Geological Survey of Canada
Commission géologique du Canada

PAPER 86-18

TERRAIN INVENTORY AND QUATERNARY HISTORY OF NAHANNI MAP AREA, YUKON TERRITORY AND NORTHWEST TERRITORIES

L.E. Jackson, Jr.

Canada

1987

GEOLOGICAL SURVEY OF CANADA
PAPER 86-18

TERRAIN INVENTORY AND QUATERNARY HISTORY OF NAHANNI MAP AREA, YUKON TERRITORY AND NORTHWEST TERRITORIES

L.E. Jackson, Jr.

1987

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Available in Canada through

authorized bookstore agents and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada K1A 0S9

and from

Geological Survey of Canada offices:

601 Booth Street
Ottawa, Canada K1A 0E8

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

100 West Pender Street
Vancouver, British Columbia V6B 1R8

A deposit copy of this publication is also available
for reference in public libraries across Canada

Cat. No. M44-86/18E Canada: $6.00
ISBN 0-660-12635-4 Other countries: $7.20

Price subject to change without notice

Cover

South Nahanni River looking upstream towards Mount Wilson.

Critical Reader

R.W. Klassen

Author's address

Geological Survey of Canada
100 West Pender Street
Vancouver, B.C.
V6B 1R8

Original manuscript received – 1985 - 02 - 13
Final version approved for publication – 1986 - 05 - 16

CONTENTS

TERRAIN INVENTORY AND QUATERNARY HISTORY OF NAHANNI MAP AREA, YUKON TERRITORY AND NORTHWEST TERRITORIES

Abstract

The Nahanni map area was intensely glaciated during the McConnell Glaciation. At the climax of this glaciation, one or more ice centres existed over the area. Climax ice flow directions were controlled by underlying topography although flow directions east of the Continental Divide were commonly opposed to present surface drainage directions; ice streams flowed west across the Continental Divide and north into the Keele River basin. The surficial deposits and landforms were deposited almost entirely during the McConnell Glaciation or during postglacial time.

Till is the most widespread glacial deposit and commonly occurs as blankets and veneers over bedrock. Glaciofluvial deposits are predominantly gravels and are common in most valleys as kames, eskers, 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.

Rock glaciers display evidence of either present or past downslope movement. Active rock glaciers contain ice either in interstices or as an ice core. Flow velocities of more than 2 m/a have been documented in the Nahanni area.

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 between talus cones and colluvial fans and between felsenmeer and solifluction deposits.

Rockfall is the most significant form of slope failure. Only a few large landslides have occurred in the map area.

Fluvial deposits, predominantly gravels, form fans and floodplains, or are terraced. Floodplains may contain a significant component of fine lacustrine sediments – primarily silts and clays; these may contain clear ice lenses and develop thermokarst. Much of the volume of 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 occur in floodplains, paludifying lakes, and as blanket bog. These deposits usually contain clear ice lenses which are subject to growth, accompanied by heave, and collapse; they are particularly sensitive to disturbance.

Résumé

La région cartographique de Nahanni a été fortement englacée au cours de la glaciation de McConnell. On y trouvait au moins un centre glaciaire à l'apogée de la glaciation. Les directions de l'écoulement glaciaire à l'apogée étaient contrôlées par la topographie sous-jacente, bien que les directions d'écoulement à l'est de la ligne continentale de partage des eaux fussent normalement opposées aux directions du drainage superficiel actuel; des langues glaciaires se sont écoulées vers l'ouest en travers de la ligne continentale de partage des eaux et vers le nord jusque dans le bassin de la rivière Keele. Les dépôts superficiels et la topographie se sont formés presque entièrement au cours de la glaciation de McConnell ou du postglaciaire.

Le till, dépôt glaciaire le plus répandu, forme normalement des couvertures et des placages sur le socle rocheux. Les dépôts fluvioglaciaires se composent surtout de graviers; ils sont communs dans la plupart des vallées sous forme de kames, d'eskers et de dépôts plans. Des limons et des argiles glaciolacustres se sont accumulés là où la glace glaciaire a empêché le drainage au cours de la déglaciation. Ces dépôts contiennent souvent des masses de glace et sont donc sujets aux glissements régressifs provoqués par le dégel.

Les glaciers rocheux présentent des indices d'un mouvement descendant récent ou ancien. Les glaciers rocheux actifs contiennent de la glace dans les vides ou sous forme de noyau. Leur vitesse d'écoulement peut dépasser deux mètres par année dans la région de Nahanni.

Les colluvions représentent la plus grande catégorie de sédiments non glaciaires dans la région étudiée. Puisque les colluvions et les formes de relief qui leur sont associées sont formées par une gamme continue de processus d'origine surtout non glaciaire, elles forment un éventail d'éléments intermédiaires; il existe par exemple une série continue de formes de relief intermédiaires entre les cônes d'éboulis et les cônes colluviaux, et entre les champs de blocs et les dépôts de solifluxion.

La principale forme de rupture de talus est la chute de pierres. Les grands glissements de terrains sont peu nombreux dans la région cartographique.

Les dépôts fluviatiles, qui se composent surtout de graviers, forment des cônes et des plaines inondables, ou encore des terrasses. Les plaines inondables peuvent contenir une quantité importante de sédiments lacustres fins, principalement des limons et des argiles; ces sédiments renferment parfois des lentilles de glace transparente et on peut y trouver des thermokarsts. Une grande partie des cônes alluviaux et des graviers en terrasses se sont accumulés au cours du début du postglaciaire, lorsque les quantités de sédiments transportés étaient fonction de la glaciation, plutôt que du régime d'érosion actuel.

On trouve des dépôts organiques dans les plaines inondables et les lacs en turbification, et sous forme de tourbières de couverture. Ces dépôts contiennent normalement des lentilles de glace transparente qui peuvent croître, se soulever et s'effondrer; ils sont particulièrement sensibles aux perturbations.

INTRODUCTION

The Nahanni map area has in recent years been the scene of impressive mineral discoveries. Only its remoteness and low metal prices have prevented the exploitation of these resources. At the same time, the Nahanni map area includes the wildlife, recreational, and scenic resources of the upper Pelly and South Nahanni river systems and some of the most spectacular alpine scenery in the Selwyn Mountains. The stage is apparently set for future land use conflicts unless careful planning is employed.

Knowledge of the surficial geology of the Nahanni map area will be an essential ingredient of such planning whether it is used to find materials for road construction, select the least hazardous routes through landslide-prone terrain, or evaluate the sensitivity of the landscape to a variety of 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.

This paper gives an inventory of the surficial materials of the Nahanni map area, describes the processes that modify them, and discusses the Quaternary history of this area.

Acknowledgments

I would like to express my thanks to G.M. MacDonald who served as my field assistant and later as a colleague in this project. Mike Bell and Mark Pawson also assisted in the field. Their help and the help of R.W. Klassen who served as critical reviewer are gratefully acknowledged.

Figure 1a. Location map of the Nahanni map area.

PHYSIOGRAPHY

Nahanni map area (105 I) comprises approximately 11 400 km^2 of the Selwyn and Mackenzie mountains (Fig. 1). The map area spans the political divide between Yukon Territory and Northwest Territories and the drainage divide between Pelly River, a major tributary of Yukon River and South Nahanni, Liard, and Keele rivers which are tributary to Mackenzie River. The land surface is predominantly in slope, summit, and plateau. Broad, low lying and valley bottom lands are not common. Elevations range from 1060 m in valley bottoms to 2500 m at the summits of the highest peaks of the Ragged Range in the southeast corner of the map area. More than 75% of the map area lies between 1220 and 1820 m.

The valley of South Nahanni River separates Selwyn and Mackenzie mountains. Its course parallels and presumably is controlled by a facies change between pre-Upper Devonian carbonate platform and turbiditic and euxinic deep basinal rocks to the northeast and southwest of the valley, respectively (see *Bedrock geology*). This course was probably cut by progressive headward erosion and piracy of streams which originally flowed north to northeast through Mackenzie Mountains from the area of the present divide. Evidence for this comes from the nature of the junctions of tributaries with a major valley in Mackenzie Mountains immediately north of South Nahanni valley (Fig. 1b). This valley is oriented northeast-southwest. The angles formed by the junctions of tributary valleys are acute in the direction of northeast flow. Present drainage, however, is to the southwest indicating drainage reversal. This valley was a segment of the course of Little Nahanni River prior to capture by South Nahanni and Broken Skull rivers. At this time, the ancient Little Nahanni was tributary to the Keele River system.

CLIMATE AND VEGETATION

The climate is marked by long cold winters and short mild summers; the area lies within the zone of discontinuous permafrost (Brown, 1967). Although no permanent weather stations exist in the map area, the Tungsten and Ross River (Fig. 1a) records shown in Table 1 provide a reasonable climatic representation of comparable elevations in the study area. Precipitation is almost entirely in the form of snow from October through April and predominantly rain from May through September; however, snow may fall during any month at higher elevations.

Vegetation is determined by substrate, elevation, topography, and microclimate. The forest is dominated by black spruce (**Picea marianna**) and white spruce (**Picea glauca**). The former is dominant under poorly drained conditions and commonly indicates the presence of underlying permafrost. Above treeline (at about 1220 m) dwarf birch (**Betula glandulosa**) blankets plateau areas. Reindeer moss (**Claddonia** spp.) dominates at yet higher elevations 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** spp. and sedge (**Carex** spp.) bogs.

Soils fall mainly into the regosolic group in steep areas and above treeline and into gleysolic and organic groups in poorly drained locations. Cryosols are present where permafrost is within 1 m of the surface. Brunisols predominate under well drained forest conditions. Although podzols occur on acidic, well and rapidly drained coarse deposits such as glaciofluvial gravels (K. Mckenna, personal communication, 1984) immediately east of the Nahanni map area, they were not observed in the study area. Local occurrences, however, may be found in similar settings to those noted above.

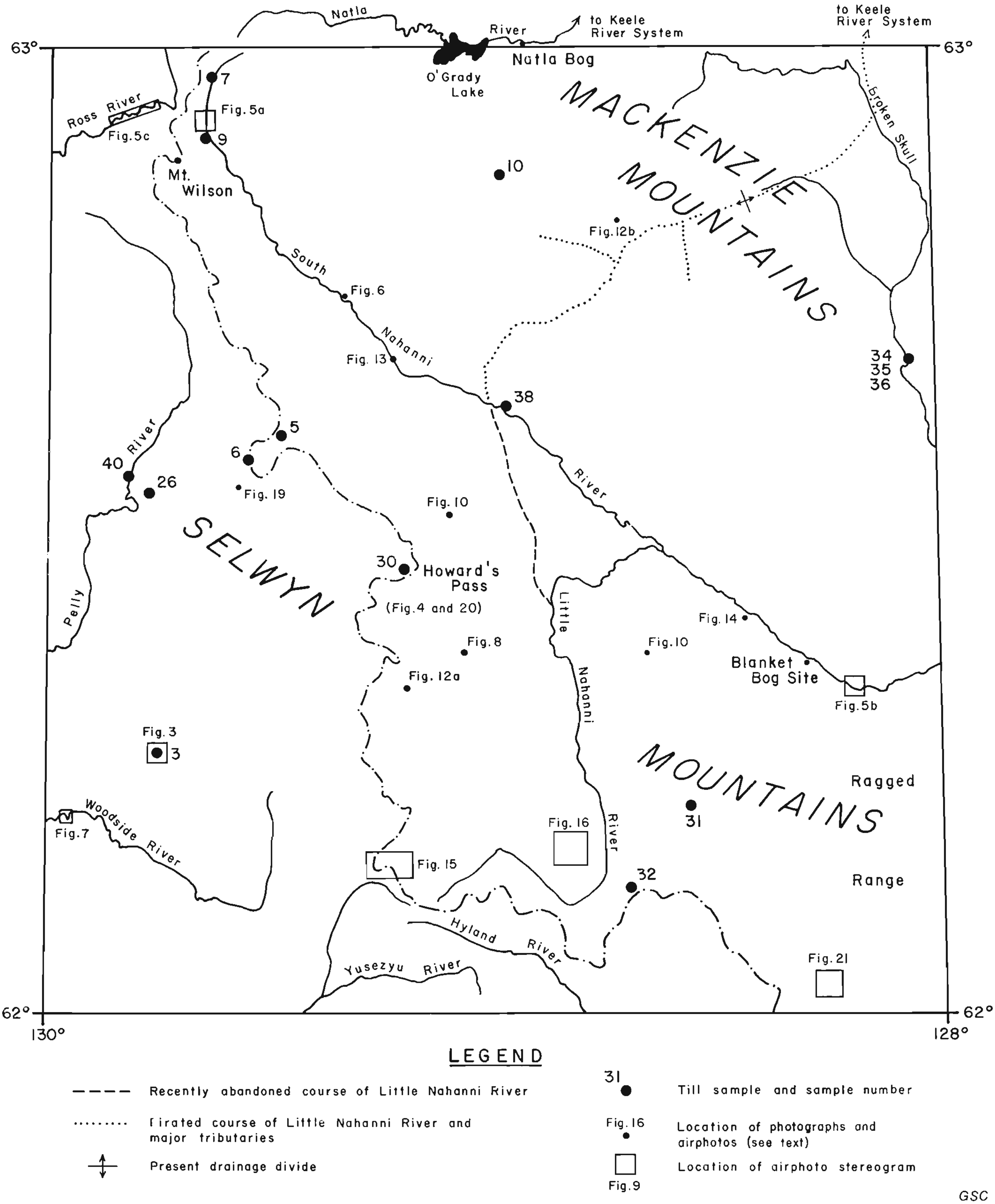

Figure 1b. Geography, reconstruction of ancient Little Nahanni River, sample locations, and location of ground and airphotos.

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

Tungsten, Northwest Territories (61°57'N, 128°15'W), elevation 1143 m

Temperature (°C)	Jan.	July	Mean annual precipitation (mm)	
Daily maximum	-19.5	16.6	Total	644.7
Daily minimum	-29.3	5.3	Snow	316.7
Annual mean	-5.7		Rain	333.6
Extremes				
Maximum 27.8				
Minimum -50.0				

Ross River, Yukon (61°59'N, 132°27'W), elevation 698 m

Temperature (°C)	Jan.	July	Mean annual precipitation (mm)	
Daily maximum	-23.6	21.8	Total	263.5
Daily minimum	-36.1	5.3	Snow	105.8
Annual mean	-5.7		Rain	152.2
Extremes				
Maximum 33.3				
Minimum -59.4				

Record period is 10-14 years (Tungsten) and 9-14 years (Ross River) depending upon the parameter measured and month of measurement.

