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Pleistocene Montane Glaciations in the Mackenzie Mountains, Northwest Territories
Les glaciations alpines pléistocènes dans les monts Mackenzie, Territoires du Nord-Ouest
Alpine Vereisungen im Pleistozän in den Mackenzie-Bergen, Nordwest-Territorien

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See table of contents

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Article abstract

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PLEISTOCENE MONTANE GLACIATIONS IN THE MACKENZIE MOUNTAINS, NORTHWEST TERRITORIES*

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ABSTRACT During the Pleistocene the Mackenzie Mountains were affected by a series of glaciations. Through all the glaciations a single pattern seems to have been repeated: a Cordilleran ice sheet formed to the west of the continental divide and montane valley glaciers formed to the east. The montane glaciers in the Mackenzie Mountains emanated from two differents sources: a) a glacial divide, lying generally along the topographic divide between Pacific and Arctic drainage, and dividing the westerly flowing Cordilleran Ice Sheet from easterly and northerly flowing montane glaciers, b) local peaks in the Canyon Ranges. There were two well defined glacial advances in this mountain region: Illinoian, Late Wisconsinan, and one or more less defined pre-Illinoian glaciation(s). Illinoian and Late Wisconsinan glaciations are herein named Mountain River and Gayna River glaciations respectively. These advances are usually identifiable in valleys by frontal and segments of lateral moraines and glacial erosional features. Pre-Illinoian glaciation(s) have been recognized so far only in stratigraphic sections. The older advances were more extensive than the Gayna River advance; associated deposits occur higher on the valley sides and further down the valley than those associated with Gayna River Glaciation. During Mountain River Glaciation some of the montane glaciers in the Canyon Ranges merged to form piedmont glaciers. In contrast, during Gayna River Glaciation, the local glaciers consisted of single tongues, and these were mostly restricted to tributary valleys that had northward facing cirques.

RÉSUMÉ *Les glaciations alpines pléistocènes dans les monts Mackenzie, Territoires du Nord-Ouest.* Au cours du Pléistocène, les monts Mackenzie ont connu une série de glaciations au cours desquelles un seul patron semble s'être répété: formation d'un inlandsis cordillérien à l'ouest de la ligne de partage continentale et formation de glaciers de vallée vers l'est. Les glaciers de vallée des monts Mackenzie provenaient de deux sources: a) la ligne de partage des glaces, qui se situait généralement le long de la ligne de partage des eaux entre le Pacifique et l'Arctique, et qui divisait l'inlandsis à écoulement vers l'ouest des glaciers de vallées s'écoulant vers l'est et le nord; b) les pics locaux des Canyon Ranges. Il y a eu deux avancées glaciaires bien définies dans cette région montagneuse: l'une à l'Illinoien, l'autre au Wisconsinien supérieur, puis une ou plusieurs glaciations moins bien définies avant l'Illinoien. La glaciation de l'Illinoien est ici appelé Mountain River et celle du Wisconsinien supérieur, Gayna River. Dans les vallées, on peut habituellement identifier ces avancées par les moraines frontales et des segments de moraines latérales et par certaines formes d'érosion glaciaire. Jusqu'à maintenant, on a pu identifier les glaciations pré-illinoiennes dans quelques coupes seulement. Les avancées plus anciennes ont été plus importantes que celle de Gayna River. Ainsi les dépôts qui leur sont associés s'observent à des altitudes plus élevées et plus loin dans la vallée que ceux de la Glaciation de Gayna River. Pendant la Glaciation de Mountain River, certains des glaciers alpins ont fusionné pour devenir des glaciers de piémont. Par contre, pendant la Glaciation de Gayna River, les glaciers locaux se présentaient comme des langues glaciaires confinées dans des vallées tributaires qui présentaient des cirques exposés au nord.

ZUSAMMENFASSUNG *Alpine Vereisungen im Pleistozän in den Mackenzie-Bergen, Nordwest-Territorien.* Während des Pleistozäns wirkten Serien von Vereisungen auf die Mackenzie-Berge ein. Durch alle Vereisungen hindurch scheint ein einziges Muster sich wiederholt zu haben: Eine Kordillereneisdecke bildete sich westlich der kontinentalen Trennungslinie und alpine Talgletscher bildeten sich östlich. Die alpinen Gletscher in den Mackenzie-Bergen ergaben sich aus zwei verschiedenen Quellen: a) eine Eistrennungslinie, die im allgemeinen längs der topographischen Wasserscheide zwischen Pazifik und Arktis lag und die westwärts fließende Kordillereneisdecke von den ostwärts und nordwärts fließenden alpinen Gletschern trennte, b) örtliche Gipfel in den Canyon Ranges. In diesem Berggebiet fanden zwei scharf abgegrenzte Eisvorstöße statt: Illinoische, spätwisconsinische und mehr oder weniger gut abgegrenzte prä-illinoische Vereisungen. Die illinoische Vereisung wird hier Mountain River Vereisung genannt und die spätwisconsinische Gayna River Vereisung. Diese Vorstöße sind gewöhnlich in den Tälern erkennbar durch frontale Moränen und Segmente lateraler Moränen und Formen glazialer Erosion. Bisher konnten präillinoische Vereisungen nur in einigen Schnitten erkannt werden. Die älteren Vorstöße waren extensiver als der Gayna River-Vorstoß; die mit ihnen in Verbindung gebrachten Ablagerungen befinden sich höher auf den Talseiten und tiefer im Tal als die zu der Gayna River-Vereisung gehörigen. Während der Mountain River-Vereisung schmolzen einige alpine Gletscher zu Vorlandgletschern zusammen. Im Gegensatz dazu bestanden während der Gayna River-Vereisung die lokalen Gletscher aus einzelnen Zungen, und diese waren meist begrenzt auf tributäre Täler mit nordwärts gerichteten Karen.

