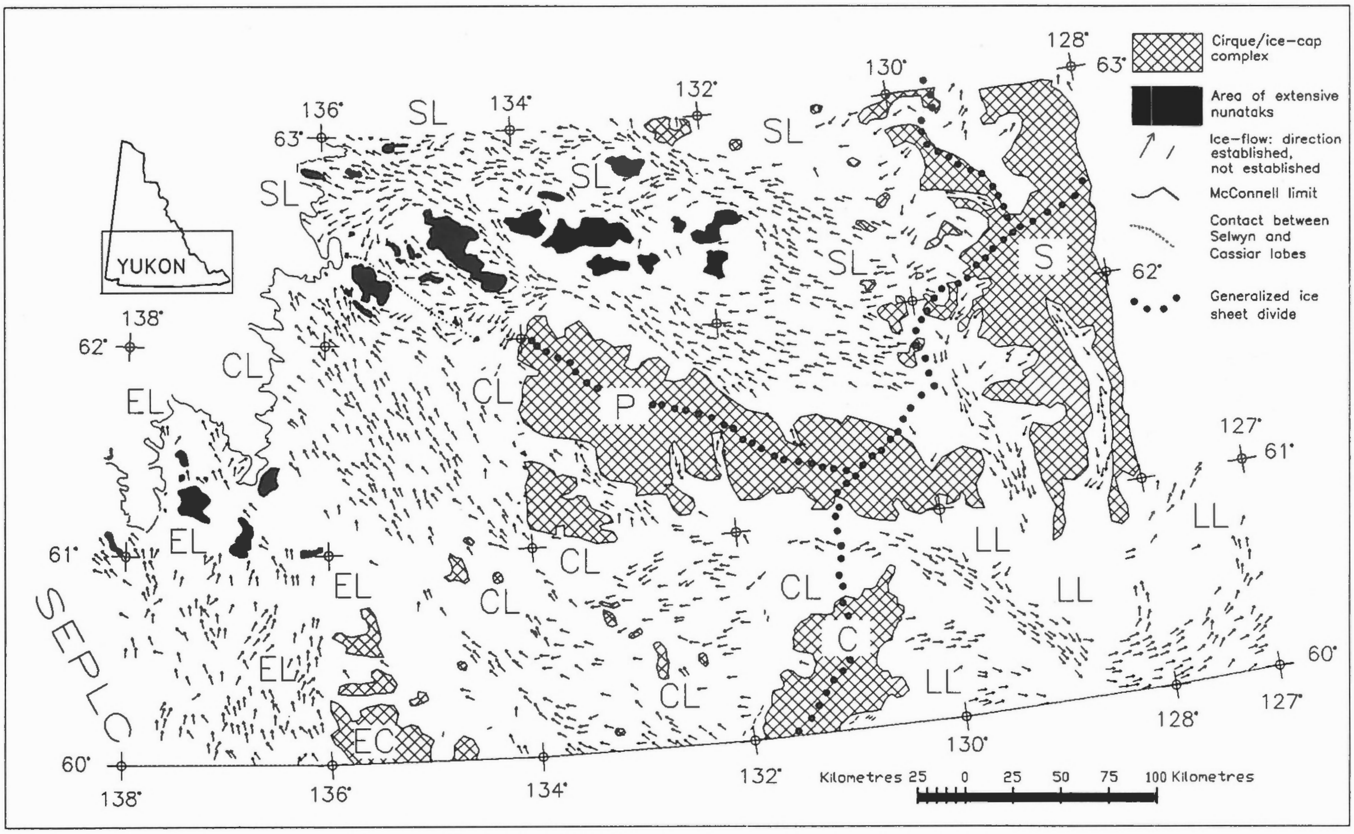

Figure 8. Ice-flow directions and limits of Cordilleran Ice in southern Yukon (generalized from Jackson and Mackay, 1991). SEPLC – St. Elias piedmont Lobe complex, EL – Eastern Coast Mountains Lobe, EC – Eastern Coast Mountains, CL – Cassiar Lobe, C – Cassiar Mountains, P – Pelly Mountains, SL – Selwyn Lobe, S – Selwyn Mountains, LL – Liard Lobe. The boundaries between the Eastern Coast Mountain Lobe and the Cassiar Lobe and St. Elias piedmont Lobe complex have not been defined.

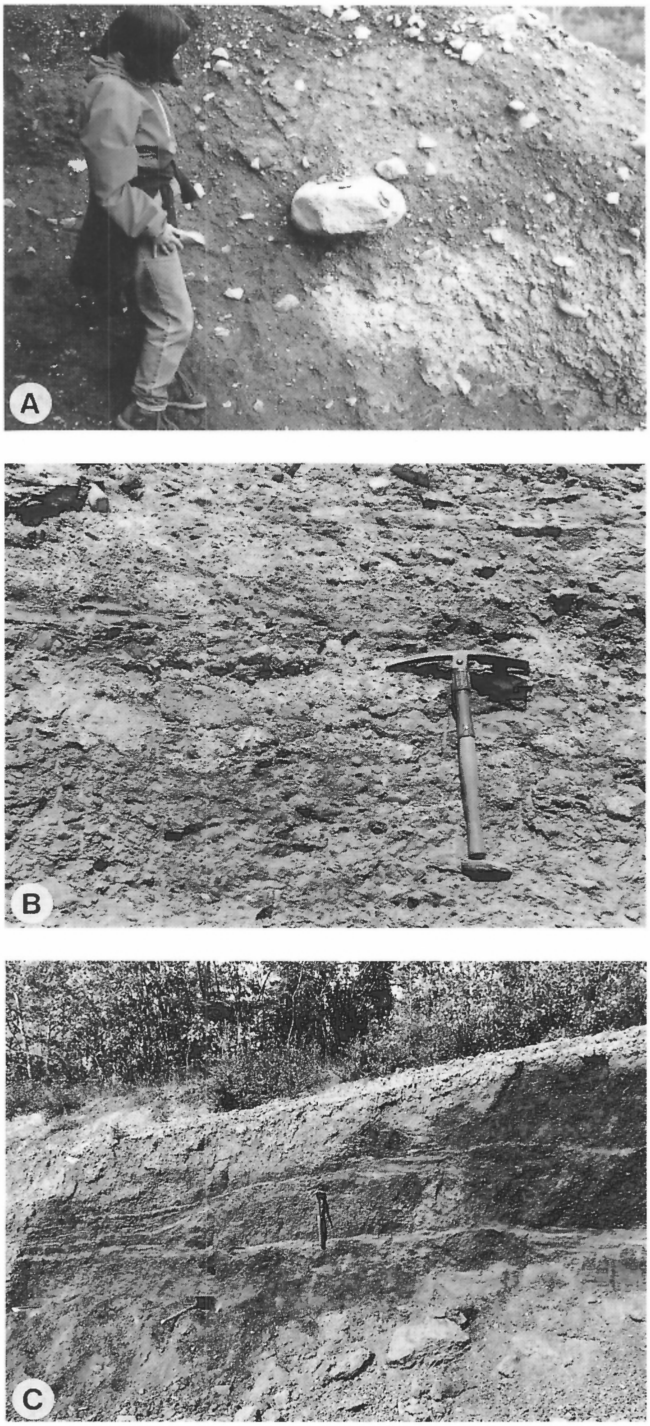

Figure 9. Examples of till from contrasting depositional environments. ***A*** *- bouldery lodgment or meltout till (GSC 1992-113B).* ***B*** *- a complex of stratified lensoidal diamictons and sand and poorly sorted gravel lenses along the flank of a whaleback ridge. The diamictons likely formed as sediment gravity flows from the summit of the whaleback during or shortly after emergence from beneath glacial ice (GSC 1992-113C).* ***C*** *- interstratified diamicton and clayey silt at the margin of lacustrine sediments. The diamictons originated as sediment gravity flows from stagnant ice into the adjacent lake (GSC 1992-113F)*

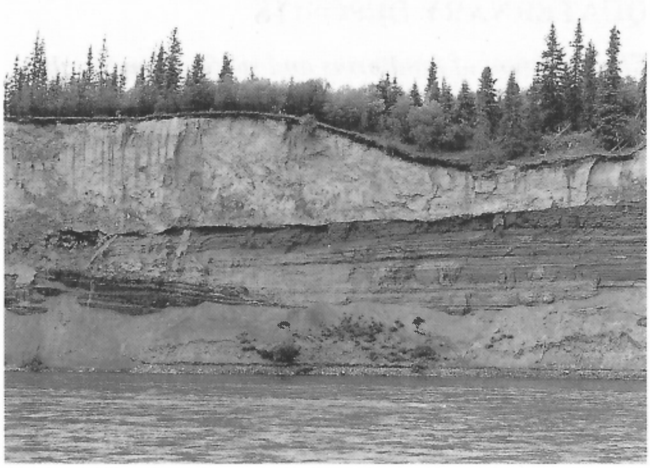

Figure 10. *Morainal (till) blanket overlying sands and fine gravels filling a buried valley along Pelly River. (GSC 1992-113G)*

Table 3. Calcite and dolomite contents.

	Mean	Standard Deviation	Maximum	Minimum	Samples
			Tintina Trench		
Calcite	3.2	2.9	15.5	0.3	83
Dolomite	2.3	1.6	7.3	0.0	83
			Selwyn Basin		
Calcite	2.7	7.5	42.0	0.05	50
Dolomite	2.6	7.9	50.0	0.0	50
			Pelly Mountains		
Calcite	6.3	6.0	27.8	0.4	39
Dolomite	4.3	3.0	8.6	0.0	39

[1] Determined by the standard Chittick Method on the < 63 μm fraction.

America for morainal deposits. Recent studies of sedimentary processes around the margins of active glaciers, notably Lawson, (1979) and Eyles (1983) have placed the applicability of this term in question. These authors suggest the term till should be restricted to sediments that have melted out directly from glacial ice with no subsequent resedimentation. In this report, the term "till" is applied to sediments that are entirely or predominantly diamictons, either directly deposited by glacial ice or apparently contemporaneously redeposited by gravitational processes, that is, while ice still underlies or is in the vicinity of the sediments. Thicknesses range from thin and discontinuous veneers less than 1 m thick to 5 m or more (Fig. 4, 9, and 10).

Till is also a component of hummocky ice-stagnation topography and of lateral and end moraines near present-day glaciers. Ice stagnation topography is characterized by closely spaced small hillocks and ridges several to 10 m in height. This topography likely formed as till melted out from the ice or slid into depressions between blocks of stagnant ice (Boulton and Eyles, 1979).

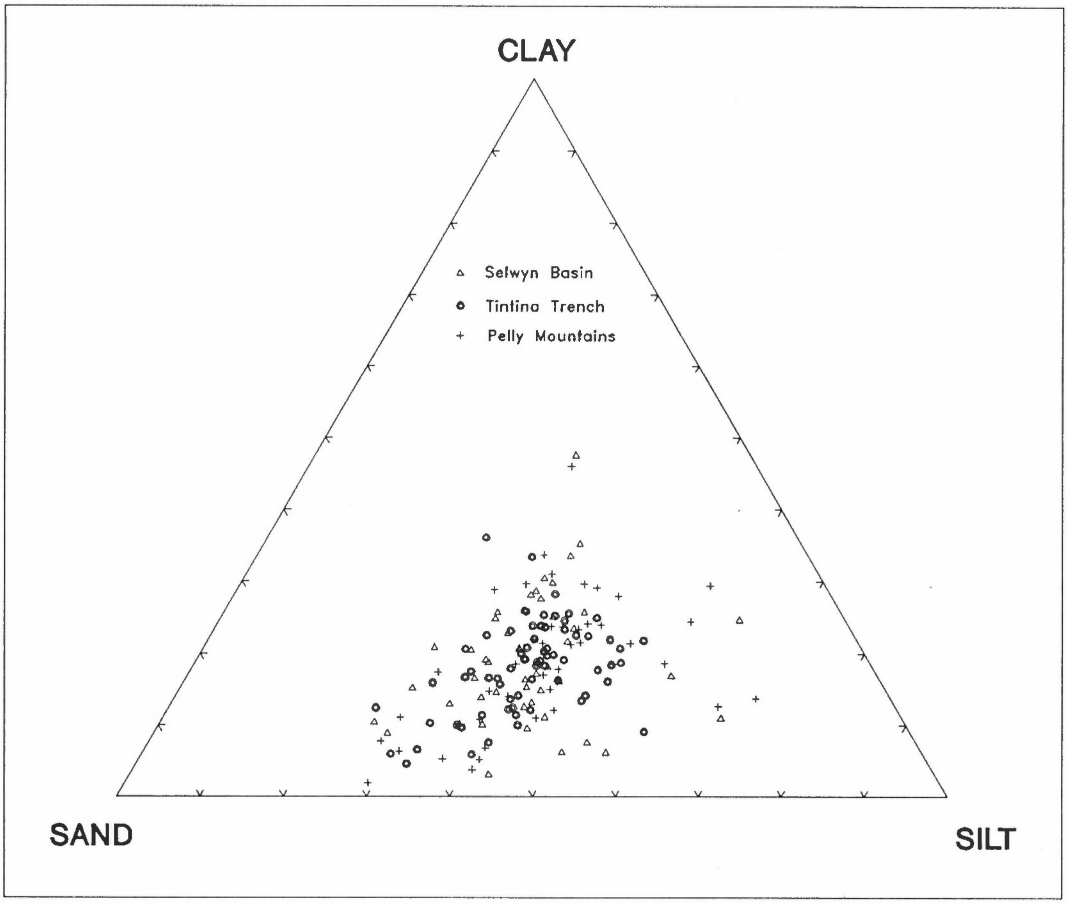

Figure 11. Textures of the ≤2 mm fractions of tills in the study area (sand ≤2 - ≥0.065 mm, silt <0.065 mm- >0.002 mm, clay ≤0.002 mm).

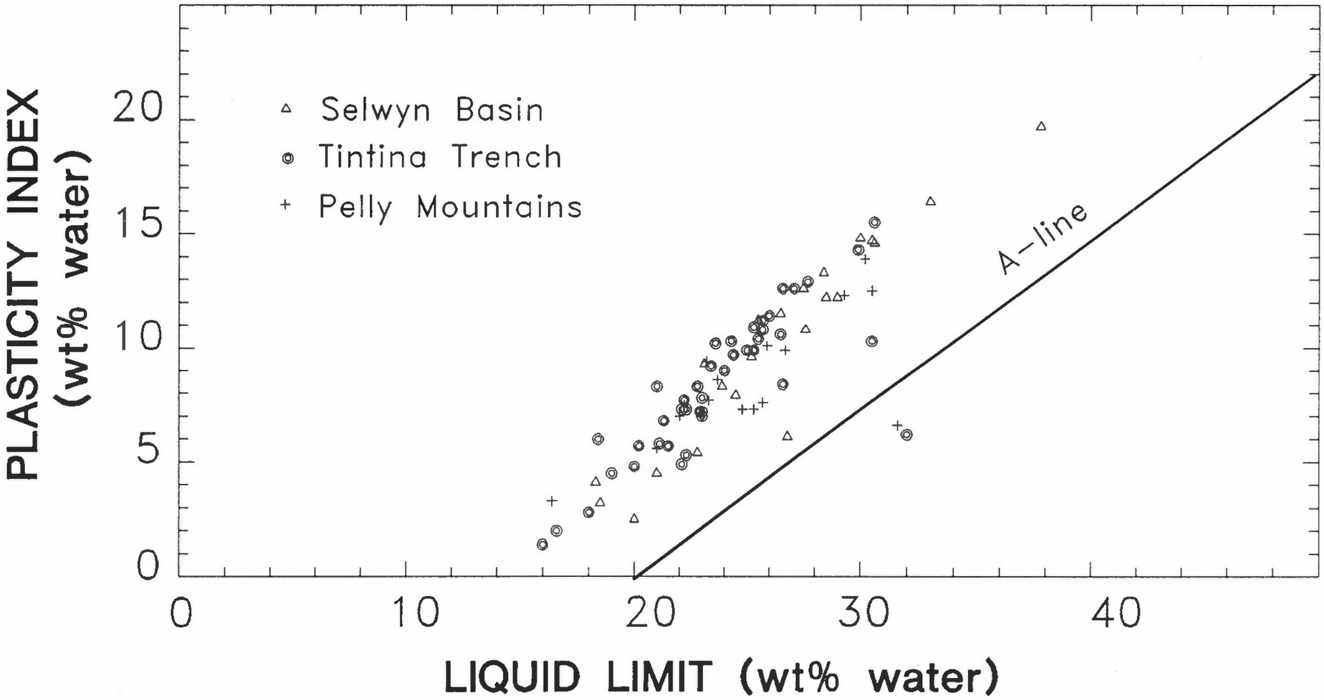

Figure 12. Atterberg limits determined on tills of the study area.