PREVIOUS WORK

Geological investigations in this region began with George M. Dawson who traversed south and southwest of the Nahanni map area during exploration of the southern Yukon in 1887. The bedrock and surficial geology of the region are mentioned in his account of this exploration (Dawson, 1887). Keele (1910) followed Pelly River upstream from Ross River to Wolf Canyon, immediately west of the Nahanni map area, during the summer of 1907 and traversed the northwest corner of the map area during his crossing of Selwyn and Mackenzie mountains in the winter and spring of 1907-1908. He commented on the distribution of surficial deposits and the general flow patterns of an ice sheet which he estimated to have been 900 m thick over the Selwyn Mountains.

Adventurous explorations by Pike (1896) and Snyder (Snyder, 1937; Goodwin, 1937; Lambart, 1938) contributed further geographic knowledge of the Nahanni area. Snyder's expedition is noteworthy in that it included the first documented aerial reconnaissance of what is now part of the Nahanni map area. Systematic geological mapping of the area at 1:250 000 scale was initiated in 1960 (Green and Roddick, 1961) and was facilitated by the use of aerial photography completed for the area in 1949; Green et al. (1968) indicated past directions of ice flow based upon striae and fluted landforms and noted that the area had been glaciated to at least 1980 m; they concluded that topography did not control ice flow directions during the maximum phase of the last glaciation. During the glacial maximum, an ice centre or dome existed over the map area "... away from which ice at higher levels moved northeast, west and southwest" (Green et al., 1968).

The discovery of large deposits of lead-zinc, tungsten and barium within the map area and elsewhere in the Selwyn Mountains spurred remapping and detailed stratigraphic studies (Gordey, 1981; Morganti, 1981). Studies of Quaternary deposits within and adjacent to the map area have dealt largely with specific phenomena such as palsas (Kershaw and Gill, 1979), rock glaciers (Kershaw, 1978; Jackson and MacDonald, 1980), Holocene palynology (MacDonald, 1983), and an occurrence of Holocene ore deposition (Jonasson et al., 1983). Surficial geology mapping in the immediate vicinity has been carried out by Dyke (1983), Jackson (1982), and Jackson et al. (1984).

PRESENT STUDY

The present study of the surficial geology of the Nahanni map area began in 1979 as a part of the Geological Survey of Canada's Interdisciplinary Mapping Pilot Project (IMPP). Most of the field work for the surficial geology component of this project was carried out during the summer of 1980 with supplementary visits during the summers of 1981 and 1982. Map units delineated on air photographs were field checked by helicopter, foot, and boat traverses. The stratigraphy of the deposits was also investigated at this time where exposures were present.

BEDROCK GEOLOGY

Weakly metamorphosed sedimentary rocks of late Precambrian to Triassic age underlie most of Nahannni map area. These can be subdivided into three stratigraphic sequences. The history, lithology, and stratigraphy of these are summarized as follows (S.P. Gordey, personal communication, 1984):

From the late Precambrian to Middle Devonian the area was segmented into two contrasting facies belts. Shallow water sandstones, dolostones, and limestones were deposited in the northeast whereas gritty quartzose turbiditic sandstone, deep water limestone, shale, and chert were deposited in the southwest. Within the latter facies, euxinic black shales of Early Silurian age host important deposits of stratiform lead-zinc.

An abrupt change in depositional regime occurred in Late Devonian time. Shale was deposited across the older shallow water carbonate-clastic strata to the northeast and turbiditic quartz-chert sandstone, and chert pebble conglomerate was deposited to the southwest. Stratiform barite and barite-lead-zinc deposits, associated with local faulting, form important deposits within black siliceous shale of Middle to Late Devonian age.

The turbiditic clastic sequence was succeeded by quartz sandstone and shale in Early Mississippian time. Shale, chert, minor sandstone, and siltstone form strata of Early Permian and Triassic age.

During the Early Cretaceous, the area was subjected to northeast-southwest compression leading to the development of northwest-trending folds and minor thrust faults. Competent lower Paleozoic strata in the northeast formed large-scale open folds without developing slaty cleavage. The largely incompetent basinal strata in the southwest formed small to large scale open to tight folds with pervasive axial-planar slaty cleavage. Granite and granodiorite intrusions of mid-Cretaceous age underlie about 7% of the map area. They intrude and have metamorphosed to hornfels strata as young as Mississippian. They also crosscut folds and locally faults. Major tungsten showings are associated with skarns developed where these plutons contact argillaceous limestone of various ages.

Resistant Paleozoic carbonate and clastic strata northeast of South Nahanni River form the rugged resistant bedrock ridges of Mackenzie Mountains. Paleozoic clastic strata to the southwest of South Nahanni River underlie

Selwyn Mountains and are characterized by subdued, recessive topography and well rounded, scree-covered slopes. Cretaceous granitic rocks underlie the highest and most rugged parts of the area.

PLIOCENE OR EARLY PLEISTOCENE DEPOSITS

Deposits of late Tertiary or perhaps early Pleistocene age have been found in only one locality along the northern boundary of the map area west of O'Grady Lake (Jackson et al., 1985). A few metres of these poorly consolidated siltstones, weathered gravels, and marls are exposed. These sediments have been tilted to the east by postdepositional tectonism. The generally fine textures of the sediments and the presence of abundant marl within them indicate a lacustrine origin. Constituent mollusc remains reflect a climate during deposition similar to that of todays. Geomorphic considerations as outlined by Jackson et al. (1985) indicate these deposits to be mid-Pleistocene or older.

QUATERNARY DEPOSITS

The Quaternary deposits of the Nahanni area are largely the result of the last glaciation and postglacial events. The reader is referred to Jackson (1982) for a map, at 1:125 000 scale, showing the distribution of surficial materials; this surficial geology map should be used in conjunction with this report. These materials are described in detail in the following sections.

Deposits of glacial environments

Drift

In many areas, airphoto interpretation and the scale of mapping do not permit the resolution of glacial sediments of diverse origins into mappable units. In these situations, the term drift is applied. Abrupt lateral changes in sediment texture and thickness are to be expected in such areas.

Morainal deposits

Morainal deposits, typically refered to as till, are sediments directly deposited by glacier ice. Recent studies of sedimentary processes around the margins of active glaciers (for example, Lawson, 1979; Eyles et al., 1983) have placed the applicability of the term "till" in question. Some authors would suggest that the term be restricted to sediments that have directly melted out from glacial ice with no subsequent resedimentation. In this report, till is applied to sediments directly deposited by glacier ice or

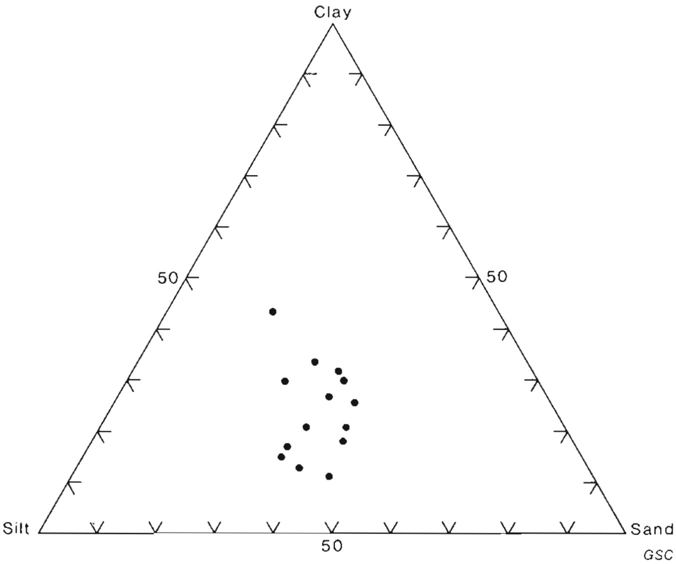

Figure 2. Ternary plot of per cent sand, silt, and clay size contents of the <2 mm fraction of till samples from the Nahanni area.

Table 2. Till texture, carbonate content, and Atterberg limits

Texture						Carbonates					
Wt% <2 mm			Wt% <0.064 mm			Wt% calcite			Wt% dolomite		
X	max	min	X	max	min	X	max	min	X	max	min
						West of South Nahanni River					
36.6	52.6	28.7	63.2	82.4	38.1	0.42	1.5	0.05	1.0	3.7	0.05
s = 6.7			s = 9.5			s = 0.38			s = 1.0		
n = 16			n = 16			n = 13			n = 13		
						East of South Nahanni River					
						29.6	42.0	14.4	59.6	64.4	52.4
						n = 3			n = 3		

Atterberg Limits

Liquid limit				Plastic limit				Plasticity index			
X	max	min	s	X	max	min	s	X	max	min	s
30.3	42.1	16.2	11.7	19.6	30.3	12.4	7.8	10.7	17.0	3.8	5.4
n = 4											

X - arithmetic mean; max - maximum value; min - minimum value; s - standard deviation;
n - number of samples

contemporaneously redeposited by gravitational processes, that is while ice still underlies or is in the vicinity of the sediments. Problems with the consistency of this working definition are further discussed in the section dealing with fluvial deposits.

Till is characteristically a matrix-supported diamicton, that is, an unsorted and usually poorly stratified sediment with clasts ranging from clay to cobbles (Table 2). Tills in the study area are usually matrix supported. The matrix typically has approximately equal proportions of sand and silt size particles (2-0.065 mm and 0.065-0.002 mm, respectively). Together, they usually exceed 65% of the less than 2 mm fraction (Fig. 2) and the remainder is made up of clay size particles (less than 0.002 mm). Particles larger than 2 mm make up more than 30 per cent of till by weight. Atterberg limits were determined on four till samples and all were low in plasticity (Table 2).

Non-clay minerals in the till matrix are dominated by quartz, feldspar, and varying amounts of carbonates. These minerals are directly determined by bedrock geology in the area. Tills derived from the clastic units southwest of South Nahanni River valley are low in carbonate content (Table 2; samples 3, 5-7, 9-10, 26, 30-32, 38, 40 of Fig. 1b) whereas northeast of South Nahanni River valley, they are rich in carbonates (Table 2; samples 34-36 of Fig. 1b). These reflect the influence of the lower Paleozoic carbonates which are common northeast of South Nahanni River valley.

Till commonly directly overlies bedrock as a blanket or a veneer[1]. The rolling terrain adjacent to upper South Nahanni and Pelly River valleys, and wide alpine valleys such as the uplands immediately east of Gull Lake and "Howard's Pass" (Fig. 3, 4) typify this type of terrain. Locally along South Nahanni and Pelly rivers, till overlies glaciofluvial gravels. These gravels were likely deposited as outwash at the onset of the last glaciation beyond glaciers advancing outward from the mountains in the map area.

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 to 10 m in height. These were formed as till melted out from the ice or slid into depressions between blocks of stagnant ice (for example, Boulton and Eyles, 1979).

Lateral and end moraines, formed at the margins of modern glaciers during the past few centuries, typically occur within 1-2 km of the present glacier margins as one,

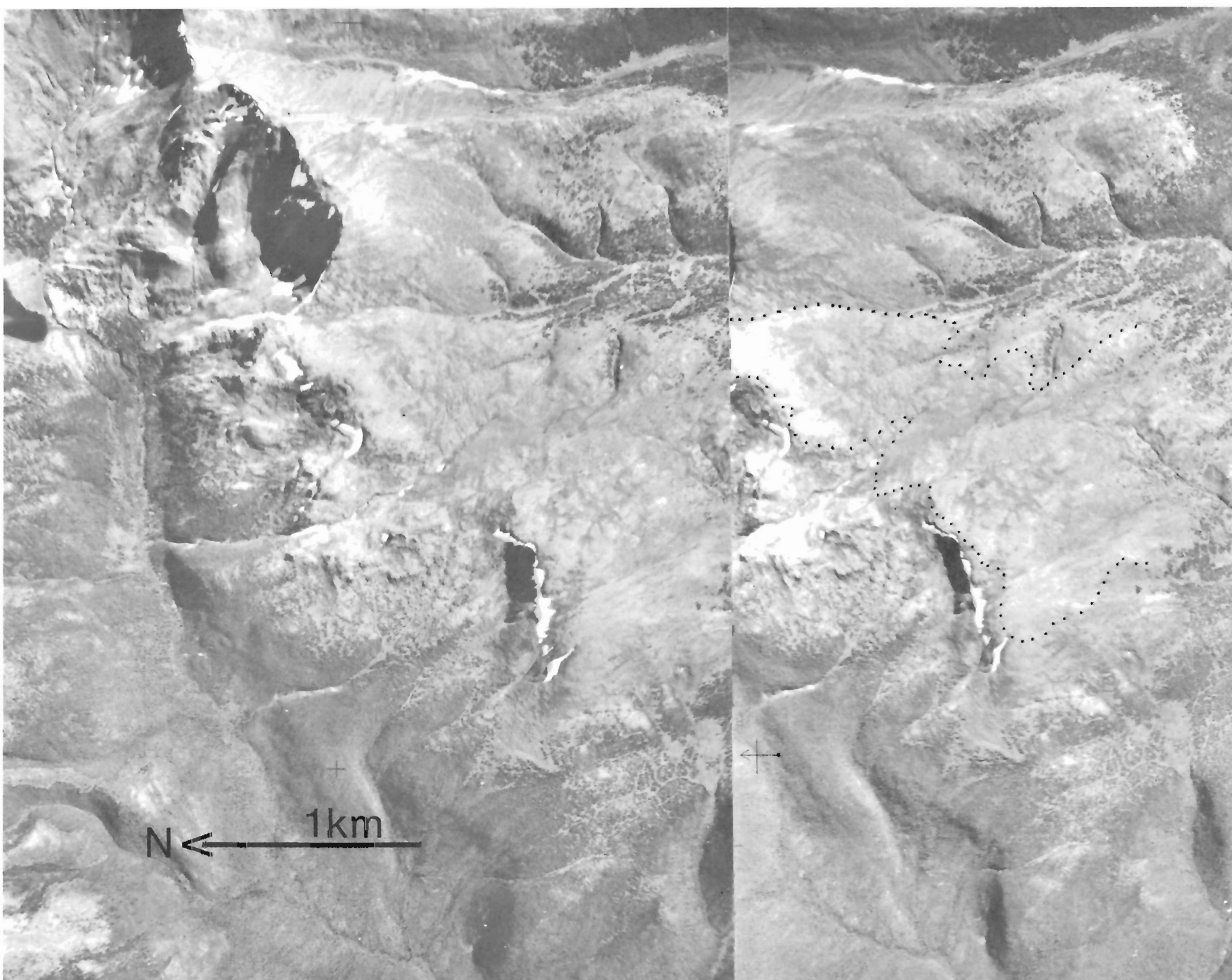

Figure 3. Uplands near Gull Lake; the area within the dotted line is mantled by a till veneer. NAPL A12245 322,333

[1] Blankets are continuous sheets more than 1 m thick; veneers are discontinuous sheets less than 1 m thick.