* The present article is a follow up to the special issue dedicated to the Cordilleran Ice Sheet (Vol. 45, No. 3) / Cet article constitue la suite du numéro spécial consacré à l'Inlandsis de la Cordillère (vol. 45, n° 3).

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INTRODUCTION

The Mackenzie Mountains have been glaciated several times by montane valley glaciers during the Pleistocene. The arcuate shape of the mountains permitted the formation during pre-glacial time of a radial system of valleys that was followed by large montane glaciers. Small glaciers were formed on the highest peaks of the outer ranges. According to geologic evidence the last two glaciations correspond to the same glacial periods that affected central Yukon and Ogilvie Mountains during Illinoian and Late Wisconsinan time. The differentiation of these two glaciations, named herein Mountain River and Gayna River, has been accomplished in the course of regional mapping. Evidence of pre-Illinoian glaciations has been found only in stratigraphic sections, but that does not exclude the possibility of pre-Mountain River glacial features in the Mackenzie Mountains. Mapping the surficial geology of the outer ranges of the Mackenzie Mountains made clear the necessity of age distinction between glacial deposits of different origin: montane and Laurentide. The determination of provenance and extent of glacial features is tied to the spatial distribution of fairly well to well preserved montane glacial features and their relationships with Laurentide features. Therefore, the studied area included most of the Backbone, Landry, Redstone and Canyon ranges in order to establish criteria for identification and distribution of glacial features. The spacio-temporal distribution of glacial features in the western extremity of the Mackenzie Mountains was described by Hughes (1972). The remainder of the area has been studied by Duk-Rodkin.

REGIONAL SETTING

The Mackenzie Mountains are part of the eastern belt of the Northern Cordillera. They form an arc bordered by the Mackenzie Lowland to the east and northeast, Peel Plateau to the north, and the Rocky Mountains to the south (Fig. 1, 2). They comprise two main physiographic features, the Backbone Ranges along the main continental axis and the outer ranges, of which the largest group are known collectively as the Canyon Ranges (Fig. 2). The western boundary of the Backbone Ranges is crowned by peaks over 2000 m, up to a maximum of 2438 m high at the headwaters of Mountain and Arctic Red rivers. The Backbone Ranges form a massive mountain range without the large longitudinal valleys trending parallel to the ranges that divide the Canyon Ranges (Fig. 3). The ranges nourished large montane glaciers during past glacial times, in valleys such as Keele, Redstone, Twitya, Mountain, Stone Knife, Gayna and Arctic Red (Fig. 4). A few peaks in the headwaters of Keele, Mountain and Arctic Red rivers are high enough to support modern glaciers. In general the valleys have the glaciated typical U shape. However, valleys in the interfluve area between Gayna River valley and an eastern tributary of Arctic Red River valley have straight slopes with peaks up to 2000 m (500 m above the equilibrium line of last glaciation) without traces of glaciation.

The Canyon, Redstone and Landry ranges border the Backbone Ranges on the north and east. The ranges are cut into rectangular arcuated segments by structural and erosional valleys. The interfluve areas have individual peaks that range from 1980 m west of Arctic Red River to 2361 m (Mt. Eduni) to 2263 m to the southeast. The outer ranges continue to rise to the southeast into Landry Ranges which attain elevations up to 2500 m. Also, as can be observed in Figure 3, the highest peaks are located along the west side of the ranges, dropping to the east. In contrast with the Backbone Ranges, the outer ranges are less affected by glaciation and remnants of pre-Quaternary erosional surfaces are preserved in places such as the Plains of Abraham (Fig. 5). The individual ranges are separated by broad structurally controlled valleys, many of them broader than those that carry the major rivers across the mountain trend to Mackenzie Lowland. The valley floors are formed by gently sloping pediment surfaces of Tertiary (Pliocene?) age that border the individual ranges. Similar pediments bordered the northeastern flanks of the outermost ranges, but glacial erosion and subsequent incision of the deep canyons that characterize the Canyon Ranges, have removed all but a few pediment remnants.