There are no systematic differences in the ranges of texture among the matrices of tills from the three geological provinces within the report area. Sand contents range from 20 to 70 %, silt from 20 to 80 % and clay from 5 to 30 % (Fig. 11). The generally low clay content is reflected in the low range of plasticity based upon the Atterberg limits determined on till samples (Fig. 12).

Carbonate content of till in the study area varies with the mineralogy of bedrock in the immediate up paleo-ice flow direction (Table 3). The highest mean calcite and dolomite contents are found in Pelly Mountains where carbonate bedrock is locally extensive. However, scattered out-croppings of carbonate rocks have locally enhanced the carbonate contents of till in both the allochthanous terrane north of Tintina Trench and the carbonate platform facies of Selwyn Basin rocks (Fig. 6) in Selwyn Mountains to the east of the study area. The highest sample values were found in tills resting on Selwyn Basin rocks.

Till stone lithology (Fig. 13) is relatively constant with the exceptions of increased contents of mylonites and quartz porpyry (felsic volcanics) in Tintina Trench. The sampling is somewhat biased by access and exposures; much of the sampling in Pelly Mountains and Selwyn Basin was done near the margins of the allocthanous terrane north of Tintina Fault (Fig. 14). Contents of cataclastic rocks, ultramafics, and felsic volcanics drop to zero in areas removed from allochthanous rocks and the felsic volcanics of Tintina Trench and away from outcrops of the South Fork Volcanics.

The influence of allochthanous ophiolitic rocks on till geochemistry is particularly significant. Mean and maximum values for elements such as chromium, manganese, cobalt, and

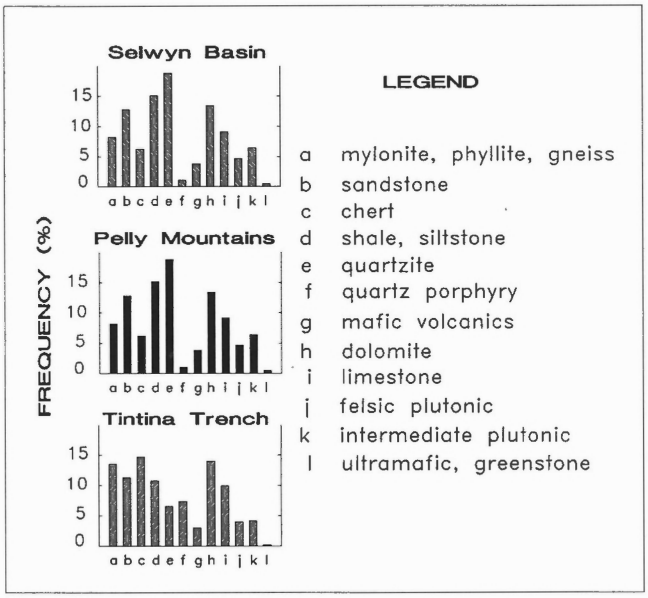

Figure 13. Lithologies of till stones from Selwyn Basin (23 samples), Tintina Trench (53 samples), and Pelly Mountains (42 samples).

Table 4. Till geochemistry from autochthanous and allochthanous terrains[1,2]

	Cr	Mn	Fe	Co	Ni	Cu	Zn	Mo	Ag	Cd	Pb	Ufl	As
					Selwyn Basin (autochthanous)								
$\overline{X}$	30	486	3.9	12	51	73	270.0	4	0.5	1.5	27	2.1	28
S	14	161	0.6	4	13	24	66.8	2	0.3	1.3	6	0.9	14
Max	88	740	5.4	19	76	119	405.0	7	1.3	4.5	43	4.2	73
Min	16	132	3.3	8	23	32	160	1	<0.1	<0.2	17	1.0	13
n	25	25	25	25	25	25	25	25	25	25	25	25	17
					Tintina Trench and Pelly Mountains (allochthanous and autochthanous)								
$\overline{X}$	48	853	4.5	19	94	81	304.0	4	0.4	2.4	34	2.0	47
S	33	302	0.8	13.9	146	27	59.0	5	0.3	1.0	19	0.7	19
Max	194	1320	6.4	84	820	141	496	8	1.2	4.0	87	3.4	85
Min	18	340	3.4	9	38	11	203	2	0	0.2	19	1.1	31
n	27	27	27	27	27	27	27	27	27	27	27	27	7

[1] values in parts per million

[2] Determined by by atomic absorbtion analysis of extract obtained by hot H_2NO_3-HCl digestion of ≤2 μm fraction.

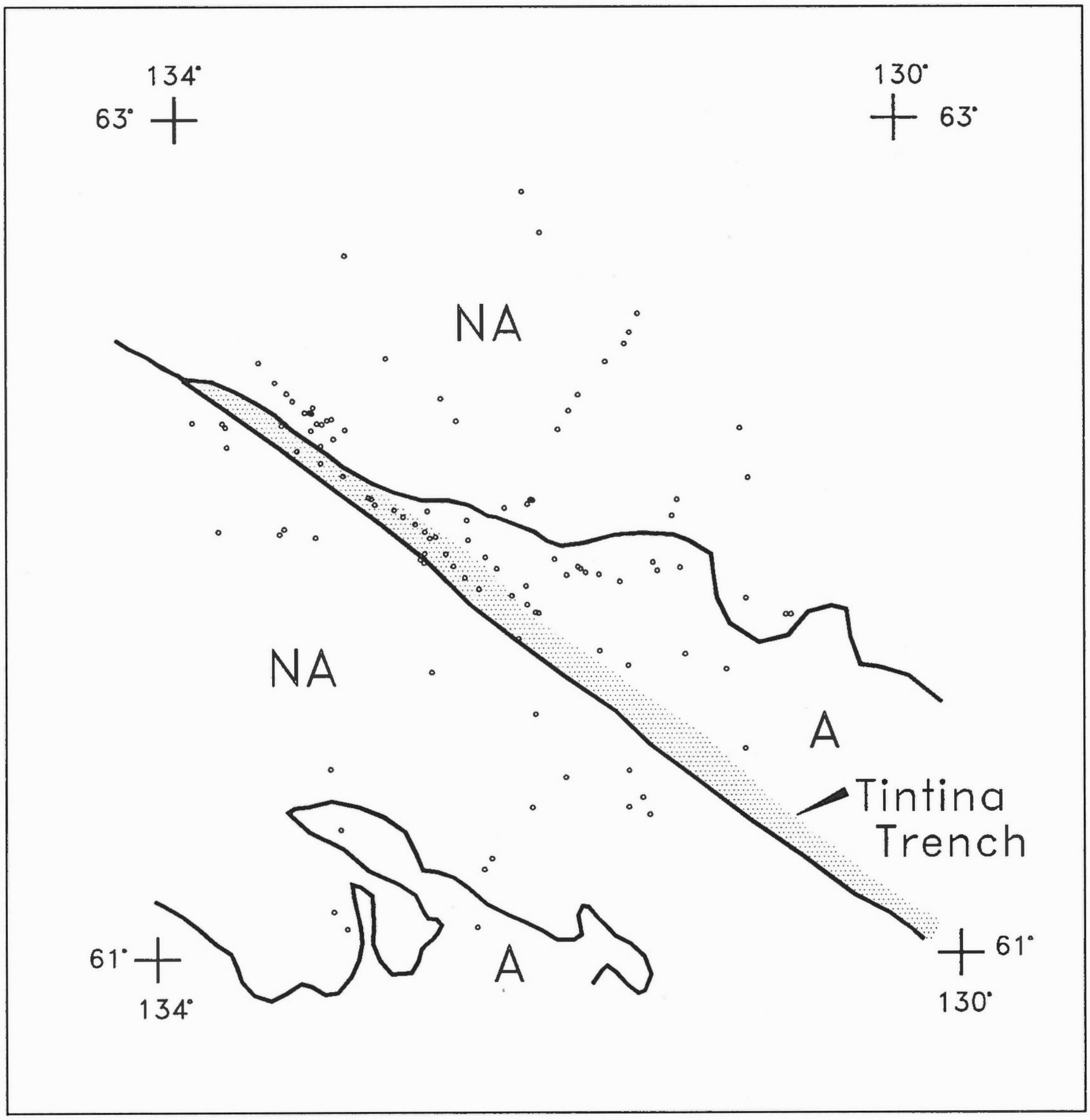

Figure 14. *Locations of till samples. NA – predominantly folded and thrusted late Precambrian to Triassic miogeoclinal rocks deposited along the North American margin (Selwyn Basin rocks and correlative rocks in Pelly Mountains); A – predominantly allochthons of mylonite, ophiolite, and granite (Tintina Trench, Pelly Mountains, and Campbell Range).*

nickel, which are found in greater concentrations in mafic and ultramafic plutonic rocks than in sediments, are significantly higher in areas underlain by allochthanous rocks (Table 4).

G – Glaciofluvial deposits

Glaciofluvial deposits are deposits of silt, sand, and gravel with varying contents of diamicton that are laid down either by running water or within standing water on top of, against, and beyond glacial ice (Fig. 15A-C). Sorting ranges from good to poor, and stratification from thin-bedded to massive. Beds are commonly lensoidal, and textures and sedimentary structures may change dramatically both laterally and vertically over a few metres. Sediments commonly display evidence of syndepositional collapse resulting from the meltout of buried or supporting ice.

Glaciofluvial sediments include outwash plains, ice-walled channels, kames, deltas, eskers, and crevasse fillings (Fig. 16A-C). These deposits are found in the following two general sedimentary environments: (1) proximal deposition adjacent to, on top of, and beneath glacial ice; and (2) distal deposition away from ice in broad plains or fans.

L – Glaciolacustrine deposits

Glaciolacustrine sediments are predominantly silts, clays, and fine sands deposited in glacial lakes. Such lakes formed in valleys by the wasting Cordilleran Ice Sheet or by glacial damming and isostatic depression within Tintina Trench in the northwest quadrant of the study area. Thicknesses ranges from 1 m to more than 100 m. Where distal sedimentation prevailed, topography on these sediments is typically rolling to planar. In proximal areas, where sedimentation occurred on or around stagnant ice, topography is hummocky or ridged. Where sedimentation was distant (distal) from ice margins, sediments are rhythmicly bedded and normally graded sand/silt or silt/clay, couplets (Fig. 17A). Bedding is complicated locally by slumping or diapiric deformation (Fig. 17B), which reflects the rapid deposition from suspension or turbidites of these low permeablity sediments (Eyles and Miall, 1984; Smith and Ashley, 1985). Individual or clusters of dropstones released from icebergs are also common in distal sediments.

Sediments deposited near ice margins (proximal) range from silt to coarse gravel and diamicton in texture (Fig. 17C). They reflect deposition through processes as diverse as the following: meltout from floating and grounded icebergs; debris flow from ice margins; fluvial deposition by supraglacial and subglacial streams; and settling of fines from suspension and subsequent deformation, triggered by ice meltout and slumping (Eyles and Miall, 1984).

A – Alluvial deposits

Alluvial deposits are Holocene gravels and sands, which are commonly overlain by, or grade laterally into, lacustrine or organic sediments in poorly drained areas of floodplains. In practice, mapping on the basis of this definition is difficult. Although modern flood plain and alluvial fan deposits are readily identified, older terraced deposits cannot be as easily distinguished as being of fluvial or glaciofluvial origin.

A further complication is the fact that many of the terraced fluvial deposits may be of paraglacial origin (Ryder, 1971a,b; Church and Ryder, 1972; Jackson et al., 1982). Paraglacial sediments are laid down during the final stages of and following deglaciation[1]. Paraglacial sediments are included here under the fluvial (alluvial) rather than glaciofluvial heading.

Floodplain sediments are found along contemporary streams characterised by single meandering channels. Extensive oxbow and thermokarst lakes and organic deposits (Fig. 18) occur on the flood plains of the Pelly, South Macmillan, Tay, Ross, Finlayson, Nisutlin, Big Salmon, and Liard rivers and their larger tributaries. These lakes have formed in broad valley bottoms where levees along active channels have restricted floodplain drainage. Consequently, these sediments are predominantly fine-grained inorganic sands and silts and accumulations of peat and stream-transported detritus. Floodplain sediments accrete vertically through organic and overbank deposition. They are underlain at depth by gravels and sands deposited in the past by the lateral migration of the stream channel (deposition through lateral accretion).

Braided floodplains are composed of many channels that split and rejoin. Floodplain sediments from such streams are typically composed of coarse sand and gravel, because most channels carry water only during flood events. The overbank and organic deposits of meandering streams are lacking. Braided streams are rare in the study area. They occur along the upper reaches of tribuary streams where mass wasting processes apparently supply large quantities of coarse sediment (F on Fig. 19) or downstream from glacial margins.

C – colluvium

Colluvium includes the most diverse group of landforms and deposits, usually sandy diamicton, to be lumped together under a single heading. The term is applied to deposits formed by the in situ breakdown of bedrock and unconsolidated sediments, which are then transported by gravity and resedimented. Colluvial landforms of the study area (Fig. 20) are classified in continuous spectra. Most colluvial deposits and their landforms are end or intermediate members in this classification. The figure depicts plots of the texture of the colluvial sediments contained in landforms versus events that build or shape these landforms. As boulder content of colluvial sediments increases, they become increasingly clast-supported until, in talus aprons and cones, a significant void space occurs between clasts. On the other hand, increasing sand, silt, and clay content (< 2mm size fraction) results in matrix-supported sediments, such as solifluction deposits, although a significant boulder content remains. The rates of formational events (Fig. 20) are based upon rates measured for similar deposits elsewhere. Talus aprons and cones (extreme upper left Fig. 20) are built by small rockfalls from adjacent bedrock cliffs. The entire rockfall event beginning with the failure of rock on the cliff face and ending with the cessation of movement of the last rock particle on the talus apron is very short – tens of seconds. Hundreds of these short duration events may occur during a single year (Gardner, 1979, 1980, 1983). Talus aprons and cones that either prograde onto glaciers or acquire an ice matrix may grade into rock glaciers. Where bedrock slopes are less precipitous, snow avalanching, slush flows, and debris flows build colluvial fans. Fluvial processes play a secondary role in winnowing and redeposition on colluvial fans although nonfluvial gravitational processes and their deposits dominate.

Fans become increasingly fluvially dominated with increasing drainage area until debris flows no longer reach the fan (Jackson, 1987c; Jackson et al., 1987) and colluvial

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[1] Glaciation leaves significant quantities of unconsolidated and unstable glacial deposits within mountainous areas. These deposits are available for mobilization by mass wasting and fluvial erosion. Rapid delivery of sediment into the fluvial system without a commensurate increase in overall fluvial discharge leads to fan building and trunk stream aggradation followed by terrace cutting as the sediment supply wanes. This decrease in sediment supply occurs as available glacial sediment within mountain watersheds dwindles and nonglacially conditioned rates of erosion are approached.