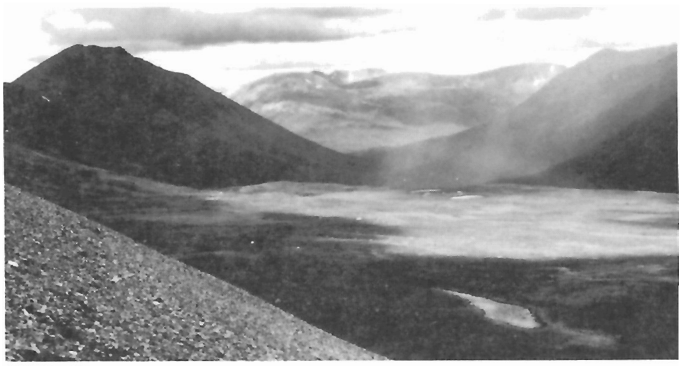

Figure 4. View looking northwest through "Howard's Pass", a major pass through the Selwyn Mountains between Yukon Territory and Northwest Territories and the site of a major lead-zinc deposit. A morainal blanket covers the valley floor and grades into a veneer at the valley margins. 204343-J

two, or three distinct ridges. The till composing these features is usually coarse and bouldery and includes buried ice masses.

Geomorphic processes affecting till blankets, veneers, and till in hummocky ice disintegration topography are commonly confined to fluvial erosion. This 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. Morainal veneers on mountain sides may be subject to burial or erosion by snow avalanches. Buried ice masses in morainal ridges make these features subject to collapse, sliding, and flow. These features may locally grade into rock glaciers.

Glaciofluvial deposits

Glaciofluvial deposits are sand and gravel laid down by running water on top of, against, and beyond glacier ice (Fig. 5). Glaciofluvial deposits are common in most valleys either as planar and terraced outwash or as kames and esker ridges. These latter deposits and landforms were laid down around and beneath stagnant ice (Fig. 5b,c). They are particularly abundant in South Nahanni River valley below the Little Nahanni River confluence and in Upper Hyland River valley. Relief ranges from zero in the case of planar deposits to 10 m or more in kame terrace deposits.

Natural hazards exist on these deposits where they border other deposits such as avalanche-modified slopes along a valley margin. Glaciofluvial deposits are the major source of gravel outside stream valleys.

Glaciolacustrine deposits

Glaciolacustrine sediments were deposited in lakes formed where glacier ice blocked drainage beyond the glacier margin. One of the most extensive lakes formed in uppermost South Nahanni River valley near Mount Wilson (Fig. 1) where retreating ice blocked the valley at the close of the last glaciation. Similar lakes formed at several localities farther down the same valley. Lake sediments are dominantly silts and clays although they may grade into gravels along their margins. One sample from upper Nahanni Valley contained 45% silt and 48% clay.

Glaciolacustrine deposits commonly contain massive ground ice lenses which in places are being eroded by streams resulting in retrogressive thaw slides (Fig. 6). Ice lenses in recent lacustrine sediments may thaw and collapse to form thermokarst lakes in the backswamp areas of Ross and Woodside rivers (Fig. 7).

Rock glaciers

Rock glaciers require a separate classification as they span both the glacial and nonglacial genetic categories. Rock glaciers (Fig. 8) are tongue- or apron-like accumulations of rock debris which display morphological features suggesting present or past downslope movement[1]. They are glacier-like in morphology ranging from lobate (length less than width), tongue-shaped (length greater than width), and spatulate (lobate in form but with an abrupt widening at the downslope extremity). Lobate rock glaciers in the Nahanni map area can be of the order of several hundred metres wide while tongue-shaped rock glaciers are of the order of 2 or 3 km long. Surfaces are marked with longitudinal and transverse furrows and collapse pits (Vernon and Hughes, 1966, p. 17-22).

Active rock glaciers in the map area can be identified by their unvegetated, steep, scarp-like snouts which may have relief from less than 15 m to more than 77 m (Kershaw 1978, p. 68-72). Inactive rock glaciers are characterized by vegetated or turf-covered, rounded snouts and 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 glaciers that have no debris on their surfaces and talus aprons and debris cones. In the Selwyn Mountains, microclimates conducive to the formation and maintenance of rock glacier ice are largely restricted to north-facing slopes (Kershaw, 1978). Rock glaciers may continue to advance during periods of retreat of nearby glaciers because of their protected northern aspects and insulating mantle of bouldery debris.

Active rock glaciers within the Nahanni map area are commonly compound features in the process of overriding more extensive, less active or inactive rock glaciers. At least three generations of rock glaciers advanced during postglacial time (Fig. 8). The oldest, most extensive, and usually inactive generation of rock glaciers may reflect a cold period during early postglacial time; the two youngest are still actively advancing and were probably triggered by the climatic deterioration of the "Little Ice Age " of the past several centuries. This same period of climatic deterioration resulted in two or more advances of cirque and valley glaciers. Jackson and MacDonald (1980) determined surface flow velocities of up to 51 m in 17 years and snout advances of 2.5 m over the same period for ice-cored rock glaciers in the Nahanni area.

Construction or any long term activities on top of or in the path of these features is not feasible because of the horizontal and vertical displacements associated with active rock glaciers and the periodic toppling of rocks from their advancing precipitous snouts.

Deposits of nonglacial environments

Colluvium

Colluvium represents the most diverse group of deposits and landforms to be lumped together under a single heading. The term is applied to deposits originating by the in situ breakdown of bedrock and unconsolidated materials followed by gravitational transportation and resedimentation. Most colluvial deposits and their landforms are end or intermediate members in continuous spectra as depicted in the classification scheme for colluvial landforms of the Nahanni map area. Figure 9 depicts a plot of the texture of the colluvial sediments comprising landforms versus the events (and duration) 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

[1] For review reports on rock glaciers the reader is directed to Wahrhaftig and Cox (1959) and White (1976).

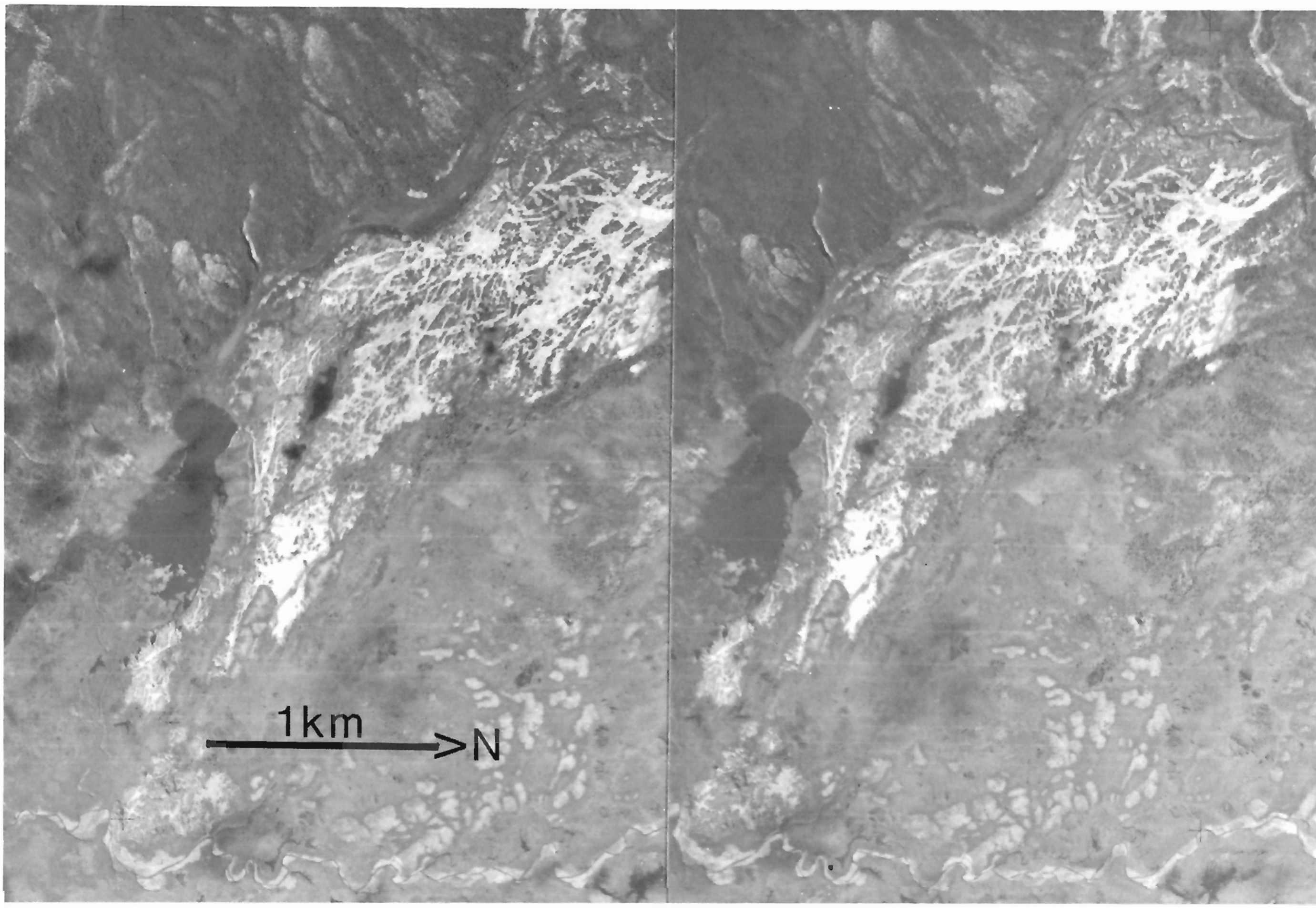

Figure 5. Planar and ridged glaciofluvial deposits from the Nahanni map area: A, Pitted planar glaciofluvial deposit near Mount Wilson (NAPL A12347 6,7). B, Kame and kettle topography along south Nahanni River; the fan encroaching onto the kame on the northeastern side of the river is active and receives both fluvial and debris flow sediments. NAPL A12270 116,117. C, A complex of eskers in Ross River valley. Overall paleoflow was east to west as is the present course of Ross River. The esker complex was formed when ice flow across the Continental Divide from South Nahanni Valley diminished to the point that the glacier occupying the valley stagnated. The intervening areas between the ridges are primarily bog. NAPL A12245 358,359

hand increasing sand, silt, and clay content (<2 mm size fraction) results in matrix-supported sediments although a significant boulder content remains, i.e. solifluction deposits. The rates of formational events indicated in Figure 9 are based upon rates measured for similar deposits elsewhere. Talus aprons and cones 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 on a mountainside in a single year (Gardner, 1979, 1980, 1983). Snow avalanches may deliver additional bouldery debris during the winter months and reshape the talus deposit (Luckman, 1972, 1978). Talus aprons and cones that 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. Figure 10 shows a mountainside subdivided according to deposit genesis and modifying processes. Units Cv_1 and Cv_2 are colluvial veneers on gentle slopes and slopes that head at the base of a steep bedrock scarp, respectively; these are being modified by snow and rock avalanches (-A) or by solifluction (-S). The gulch in the centre of the slope (arrow) receives soliflucted, avalanched, and fluvially eroded material which has contributed to the growth of the colluvial fan (Cf-A); debris flow levees are visible on the fan. Soliflucted sediment and small coalesced fans form a colluvial apron (Ca) along the base of the slope. Bedrock slopes that head on steep scarps (R_2), bedrock cliffs (Rs) and discontinuous veneers of till which grade into colluvium (Cv/Mv) also occur. Note the glacially rounded mountain summits.

Fans become increasingly fluvially dominated as the drainage area increases, to the point where debris flows no longer reach the fan (Jackson, 1987) and colluvial fans grade into alluvial fans. The duration of depositional event also lengthens with increasing drainage area; debris flows are measured in minutes rather than in seconds as in avalanches and rockfalls.

Colluvial deposits that are formed by cyclic freeze-thaw activity are associated with lengthy depositional events (Fig. 9): cycles may range from diurnal to seasonal.

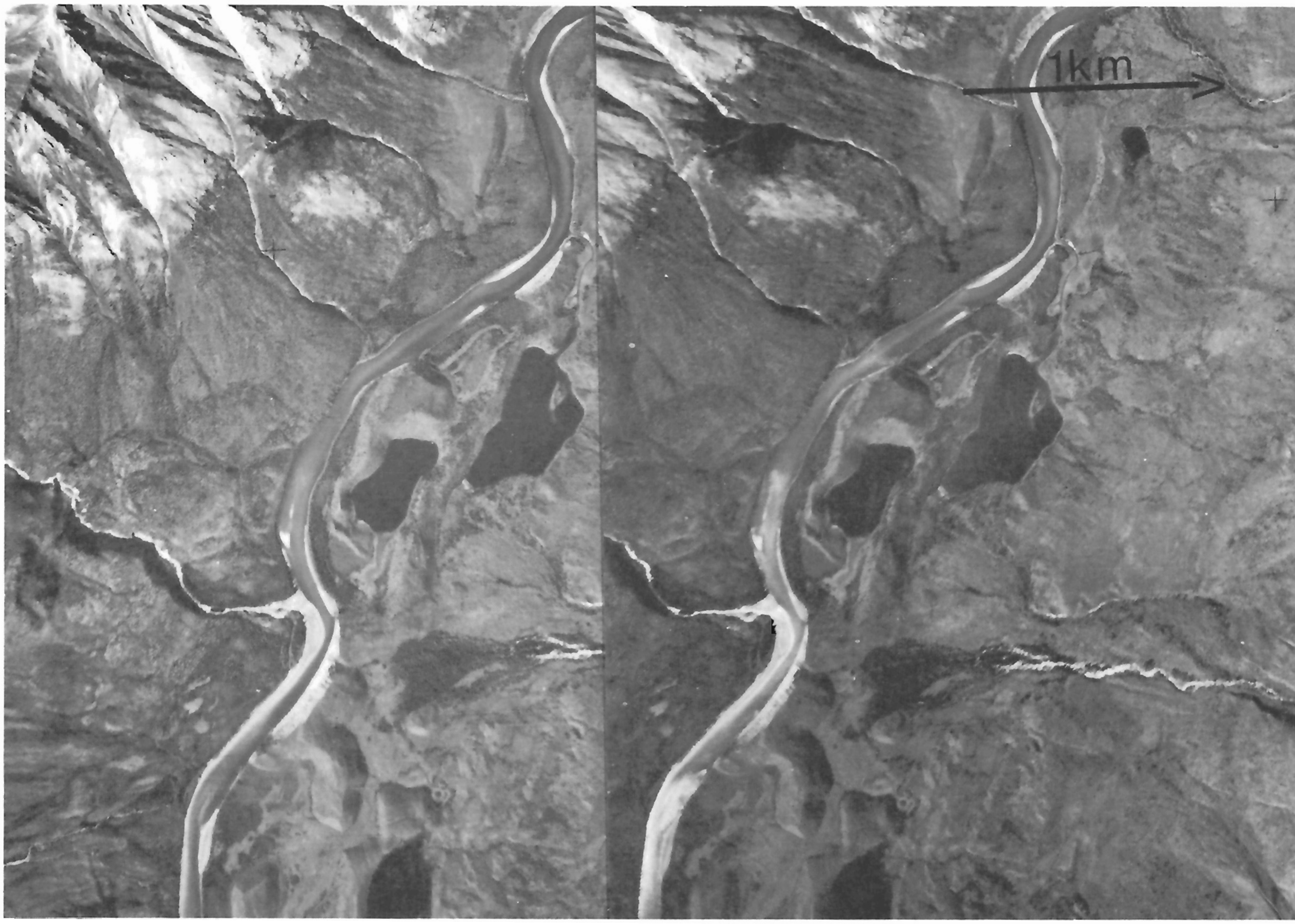

Figure 5b

Sediment texture varies with bedrock lithology, jointing patterns, and slope angle. Felsenmeer or blockfields (Fig. 11) and sorted stone polygons containing little fine sediment occur above treeline on blocky jointed resistant bedrock such as granitic rocks and hornfels. However, less resistant rocks such as shale breaks 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 to the point where slow flow or creep occurs. This typically results in the formation of solifluction lobe complexes on slopes above treeline (Fig. 10). Hillslopes undergoing 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 showing that solifluction is one of the prime processes of denudation in this area.