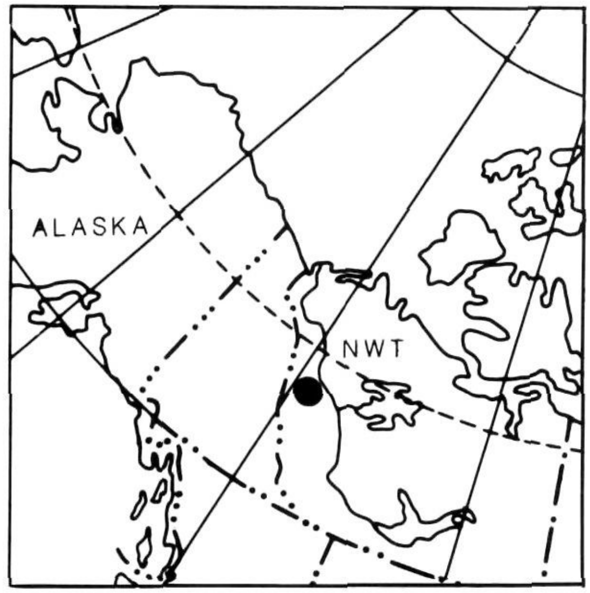


FIGURE 1. Location map.
Carte de localisation.

Cirques in higher peaks of the outer ranges supported small montane glaciers that locally merged on pediment surfaces to form piedmont glaciers. Extensive areas, however, remained unglaciated throughout the Quaternary.

PLEISTOCENE GLACIATIONS

The Mackenzie Mountains were affected by montane valley glaciers during the Pleistocene and peripherally by the Laurentide Ice Sheet during the last glaciation (Duk-Rodkin and Hughes, 1991). The montane glaciers headed from two different sources of ice: large valley glaciers headed in a ice divide near the continental divide and small glaciers headed in individual peaks of the outer ranges (Canyon, Redstone and Laundry ranges). A few small valley glaciers headed in peaks along the boundary of Backbone and Canyon ranges. The barrier of the eastern Cordillera caused the predominantly eastward flowing air masses to precipitate their moisture on the windward side of the mountains, forming an ice sheet

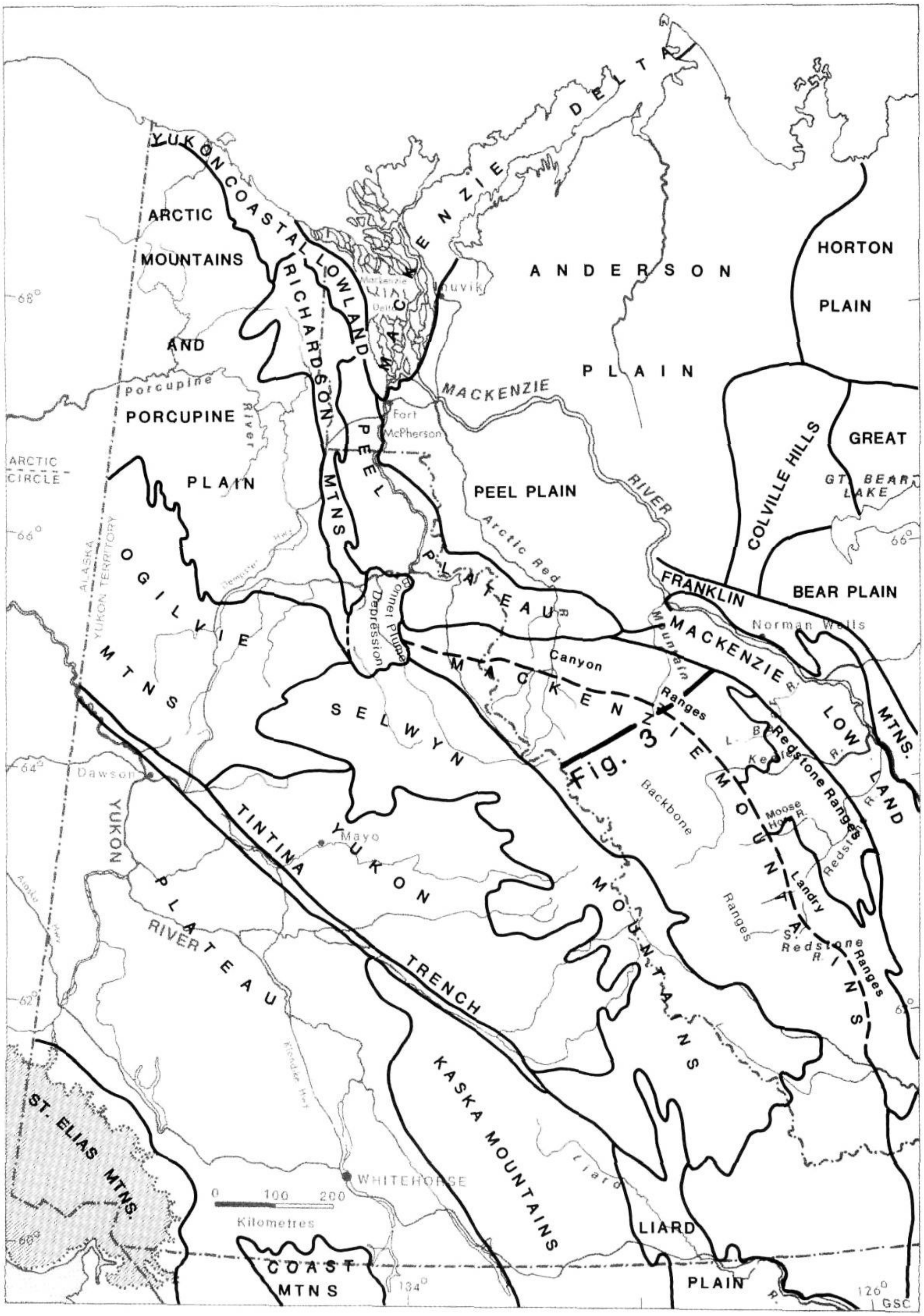


FIGURE 2. Physiography of Yukon and western District of Mackenzie after W. H. Mathews (1986). Location of topographic profile of figure 3.