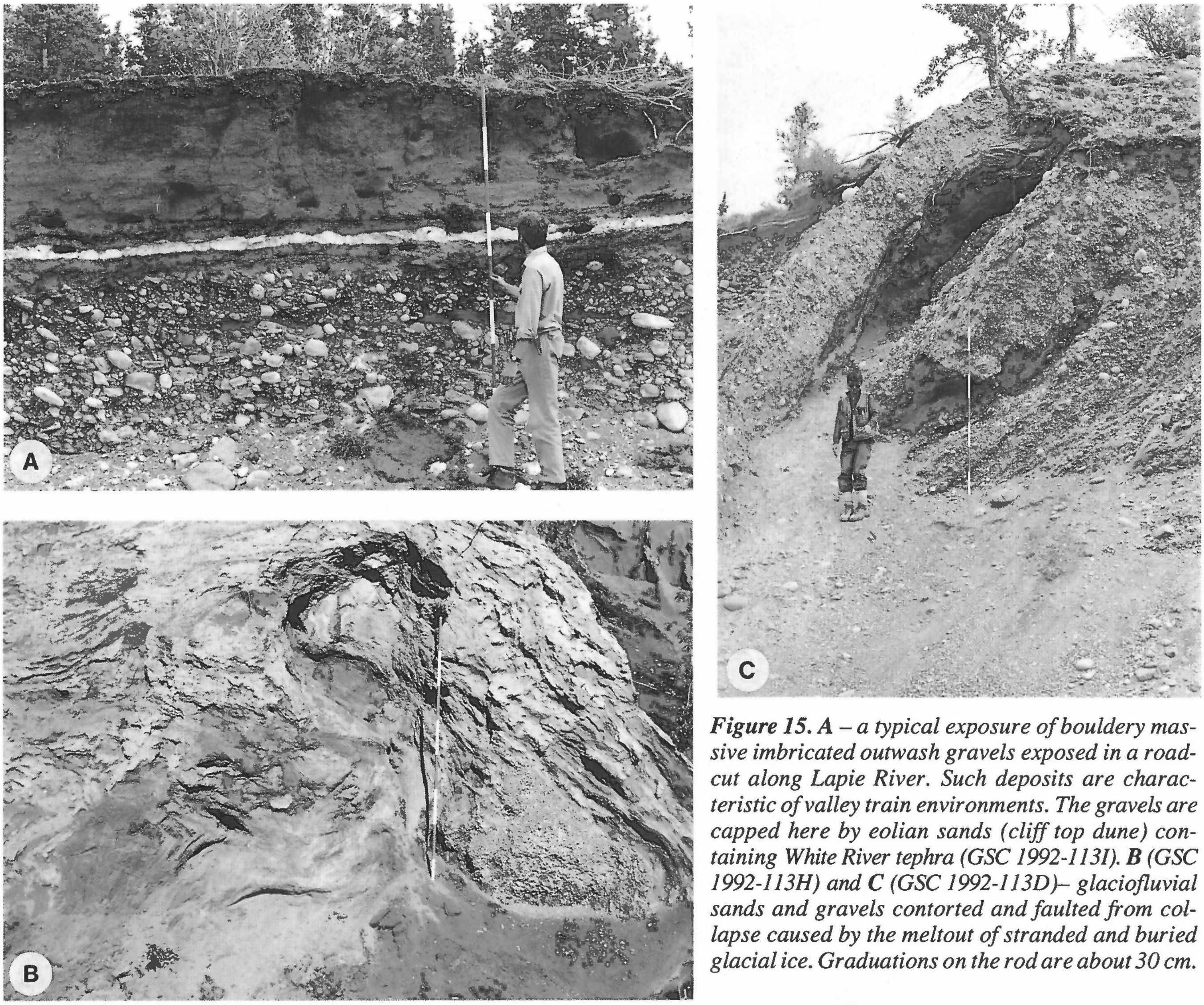

Figure 15. ***A*** *– a typical exposure of bouldery massive imbricated outwash gravels exposed in a roadcut along Lapie River. Such deposits are characteristic of valley train environments. The gravels are capped here by eolian sands (cliff top dune) containing White River tephra (GSC 1992-113I).* ***B*** *(GSC 1992-113H) and* ***C*** *(GSC 1992-113D)– glaciofluvial sands and gravels contorted and faulted from collapse caused by the meltout of stranded and buried glacial ice. Graduations on the rod are about 30 cm.*

fans grade into alluvial fans. Formational events also take longer with increasing drainage area; debris flows are measured in minutes rather than in seconds.

Colluvial deposits that are formed by cyclical freeze-thaw activity are placed on the right side of the diagram (Fig. 20). Cycles range from diurnal to seasonal. Sediment texture varies with bedrock lithology, jointing patterns, and slope angle. Felsenmeer or blockfields (Fig. 21) and sorted stone polygons occur above treeline on blocky, jointed, resistant bedrock units such as granitic rocks and hornfels; they contain few fine sediments. However, less resistant units such as shales break down to form sediments with relatively high contents of fine particles and low permeability. Saturation of the upper metre of this material during seasonal thaw reduces material strength until slow flow or creep occurs. Thus solifluction lobe complexes form on slopes above treeline (Fig. 22). Hillslopes undergoing denudation by solifluction take on an appearance reminiscent of a melting scoop of ice cream. This "melting ice cream topography" is common throughout the alpine areas of the map area.

Eolian

Eolian deposits include wind-deposited silt, fine sand, and tephra, which form thin and discontinuous cappings upon surficial deposits and bedrock (Fig. 15a). They occur mainly in lowland areas particulary within and adjacent to valleys with extensive deposits of glaciofluvial and glaciolacustrine sediments.

O – Organic

Organic deposits are accumulations of vegetal materials, chiefly peat, with minor amounts of mineral sediments. These deposits are found in areas of poor drainage or high water table conditions such as flood plains, shallow paludifying lakes, and low areas in hummocky moraine. Organic deposits also cover slopes as blanket bog where underlying permafrost forms an impervious substrate to snow melt and rain waters during the summer. These deposits may themselves contain permafrost and lenses of clear ice. Palsas and open-system pingos (Fig. 23), peaty mounds, and plateaus develop raised

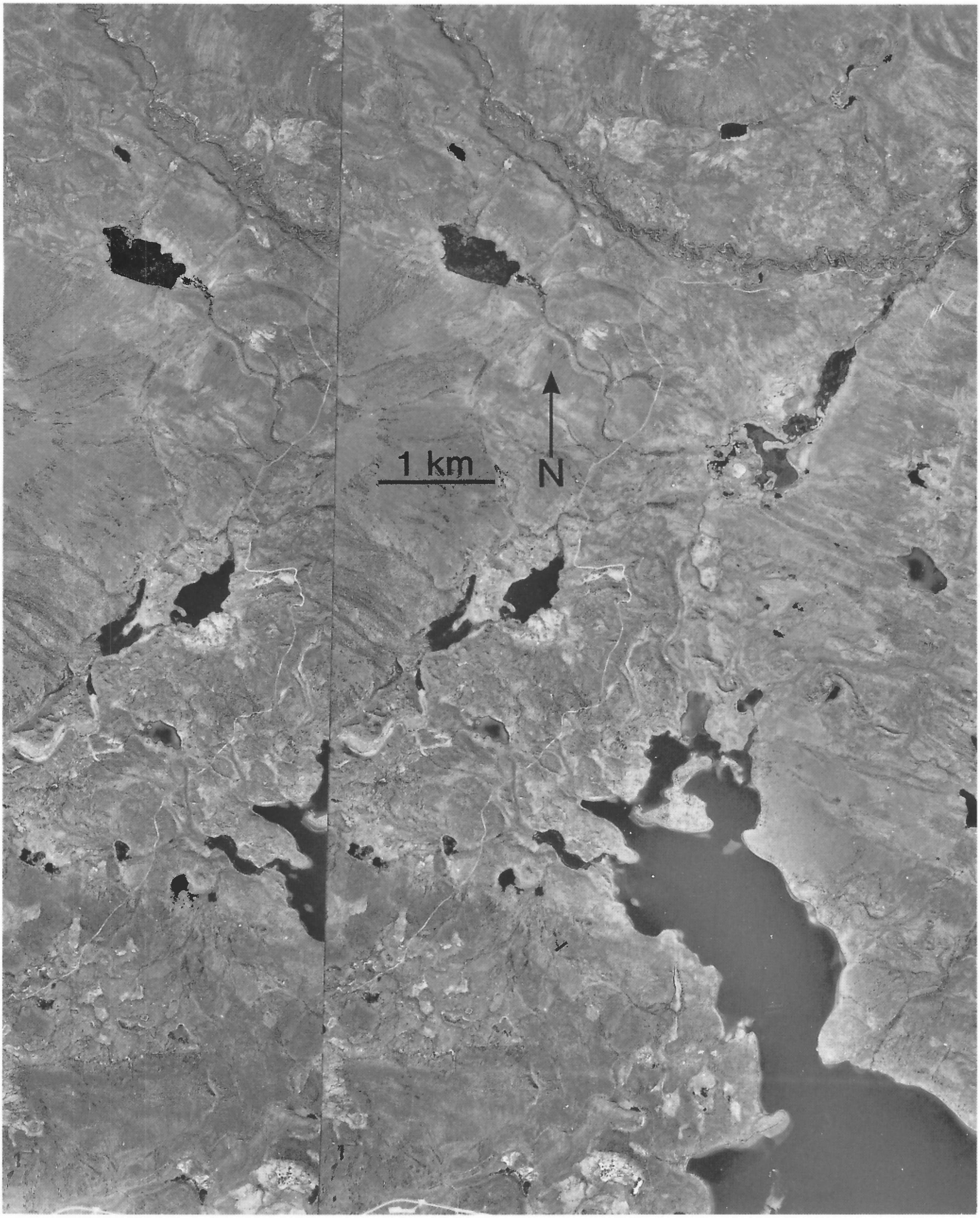

__Figure 16.__ Examples of glaciofluvial landforms: __A__ – ice-stagnation glaciofluvial complex at the northwest end of Finlayson Lake. (NAPL A20114 50-51)

above the surrounding surface by the growth of underlying clear ice lenses. They are common in organic deposits within marshes and floodplains of the study area.

Rock glaciers

Rock glaciers require a separate classification because they span colluvial and glacial deposits in the genetic categories. Rock glaciers (Fig. 24) are tongues or apronlike accumulations of rock debris that display morphological features suggesting present or past downslope movement[2]. They are glacier-like in morphology and range in shape from lobate (length less than width), to tongue-shaped (length greater than width), or spatulate (lobate in form but with an abrupt widening at the downslope extremity). Widths of some lobate rock glaciers in the study area are in the order of several hundred metres whereas tongue-shaped rock glaciers locally approach 1 km in length. Surfaces are marked with longitudinal and transverse furrows and collapse pits (Vernon and Hughes, 1966, p. 17-22).

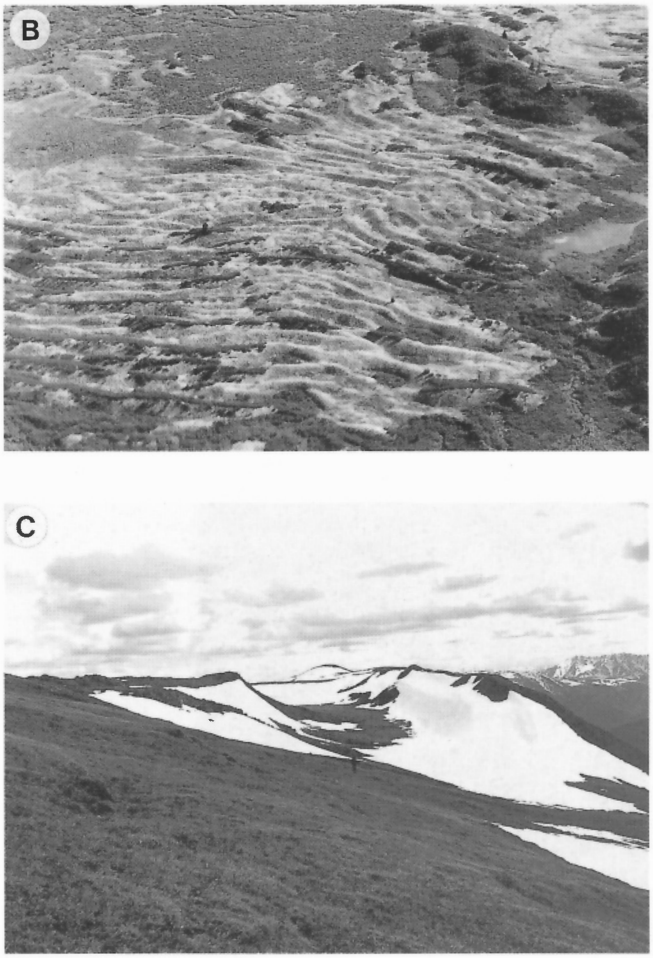

Figure 16. Examples of glaciofluvial landforms: B – complex of esker ridges formed in a succession of subparallel meltwater tunnels melted through stagnant ice (GSC 1992-113W), C – glaciofluvial channel marking the upper limit of Cordillera Ice during the last glaciation at about 1800 m elevation. (GSC 1992-113X)

Thicknesses are variable in the range of 10 m to tens of metres. Active rock glaciers can be identified by their unvegetated, steep, scarplike snouts, which may have relief from less than several to tens of metres. Inactive rock glaciers are characterized by vegetated or turf-covered rounded snouts. These have a rounded profile. Active rock glaciers contain ice, either as a core (ice-cored or debris-covered rock glacier) or as a matrix between clasts (ice-cemented rock glacier (White, 1976). Rock glaciers may grade upslope into non debris-covered glaciers, talus aprons, and debris cones.

In this region of Yukon, microclimates conducive to the formation and maintenance of rock glacier ice are largely restricted to north-facing slopes (Kershaw, 1978). Because of their protected northern aspects and insolating mantle of bouldery debris, rock glaciers may continue to advance while nearby glaciers retreat. Rock glaciers studied by Dyke (1990b) in the nearby Frances Lake Map area (105 H) showed no correspondence in their activities to glacial advance and retreat in the same area. Jackson and MacDonald (1980) determined surface flow velocities of up to 51 m and snout advances of 2.5 m over 17 years for ice-cored rock glaciers in what is now Nahanni National Park east of the study area.

I – Extant glacial ice

Glaciers are restricted to cirques in the highest parts of Pelly Mountains and Itsi Range (elevations greater than about 1900 m). They range in area from a few hectares to small ice caps up to about 3 km^2. These glaciers are currently in retreat from advances that culminated during the last century. The advances typically terminated less than 1 km beyond present ice margin.

m – made land

Made land includes extensive artificial fills of mining overburden, waste-dumps, and mill tailings. Almost all made land in the study area has been created as a result of mining activity at the Curragh Resources mine near Faro. Two textural ranges predominate: course bouldery overburden waste created during stripping of overburden above ore-bearing zones and sand- and silt-size tailings produced as a by-product of ore milling. Overburden waste usually forms steep waste dumps whereas tailings are discharged into reservoir-like impondments and are nearly flat-lying.

Landforms

Landforms are defined on the basis of slope, shape, spatial distribution, and relationship to surrounding geomorphological features. The landforms used to sudivide Quaternary deposits are listed below (modified from Clague, 1984).

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[2] For review papers on rock glaciers, the reader is directed to Wharhaftig and Cox (1959) and White (1976).

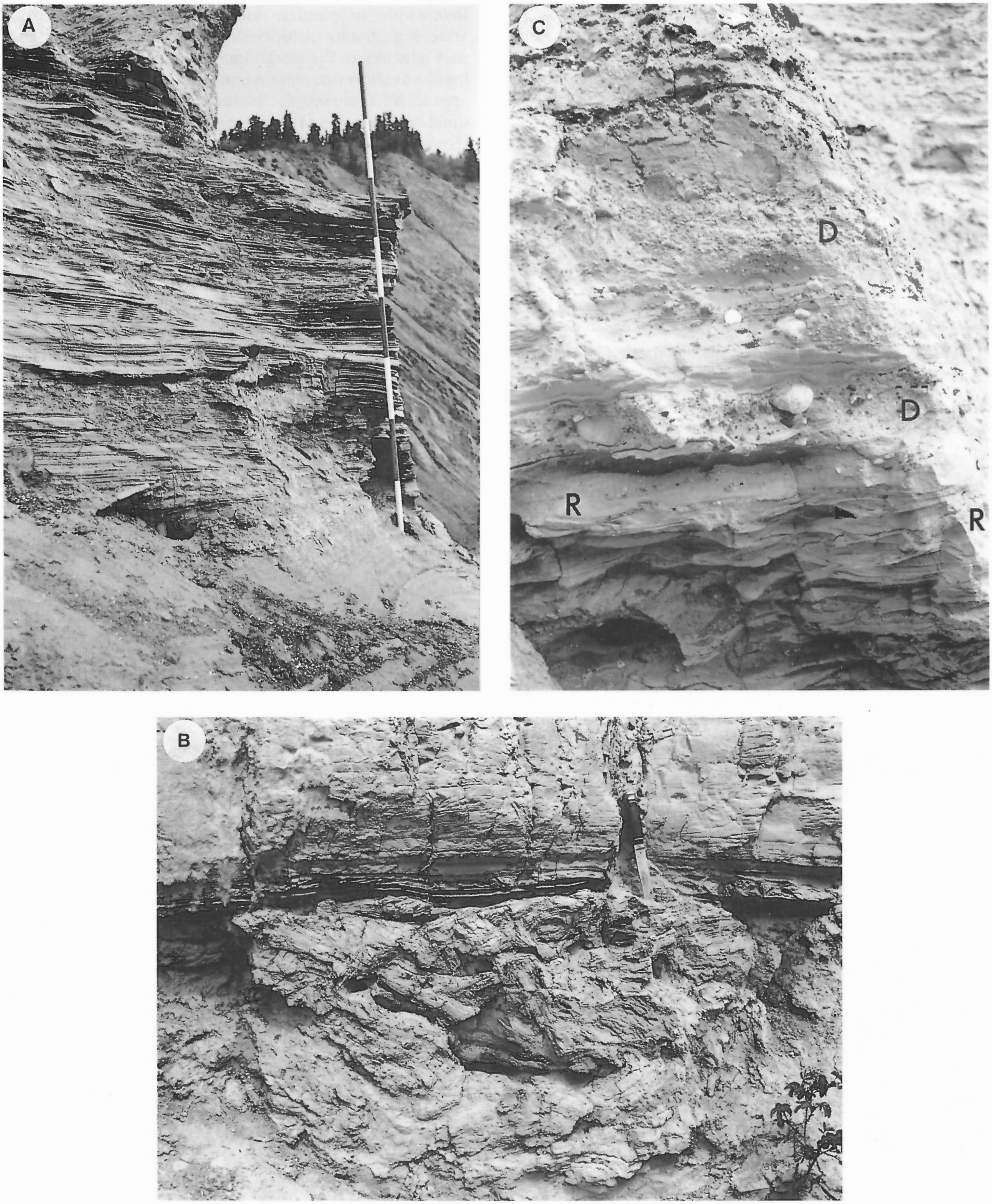
A
C
D
D
R
R
B

Figure 17. *Examples of distal (A and B) and proximal (C) glaciolacustrine deposits:* ***A*** *– rhythmicly bedded fine sand and silt (graduations on the staff are about 30 cm) (GSC 1992-113A),* ***B*** *– rhythmicly bedded silt and fine sand with recumbent fine sediment deformation structures caused by syndepositional slumping (GSC 1992-113Y),* ***C*** *– proximal glaciolacustrine deposits with characteristic sediment textures and bedding structures: stony diamicton beds (GSC 1992-113J) (D) formed from debris flows flowing to the lake bottom from the wasting glacial margin or from meltout from icebergs, (R) crossbedded sands and pebbly sands deposited by currents created by streams entering the lake from the surface or from beneath glacial ice.*

Anomalously large stones are likely of dropstones from icebergs. (Area of view is about 2 m from top to bottom).