Landslides

Landslides and landsliding may present geological hazards of larger magnitude than other colluvial landforms and processes. Landslides occur within bedrock and unconsolidated deposits in the study area. They occupy the full range of textures and rates of movement included in Figure 9. Bedrock landslides are predominantly bedding plane or cleavage-related failures; the two landslides shown in Figure 12 are the largest in the map area. Large debris avalanches or sturtzstroms (Hsu, 1975) on the scale of those reported and investigated elsewhere in the Mackenzie Mountains (Eisbacher, 1979; McLellan, 1983) have not occurred during postglacial time within the map area, although small debris avalanches with estimated volumes of less than 10^5 m^3 are common. Small rockfalls, which have built the talus cones and aprons, are the most significant form of slope failure both in frequency and cumulative volume. Next significant are failures in unconsolidated deposits typically involving the melting of ground ice (Fig. 6). These failures are generally not shown in Jackson (1982) as they are too small to be mapped at a scale of 1:125 000.

Fluvial deposits

Fluvial deposits in the Nahanni map area are almost entirely gravels and sands laid down by Holocene streams. In practice, mapping on the basis of this definition encounters some difficulties. Modern floodplain and alluvial fan deposits are readily identified whereas 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. 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. This rapid delivery of sediment into the fluvial system without a commensurate increase in overall fluvial

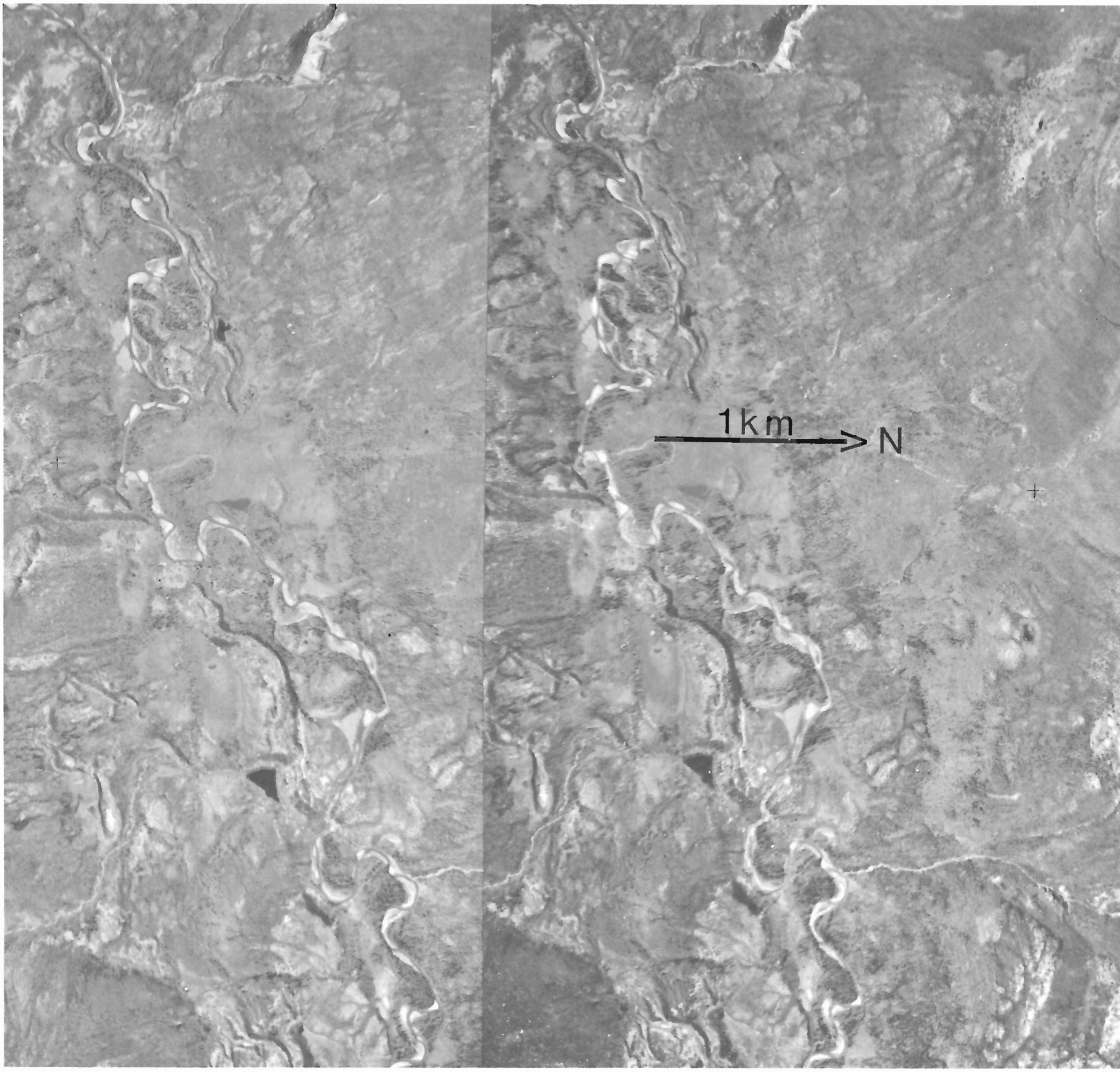

Figure 5c

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 nonglacial rates of erosion are approached. For the purposes of this report, paraglacial sediments are included under the fluvial category.

Alluvial fans

Features classified as alluvial fans include a spectrum of landforms ranging from fans that receive only fluvially deposited sediments to those that receive a significant component of sediment borne by debris flows. This classification is used because the discrimination of alluvial fans from colluvial fans is arbitrary and based upon the extent of fluvial activity on the fan surface as seen on airphotos. Alluvial fans may be active or inactive. Inactive fans are the products of paraglacial activity; they are cut by a head to toe trench (Jackson, 1987), which is eroded in response to decreasing sediment loads in the fan stream and the trunk stream to which it is tributary. Active fans may be incised at the fan head (Hooke, 1967) but not in the lower segment (Fig. 5b). The presence or absence of a head to toe trench permits the discrimination between an active fan, which is potentially hazardous due to periodic flooding and debris flows, and an inactive relict fan which is a low hazard site.

Figure 6. Slumping and flowing glaciolacustrine clays and silts containing massive ice lenses overlie stratified glaciofluvial gravels (South Nahanni River is in the foreground). 204343-G

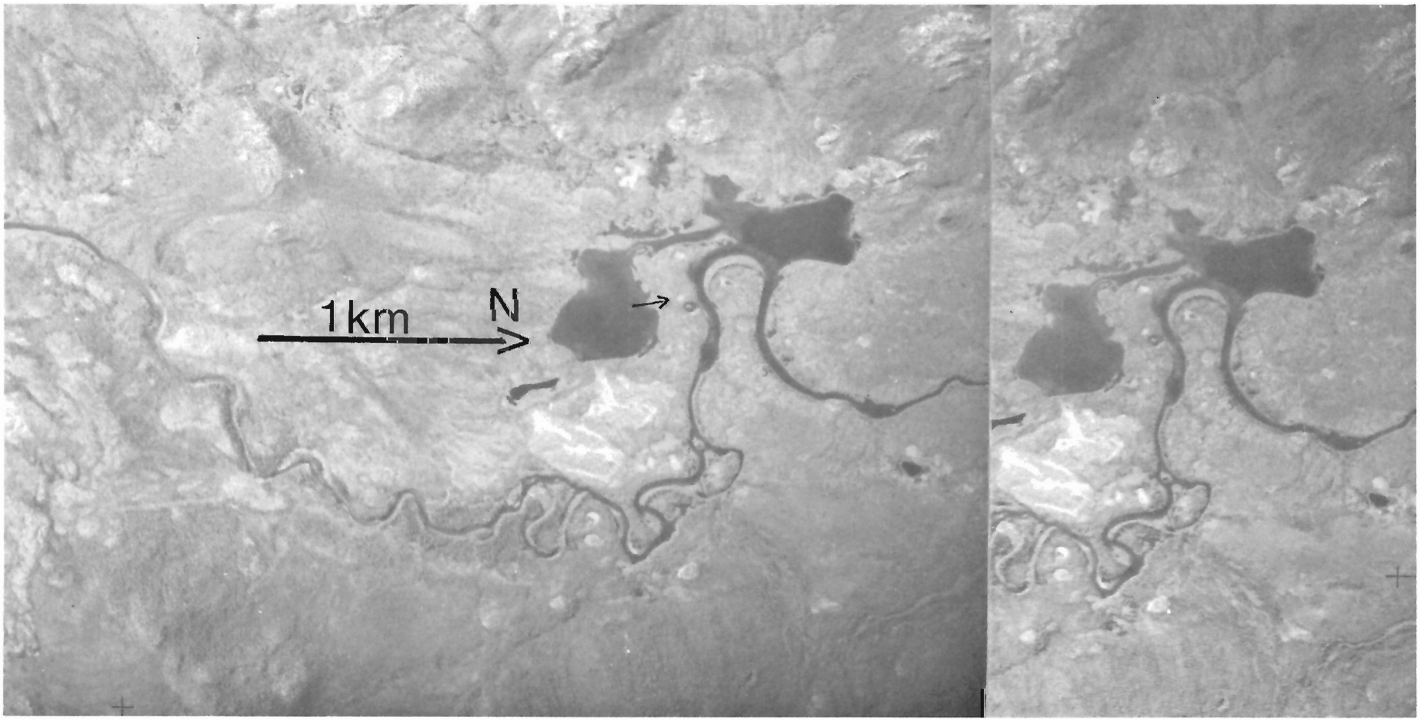

Figure 7. Floodplain of Woodside River. The crater-like lakes (arrow) and the numerous lakes with ragged margins are diagnostic of thermokarst activity in floodplain lacustrine sediments. NAPL A12185 260,261

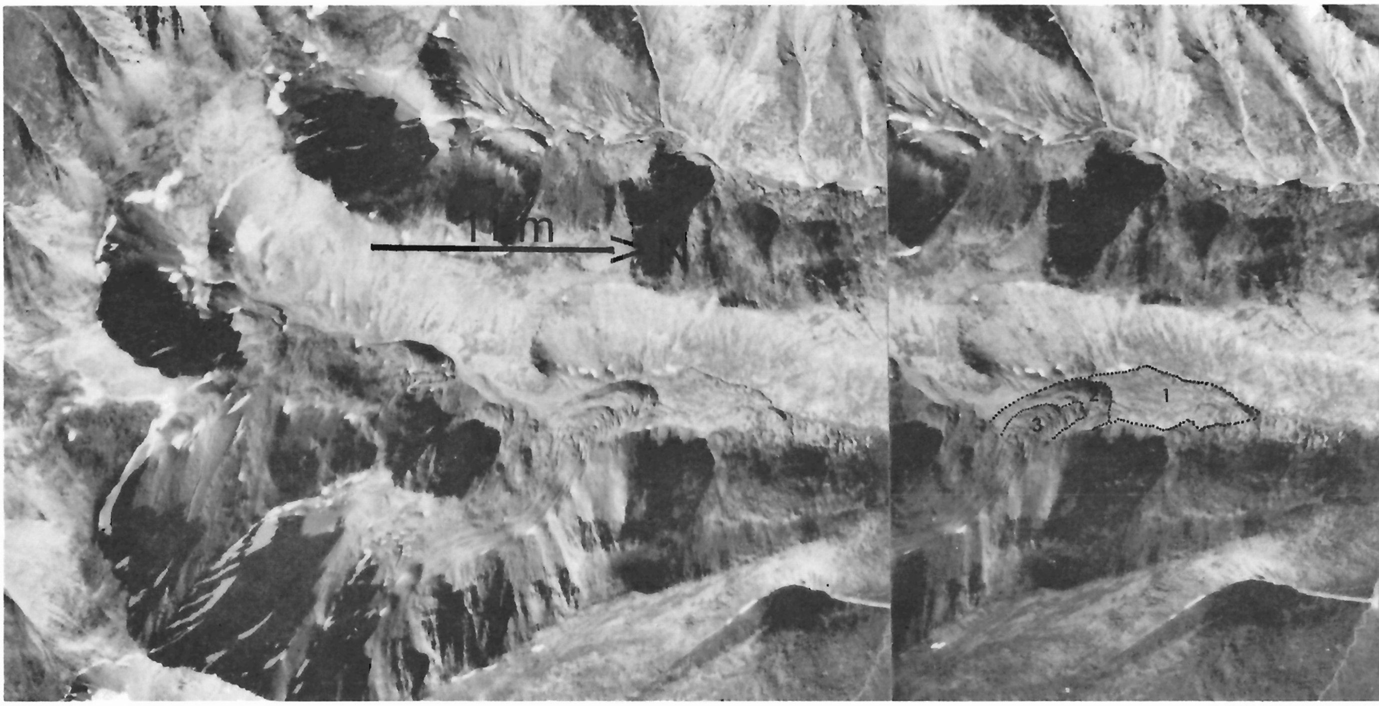

Figure 8. The snouts of three generations of rock glaciers southeast of Howard's Pass are outlined: 1 indicates the oldest and 3 the youngest. Unit 1 is vegetated and inactive; the profile of its snout smoothly merges with the valley profile. Units 2 and 3 display the steep scarp-like snouts which characterize active rock glaciers. NAPL A12345 28,29