La physiographie du Yukon et de l'ouest du district de Mackenzie, d'après W. H. Mathews (1986). Localisation du profil topographique de la figure 3.

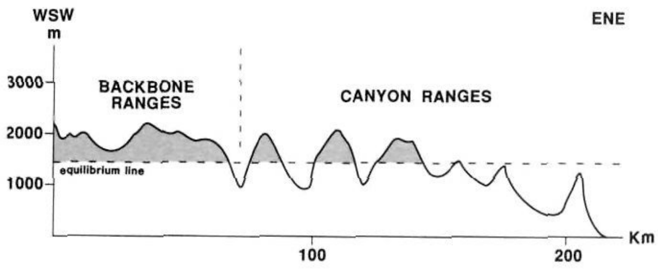


FIGURE 3. Topographic profile across the Mackenzie Mountains showing approximate paleoequilibrium line during Gayna River Glaciation (location of fig. 2).

Le profil topographique des monts Mackenzie, montrant la ligne d'équilibre pendant la Glaciation de Gayna River (localisation à la fig. 2).

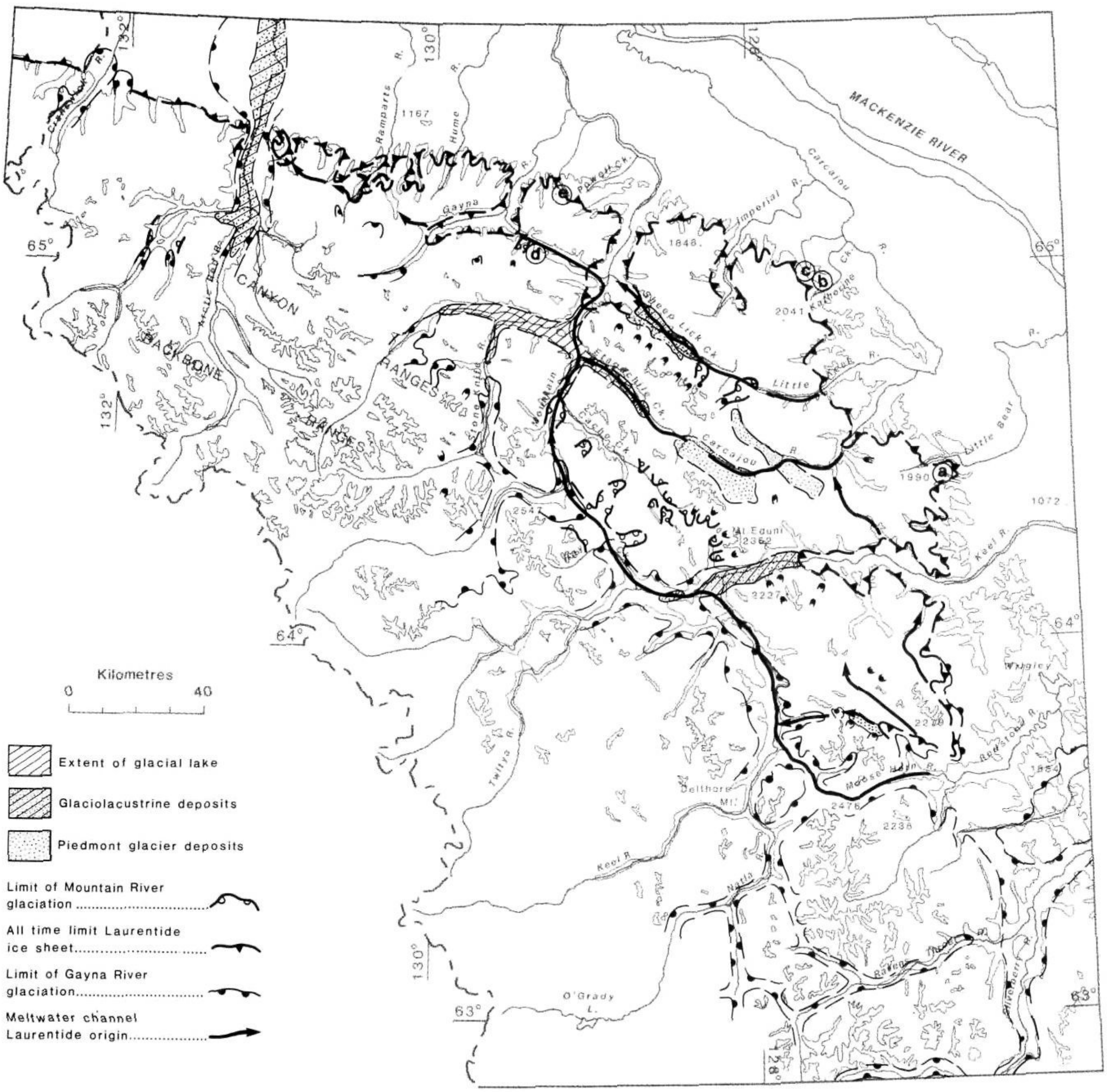


FIGURE 4. Limits of montane and Laurentide glaciations. Letters in circle indicate location of sections with paleosol data from maps in press or in preparation by the authors of this report and from Hughes (1972).