Figure 18. *Floodplain of the meandering Tay River. Circular lakes in floodplain are probably thermokarst lakes formed by collapse caused by the melting of ground ice. Elongate lakes are oxbow lakes formed by the recent abandonment of meanders. (View looking west). (GSC 1992-113K)*

a – apron

Aprons are planar to semi-planar sloping surfaces along slope toes marking areas of accumulation of sediments derived from the adjacent slope through fluvial and colluvial deposits. They typically form through the coalescence of individual fans and cones. Aprons slopes range from less than 10° to more than 35°.

b – blanket

This continuous or nearly continuous mantle of a sediment more than 1 m thick is still thin enough to conform to underlying topography.

d – delta

This delta-shaped planar surface is truncated at its broad margin by an abrupt scarp. It marks the site of sediment deposition at the former confluence of a stream with a standing body of water.

f – fan

This fan-shaped landform is a conic sector, which descends from its apex to its semi-circular margin. Fans are constructional landforms built at the mouth of a tributary valley, ravine, or gulley. Steep fans with slopes in excess of 15° are referred to as cones.

p – plain

This flat or gently sloping (0-3°) surface has local relief generally less that 1 m marking the surface of an accumulation of sediment.

t – terrace

This stepped or benched topography consists of one or more well-defined scarps separating horizontal of gently inclined (0-3°) surfaces (treads).

u – undivided

Two or more landform types of the same or related genesis cannot be subdivided at the ascale of mapping.

v – veneer

This thin (<1 m) and usually discontinuous mantle of sediment conforms to the underlying deposits or bedrock.

x – complex

Topography consists of ridges, pits, terraces, and channels with reliefs of 2 m to tens of metres distributed over the horizontal distances tens of metres. Complex landforms form by sediment deposition in and around stagnant glacial ice.

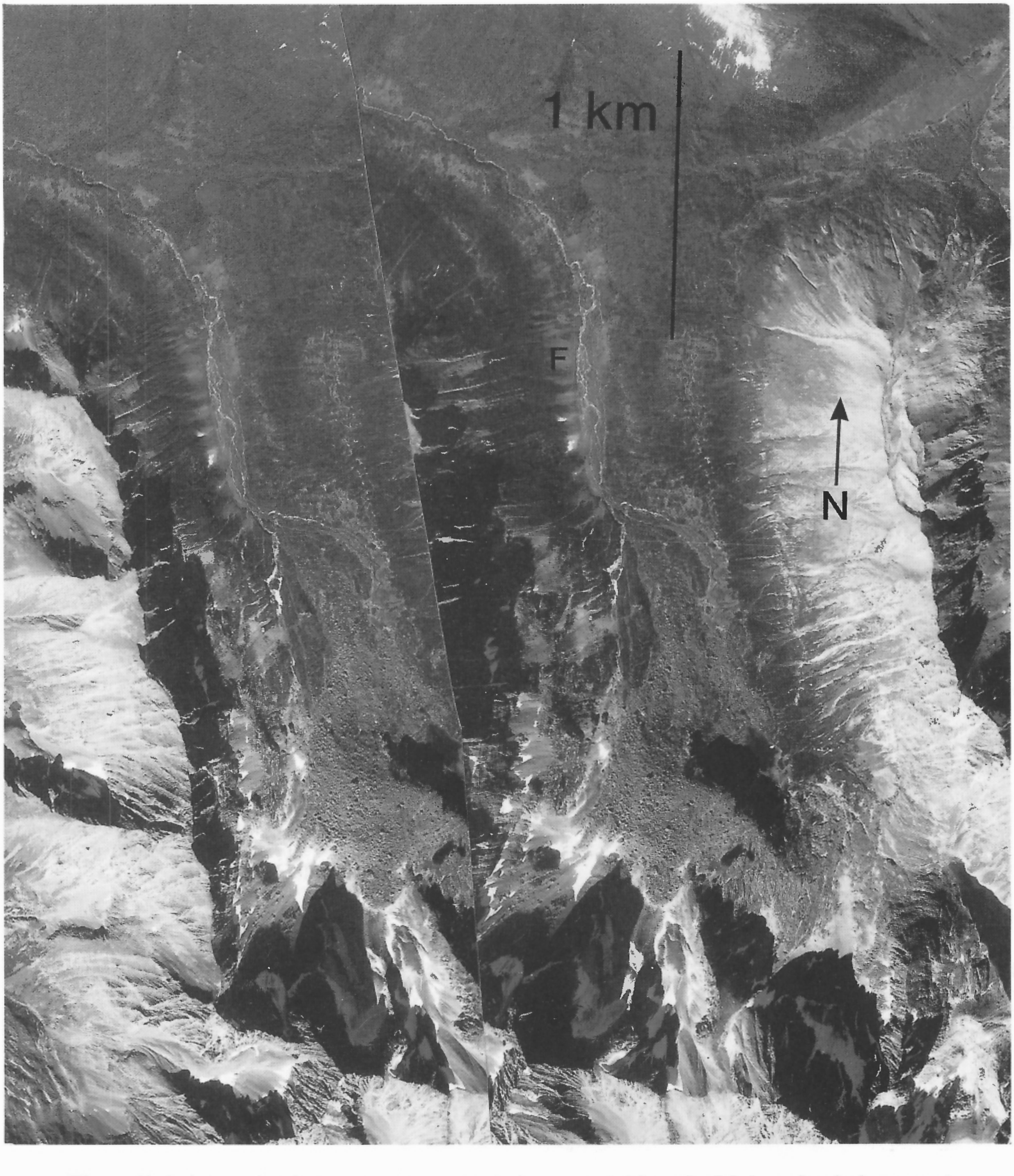

Figure 19. *Debris avalanche in quartz monzonite. Sediment eroded from the debris avalanche has caused the unnamed stream draining the avalanche to develop a braided planform. Fans along the margin of the braided floodplain (F) have been built by debris flows and debris transported by snow avalanches. (NAPL A25289 143-144)*

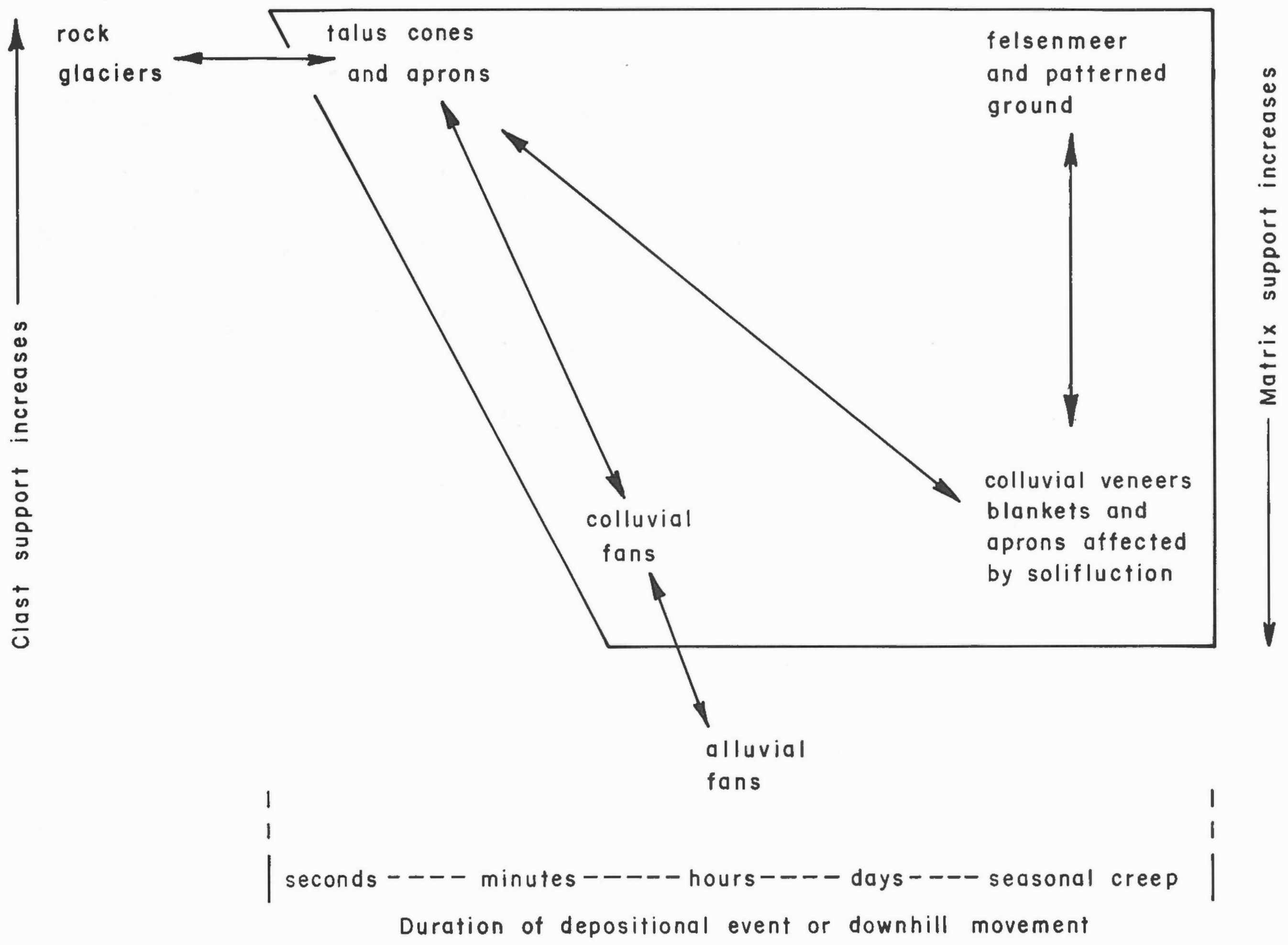

***Figure 20.** A genetic classification of colluvial landforms in the study area by the duration of formational events or ongoing gravitational transport of the deposits that comprise them. Most colluvial deposits are intergradational (indicated by the arrows) and may grade into noncolluvial landforms and deposits such as alluvial fans and rock glaciers.*

***Figure 21.** Felsenmeer on mountain summit, Selwyn Mountains. (GSC 1992-113P)*

***Figure 22.** Solifluction lobes in the headwaters of Tay River. (GSC 1992-113O)*

Description of map units

The map units defined on the bases of the genetic and morphological criteria described in the preceding sections are described below in order of decreasing age.

Bedrock (R, R-A)

Ridge summits and slopes not subject to snow and rock avalanche activity and ice-streamlined bedrock exposures in valley and plateau settings are mapped as R. Steep escarpments and ridges, including cirques and arretes, and bedrock exposures along gorges subject to snow and rock avalanching are mappped R-A. Both designations may include areas covered by thin and patch coverings of colluvium and glacial sediments.

Till blanket (Mb) and till veneer (Mv)

Till blanket and veneer commonly overlie bedrock on the sides of mountain valleys, low relief plateau elements, areas of streamlined topography, and the floors of major valleys such as much of the preglacial valley followed by Ross River (Fig 4). Till blanket grades into veneer with slope steepness and elevation. Till blanket and veneer are commonly resedimented and grade into colluvium on steep slopes. Where buried preglacial or buried valleys occur, morainal blanket overlies considerable thickesses of sands and gravels and locally older tills.

Glaciofluvial plain and fan sediments (Gp)

Coarse gravel, sand, and minor silt was deposited in a former glacial stream course distal (removed) from glacial ice margins. Internal structure is typically massive to thickly bedded gravels near the surface. These sediments frequently contain more ice-collapse structures with depth. This reflects progressive change from a proximal to distal sedimentary environment during deposition. Thicknesses range from a veneer to valley fills of many tens of metres.

Glaciofluvial terrace sediments (Gt)

Deposits of gravel, sand, and minor silt and diamicton are cut by flights of terraces. Although the sediments beneath terrace surfaces may be as little as 1 m thick, they are commonly cut into thick valley fills, glaciofluvial complexes, and glaciofluvial deltas. Beyond valley bottoms, regional stagnation of the Selwyn and Cassiar lobes resulted in the formation of flights of kame terraces. Each marks the former channel of a stream that flowed between the edge of a bedrock upland and the downwasting ice sheet. In some areas, such as the headwaters of McGundy River, flights may extend from the ridge summit to the valley floor (Fig. 5). Glaciofluvial channels locally mark the upper limit of glacial ice around nunataks (Fig. 3). These terraces are denoted by symbols on the accompanying surficial materials maps.

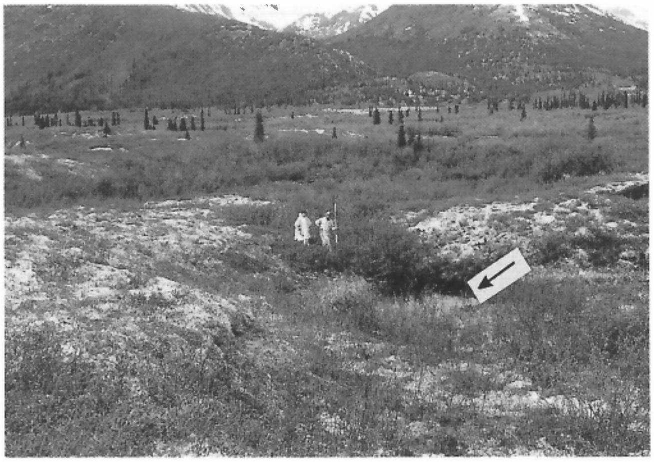

Figure 23. Collapsed open system pingo in Macmillan Pass, immediately northeast of the study area. Arrow indicates a central pond formed by the melting of the ice-core of the pingo. (GSC 1992-113M)

Glaciofluvial delta sediments (Gd)

Deposits of sand, gravel, and minor silt and clay exceed 5 m in thickness. Sands and gravels usually display the classic succession of foreset beds capped by flat-lying topset beds. These sands and gravels commonly overlie rhythmically fine sands, silts, and clays, which represent prodelta bottomset beds laid down on the floor of a glacial lake.

Glaciofluvial complex (Gx)

Deposits of gravel, sand, and diamicton form complexes of terrace, knob and kettle, and esker ridges (Fig. 16a). Stratification and textures are quite variable ranging from ripple-bedded fine sands and rhythmically bedded silts and clays in the deposits of former ice-walled lakes to massive coarse gravels. Stratification is commonly distorted and faulted as a result of syn- and post-depositional ice collapse. These complexes are particularly abundant in valleys that were oriented at right angles to regional ice flow (see *Quaternary history*), such as those situated in the headwaters of Tay River between Anvil and South Fork ranges.

Undivided glaciofluvial deposits (Gu)

This unit is characterized by interspersed hummocky deposits of gravel and sand and minor silt, usually less than 5 m thick. Till Mb and Mv covers up to 50% of this unit in some places. This unit typically occurs in upland areas away from valleys. It probably reflects sedimentation from stagnant ice but without the greater concentrations of sediment involved in the deposition of Gx deposits.

Glaciolacustrine plain sediments (Lp)

Glaciolacustrine sediments consist of usually rythmically bedded fine sand and silt and minor clay more than 5 m thick. Bedding is locally complicated by syndepositional slumping and dropstones (Fig. 17A-C). These underlie a rolling surface created by erosional modification of a former lake bottom. These sediments commonly contain extensive lenses of clear ice.

Glaciolacustrine blanket (Lb) and veneer (Lv) sediments

Deposits of silt, fine sand, and minor clay are thin enough to conform to underlying topography. These units usually represent the feather edge of thicker and more extensive L_p deposits.