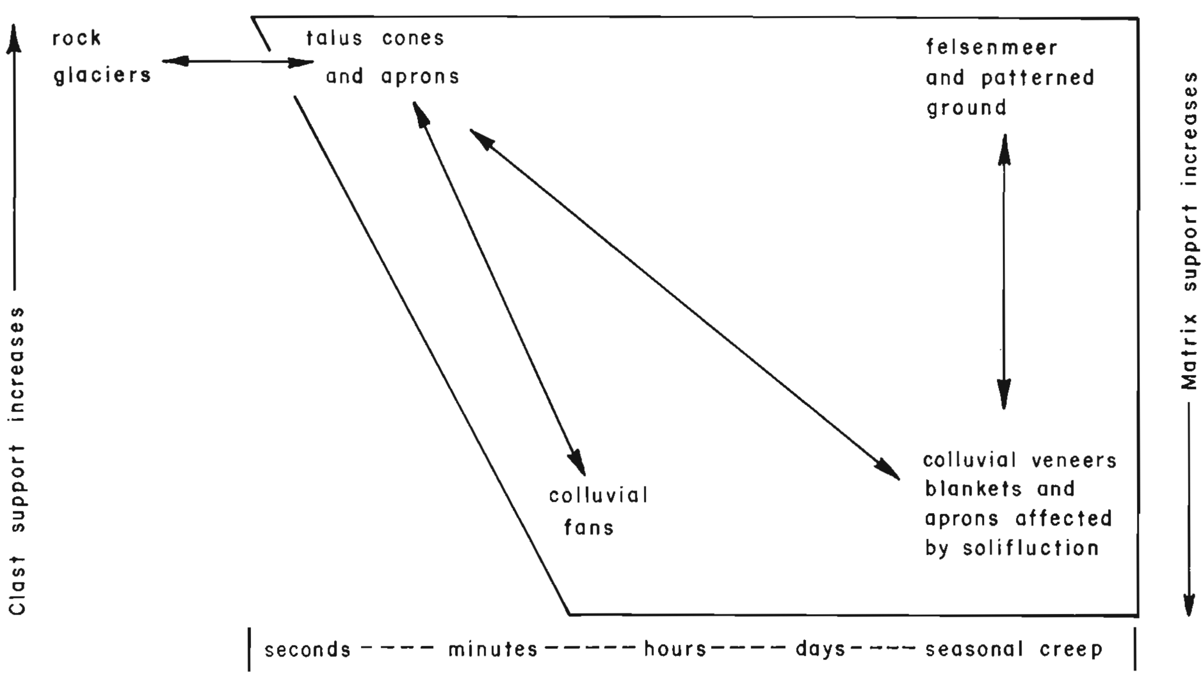

Figure 9. A genetic classification of colluvial landforms in the Nahanni map area by the duration of formational events or ongoing gravitational transport of the deposits that comprise them. Most colluvial deposits are intergradational as indicated by the arrows and may grade into noncolluvial landforms and deposits (alluvial fans and rock glaciers).

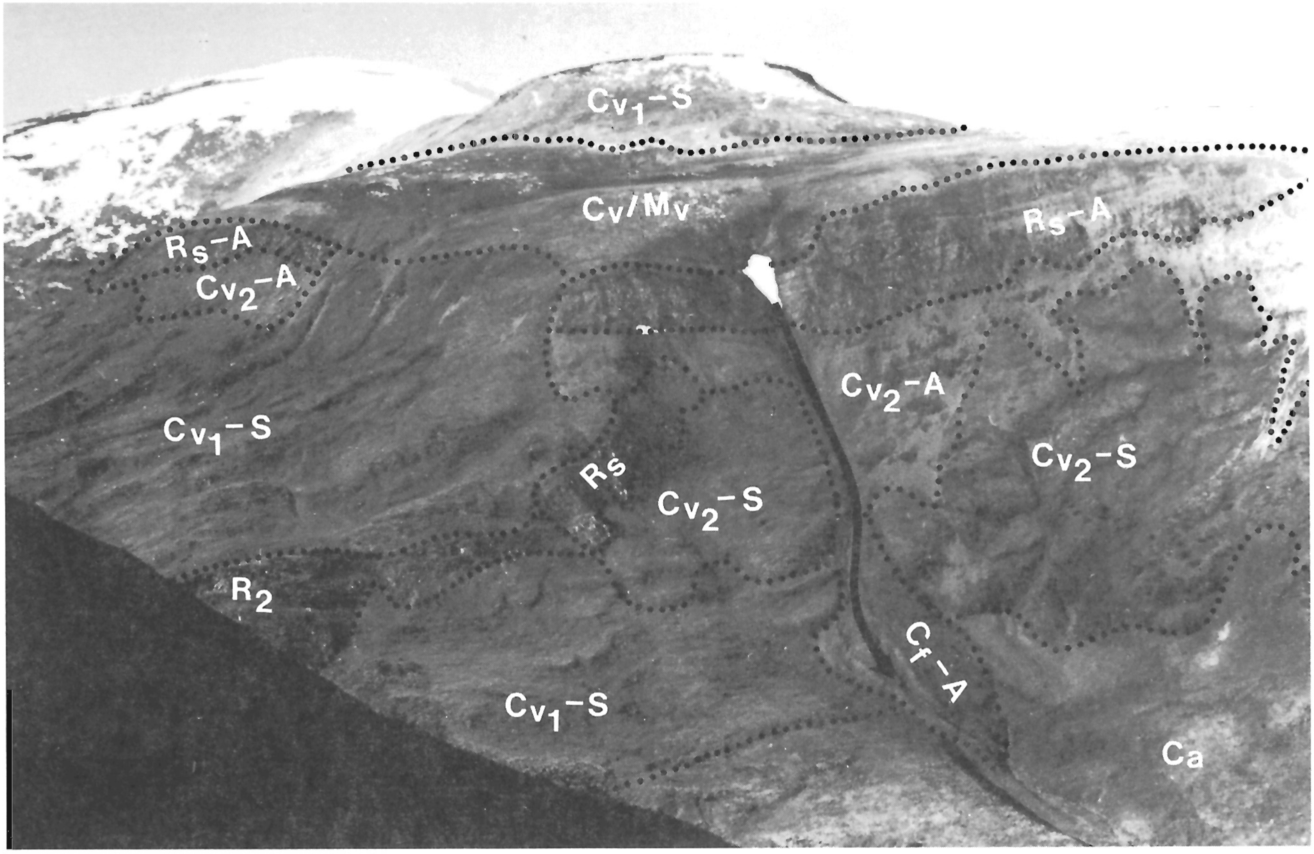

Figure 10. A mountain side in the Nahanni map area subdivided according to deposit genesis and modifying processes as described in the text. 204343-J

Figure 11. Felsenmeer developed on granite bedrock. Extremely blocky felsenmeer such as this is best developed on the felsic intrusives and the metamorphic aureoles which surround them. 204343-H

Floodplains and stream terraces

Extensive oxbow and thermokarst lakes and organic deposits (Fig. 7) occur on the floodplains of Ross and Woodside rivers where valley bottoms are broad and levees along active channels restrict floodplain drainage. A second type of floodplain is illustrated by parts of South Nahanni River (Fig. 13). The river flows on a lag of large granitic boulders, which were eroded from glacial till or glaciofluvial deposits, and are too large for the present South Nahanni River to transport. Bars of these boulders, probably built by a larger and swifter South Nahanni River at the close of deglaciation, constrict the river to form many of the rapids which mark the river in the map area. The braided floodplain is a third type that consists predominantly of gravel and sand and is usually restricted to stream reaches below glacial termini. Braided floodplains are abundant in the valleys of the extensively glacierized Ragged Range.

Stream terraces are remnants of older floodplains which mark former water levels and which are no longer flooded because of stream incision. Stream terraces along with inactive alluvial fans are good sources of sand and gravel. They are suitable for most permanent activities because they are nearly level and are free of threat from geological hazards.

Organic deposits

Accumulations of vegetal materials, chiefly peat, more than 1 m thick, with minor amounts of mineral sediments are classified as organic deposits. These 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. Organic deposits also cover slopes as blanket bog where the underlying permafrost forms an impervious substrate. Organic deposits may themselves contain permafrost and lenses of clear ice. Palsas (Fig. 14), peaty mounds and plateaus raised above the surrounding surface by the growth of underlying clear ice lenses, are common in organic deposits within marshes and floodplains of

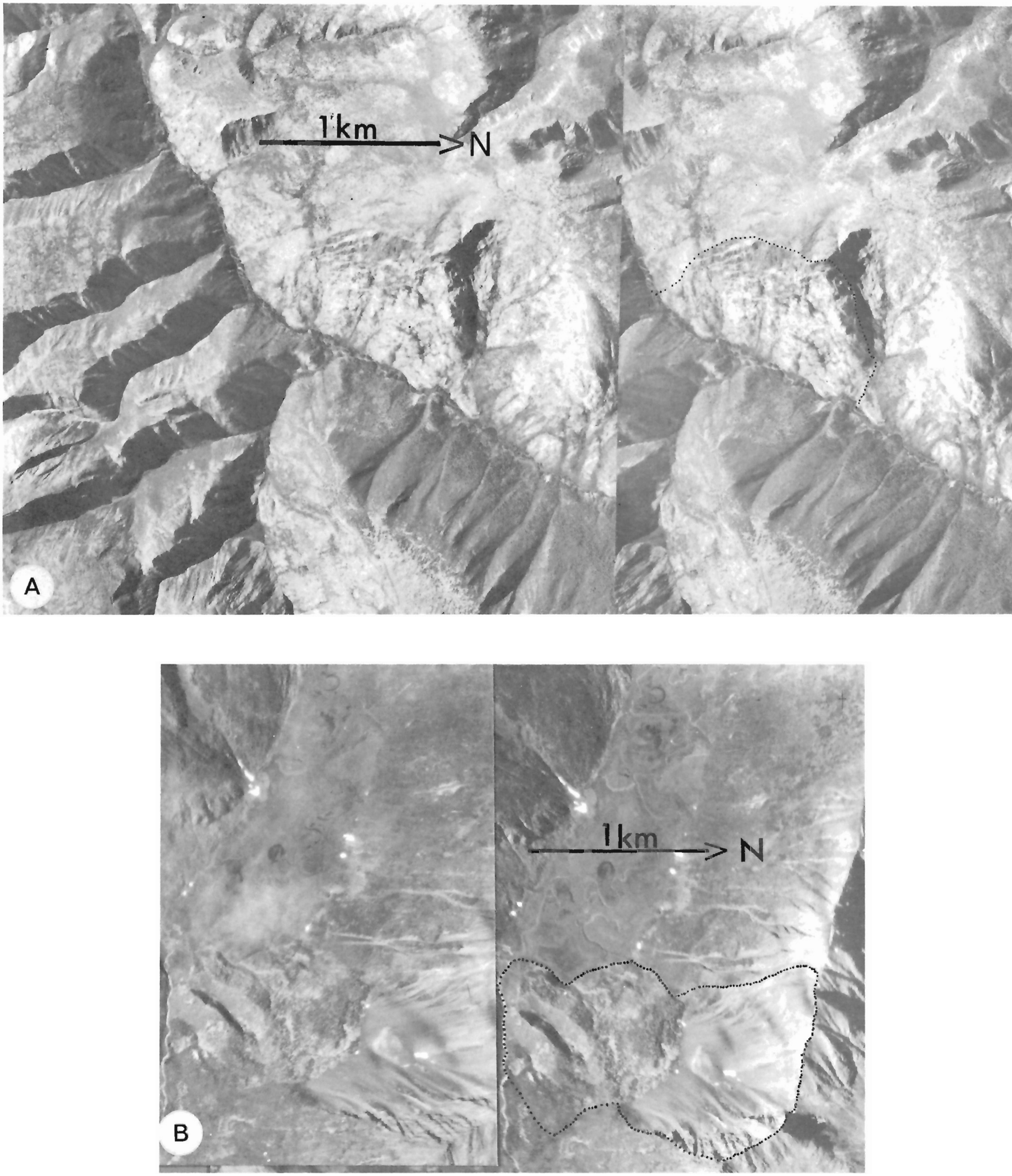

Figure 12. Examples of large landslides in the Nahanni area: **A,** landslide in Precambrian slates south of Howard's Pass; failure planes are likely controlled by slaty cleavage. NAPL A20850 44,45. **B,** Landslide in partly contact metamorphosed Cambrian cherts and pelites; the landslide occurred over at least two episodes of rotational slumping or block slumping. NAPL A122249 163,164

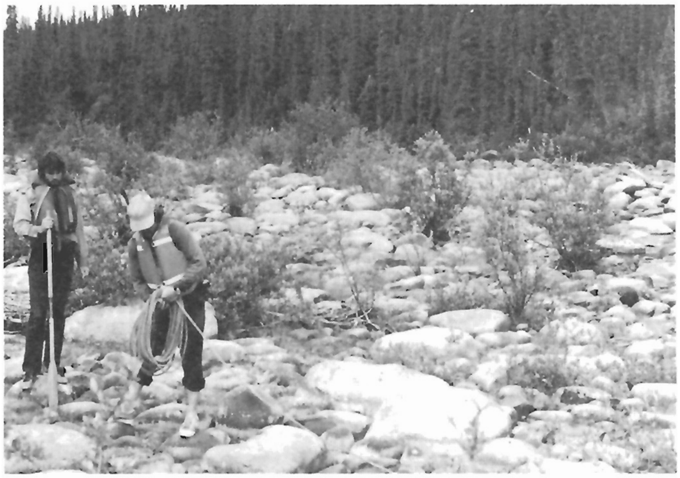

Figure 13. A lag of granite boulders which floors much of South Nahanni River valley; the lag was created by the winnowing out of finer material from a till and glaciofluvial fill during deglaciation and early postglacial time. 204343-N

Figure 14. A sectional exposure through a palsa in Macmillan Pass immediately northwest of the Nahanni map area. The interior is composed of thin beds of clay and marl (light bands), and peat containing lenses of clear ice (dark bands).

the area. The low bearing strength of organic deposits, coupled with the presence of ice lenses, makes them sensitive to disturbance and totally unsatisfactory as foundation substrates.

Organic deposits locally have proven to be valuable as an exploration tool within the Nahanni map area. Base metal prospectors have found that high contents of dissolved zinc in spring waters cause the mosses at the surface of organic deposits to change from their normal dull green to a bright lime green which can be easily spotted from the air. Zinc from spring waters in the "Howard's Pass"[1] area has been concentrated by the high chemical exchange capacity of blanket bog to the extent that it is rich enough to mine as a smithsonite ore deposit (Jonasson et al., 1983).