Limites entre les glaciers alpins et l'Inlandsis laurentidien. Les lettres encerclées montrent l'emplacement des coupes comprenant un paléosol. Les données proviennent de cartes en préparation ou sous presse des présents auteurs et de Hughes (1972).

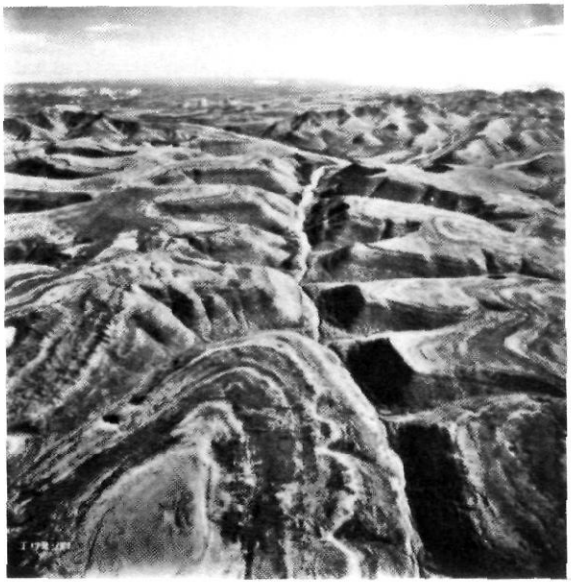


FIGURE 5. The Plains of Abraham, an unglaciated dissected plateau element within the Canyon Ranges.

Les Plaines d'Abraham, un plateau disséqué libre de glace dans les Canyon Ranges.

(Cordilleran Ice Sheet), and starving the glaciers on the leeward side. This pattern of glaciation seems to have been repeated through all the glacial periods. The distribution of glaciers was very similar to modern day distribution within St. Elias Mountains, where there is a nearly continuous carapace of ice to the southwest of the ice divide, large montane glaciers to the northwest, and small local montane glaciers in the lower outer ranges further east.

Differentiation of deposits of Mountain River and Gayna River age, particularly terminal deposits of the respective glaciations, is based mainly on two criteria: the relative sharpness and freshness of landforms of Gayna River age compared with the relatively subdued form of those of Mountain River age and relative positions of the terminal deposits down the valley from source areas. A third criterion, applicable only locally, is that in valleys within the outer ranges, moraines of Mountain River age may be cut by discharge channels that extend from the maximum position of the Laurentide ice margin and clearly predate the channels. At several localities, moraines of Gayna River age extend across Laurentide discharge channels, and clearly post-date the channels (Duk-Rodkin and Hughes, 1991).

The difference in degree of preservation parallels that recorded throughout glaciated parts of Yukon between the last (Late Wisconsinan) and penultimate (Illinoian) deposits and associated features, *i.e.* between McCauley and Mirror Creek deposits of the piedmont glacier complex of southwestern Yukon (Rampton 1971), between McConnell and Reid deposits of the Cordilleran Ice Sheet in central Yukon (Bostock, 1966: Hughes *et al.*, 1969) and between last and intermediate glaciations in Southern Ogilvie Mountains (Vernon and Hughes, 1966) and Wernecke and Northern Ogilvie Mountains (Hughes, 1972).

Differences in landforms of the two ages have been quantified only in southwestern Yukon, where Rampton (1971) found that hummocky moraine of McCauley age retains steeper slopes than those of hummocky moraine of Mirror Creek age (average slope 5.9° to 12.2° for 17 sample grids in McCauley moraines; average slope 3.4° to 4.9° for three sample grids in Mirror Creek moraines).

Although hummocky moraine is uncommon amongst terminal deposits of either Gayna River or Mountain River age in Mackenzie Mountains, qualitative assessment indicates a comparable difference in steepness of slopes. Crests of ridges are typically sharper and side slopes steeper in terminal moraine deposits of Gayna River age. Associated ice marginal channels are also typically better preserved, retaining steeper side slopes and the original gradient. Streams are commonly incised into the floors of valleys that were last glaciated during Mountain River Glaciation, with much less incision in the case of valleys last glaciated during Gayna River Glaciation. A comparable difference in stream incision has been reported from Southern Ogilvie Mountains for valley floors last glaciated during the intermediate and last glaciations of that area (Vernon and Hughes, 1966).