Glaciolacustrine complex (Lx)

Sand, silt, gravel, and diamicton underlie a hummocky ridged and pitted surface. Stratification ranges from massive to thinly and rhythmically bedded and has been extensively disrupted by syndepositional slumping. Strata are lensoidal and usually difficult to trace for more than 10 m. This unit represents glaciolacustrine sediments deposited adjacent to an ice margin by and from the following: suspension,

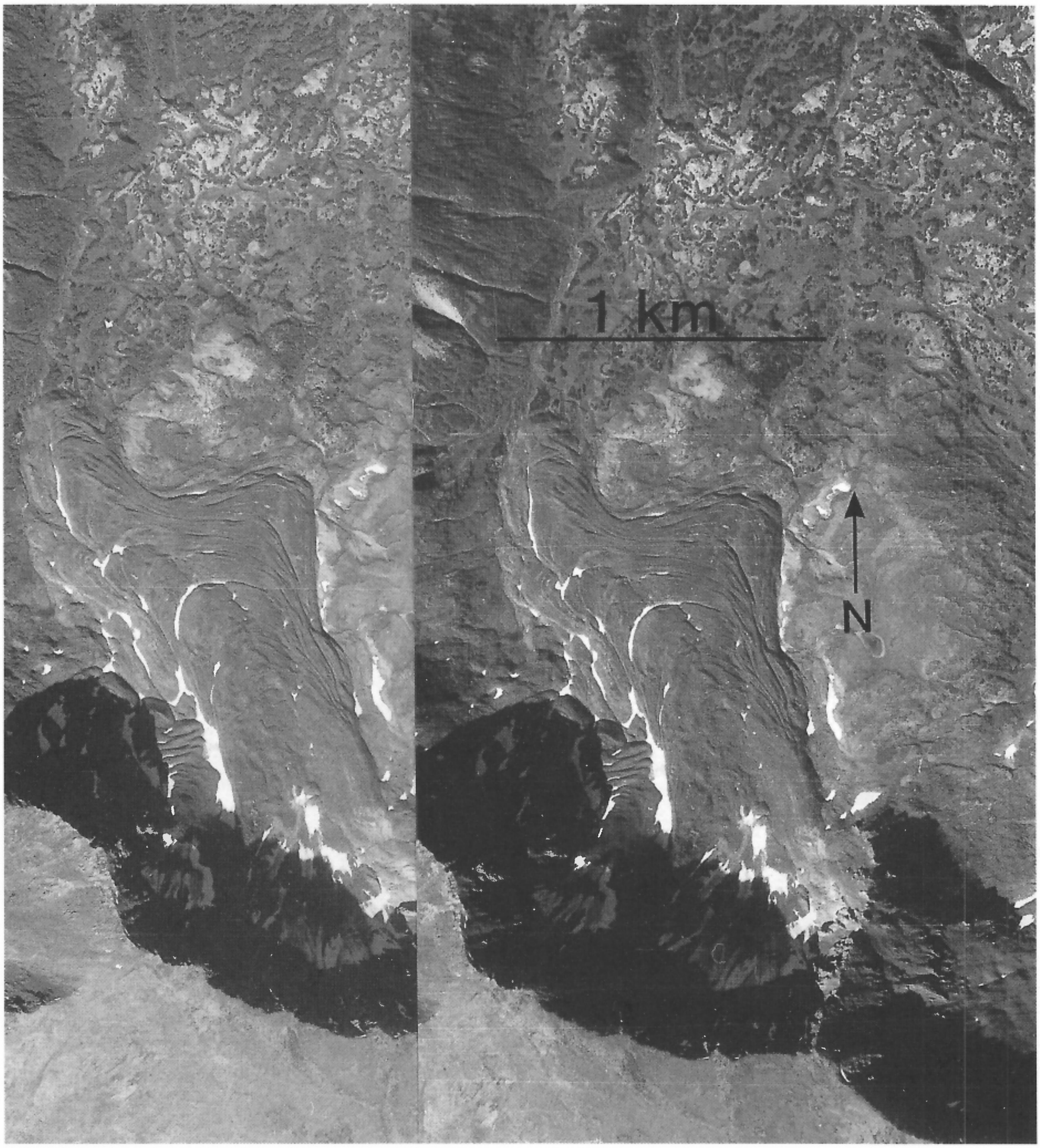

***Figure 24.** Spatulate rock glacier in Pelly Mountains. Lateral moraines at the head of the rock glacier were created by ablation of glacial ice since the end of the Little Ice Age in the middle of last century. (NAPL A25289 137-138)*

glaciofluvial streams flowing off and from beneath glacial ice and adjacent emergent terrain, sediment gravity flow (debris flow) from ice and emergent terrain, and deposition from ice bergs.

Floodplain sediments (Ap)

Flat-lying gravel and sand, more than 1 m thick, may include minor to extensive lacustrine fine sand and organic sediments. These lacustrine and organic sediments were deposited in abandoned channels (ox-bow lakes) and backswamp areas on top of gravel and coarse sand where they are loci for thermokarst activity.

Alluvial terrace sediments (At)

Flat-lying gravel and sand with minor silt form terraces more than 1 m thick. Stream terraces are remnants of older flood plains now out of reach of flooding because of stream incision. Except for the lowest terraces, alluvial terrace sediments are predominantly horizontally bedded to trough crossbedded clast-supported gravels. They indicate sedimentation in braided stream environments in contrast to the meandering stream sedimentary environments that predominate along contemporary streams.

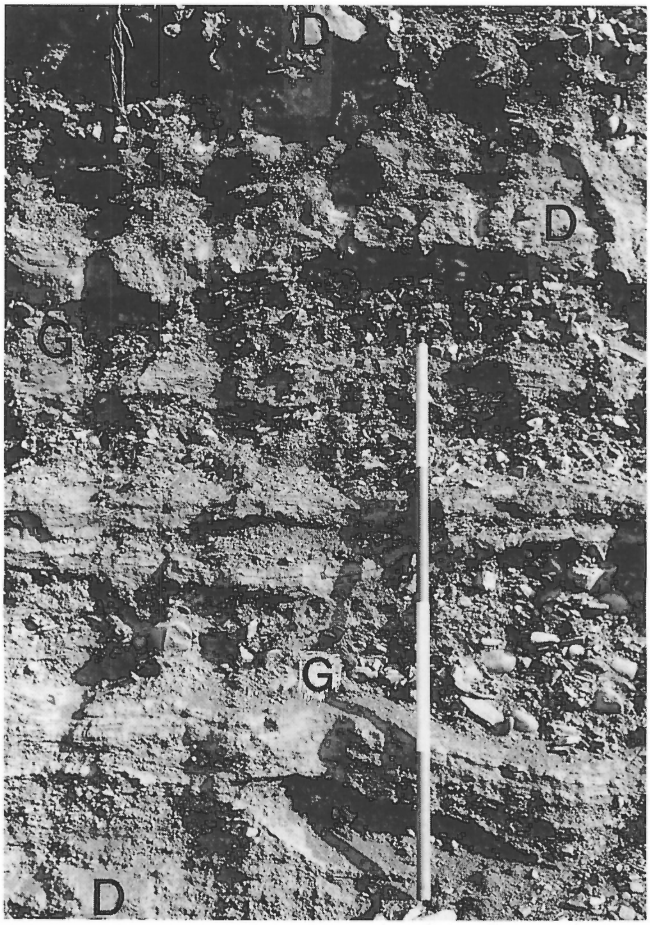

Figure 25. Debris flow diamicton (D) and very poorly sorted gravels (G) exposed in a roadcut through an alluvial fan in the Lapie River valley, Pelly Mountains. (Graduations on the rod are about 30 cm.) (GSC 1992-113N)

Alluvial fan sediments (Af)

Features classified here as alluvial fans include a spectrum of landforms ranging from fans which receive only fluvial sediments, to those that receive considerable debris flow and avalanche-borne sediment (Fig. 25). This arbitrary classification is based upon the extent of fluvial activity versus avalanche and debris flow activity perceived on the fan surface from airphoto interpretation. Fans exceeding 15° with surface indications of snow or rock avalanche or debris flow deposition were mapped as colluvial fans and labelled as Ca because such fans usually have coalesed to form aprons.

Alluvial fan sediments are predominantly gravels and diamicton. Sorting is usually increasingly poor as fans become dominated by debris flow and avalanches (Fig. 19). Evidence from comparable montane terrain in Rocky Mountains of Alberta and British Columbia suggests that fans with gradients over their upper halves exceeding 4° usually receive debris flow sedimentation. They become progressively dominated by debris flow deposits with increasing fan slope. Conversely, fans with upper half gradients of less than 3° are not prone to debris flow sedimentation (Jackson 1987b; Jackson et al. 1987).

Alluvial sediments, undivided (Au)

Sand, gravel, silt, and organic deposits underlie floodplain and low-lying terraces. The latter may be subject to inundation during summer and ice-jam flooding.

Colluvial apron sediments (Ca)

Bouldery diamicton and poorly sorted sands and gravels form a wedgelike slope-toe complex of coalescent fans and solifluction deposits dominated by debris flow and avalanches (F on Fig. 19). Although fluvial processes do deposit and redeposit these sediments to some degree, they play a secondary role to nonfluvial gravitational processes. Their deposits dominate. However, with increasing drainage area, colluvial fans grade progessively alluvial fans. Slopes range from less that 10° near the slope toe to more than 30°. Thickness ranges from nothing along the upper edge to 10 m or more along the toe.

Rockfall deposits (bCa)

Rockfall deposits (talus) are metastable accumulations of angular bouldery debris resting at the angle of repose, which ranges from about 30° to 40°. Thickness ranges from nothing at the upper margin to 10 m or more along the base.

Organic deposits (O)

Accumulations of peat and minor organic sediments are sufficiently thick (usually greater than 2 m) to mask the morphology of underlying deposits. Blanket bog (denoted by a pattern) is thin enough (usually less than 2 m) to conform to the contours of underlying sediments. Organic sediments covering areas too small to resolve at the scale of mapping are common throughout the study area.

QUATERNARY STRATIGRAPHY

The deposition of glacial sediments within the study area was controlled chiefly by topography. Till is the dominant sediment on plateau remnants. Ice stagnation gravels are extensive in valleys, particularly those oriented at 90° to former ice flow. Glaciolacustrine sediments occur in valleys that were either blocked by ice or isostatically depressed during deglaciation. Sediments from older glaciations have been all but removed during the late Wisconsinan by glacial and glaciofluvial erosion associated with McConnell Glaciation (Bostock, 1966).

Only the Tay River valley and Tintina Trench in the area of Ross River were wide and deep enough to accumulate and preserve sediments representing more than one glacial interval. Figures 26-28 summarize the stratigraphy of the most informative sections presently known within the region covered by Selwyn Lobe during McConnell Glaciation. Of these, sections along Pelly River (14686 S-1; Fig. 27, 28) and Lapie Canyon (7686 S-2; Fig. 27) provide the most complete record of depositional and erosional events over the last and the penultimate glaciations. Both sections contain two tills. These units were deposited by separate advances of flowing ice as indicated by the eroded and sheared contacts beneath the tills and the glaciofluvial and glaciolacustrine sediments that separate them.

Pre-McConnell Till

The pre-McConnell Till is the oldest widely exposed stratigraphic unit in the study area. However, Plouffe (1989) described one small exposure as above Lapie River where it overlies gravels along a striated contact. Pre-McConnell and McConnell tills are indistinguishable based on clast lithology and weathering. Plouffe (1989) found the fabric of the pre-McConnell Till to indicate a lodgment origin during a west to northwest ice flow. He noted that the pre-McConnell Till differs texturally from McConnell by having about half the silt to clay ratio. He suggested this difference might result from the differing terrain traversed by each depositing glacier: the pre-McConnell glacier traversed schistose bedrock in Tintina Trench whereas the McConnell glacier traversed drift left in the wake of the pre-McConnell glacier.

Glaciolacustrine and glaciofluvial deposits beneath McConnell Till

The McConnell Till is underlain by sheared silt and clay with dropstones in the Tay River valley, by stratified fine sands and silts and massive stratified gravels in the Pelly River valley, and by massive to horizontally stratified gravels and sands in the Lapie River valley (Fig. 27, sections 23685 C-3, 14686 S-1, and 7686 S-2; Fig. 28). Without absolute dating of these deposits, a single explanation for this succession is difficult. If the glaciolacustrine and glaciofluvial sucession that overlies the McConnell Till in the same area is used as an analogue (see below), the succession of fine textured sediments below the McConnell Till represents glaciolacustrine sediments deposited in an ice-dammed or isostatically depressed Tintina Trench and Tay River valley during glacial retreat. The gravels truncating the sands and silts in the Pelly River valley (Fig. 27, 28, section 14686 S-1) could have been deposited during a subsequent period of fluvial incision following draining of the lake. Alternatively, they could have been deposited as aggradation caused by the onset of the next glacial advance. The gravels and sands in the Lapie River valley (Fig. 27, section 7686 S-2) form a fining-up sequence from the base to the middle of the unit grading into a coarsening-up sequence capped, above a striated contact, by McConnell Till. This succession likely reflects glacial retreat of the pre-McConnell glacier and advance of the McConnell glacier.

McConnell Till

McConnell Till, described under *Morainal deposits* within the *Quaternary deposits* section, is found at or near the surface throughout the study area. It mantles streamlined landforms such as whalebacks and drumlins (Fig. 4), which mark the flow directions of the last glaciation to affect the study area. Plouffe (1989) found McConnell Till in Tintina

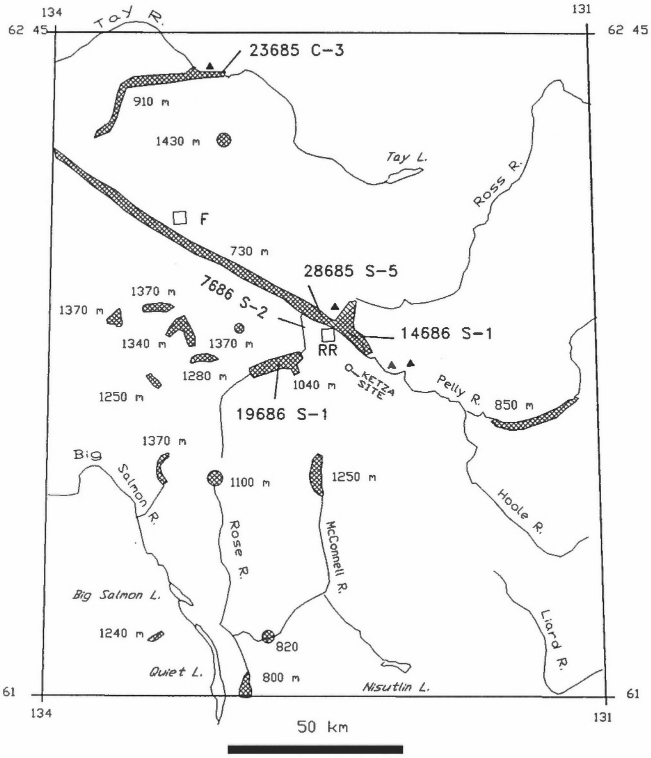

Figure 26. Location of the stratigraphic sections shown in Figure 27; locations of subglacial deposits disturbed by thrusting and folding (triangles); and locations and elevations of glacial lakes formed during deglaciation.