QUATERNARY HISTORY

Glacial deposits that predate the last glaciation of the region were not identified in the Nahanni map area. The mountainous setting of the study area makes it likely that the passage of ice from one glaciation removes much of the deposits from previous ones (Gibbons et al., 1984). The events that occurred between the onset of glaciation and its climax may, however, be deciphered based upon known ice flow directions, stratigraphic evidence, geomorphic observations, and models of Cordilleran ice sheet development.

Kerr (1934) proposed four phases or styles of glaciation for the Canadian Cordillera. These were expanded upon by Davis and Mathews (1944) and abstracted in Flint (1971). Each of these phases yielded diagnostic erosional landforms. In brief, these four phases are as follows:

> Phase 1: land surface relief greatly exceeds the thickness of glacial ice. Ice flow is entirely dictated by the existing topography.
>
> Phase 2: land surface relief slightly exceeds ice thickness. Topography still largely controls the direction of ice flow.
>
> Phase 3: ice thickness exceeds land surface relief. The underlying surface still influences overall ice flow direction.
>
> Phase 4: ice thickness greatly exceeds relief. Topography has little control over flow directions of the upper levels of the ice sheet. Rather, flow is radial from centre(s) of snow ergo ice accumulation. Topography directs basal flow but the flow direction may or may not be in the same direction as bedrock slope.

During phases 1 and 2, characteristic alpine landforms such as cirques, arêtes and horns are created. During phase 2, ice spills across low divides between valleys creating "through valleys" and as a consequence, a reticulate valley pattern (Davis and Mathews, 1944). Erosion during phases 3 and 4 is characterized by smoothing of the underlying topography. Horns and arêtes that are formed as the result of marginal undercutting by ice combined with subaerial mass wasting are smoothed into domed peaks and rounded ridges, respectively, once submerged beneath flowing ice.

Horns, cirques, and arêtes occur widely in the Nahanni map area above 1520 m (Fig. 15). These were formed during phases 1 and 2 and indicate peaks which extended above the ice sheet during glacial maxima, or were reoccupied by cirque glaciers following emergence from the ice sheet during deglaciation (see *Deglaciation*). These features are freshest and most spectacular in currently glacierized ranges or ranges with summits above 1830 m such as the Ragged Range. Glacially rounded mountain summits, characteristic of phases 3 and 4, are ubiquitous west of the Ragged Range and south and west of Nahanni Valley (Fig. 10, 16). Ice flow directions reflected by fluting and the distribution of erratics, however, indicate that the transition between phase 3 and phase 4 was not reached in the map area; even at the maximum of the last glaciation – the McConnell – ice sheet flow was directed by the underlying topography even though the direction of flow may have been in opposition to present stream flow.

[1] Unofficial name

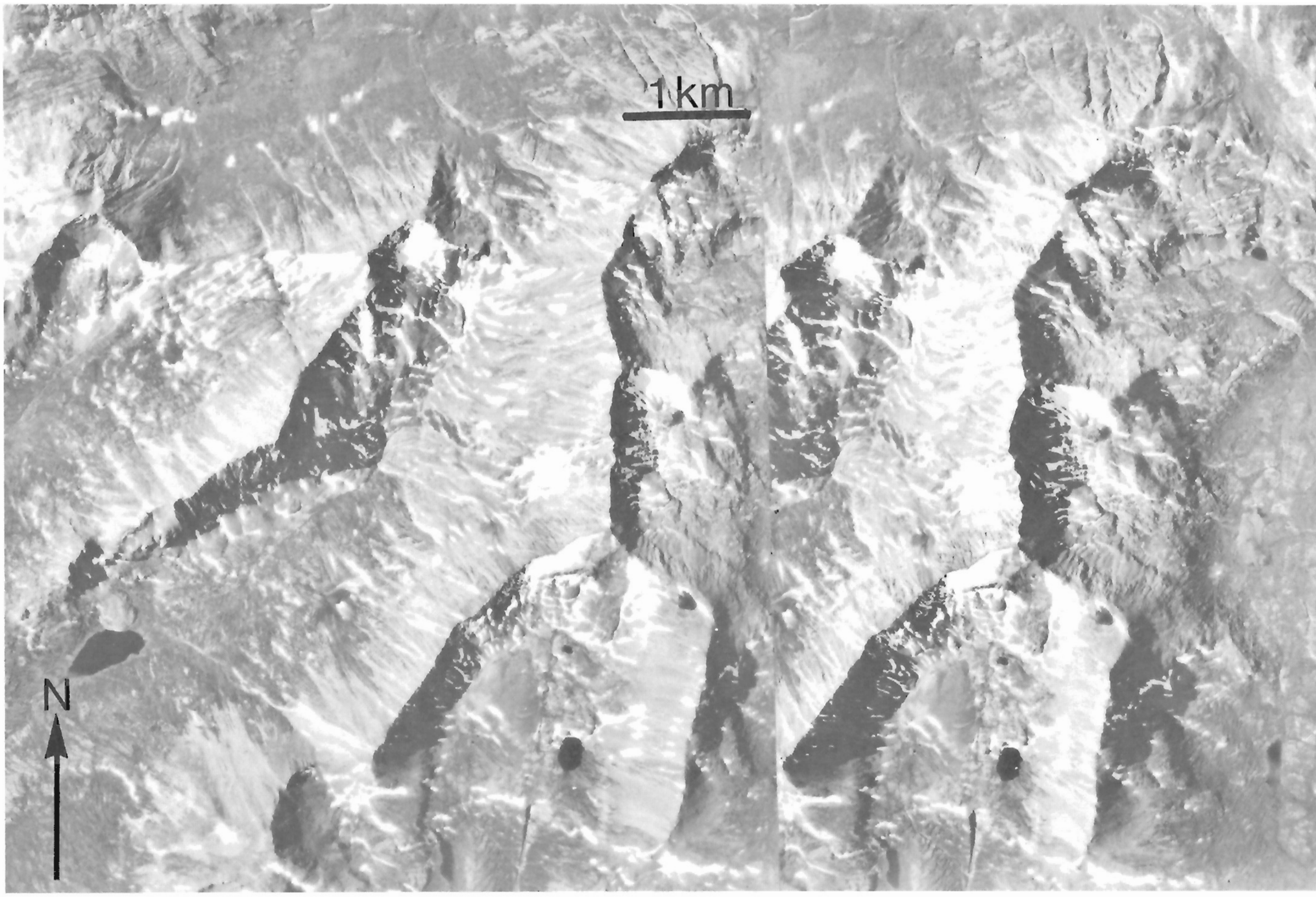

Figure 15. Landforms characteristic of recent alpine glaciation such as undissected cirques and knife-edge arêtes; cirque floors are above 1520 m in this area. NAPL A20851 11,12

Ice flow patterns at the maximum of the last glaciation

Ice divides and areas of divergent flow existed in several areas at the climax of the last glaciation (Fig. 17). In the area of the present divide between the headwaters of Pelly, Prevost, and Ross rivers and the headwaters of the South Nahanni (A-A', Fig. 17), divergent ice flow occurred. Ice flowed from this area west into the Ross River drainage system and northeast through the O'Grady Lake area into the Keele River drainage system (B, Fig. 17) north of the study area. Similar areas of divergent flow may have occurred in the vicinity of locations C and D (Fig. 17) between ice flowing west and ice flowing northeast. An ice divide, marking the divergence of ice flow in opposite directions, along South Nahanni Valley must have existed; however, its position was not determined and it may possibly lie east of the map area. The position of the main ice divide or divides occupied the southern part of the map area.

Deglaciation

Davis and Mathews (1944, p. 404) suggested that a montane glaciation repeats the stages of glacial onset in reverse order. For example, a glaciation which has reached the phase 4 stage would repeat phases 3 to 1 during deglaciation. The onset of glaciation is triggered by substantial falling of the firn line which initiates the growth of cirque glaciers and their expansion into valley glaciers. Conversely, the gradual thinning of a montane ice cap due to a slow progressive decrease in precipitation and gradual rising of the firn line during the initial stages of deglaciation would result in the reestablishment of cirque glaciers in emerging cirques provided that the cirques were above the local firn line. Ice from these cirques would contribute to progressively thinning and ablating glaciers in the adjacent valleys. Flowing ice would retreat into the cirques. Valleys would essentially be free of ice prior to its disappearence from the cirques. Hence deglaciation, in its final stages, would progress from the valley bottom to mountain top.

Geomorphic evidence from the Nahanni map area indicates that deglaciation did initially proceed in this manner; cirques as low as approximately 1680 m[1] (Fig. 18) were reoccupied by glaciers as the ice sheet thinned over the area during deglaciation. The cirque glaciers expanded headward into the rounded summits (Fig. 16). Some time after reaching this stage, however, the firn line apparently rose abruptly and/or snowfall was radically attenuated resulting in the stagnation of the ice sheet. Upland areas then became ice free followed by deglaciation of valley and lowland areas. The geomorphic evidence for this is as follows.

Cirques below approximately 1680 m elevation (Fig. 19) are generally degraded in appearance relative to those above 1680 m elevation, indicating that the degraded cirques were below the firn line when they emerged from the downwasting ice sheet.

Major valleys across the Continental Divide commonly have meltwater channels and ice-stagnation landforms including crevasse fillings, eskers, and kames on their floors.

[1] This figure is approximate because the only available topographic map for the area at the time of this study is at 1:250 000 scale and has a contour interval of 500 feet, which is too large to determine cirque elevation more accurately.

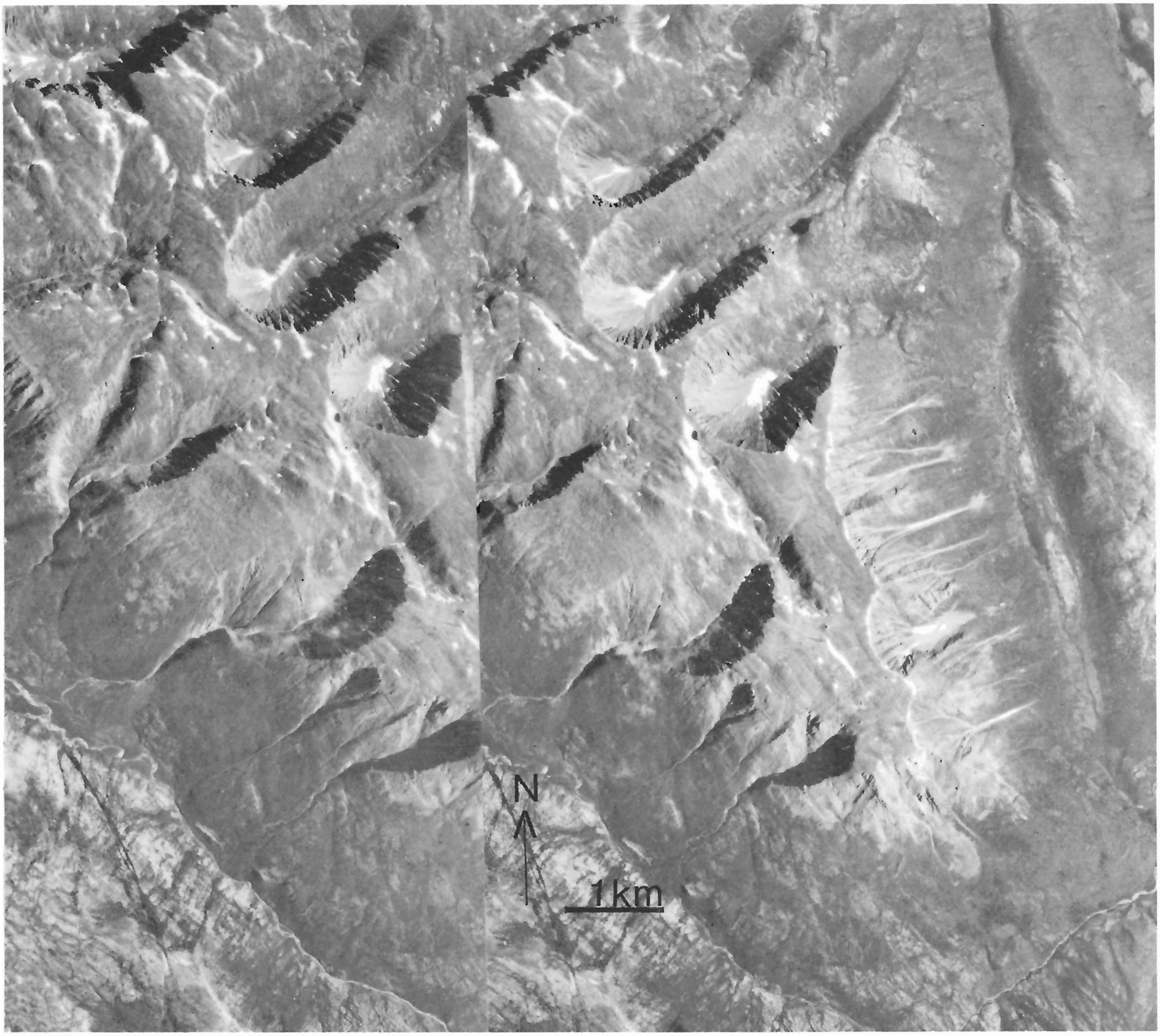

Figure 16. Fresh cirques which have expanded into the rounded summits characteristic of phase 3 or 4; cirque floors lie at about 1980 m. NAPL A20851 6,7

These deposits and channels are continuous with those in adjacent valleys on both sides of the divide; this continuity indicates that stagnation occurred when ice in valleys that cross the divide was cut off from trunk glaciers east of the divide rather than from local glaciers which headed in uplands immediately adjacent to cross-divide valleys (A,B,C, Fig. 18).

Gravelly, ridged ice-stagnation deposits cross the mouths of cirques at two locations along the Continental Divide in the study area (Fig. 20; elevations of these features range between 1520 and 1830 m. These features could not have formed if ice had been flowing from the cirques to adjacent valley glaciers. Rather, ice in these cirques and adjacent valleys must have been stagnant and therefore below the firn line when the ridged deposits were laid down.

It is not known how high the firn line rose during deglaciation; however, since ice stagnation deposits that block cirques range up to 1830 m, the firn line must have been in excess of this elevation. Cirque glaciers, small ice caps, and valley glaciers may have remained active over the highest areas of this region during deglaciation or disappeared from the area only to reform later during the Holocene.

This style of deglaciation is not unique to the Nahanni region. Fulton (1967) documented a similar sequence of events for the deglaciation of the Cordilleran Ice Sheet in southern British Columbia. A similar dramatic rise in the firn line has been implicated in the rapid disappearance of the Yellowstone Plateau ice cap (Porter et al., 1984, p. 99).