Relative preservation of landforms strongly supports correlation of the last and penultimate glaciations (McConnell and Reid of central Yukon; Bostock, 1966) throughout eastern Cordillera and central Yukon. The correlation is supported by consistent differences in soil development on deposits of the respective glaciations, at least at sites below altitudinal tree line, where disturbance of soil by cryoturbation is minimal.

In the Mackenzie Mountains, each successive glaciation was less extensive than its predecessor. This resembles to the pattern of advances of the Cordilleran glaciation (Bostock, 1966), and the pattern of montane glaciations in Southern Ogilvie Mountains (Vernon and Hughes, 1966) and in Wernecke and Northern Ogilvie Mountains (Hughes, 1972). Deposits and landforms attributed to both large and small montane glaciers of the last two glaciations can be found throughout the study area (Fig. 4). Evidence of still older glaciations has been found in stratigraphic sections.

The respective areas (Yukon and Mackenzie Mountains) are, however, very diverse physiographically, so that they may have responded differently to climatic change, with resultant differences in timing of glacial advances and retreats. Therefore, we establish separate nomenclature for the montane glaciations described below. Type localities were chosen along Mountain and Gayna rivers for the penultimate and last glaciations, respectively, and the names are here applied to the respective landforms and deposits. No type localities were chosen for pre-Illinoian glacial deposits because among the numerous sections of the area that display multiple tills with paleosols, only a section on Little Bear River has been studied in any detail (Hughes *et al.*, in press). Four of the five montane tills exposed in that section record pre-Illinoian advances.

PRE-MOUNTAIN RIVER (PRE-ILLINOIAN) GLACIATIONS

Pre-Mountain River glaciations are represented in this region by deposits exposed in a series of sections in the

Canyon Ranges near the mountain front. These glacial drifts below Mountain River deposits were deposited by glaciers that emanated from peaks in the outer ranges. They have the following characteristics:

1) *Degree of preservation of glacial forms*: No glacial features have been found within the Mackenzie Mountains that are comparable in degree of preservation with those of pre-Reid age in central Yukon. Moraine ridges of pre-Illinoian age, located beyond the area of study near the southern margin of Bonnet Plume Depression are the only glacial features known at present.

2) *Extent of glacial activity*: The location of exposures of pre-Mountain River deposits suggests that montane glaciers of this age extended beyond the mountain front, forming piedmont (Fig. 4) glaciers on pediment surfaces that lay along the northeast side of the Canyon Ranges.

3) *Stratigraphy*: most exposures of pre-Illinoian deposits are located in small valleys near the mountain front; all of the drift in the sections is attributable to local montane glaciers. The exposures are characterized by drift units separated by paleosols. In some places the highest montane till with a paleosol could be of Mountain River age, as at Little Bear River Section. The paleosols have not been studied in detail but in general they resemble a series of five paleosols at Little Bear River Section. There all the paleosols are Eutric Brunisols, judged to have formed under closed canopy boreal forest (Hughes *et al.*, in press, Table 4). These paleosols have thick brownish Bm horizons that grade downward to more yellowish C horizons.

At the Little Bear River Section (Fig. 6a) the five montane tills, are capped by boulder gravel of Laurentide origin. The gravel was deposited during a late readvance of the Laurentide Ice Sheet, the Late Wisconsinan Katherine Creek Phase (Duk-Rodkin and Hughes, 1991). The uppermost montane till is considered to be of Mountain River age.

A succession similar to that at Little Bear River is exposed along a tributary of Katherine Creek (Fig. 6b). The creek occupies a meltwater channel of Laurentide origin that was initiated during Katherine Creek Phase. Four montane tills with paleosols are capped by Laurentide till. The lithology of the montane tills suggests that they were deposited by advances emanating from cirques in headwaters of Katherine Creek. The uppermost montane till could be of Mountain River age; the other three are the products of pre-Mountain River glaciations. The surface Laurentide till is of Katherine Creek Phase age.

The next section (Fig. 6c) is located 5 km to the west on the left side of a small creek connecting with deeply encised canyons. A single montane till with a well developed paleosol overlies bedrock of Saline River Formation (shale, siltstone, sandstone; evaporites) and Franklin Mountain Formation (dolomite, chert; sandstone, red shales) (Cook and Aitken, 1975), and is overlain by Laurentide drift. The right side of the creek exposes glaciofluvial delta gravels that were deposited by the Laurentide meltwater channel previously described, into a small glacial lake.

Till with a paleosol at the top underlies till which forms lateral moraines of Mountain River age bordering an unnamed creek that flows northeasterly to an abandoned meltwater channel that connected Mountain and Gayna rivers during the Laurentide maximum (d of Fig. 4, Fig. 6d). The lateral moraines, which lie on either side of the creek, are considered to be of Mountain River age because they are truncated by the Laurentide meltwater channel. Lithology of the tills suggest that they were deposited by repeated advances of glaciers that originated in headwaters of the unnamed creek.