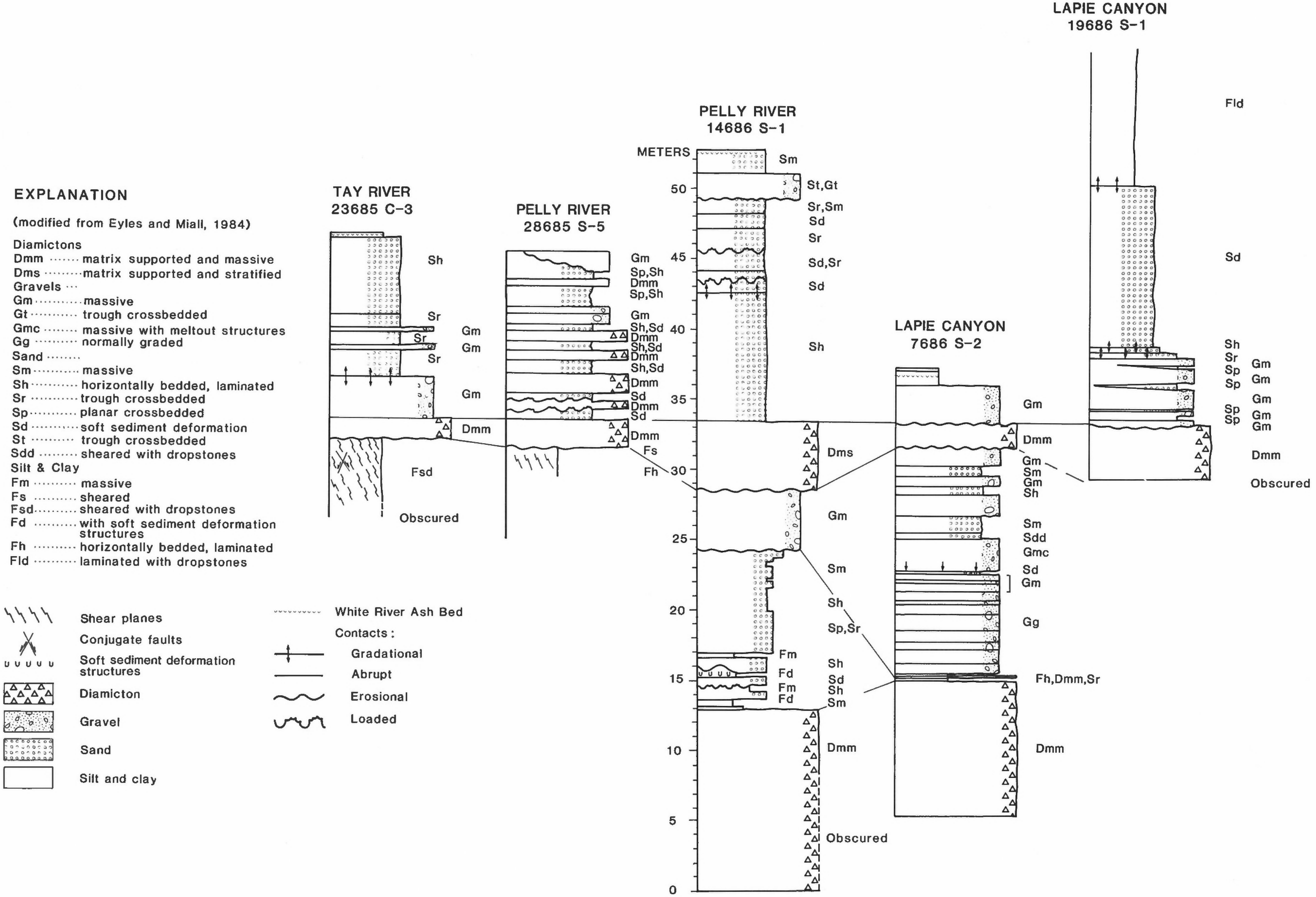

Figure 27. *Litho-stratigraphy along a line of section from the Tay River valley to the Lapie River valley (locations of sections shown in Figure 26). The section is constructed using the top of the McConnell Till (M) as a datum. PM denotes a till deposited prior to McConnell Glaciation or during an early phase of it.*

Trench to have strong fabrics reflecting predominantly west to northwest iceflow, which agrees with iceflow directions indicated by ice-molded landforms. He concluded that McConnell Till is predominantly of lodgment origin. However, he cautioned that the sorted intratill sand lenses found at some exposures might be attributable to meltout processes. Similar observations made during the present study, along with stratification of lenticular diamicton with stratified sands and gravels, indicate resedimentation of McConnell Till by debris flow (Fig. 9b,c; Lawson, 1979; Shaw, 1985). From these observations, the author concludes that lodgment, meltout, and sediment gravity flow facies are included and should be expected within McConnell Till.

Glaciofluvial and glaciolacustrine sediments

The glaciofluvial and glaciolacustrine sediments above the McConnell-age till have been described under *Quaternary sediments*. The glaciofluvial gravels were deposited by torrents fed by the stagnating and downwasting Cordilleran Ice Sheet. The glaciolacustrine sediments were deposited in valleys blocked by ice during downwasting. Consequently, the ages of these sediments decrease with decreasing elevation. Glaciolacustrine sediments along Pelly River from the western margin of the study area to the Ross River area were deposited in a lake at least partly ponded by isostatic depression. The differences in elevation between the upper limits of glaciolacustrine sediments near Ross River are 25 to 40 m higher than the upper limit at Faro[3], which gives a gradient of 0.5 to 0.7 m/km. This gradient is somewhat less than the 1.6 to 2.5 m/km determined for the rebound reported by Fulton and Walcott (1975) for glacial lakes in southern British Columbia. Distal facies of glaciolacustrine sediments are typically composed of silt and clay rhythmites. Exposures are usually not extensive enough to determine wheter these couplets represent annual sedimentation using the criteria of Smith and Ashley (1985). Assuming they are, even the largest of these lakes were short-lived. An 18 m exposure at Pelly Crossing at Faro contained an estimated 122 couplets. This depth represents about one-third of the thickness of glaciolacustrine sediments in this area of the Pelly River valley and occurs within what was the largest glacial lake basin within the study area[4].

QUATERNARY HISTORY

Onset of McConnell Glaciation

Little is known about the pattern of ice flow during the initial stages of McConnell glaciation. Indeed, as previously discussed the pre-McConnell till may represent either an early stade of the McConnell glaciation or a separate glaciation. What is known about the onset of McConnell Glaciation has been gleaned from sediments in Tintina Trench where the most extensive natural exposures occur. Plouffe (1989) determined fabrics and clast compositions through vertical profiles of McConnell Till in Tintina Trench at the confluence of the Lapie River valley. He noted changes in fabrics and pebble contents compatible with an initial north-directed advance of a valley glacier from Pelly Mountains followed by flow to the northwest parallel to Tintina Trench as valley glaciers merged to form Selwyn Lobe. This pattern likely was repeated throughout the study area with glacial onset along the lines of the model for Cordilleran glaciation documented by Kerr (1934) and Davis and Mathews (1944). Glaciers formed and expanded in upland areas such as Pelly, Selwyn, and Cassiar mountains with descent of the firn line[5] to about 1500 m elevation. Valley glaciers expanded beyond the mountains into lower lying areas thickening and coalescing in the process to form an ice sheet.

Striated gravel and bedrock below McConnell Till documents basal sliding of wet-based glacial ice throughout the study area. However, scattered evidence exists to suggest cold-based conditions existed locally during glacial onset. Folded and thrust-faulted gravels and sheared and drag-folded glaciolacustrine sediments are common below McConnell Till along Tintina Trench (Fig. 29A; section 28685 S-5). Sheared and folded glaciolacustrine lacustrine sediments have also been noted beneath McConnell Till along Tay River (Fig. 29B; Fig. 27, section 23685 C-3). Similar glaciotectonic structures beneath till were described by McConnell (1903, p. 59) along Macmillan River. Such structures have been investigated elsewhere (e.g. Klassen 1989, p. 147-189; Moran et al. 1980) and the conditions favourable to their formation have been attributed to high pore pressures generated by the freezing of the glacier sole in advance of wet-based ice flow. Such conditions would be expected as the relatively thin and easily chilled margin of ice advanced over terrain that certainly was marked by as much and probably more permafrost than characterizes the region today.

Ice flow at climax of McConnell Glaciation

Reconstruction of ice flow within the study area at the height of McConnell Glaciation has been based upon drumlinoid landforms and striations (Fig. 30). Numerous nunataks projected above Selwyn Lobe in the northwest quadrant of the study area (Fig. 3, 16c; McConnell, 1903; Duk-Rodkin et al., 1986; Jackson, 1989; Jackson and MacKay, 1991). Upper ice limits defined by moraines, ice-marginal meltwater channels, and the lower limits of craggy periglacial landforms allow reconstruction of the former ice surface in that area.

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[3] Determined by surveying altimeter on two seperate days.

[4] If these couplets are not annual, then they likely represent sedimentation events occurring over less than 1 year indicating an even shorter life for the lake.

[5] The floors of cirques that supported cirque glaciers during McConnell Glaciation in the Ogilvie Mountains and Glenlyon and Ruby ranges, elsewhere in central Yukon, indicate that the paleo-firn line fell to around 1500 m during the climax of McConnell Glaciation.

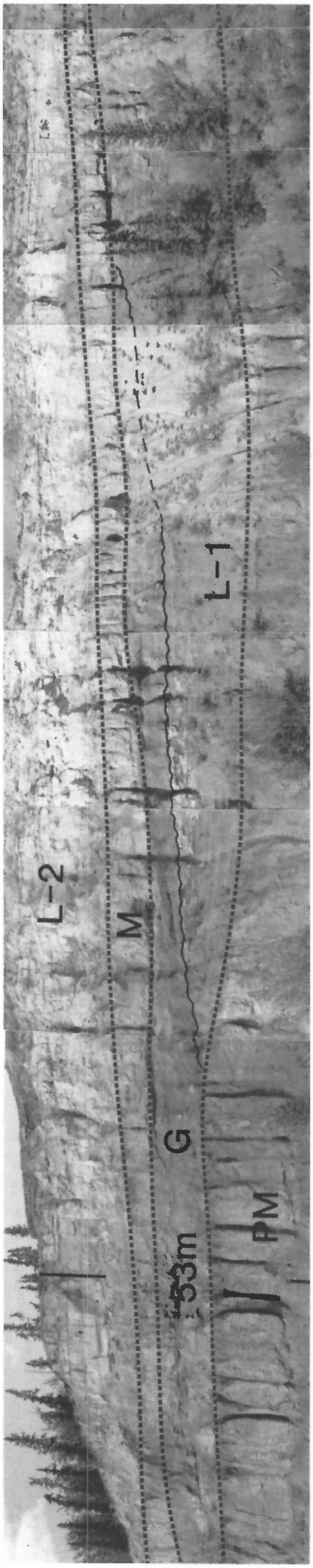

Figure 28. Section 14686 S-1. M – till deposited during McConnell Glaciation; PM – till deposited during the penultimate glaciation or an early phase of McConnell Glaciation. (Broken lines bracket tills; wavy and broken wavy lines mark an erosional between outwash and glaciolacustrine sediments.) L-1 – glaciolacustrine sediments laid down between the deposition of PM and M. L-2 glaciolacustrine sediments deposited at the close of McConnell Glaciation. GSC 1992-113L

Observations from the area of Selwyn Lobe certainly apply to the areas of Liard and Cassiar lobes where similar sharply defined ice limits are not found. Both lobes descended from and traversed common and comparable terrain. Ice limits range from about 1550 m at 134°W to 1890 m along 132°W, which gives an overall gradient of about 4 m/km or 0.2° along the general direction of flow. The profile of Selwyn Lobe is flatter than those of contemporary Greenland and Antarctica ice sheets (Paterson, 1969, p. 145-162; Duk-Rodkin et al., 1986). The best numerical approximation to the measured profile is the curvilinear profile of a valley glacier modelled by Shilling and Hollin (1981) after Nye (1952 a,b). This finding is not surprising because flow in Selwyn Lobe was similar to flow in a valley glacier; shear stress not only occurred along the sole of the ice sheet but along the sides of high relief roughness elements, that is, valley and mountain sides. Flow within the ice sheet, based upon ice flow indicators such as whalebacks and crag-and-tails, occurred as a complex of bifurcating and reuniting valley glaciers that followed major east-west trending valleys such as Tintina Trench, South MacMillan River, Big Salmon River, Little Salmon River, and the Yusezyu and Frances river valleys (Fig. 1, 30). Ice flow was entirely channelled by underlying topography rather than being predominantly independent of it as is largely the case in the contemporary ice sheets of Greenland (Flint, 1971, p. 51-54; Reeh, 1989) and Antarctica (Denton et al., 1971). Consequently, the Cordilleran Ice Sheet within the study area never exceeded phase 3 of Cordilleran glaciation of Davis and Mathews (1944). Topography always directed ice flow.

The area of most complicated ice flow was in Pelly Mountains, where numerous divides likely existed over these rugged mountains between ice caps. They are difficult to reconstruct because ice directional features are not well preserved and distinctive rock types with small aerial extents are not common. However, one such divide was documented in the Pony Lakes area (Fig. 1, PL). Radial dispersion of texturally and petrologically distinctive plutonic rocks demonstrate the existence of a former ice divide over Pony Lakes with ice flow away from the lakes to the northwest and southeast. Such apparent complications to ice flow history makes Pelly Mountains the most difficult area to carry out drift prospecting within the study area.

Disappearance of Cordilleran Ice Sheet

Selwyn Lobe disappeared rapidly at the close of McConnell Glaciation through a combination of downwasting and stagnation. Many cirques in Selwyn and Pelly mountains have ice stagnation landforms on their floors, which are continuous with similar features in adjacent valleys (Fig. 31; Jackson 1987b). The author concludes from these relationships that ice stagnated in these cirques during or prior to stagnation in adjacent valleys. These stagnation features occur up to 1830 m elevation. Consequently, it appears that early in the deglaciation of Selwyn Lobe, the equilibrium line rose significantly above, and remained above, 1830 m elevation until the present day. This rise in the equilibrium line above the ice sheet resulted in the wholesale starvation of Selwyn Lobe. The resulting thinning of the ice sheet is documented by flights of former ice walled channels along many valley sides (Fig. 5). Ice in valleys oriented at 90° to the general direction of glacial flow stagnated between ice streams and giving to extensive complexes of stagnation landforms.

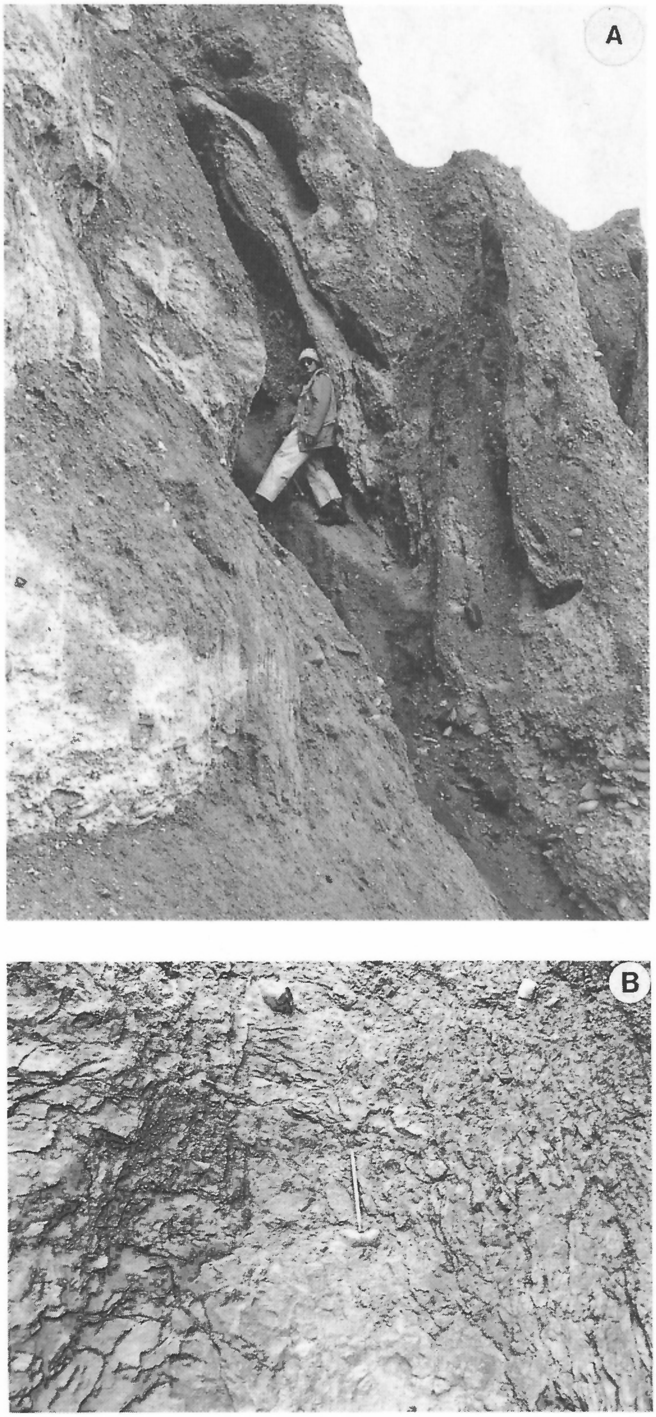

Figure 29. Glacial tectonically disturbed sediments below McConnell till. A – isoclinally folded gravels north of Ross River (GSC 1992-113S); B – isoclinally folded and pervasively sheared clayey glaciolacustrine silts along Tay River. (Pencil is 18 cm long.) Clasts are dropstones. (GSC 1992-113T)

The succession of progressively lower and younger lakes ponded within Pelly Mountains, Anvil and South Fork ranges and Tintina Trench during downwasting have been previously described. The mechanisms by which some of these lakes were ponded is problematic if the ice sheet is conceived as downwasting uniformly. The thicknesses of distal glacial sediments of many tens of metres require that substantial ice dams be placed across valley mouths to produce an adequate depth of closure (Fig. 32). An alternative to differential wasting as a mechanism to produce such closure is the readvance of ice into mountain valleys from adjacent trunk valleys. Surging within trunk glaciers is one mechanism could account for the reversal of ice flow into mountainous areas where ice could have blocked valleys and ponded these lakes.