Meltwater drainage on the west side of the Continental Divide was east to west and on the east side was initially through cross-divide valleys (Fig. 18). From the time the ice

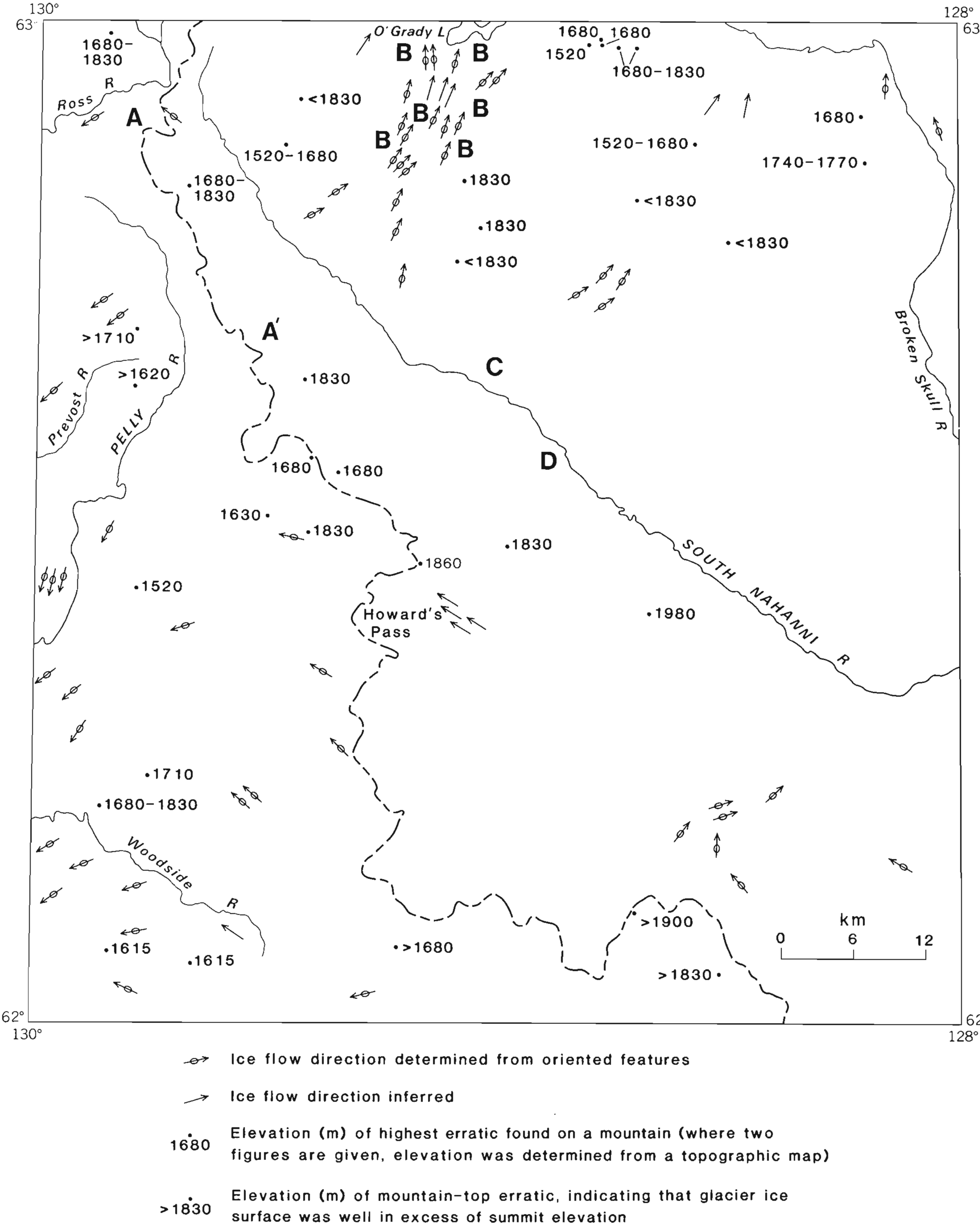

Figure 17. Paleo ice-flow directions and elevations of highest erratics. Several ice domes existed over the map area. Ice crossed ridges in excess of 1900 m along the Yukon/Northwest Territories divide. Diffluence of ice flow occurred between A and A' and in the areas of C and D. A major ice stream crossed the divide between the South Nahanni and Keele river basins (B). Elevations of highest erratics provide greater-than elevations for the former ice sheet surface.

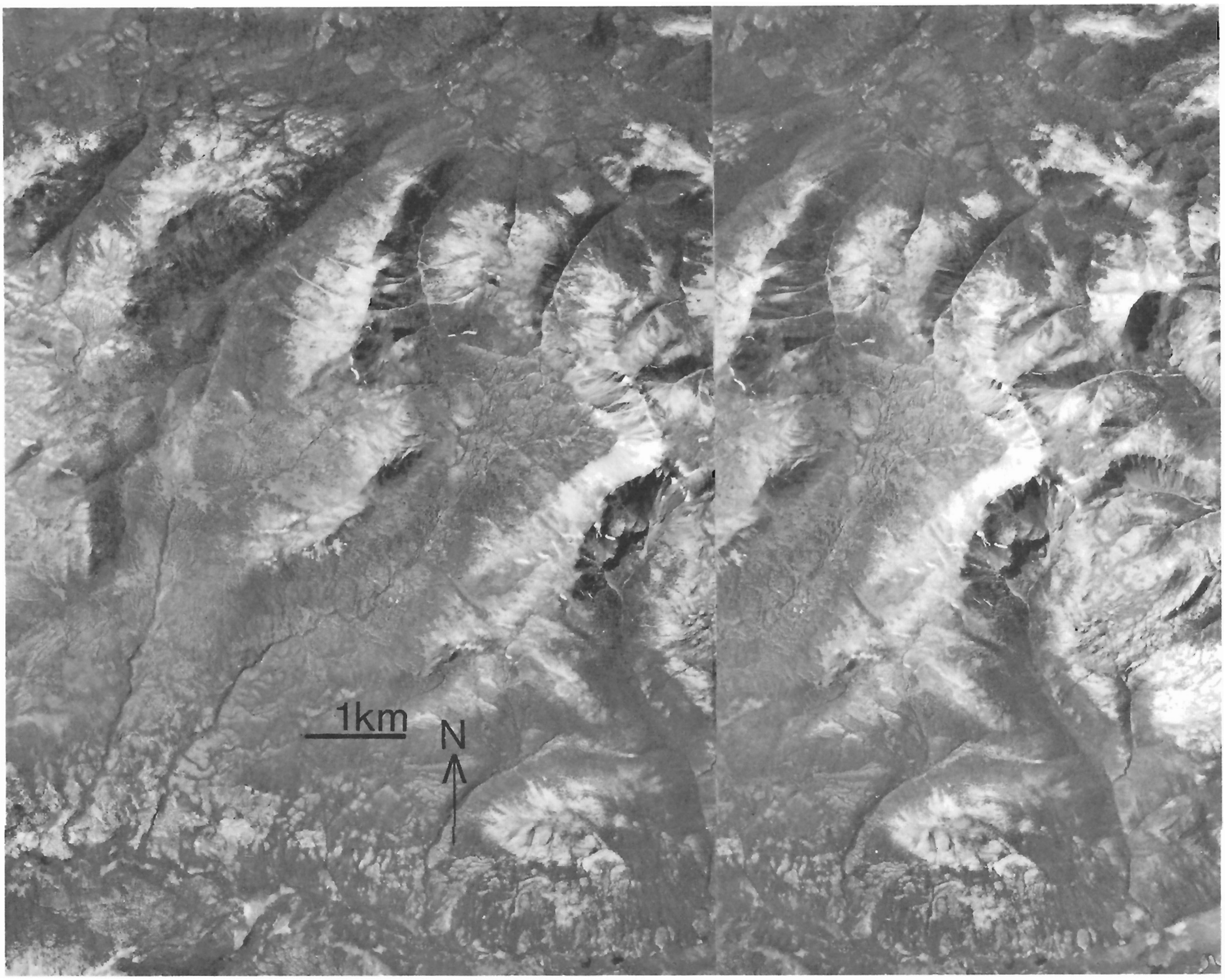

Figure 19. An upland area with the floors of cirque-like features below 1680 m. Such cirque-like features are incised by a well developed dendritic drainage system. The typically degraded state of these features indicates that active cirque glaciers were not present within them after the last ice sheet downwasted to their elevations. NAPL A24778 136,137

sheet downwasted below the elevation of the divide, drainage direction and presumably remaining ice flow were controlled by the topography of the emergent land and was to the south and southeast (Fig. 18).

Readvances

Ford (1976) noted evidence southeast of the map area for a readvance from the Ragged Range into Hole-in-the-Wall valley following the culmination and substantial retreat of the last major glaciation. Only scattered evidence for the "Hole-in-the-Wall" readvance is present in the Nahanni Map area; lateral moraines approximately 150 m above the floors of two valleys in the Ragged Range may be correlative (Fig. 21). End moraines correlative to these lateral moraines are not present in adjacent main valleys. It is possible that these lateral moraines mark a thickening of ice during overall retreat rather than a distinct readvance.

Glacial Chronology

Bostock (1966) detailed evidence for four glaciations of the southern Yukon. The youngest of these, which he named the McConnell Glaciation, obliterated or covered all the deposits of older glaciations. Hughes et al. (1968) indicated that the Selwyn Mountains were a major source area for glacier ice in the southeastern Yukon during the McConnell Glaciation. Radiocarbon dates determined on wood from beneath McConnell age till in the Watson Lake area to the south indicate that ice reached this area sometime after 23 900 ± 1140 BP (GSC-2811) (Lowdon and Blake, 1981, p. 10). Consequently, the McConnell Glaciation probably reached its climax in the Nahanni map area some time after this. Minimum dates for deglaciation within the Nahanni map area are 8630 ± 160 BP (GSC-3097) from Natla Bog (MacDonald, 1983) and 8800 ± 90 BP (GSC-3198) from South Nahanni valley; both dates are related to the initiation of blanket bog development and significantly postdate deglaciation. An older date of 9610 ± 100 BP (GSC-3428)

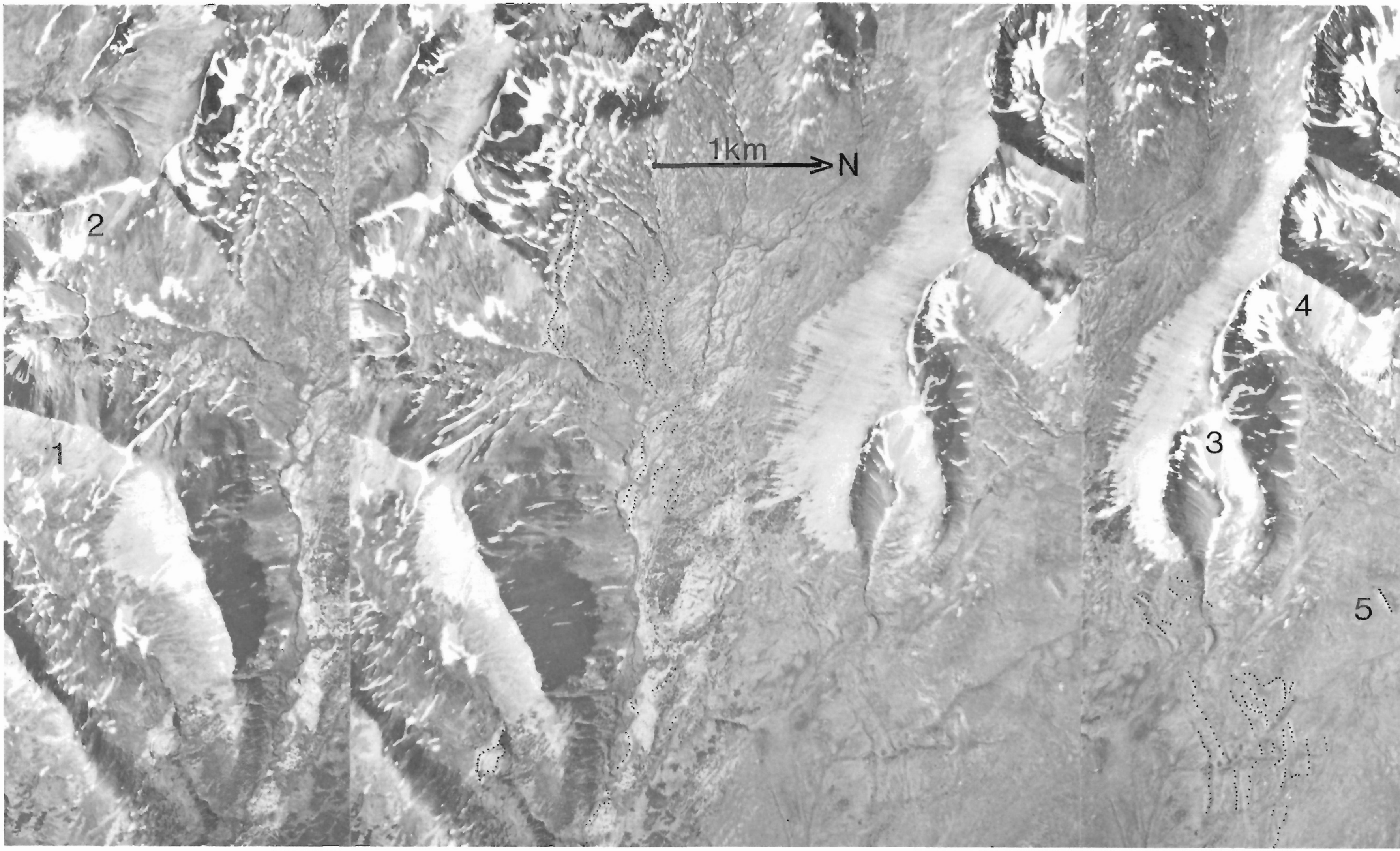

Figure 20. Stereotriplet of the Howard's Pass area. Ice flow here was generally west to northwest; ice downwasted and progressively retreated towards the east. The dotted lines mark the crest of ice-stagnation glaciofluvial features which are transverse to or lie at the mouth of cirques 1-4, indicating that active ice was not flowing from cirques in this area during ice stagnation. This in turn indicates that the paleo snowline was above the elevation of these cirques at that time. The elevation of the base of feature 5, a moulin kame, is 1580 m. The kame is on the Continental Divide between Yukon River drainage (west) and Arctic drainage (east). NAPL A12247 407-409