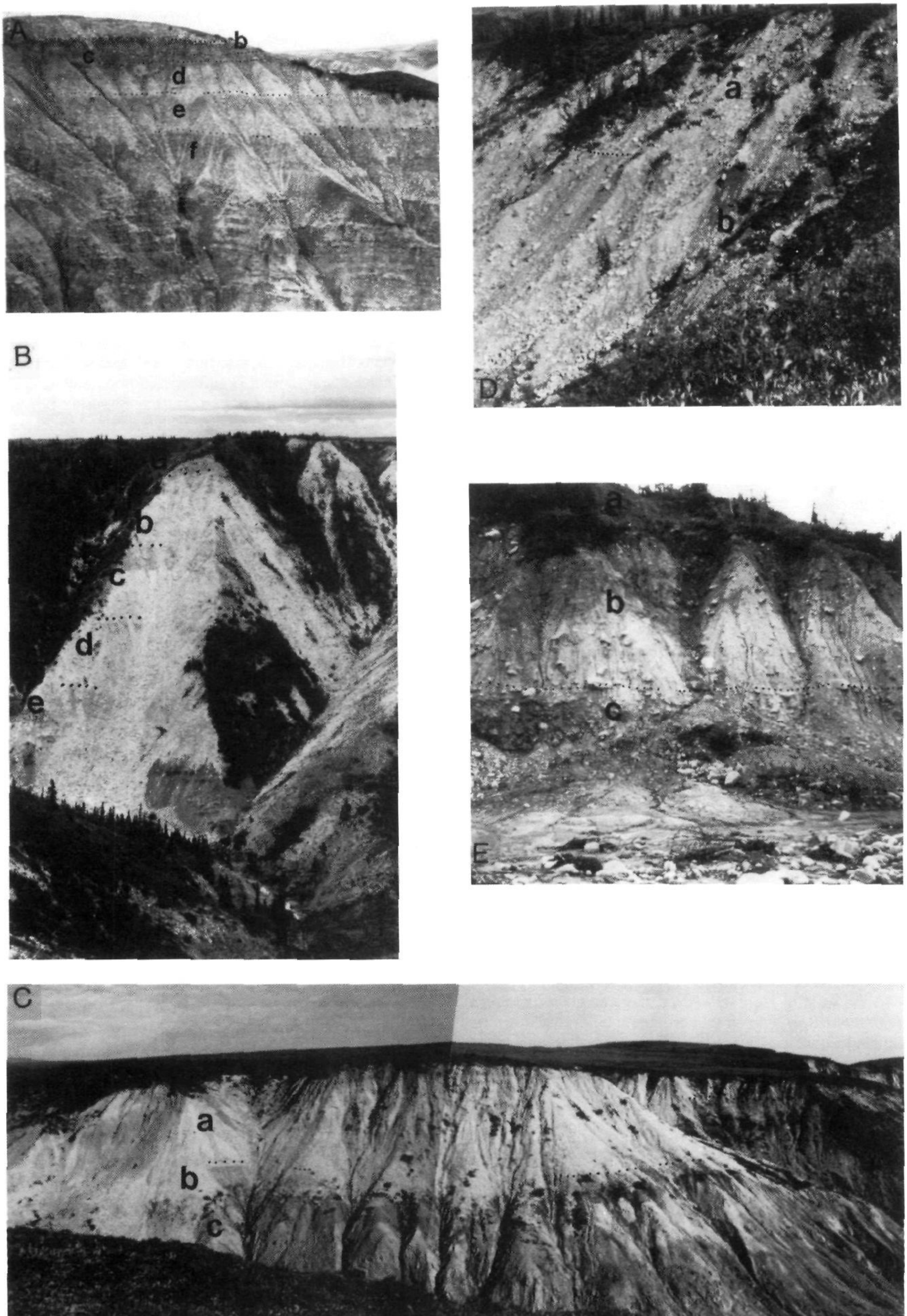
In section "e" (Fig. 6e) on the right bank of an unnamed creek a paleosol developed on montane drift is overlain by a second layer of montane drift. Both drifts were deposited by successive glaciers that emanated from cirques in the nearby headwaters of the unnamed creek. Higher in the section are ice-rich glaciolacustrine sediments, which liquify on thawing, and become draped over the upper part of the second drift, so that possible soil development on that unit has not been studied. Granitic erratics of shield origin are found as float in a gully incised into the section. The erratics could have been dropstones in the glaciolacustrine sediments, but more likely are derived from Laurentide till concealed beneath the slumped sediments. On the basis of their stratigraphic position beneath deposits of Laurentide origin, the montane drifts are considered to be of Mountain River and pre-Mountain River age, respectively.

MOUNTAIN RIVER GLACIATION

Mountain River Glaciation, the penultimate glaciation in the Mackenzie mountains, is here named for the glacial complex that defines the frontal position of this glaciation in Mountain River valley at the confluence with Cache Creek (Fig. 4). Glacial features of Mountain River age can be observed in most of the large and small valleys of the area. They are particularly conspicuous in segments of valleys beyond Gayna River glacial features. Streams in valleys that were last glaciated during Mountain River Glaciation are commonly incised into V-shaped

FIGURE 6. Sections showing paleosols on montane glacial drift. A. Little Bear Section: a) Laurentide drift; b,c,d,e,f) montane tills with paleosols. B. Section on a tributary of Katherine Creek: a) Laurentide drift; b,c,d,e,f) montane tills with paleosols. C. Section 5 km from B section: a) Laurentide drift; b) montane till with paleosol; c) bedrock. D. Section on an unnamed creek tributary of Gayna River: a) montane moraine; b) montane moraine with paleosol. E. Section on an unnamed creek a few kilometres from the mountain front between Mountain and Gayna rivers: a) Laurentide glaciolacustrine sediments; b) montane till; c) montane till with paleosol. A covered interval between units a and b may conceal a paleosol at the top of unit b and a possible till intercalated between units a and b.