The one locality where an ice flow reversal has been documented is the Lapie River valley within Pelly Mountains immediately adjacent to Tintina Trench. An extensive lake with a maximum surface level of between 1040 and 1080 m was ponded in this area. Plouffe (1989) found clasts of South Fork Volcanics cystal tuff 9 km upstream of the mountain front. The nearest outcrop of these rocks is north of Tintina Trench (Fig. 4). These clasts could only have been carried into the Lapie River valley by ice flow into the valley from Tintina Trench.

Glacial and postglacial chronology

The length of time separating the deposition of the pre-McConnell and McConnell tills cannot be determined. They may have been deposited during two stades or advances of the same glaciation. Bostock (1966) described evidence of four glaciations in central Yukon. The two oldest (pre-Reid glaciations) predate 790 ka BP (Jackson et al., 1990). Drift from these glaciations is typically deeply weathered and capped by paleosols, which have distinctive reddish coloration and conspicuous illuviated clay in their paleo B-horizons, among other diagnostic properties (Tarnocai, 1987). No evidence of paleosol formation has been found within sediments separating the two tills previously described in Tintina Trench. Consequently, on the basis of its freshness, it is unlikely that the pre-McConnell Till dates from the pre-Reid glaciations. Rather, if the unit does predate McConnell Glaciation, it was likely a product of Reid Glaciation, which has not been dated but is thought to be early Wisconsinan or Illinoian (Hughes, 1989; Hughes et al., 1989).

Age of McConnell Glaciation

Buried outwash gravels are exposed along Ketza River (Fig. 1) in a stratigraphic position analogous to intertill outwash gravels in depicted in Figures 27 (sections 14686 S-1 and 7686 S-2) and 28. These gravels yielded bone fragments from large and small mammals (Jackson and Harington, 1991). A *Bison priscus* radius fragment from these gravels yielded a radiocarbon age of 26 350 ± 280 BP (TO-393; Jackson, 1989). This date provides a maximum age for the overlying McConnell Till in the Ketza River valley and the upper (McConnell) and a minimum age for lower (pre-McConnell) tills (Fig. 27).

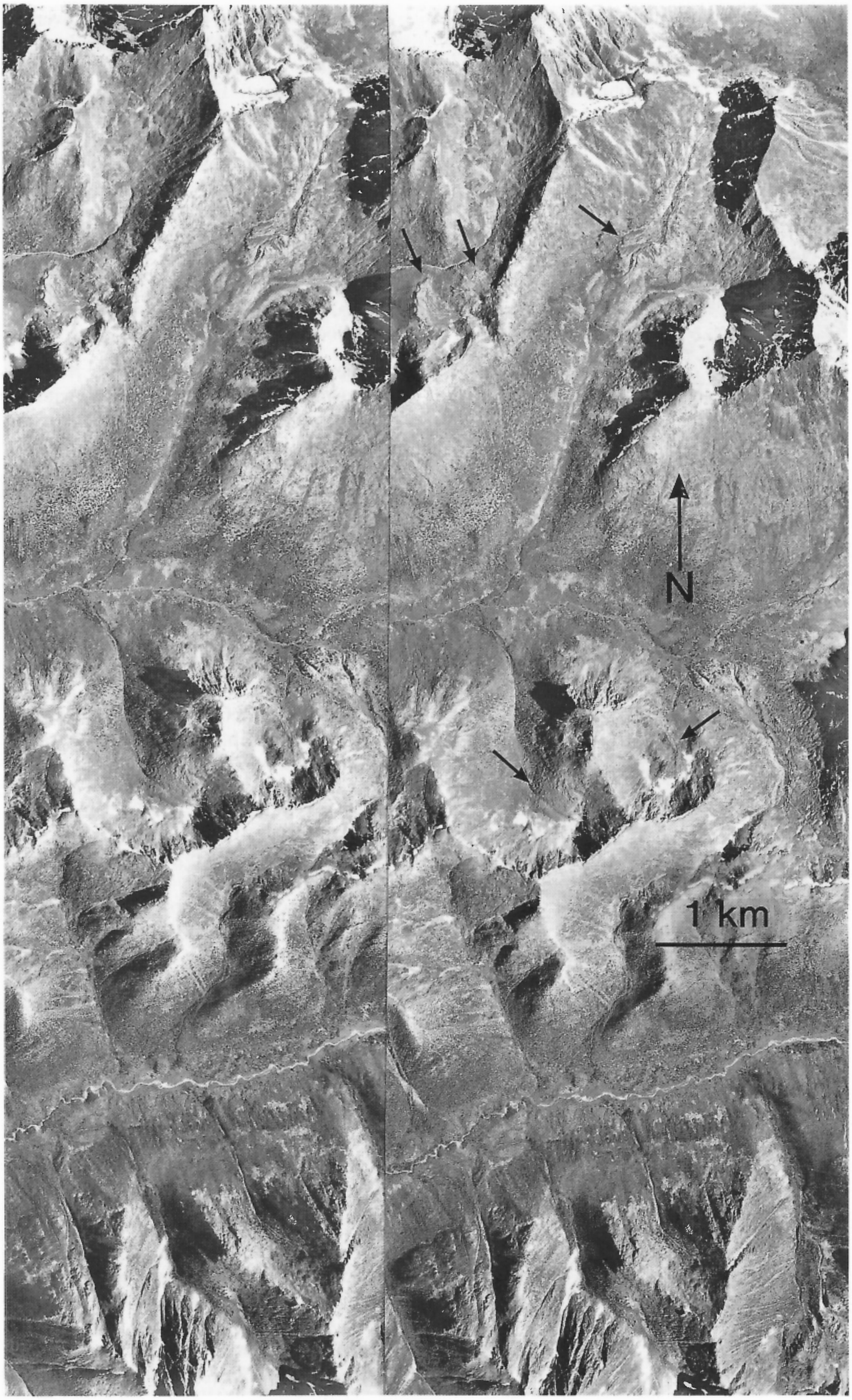

Figure 31. *Ice stagnation landforms including small deltas (arrows) within or adjacent to the floors of cirques in Pelly Mountains.* *(NAPL A20061 49-50)*

This age agrees with ages determined on organic material from beneath McConnell Till near Mayo of 29 600 ± 300 BP (TO-292; Matthews et al., 1990) and 23 900 ± 1140 BP (GSC-2811; Klassen, 1987) at the Tom Creek section in the Watson Lake area (location on Fig. 1). These latter two sites lie northwest and southeast of the study area, respectively, and bear on the chronology of the growth of Selwyn Lobe (Mayo) and Liard Lobe (Watson Lake area) and Cordilleran Ice Sheet in central Yukon in general. The interpretation of the paleoenvironmental record at Mayo (elevation 490 m a.s.l.), which lies a few kilometres inboard of the limit of Selwyn Lobe in the Stewart River valley (Matthews et al., 1990) documents ice-free conditions with spruce forest present there until at least 38 ka BP. Stewart River was aggrading at that time. Whether this aggradation was in response to the expansion of glaciers upstream in Selwyn Mountains or to other factors has not been determined.

By ca. 29.6 ka BP, however, spruce had disappeared and a tundra environment existed. Matthews et al. (1990) estimated the depression of treeline to have been about 850 m relative to contemporary treeline. This date and environmental reconstruction agrees with sequences studied at Hanging Lake in northern Yukon (Cwynar, 1982) and Antifreeze Pond in southwestern Yukon (Rampton, 1971). This agreement suggests that conditions conducive to the expansion of glacial cover existed at that time in central Yukon. Stewart River at Mayo was aggrading at that time, perhaps in response to increased load associated with glacierization of Selwyn Mountains. However, if glacial cover was increasing in the mountainous areas of the region, expansion must have been gradual. The approximate 26.4 ka BP age from the Ketza River site, at 1170 m a.s.l. immediately adjacent to the northern margin of Pelly Mountains, precludes formation of the south-central part of Selwyn Lobe until after that time. The 23.9 ka BP age from the Tom Creek section (750 m a.s.l.) in the Watson lake area limits the expansion of Liard Lobe until after that time. Consequently, glaciation must have been restricted to alpine areas until sometime after about 26 ka BP and ice sheet formation culminated after about 24 ka BP.

Few radiocarbon ages exist to date the termination of McConnell Glaciation. Radiocarbon ages from the continental divide in Selwyn Mountains indicate that ice had disappeared from the divide before about 9.0 ka BP (Jonasson et al., 1983; MacDonald, 1983). Ward (1989) reported a minimum age of 12 590 ± 540 BP (TO-931) for the deglaciation of the Pelly River valley 30 km west of the study area. This age, determined on shell, should be regarded with caution because of the dead carbon effect that complicates such dates (Clague, 1982). Elsewhere in Yukon, Arctic tundra is known to have persisted until 14.5 to 10 ka BP (Rampton, 1971; Cwynar, 1982) before vegetation communities indicative of warmer climate became established.

Holocene events and chronology

As has been demonstrated elsewhere in glaciated regions of the Cordillera, geomorphological events during the Holocene reflected the readjustment of slopes and streams from a glacial to a nonglacial regime. Initially, sediment supply to the fluvial system is conditioned by glaciation. Sediments left behind by melting glacial ice in upland areas rapidly erode and mass waste. Rates of sediment transport from upland to lowland areas are initially high. Alluvial fans are built rapidly by alluvial and debris flow deposits, and trunk streams respond to the increased load by aggrading and braiding. The rate of supply of upland sediments is eventually reduced to values controlled by nonglacial processes. Gradually fans and flood plains become incised and stream patterns change from braided to meandering (Ryder, 1971a,b; Church and Ryder, 1972; Jackson et al., 1982; Ritter and Ten Brink, 1986). The growth and spread of blanket bog throughout the region is second only to paraglacial sedimentation in its modification of the land surface during the Holocene epoch.

A skeletal chronology of Holocene geomorphological events has been established for the Pelly River basin only. However, this chronology can likely be applied generally throughout the study area. A radiocarbon age of 8 000 ± 90 BP (GSC-3426) was determined on peat from the base of blanket bog deposited on outwash gravels exposed along Pelly River (61°54′N, 131°08′W). The age marks the beginning of blanket bog growth at this site and places a minimum age on the cessation of outwash deposition and incision of outwash by Pelly River. Incision continued until sometime after 5920 ± 70 BP (TO-196), an age determined on woody detritus from a terrace along Pelly River, 14 m above its present floodplain, near Ross River. Incision was complete prior to the start of the present millennium. The White River tephra (ca. 1.2 ka BP (Lerbekmo et al., 1975) is within the overbank sediment of the present Pelly River floodplain and in contemporary flood plain deposits throughout the study area.

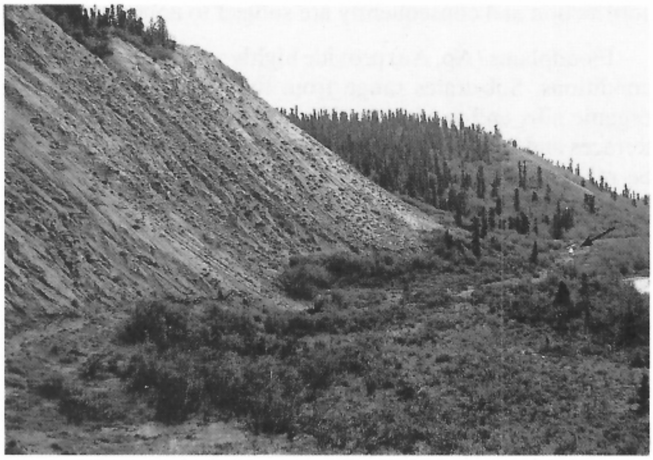

Figure 32. *About 50 m of glaciolacustrine fine sands and silts in an alpine valley (elevation of top of sediments 1340m) between cirque and confluence with a trunk valley, Magundy River system (see Fig. 17A for view of bedding). (Arrow indicates a helicopter for scale.) (GSC 1992-113Q)*

APPLICATIONS

Engineering applications and geological hazards

Few detailed geotechnical investigations have been carried out within the study area. Consequently, characteristic values for such basic soil engineering parameters as unconfined compressive strength and optimum Procter density for terrain units cannot be reported. However, some observations of the performance of these units in natural settings may prove valuable and are reported here.

Foundation conditions

Although bedrock landslides can and have occurred locally in the area (see *Natural hazards*), their occurrence has apparently been controlled by site-specific factors such as jointing plane and bedding plane orientations and slope steepness and relief. No bedrock units presently can be identified as being characteristically incompetent.

The distribution of permafrost and the presence of massive ice lenses in Quaternary deposits are preeminent factors to consider in evaluating foundation conditions within the study area.

Colluvial deposits vary greatly in texture and consequently are highly variable as foundation materials. Rockfall deposits (bCa) are coarse and porous but are commonly close to the angle of repose and so are metastable and subject to creep (Gardner, 1969, p. 318). They may also locally grade into rock glaciers and consequently creep and collapse. Colluvial apron deposits (Ca) may be covered by blanket bog or contain buried organic material, for example, peat, soil, logs, which could pose differential settlement problems. Those with matrices with sufficiently large silt fractions may contain segregated ice lenses. In addition to foundation concerns, both Ca and bCa may lie in the path of periodic avalanching and debris flows. Colluvial blankets and veneers, which occur in areas marked Mv are usually affected by solifluction and consequently are subject to annual creep.

Floodplains (Ap, Au) provide highly variable foundations conditions. Substrates range from thick gravels to ice-rich organic silts and to interstratifications of the two. Alluvial terraces and fans (At, Af) are usually well drained and should be relatively free of massive ground ice. However alluvial fans are prone to innudation by flood water and debris flows.

Till (Mb, Mv) usually provides a stable, strong substrate. Geomorphological processes affecting till blankets, veneers, and till in hummocky ice disintegration topography are commonly confined to fluvial erosion. However, if segregated ice is present, moisture contents upon thawing may well exceed the liquid limit and till will flow on gradients as low as 4° (see *Landsliding* below). Erosion is only of concern to the planner where erosion rates are rapid enough to cause gulleying. Under natural conditions, such erosion is confined to river-cut cliffs and Neoglacial moraines. Lateral and end moraines left in the wake of Neoglacial advances are composed of bouldery till and stagnant glacial ice. Thawing and collapse of this stagnant ice makes these features prone to collapse and failure as debris flows and slumps.

Figure 33. *Retrogressive thaw slide along Pelly River. Bands in headwall are segregated ice lenses. (GSC 1992-113R)*

Glaciolacustrine deposits commonly contain massive ice lenses. Where they have been eroded, such as along the outside of river bends, the thawing fine sediments retreat rapidly as retrogressive thaw slides (Fig. 33)[6]. Where ice lenses are degrading at level sites, glaciolacustrine sediments are prone to vertical (thermokarst) collapse.

Rock glaciers (designated by a symbol) and areas within their paths are unsuited for any construction activities because of the continuous horizontal and vertical displacements associated with their flowage, matrix or ice-core meltout, and the periodic toppling of rocks from their advancing, precipitous snouts.

The low bearing strength of organic (O) deposits coupled with their extensive contents of ice lenses makes them sensitive to disturbance and totally unsatisfactory as foundation substrates.

Thin colluvial veneers in areas mapped as bedrock (R) or till veneer (Mv) are usually coarse or bouldery sediments. Because bedrock lies less than 1 m below the surface of these deposits, foundation problems are not a concern.

Granular materials

Bulk fill. Till (Mb, Mv) is the most widespread glacial sediment in the study area. It is low in plasticity (Fig. 12) and, if in situ moisture contents are low, is easily exploited as a source of low permeablity bulk fill. It has been widely used in fills and as a surface material in Robert Campbell Highway, the major transportation artery through the study area. Glaciolacustrine sediments (L units) are locally extensive in

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[6] Dawson (1888) made his first observations of permafrost in Yukon at such a location along Pelly River.