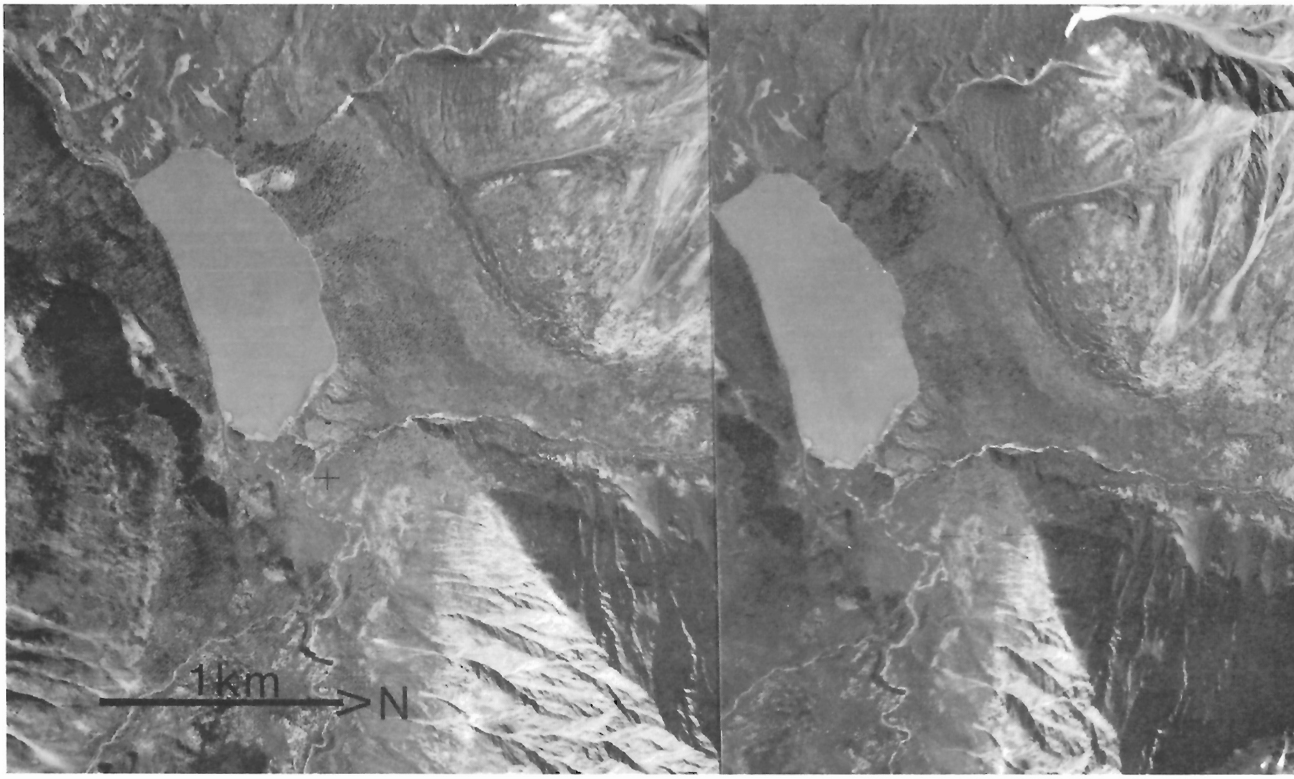

Figure 21. A lateral moraine approximately 150 m above the floor of an unnamed tributary to Flat River on the western margin of the Ragged Range. This moraine may represent a stillstand or readvance during deglaciation. NAPL A12270 131-132

from Howard's Pass (Jonasson et al. 1983, Blake, 1983, p. 23) indicates that initiation of blanket bog growth was even earlier. However, because the dated moss likely contained a significant amount of dead carbon, the date is suspect.

Postglacial Events

Postglacial time was marked by alterations of the land surface caused by the adjustment from glacial to nonglacial conditions. Rapid erosion and transportation of glacial sediments from watershed slopes to valley floors resulted in fan construction along valley margins and aggradation by trunk streams. This was followed by stream incision as glacial sediment supplies waned and sediment production in montane basins began to approach nonglacial conditions. Some slopes which had been oversteepened by glacial erosion failed following the removal of lateral ice support. In areas of poor drainage, resulting from glacial disruption of drainage or from permafrost aggradation, blanket bogs formed and expanded. Permafrost aggraded in organic and lacustrine sediments in floodplains which led to thermokarst activity and the growth of palsas. Mass wasting of steep rock slopes resulted in the accumulation of talus fans and aprons and the growth of rock glaciers.

SUMMARY

Tills in the Nahanni area generally occur as veneers or blankets, are stony, and have low plasticity. Their carbonate contents are low over basin rocks of the Selwyn Mountains and high over correlative carbonate platform rocks. Glaciofluvial deposits are present in ice stagnation complexes in mountain valleys or locally as outwash plains and kame terraces; they represent the major source of gravel exclusive of major stream valleys. Major deposits are confined to South Nahanni River valley. Lacustrine and organic deposits are major components of floodplain deposits in larger river valleys. They are subject to thermokarst activity. Glaciolacustrine deposits commonly contain massive ground ice and are subject to thaw-sliding and collapse.

Rock glaciers in the study area are tongue- or spatula-shaped accumulations of angular bouldery debris. Active rock glaciers are cemented or cored by ice and may flow at rates of several metres per year. They are also subject to vertical displacement due to the meltout of interstitial ice or the ice core. At least three advances of rock glaciers have taken place in the Nahanni area.

Colluvial materials were transported and deposited by largely nonfluvial processes. Transport may be at high speed in the case of rockfall, slower speeds in debris flow, or imperceptible rates in solifluction.

The Nahanni map area was intensely glaciated during the McConnell Glaciation. At the climax of that glaciation, one or more ice domes existed over the map area. At that time ice flow was directed by the the underlying topography. During deglaciation, the firn line was above the level of the ice surface over much of the area resulting in widespread stagnation. As a result, classical alpine topography is restricted to the highest mountains where cirque glaciers and ice fields persisted during and after regional deglaciation. All other areas are marked by generally rounded slopes characteristic of topography moulded by flowing ice.

REFERENCES

Blake, W., Jr.

1983: Geological Survey of Canada radiocarbon dates XXIII; Geological Survey of Canada, Paper 83-7, 33 p.

Bostock, H.S.
1966: Notes on glaciation in central Yukon Territory; Geological Survey of Canada, Paper 65-36.

Boulton, G.S. and Eyles, N.
1979: Sedimentation by valley glaciers: a model and genetic classification; in Moraines and Varves, ed. C. Schluchter; Balkema Press, Rotterdam, p. 11-24.

Brown, R.J.E.
1967: Permafrost in Canada; Geological Survey of Canada, Map 1246A.

Church, M. and Ryder, J.M.
1972: Paraglacial sedimentation: a consideration of fluvial processes conditioned by glaciation; Geological Society of America Bulletin, v. 83, p. 3072-3095.

Davis, N.F.G. and Mathews, W.H.
1944: Four phases of glaciation with illustrations from southwestern British Columbia; Journal of Geology, v. 52, p. 403-413.

Dawson, G.M.
1887: Report on an exploration in the Yukon district, Northwest Territories, and adjacent northern portion of British Columbia; Geological Survey of Canada, Summary Report 1887, Volume III, Part B.

Dyke, A.S.
1983: Surficial geology, of Frances Lake (105H), Yukon Territory; Geological Survey of Canada, Open File 895.

Eisbacher, G.H.
1979: Cliff collapse and rock avalanches (sturtzstroms) in the Mackenzie Mountains, northwestern Canada; Canadian Geotechnical Journal, v. 16, p. 309-334.

Eyles, N., Eyles, C.H., and Miall, A.D.
1983: Lithofacies types and vertical profile models; an alternative approach to the description and environmental interpretation of glacial diamict and diamictite sequences; Sedimentology, v. 30, p. 393-410.

Flint, R.F.
1971: Glacial and Quaternary Geology; John Wiley and Sons, 892 p.

Ford, D.C.
1976: Evidence of multiple glaciation in South Nahanni National Park, Mackenzie Mountains, Northwest Territories; Canadian Journal of Earth Sciences, v. 13, p. 1433-1445.

Fulton, R.J.
1967: Deglaciation studies in Kamloops region, an area of moderate relief, British Columbia; Geological Survey of Canada, Bulletin 154, 36 p.

Gardner, J.S.
1979: Movement of material on debris slopes in the Canadian Rocky Mountains; Zeitschrift fur Geomorphologie, v. 23, p. 45-57.

1980: Frequency, magnitude and spatial distribution of mountain rockfalls and rockslides in the Highwood Pass area, Alberta, Canada; in Thresholds in Geomorphology, ed. D.R. Coates and J.D. Vitek: Allen and Unwin, p. 267-295.

1983: Rockfall frequency and distribution in the Highwood Pass area, Canadian Rocky Mountains; Zeitschrift fur Geomorphologie, v. 27, p. 311-324.

Gibbons, A.B., Megeath, J.D., and Pierce, K.L.
1984: Probability of moraine survival in a succession of glacial advances; Geology, v. 12, p. 327-330.

Goodwin, G.G.
1937: The Snyder Mountains; Natural History Magazine, v. XL, no. 5, p. 750-780.

Gordey, S.P.
1981: Geology of the Nahanni map area, Yukon Territory and the District of Mackenzie; Geological Survey of Canada, Open File 780.

Green, L.H. and Roddick, J.A.
1961: Geology, Nahanni, Yukon and District of Mackenzie; Geological Survey of Canada, Map 14-1964.

Green, L.H., Roddick, J.A., and Blusson, S.L.
1968: Geology, Nahanni, District of Mackenzie and Yukon Territory; Geological Survey of Canada, Map 8-1967.

Hooke, R. LeB.
1967: Processes on arid alluvial fans; Journal of Geology, v. 75, p. 438-460.

Hughes, O.L., Campbell, R.B., Muller, J.E., and Wheeler, J.O.
1968: Glacial flow patterns, Yukon Territory south of 65 degrees north latitude; Geological Survey of Canada, Paper 68-34.

Hsu, K.
1975: Catastrophic debris streams (sturtzstroms) generated by rockfalls; Geological Society of America Bulletin, v. 86, p. 129-140.

Jackson, L.E., Jr.
1982: Terrain conditions, Nahanni, Yukon and Northwest Territories; Geological Survey of Canada, Open File 886.

1987: Debris flow hazard in the Canadian Rocky Mountains; Geological Survey of Canada, Paper 86-11, 20 p.

Jackson, L.E., Jr. and MacDonald, G.M.
1980: Movement of an ice-cored rock glacier, Tungsten, N.W.T., Canada, 1963-1980; Arctic, v. 33, no. 4, p. 842-847.

Jackson, L.E., Jr., MacDonald, G.M., and Wilson, M.C.
1982: Paraglacial origin for terraced river sediments in Bow Valley, Alberta; Canadian Journal of Earth Sciences, v. 19, p. 2219-2231.

Jackson, L.E., Morison, S.R., Mckenna, K., and Duk, A.
1984: Terrain inventory, Sheldon Lake (105 J); Geological Survey of Canada, Open File 1033.

Jackson, L.E., Jr., MacDonald, G.M., Foscolos, A.E., and Clarke, A.H.
1985: An occurrence of pre-McConnell nonglacial sediments, Selwyn Mountains, Northwest Territories; in Current Research, Part B, Geological Survey of Canada, Paper 85-1B, p. 169-175.

Jonasson, I.R., Jackson, L.E., and Sangster, D.F.
1983: A Holocene orebody formed by the supergene replacement of mosses; Journal of Geochemical exploration, v. 18, p. 189-194.

Keele, J.
1910: Explorations on the Pelly, Ross and Gravel rivers in the Yukon and Northwest Territories; Sessional paper 26, Summary report of the Geological Survey Branch, Department of Mines, 52 p.

Kerr, F.A.
1934: Glaciation in northern British Columbia; Transactions of the Royal Society of Canada, Series 3, v. 28, p. 17-31.

Kershaw, G.P.
1978: Rock glaciers in the Cirque Lake area of the Yukon-Northwest Territories; The Albertan Geographer, no. 14, p. 61-88.

Kershaw, G.P. and Gill, D.
1979: Growth and decay of palsas and peat plateaus in the MacMillan Pass-Tsichu River area, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 16, p. 1362-1374.

Lambart, H.F.
1938: The Harry Snyder Canadian expedition; Canadian Alpine Journal, v. XXV, p. 1-17.

Lawson, D.E.
1979: Sedimentological analysis of the western terminus region of the Matanuska Glacier, Alaska; U.S. Corps of Engineers Cold Regions Research and Engineering Laboratory, Report 79-9, 112 p.

Lowdon, J.A. and Blake, W., Jr.
1981: Geological Survey of Canada radiocarbon dates XXI; Geological Survey of Canada, Paper 81-7, 22 p.

Luckman, B.H.
1972: Some observation of the erosion of talus slopes by snow avalanches in Surprise valley, Jasper National Park, Alberta; in Mountain Geomorphology, ed. O. Slaymaker, and H.J. McPherson; Tantalus Research Ltd., p. 85-92.

1978: Geomorphic work of snow avalanches in the Canadian Rocky Mountains; Arctic and Alpine Research, v. 10, p. 261-276.

MacDonald, G.M.
1983: Holocene vegetational history of the upper Natla River area, Northwest Territories, Canada; Arctic and Alpine Research, v. 15, p. 169-180.

McLellan, P.J.A.
1983: Investigation of some rock avalanches in the Mackenzie Mountains; unpublished M.Sc. thesis, Department of Civil Engineering, The University of Alberta, Edmonton, 281 p.

Morganti, J.M.
1981: Ore deposit models-4. Sedimentary-type stratiform ore deposits: some models and a new classification: Geoscience Canada, v. 8 n. 2, p. 65-75.

Pike, W.
1896: Through the Subarctic Forest; Arno Press, New York.

Porter, S.C., Pierce, K.L., and Hamilton, T.D.
1984: Late Wisconsin mountain glaciation in the western United States; in Late Quaternary Environments of the United States, Volume 1, The Late Pleistocene, ed. H.E. Wright and S.C. Porter;

Ryder, J.M.
1971a: The stratigraphy and morphology of paraglacial alluvial fans in south-central British Columbia; Canadian Journal of Earth Sciences, v. 8, p. 279-298.

1971b: Some aspects of morphology of paraglacial alluvial fans in south-central British Columbia; Canadian Journal of Earth Sciences, v. 8, p. 1252-1264.

Snyder, H.
1937: The Harry Snyder expedition to the South Nahanni River and Snyder Mountains in 1937; Canadian Geographical Journal, v. XV, no. 10, p. 169-200.

Vernon, P. and Hughes, O.L.
1966: Surficial geology, Dawson, Larsen Creek and Nash Creek map areas, Yukon Territory; Geological Survey of Canada, Bulletin 136, 25 p.

Wahrhaftig, C. and Cox, A.
1959: Rock glaciers in the Alaska Range; Geological Society of America Bulletin, v. 70, p. 383-436.

White, S.E.
1976: Rock glaciers and blockfields, review and new data; Quaternary Research, v. 6, p. 77-97.

Energy, Mines and
Resources Canada

Énergie, Mines et
Ressources Canada