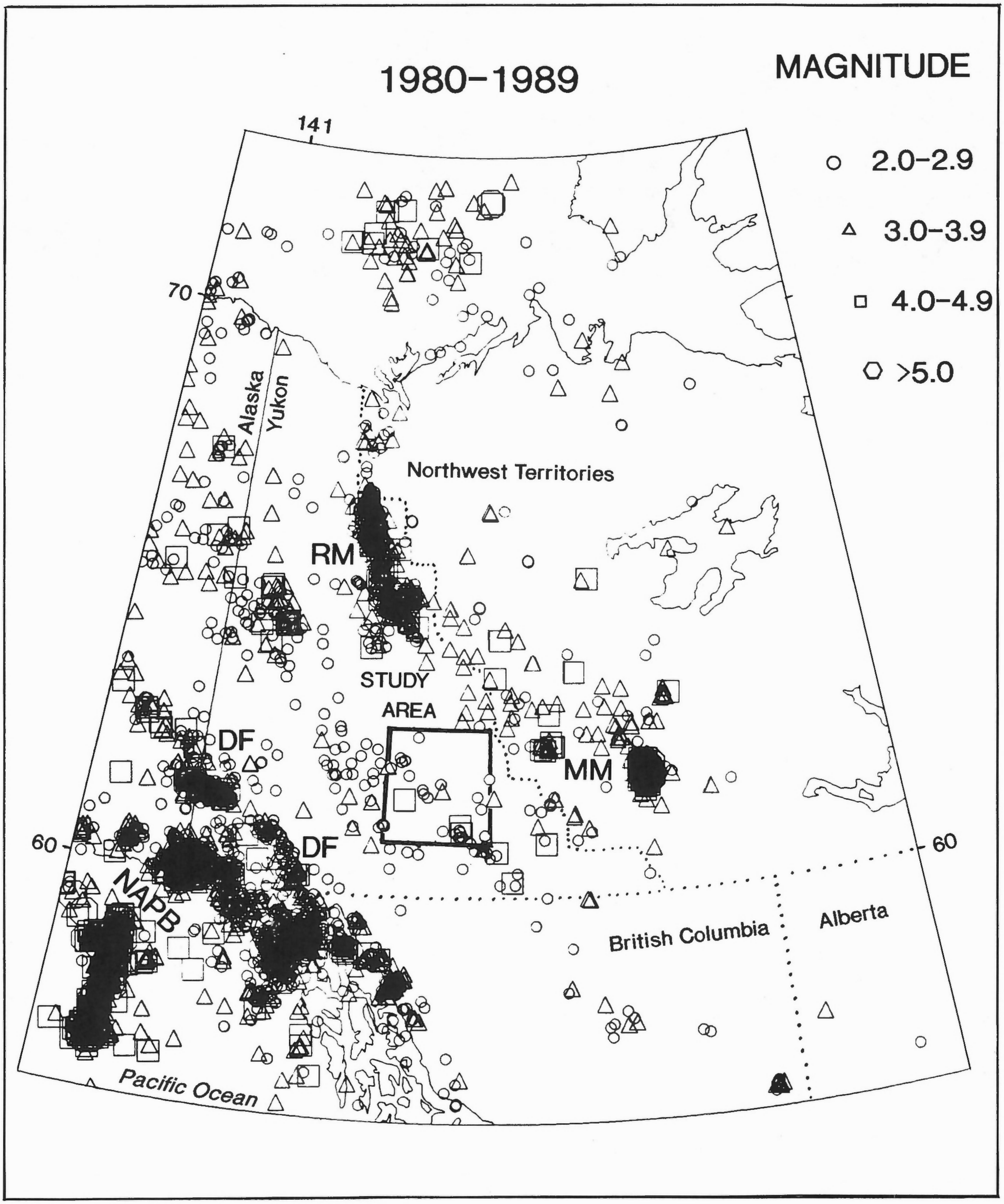

Figure 34. Earthquakes in Yukon and adjacent regions, 1980-1989: RM – Richardson Mountains, MM – Mackenzie Mountains, DF – Denali Fault, NAPB – North American Plate Boundary (data from the Geological Survey of Canada).

***Figure 35.** View of a large debris avalanche of ultramafic rock on an unnamed tributary to Big Creek. The event occurred in postglacial time prior to the eruption of the White River tephra ca. 1300 BP. The volume of the debris avalanche is estimated at between 3-15 x 10^6 m^3 (view looking south). Length of slide is about 5 km. Failure area at top centre of view (defined by broken line) is about 600 m high. (GSC 1992-113U)*

major valleys. Where they are free of ground ice, they are good sources of bulk fill. However, where ground ice is present, the in situ mositure content of glaciolacustrine sediments will exceed the liquid limit upon thawing causing it to flow on very low gradients and making it very difficult to handle.

Sand and gravel. Sand and gravel are plentiful throughout the study area but accessiblity and quality in terms of sorting (grading) and the content of undesirable or weak lithologies within may vary markedly. Any alluvial units (A) or glaciofluvial (G) units are potential sources. Units Ap and Au are at or close to the water table and some are capped by organic and lacustrine sediments. Exploitation will disrupt streams and wetland environments. At and Af are typically well drained. Af deposits, however, particularly those below watersheds with areas less than a few square kilometres, may be bouldery and may contain poorly sorted debris flow diamicton. Glaciofluvial deposits are the major source of gravel outside stream valleys. Glaciofluvial units vary greatly in texture and sorting over short distances both laterally and vertically and may contain variable amounts of diamicton.

Natural hazards

The processes that shape the earth's surface are relentless. Where these processes such as flooding and landsliding have the potential to threaten lives and property, they may be labelled natural hazards. The following hazards are discussed in addition to the widespread permafrost-related problems previously described.

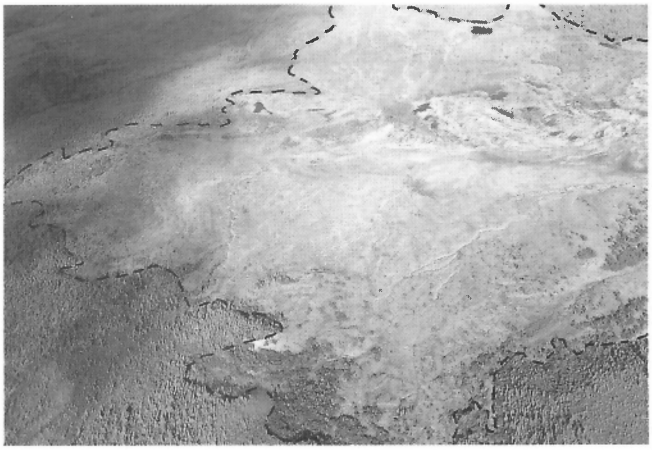

***Figure 36.** Surprise Rapids Landslide, looking west from the head of the landslide. Failure has been by earth and debris flow in till triggered by the melting of ground ice. The landslide is 2 km wide at the widest point. (GSC 1992-113V)*

Earthquakes

Although the study area is located in a region of apparently low magnitude seismic activity, two belts of seismic activity concentrated along the North American Plate margin and the Denali Fault lie to the west (Fig. 34). The former zone has produced some of the largest earthquakes recorded on the planet with magnitudes up to 8.6 (Stover, et al. 1980; Horner, 1983). To the east and north is a belt defined by the Mackenzie and Richardson mountains, which has produced earthquakes with magnitudes to 6.8 (Wetmiller et al., 1988). The study area is distant enough from earthquake sources west, east, and north so that events in these seismically active belts have not produced locally destructive effects during historic time.

Detection of earthquakes occurring within the study area by the seismological network of the Geological Survey of Canada is recent (Fig. 34). The capacity to record earthquakes as low as magnitude 4 has existed since 1978 and magnitude 2 since 1984. Since 1978, all recorded earthquakes within and immediately adjacent to the study area have been less than magnitude 5 and have clustered along or close to Tintina Trench. However, it must be cautioned that the historic period of record in Yukon is brief and only locally extends back to 1850 (Milne, 1964; Jackson, 1990). Scarps along Tintina Fault and the traces of parallel splinter faults are fresh features. The seismic hazard presented by this fault system has yet to be adequately evaluated.

Floods and debris flows

Floods caused by ice-jamming during spring break-up, snow melt, and summer rainstorms pose potential hazards along streams throughout the study area. Areas designated Ap and Au should be regarded as flood plain. Alluvial fans (Af) are also flood hazard areas. They are subject to both innudation by flood waters and stream avulsion with the added hazard of inundation by debris flows on fans with gradients in excess of 4°. Only alluvial terraces (At), of all alluvial units can be regarded as being beyond the reach of flood waters. Colluvial aprons (Ca) are also prone to inundation by debris flows and waterfloods with accompanying stream avulsion.

Landslides

Landslides occur within bedrock and unconsolidated deposits within the study area (Fig. 19, 35-37). They have occurred in a variety of lithologies and have as a rule only been studied from air photography (Jackson and Isobe, 1990). As previously noted, no common factors can be established to link the bedrock failures except for the widespread steepening of slopes attendant with the last glaciation. Five large rock avalanches or sturzstroms (Hsu 1975) have occurred in Pelly Mountains in postglacial time (Jackson and Isobe, 1990; Fig. 19 and 35). These failures are on the same scale and have excessive travel distances and effective coefficients of friction comparable to those investigated in Mackenzie Mountains (Eisbacher, 1979; McLellan, 1983). Instabilities that triggered large rock avalanches may persist in adjacent and unfailed mountain slopes. Consequently, construction and settlement on or near to large rock avalanche deposits should be avoided.

Rockfall, ranging from the fall of individual clasts to small debris avalanches with estimated volumes of up to 10^5 m^3, have built the talus cones and aprons throughout the mountainous areas of the study area. This form of slope failure is the most significant both in frequency and cumulative volume. Construction and settlement on or near R-A and bCa units should be avoided.

Failures in bedrock are followed in significance by failures in unconsolidated deposits typically involving the melting of ground ice. One of these, informally named "Surprise Rapids landslide" by Ward et al. (1992) along South Macmillan River (Fig. 36), is believed to have grown to an area of more than 3 km^2 in less than 100 years. However, most of these failures are typically too small to be delineated at a scale of 1:100 000. Areas where glaciolacustrine sediments are being actively eroded, such as along the outside bends of streams, are

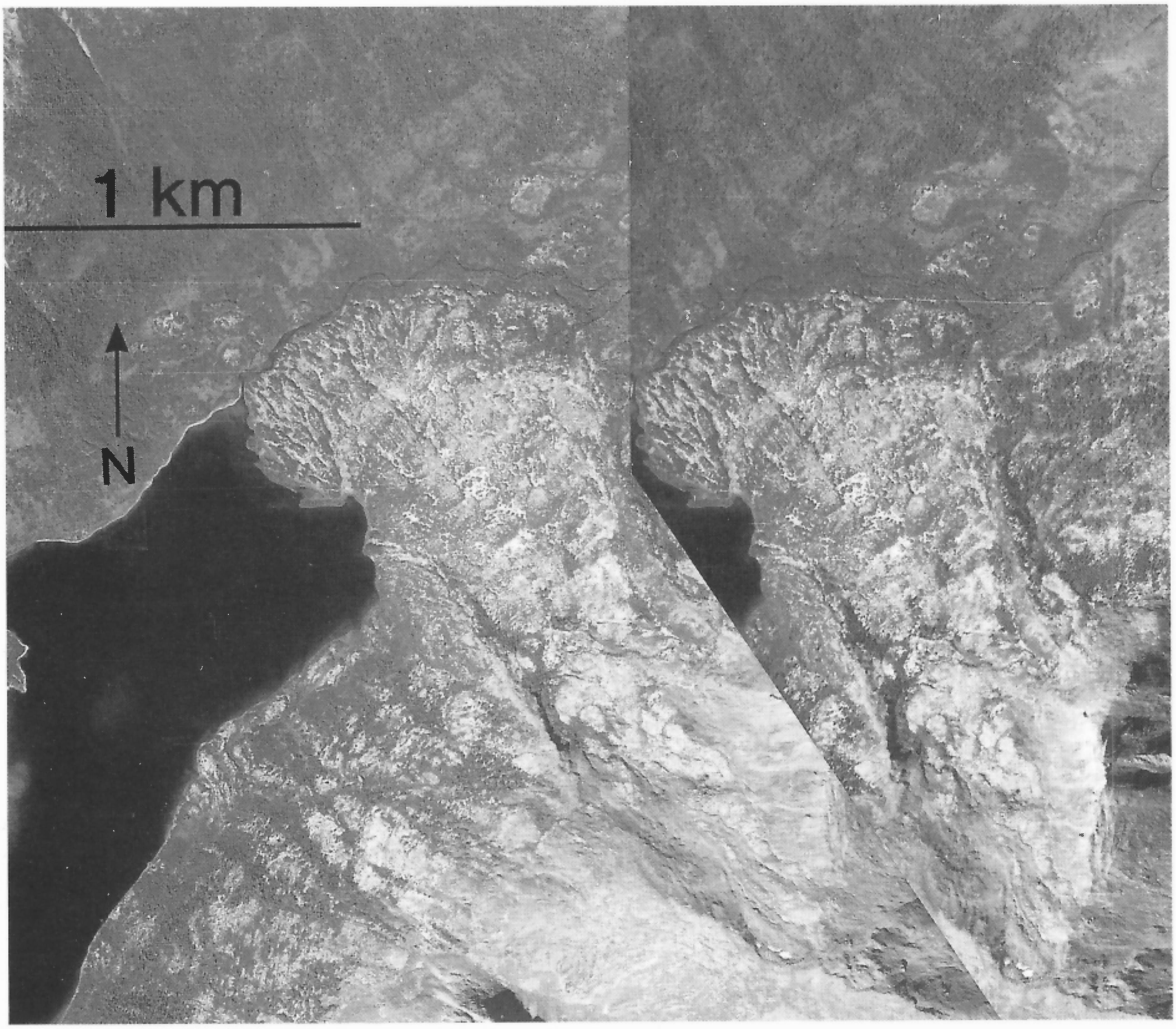

Figure 37. Large complex landslide has dammed a lake in Campbell Range. (NAPL A25289 131-132)

most at risk for these types of failures. Stability of till on sloping sites would be difficult to assess without drilling to determine whether segregated ice lenses exist.

Large, complex bedrock landslides are relatively rare. The landslide illustrated (Fig. 37) is the largest known in the study area. Like large rock avalanches, the factors that caused the instability that resulted in an extant failure may persist in adjacent slopes. Consequently, areas in and around these landslides are poor choices for settlement.

Snow avalanches

Snow avalanching is widespread in alpine areas and adjacent valleys of the study area. They are among the most widespread and destructive natural hazards in the Canadian Cordillera (Evans and Gardner, 1989). Avalanches originate in areas of snow accumulation above treeline; they traverse treed valley sides and run out onto valley floors. Although avalanches cut tracks through forest areas, "green" avalanches in areas between active avalanche tracks are always a possibility. Areas denoted R-A are prone to avalanches. Areas denoted Mv, Mb, Ca, bCa, and Af downslope of R-A areas should be regarded as areas for potential avalanche runout.

Snow avalanches also erode and transport rock and soil material that becomes entrained in the avalanche. They deliver bouldery debris to talus and colluvial aprons and are important agents in shaping these landforms (Luckman, 1972, 1978).

Drift prospecting

The passage of ice erodes rock and redeposits the resulting sediments down ice flow. The geochemistry of till at any point is "lithological summation of source units up-ice from the site" (DiLabio, 1989, p. 649). In drift-covered areas, this fact may be exploited in the search for ore deposits. For example, ore deposits masked by drift may be located by tracing visually recognizable ore fragments in till or other glacial sediments up the flow of paleo-ice. Similarly, chemical analysis of the fine fraction of till can detect geochemical anomalies, which can be traced up the flow of paleo-ice to their bedrock source. Discussions of till carbonate content, pebble lithology and geochemistry have already been presented in the "Morainal Deposits" section. The information presented in this section may be compared to the results of future drift-prospecting surveys so that true anomalies may be distinguished from normal regional variations in chemistry and lithology. Multi-element geochemical analyses reported in Table 4 were carried out on clay-sized fractions (≤2μm). Consequently, gold, which is usually concentrated in silt or larger fractions (Often and Olsen, 1986; Sopuck et al., 1986), is not addressed. Information on gold in drift in the study area is contained in the study by Plouffe (1989).

Till pebble lithology

The lithologies of till pebbles (2-6 cm) were recorded for all samples (Fig. 13). Till sampling was biased by access and the distribution of natural and man-made exposures. Thus much of the sampling in Pelly Mountains and Selwyn Basin was done along transportation corridors and along Tintina Trench (Fig. 14). Till pebble lithology appears to be relatively constant throughout the study area, with the exception of increased contents of mylonites and quartz porphyry (felsic volcanics) in Tintina Trench. Contents of cataclastic rocks, ultramafics, and felsic volcanics drop to zero in areas removed from allochthanous rocks, the felsic volcanics of Tintina Trench, and outcrops of the South Fork volcanics.

Carbonate content

Total carbonate content of till in the study area varies with the mineralogy of bedrock immediately up flow of paleo-ice direction (Table 3). The highest mean contents of calcite and dolomite are found in Pelly Mountains, where carbonate bedrock is locally extensive. However, scattered outcroppings of carbonate rocks in the allochthanous terrane north of Tintina Trench and carbonate platform facies of Selwyn Basin rocks (Fig. 6) in Selwyn Mountains have locally enhanced the carbonate contents of till. The highest values were recorded locally in tills in Selwyn Mountains.

Till geochemistry

The values of chemical analyses determined on the clay-sized fractions of till samples are listed in Table 3. The mean and maximum values for all metals reported are generally higher from tills derived from the mixed allochthanous and autochthanous rocks of Pelly Mountains and Tintina Trench than from those derived from the strictly autochthanous sedimentary rocks of Selwyn Basin. This difference is particularly noteworthy for those metals having an affinity for ultramafic rocks, that is, chromium, manganese, cobalt, and nickel. These rocks are associated with allochthons.

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