Coupes montrant des paléosols développés sur des dépôts glaciaires, A. Coupe de Little Bear: a) dépôts laurentidiens; b,c,d,e,f) till de glacier alpin et paléosols. B. Coupe à un tributaire du Katherine Creek: a) dépôts laurentidiens; b,c,d,e,f) tills de glacier alpin et paléosols. C. Coupe à 5 km de la coupe B: a) dépôts laurentidiens; b) till de glacier alpin et paléosols; c) substratum. D. Coupe à un tributaire sans nom de la Gayna River: a) moraine de glacier alpin; b) moraine de glacier alpin et paléosol. E. Coupe à un ruisseau sans nom à quelques kilomètres du front montagneux entre les rivières Mountain et Gayna: a) sédiments glaciolacustres laurentidiens; b) till de glacier alpin; c) till de glacier alpin et paléosol. Un intervalle recouvert entre les unités a et b pourrait dissimuler un paléosol au sommet de l'unité b et un till peut-être intercalé entre les unités a et b.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channels. There is little or no incision of U-shaped valleys that were glaciated during Gayna River Glaciation. Examples can be found in the valleys draining to the west from Mount Eduni (Fig. 4).

1) *Degree of preservation of Mountain Riverglacialforms*: Most of the valleys in the Mackenzie Mountains (large and small) are flanked by ice marginal features similar in degree of preservation to the Reid age glacial features of central Yukon (Bostock, 1966; Hughes et *al.*, 1968). In general they are massive and subdued, in contrast to the Gayna River glacial features that are sharp and narrow. In places they form very well defined moraine complexes (Fig. 7a). At the type locality well defined but somewhat subdued glacial features indicate that the terminus of Mountain River glacier stopped at a constriction of Mountain River Valley, at the confluence with Cache Creek, forcing the ice to bulge up side valleys. The glacial limits at the type locality are marked by segments of moraine ridges, by an ice marginal channel through which a tributary stream was diverted around the glacial terminus, and by a large glaciofluvial delta complex that may conceal other terminal moraine deposits.

2) *Extent of Mountain River Glaciation*: Although large montane glaciers extended down all the major valleys of Mackenzie Mountains during Mountain River Glaciation, terminal deposits of such glaciers are found only at the type locality. All other large glaciers extended out to the mountain front, or at least beyond the later limit of Laurentide glaciation, so that their terminal deposits were destroyed by Laurentide ice or buried beneath Laurentide drift.

The terminal zone at the type locality is about 140 km downvalley from the headwaters of Mountain River. The longest of the large valley glaciers extended 210 km from the headwaters of Keele River to the Laurentide limit and some unknown distance beyond. Small valley glaciers, located mainly in the Canyon Ranges, varied in length according to the slope orientation (Fig. 8). They had an average length of 16 km along north facing slopes, but only 8 km along south facing slopes. In that part of the Canyon Ranges between Moose Horn and Mountain rivers local montane glaciers on the northeast facing slopes extended onto bordering pediments to form piedmont glaciers. The terminal zones of the complexes are marked by parallel to subparallel moraine loops. Southwest facing slopes however, developed single ice tongues.

To the west of Mountain River, the glaciers were single tongues mostly restricted to individual tributary valleys. The restricted extent was due to the relatively small accumulation areas above equilibrium level altitude. In the higher Landry Ranges in the southernmost part of the study area, some local glaciers were extensive enough to merge with the larger montane glaciers that emanated from the Backbone Ranges.

3) *Stratigraphy*: The type section for this glaciation is located at the left side of Cache Creek 1 km up stream from the confluence of Mountain and Cache valleys. The section (Figs. 9a, 9b, 10) exposes gravel approximately 30 m thick over a distance of 1 km. The gravel is considered to be glaciofluvial in origin and to be an integral part of the terminal complex.

The gravels are capped by a discontinuous layer of silt (loess ?) up to 50 cm thick, which is overlain in turn by about 10 m of glaciolacustrine silt and clay of Late Wisconsinan age. These sediments were deposited in a glacial lake formed when the Laurentide Ice Sheet, during its maximum, blocked the drainage of Mountain River valley. The silt and clay were deposited above the gravels and against the sandy deltaic deposits of Mountain River age (Fig. 11). The thick deltaic deposits may conceal terminal moraine deposits, but no exposures have been seen in sections.

The most significant aspect of this succession is a paleosol developed at the top of the gravel. The upper 50 cm of soil has the brown coloration of the Bm horizon of a Brunisol (paleo) but within the uppermost 20 cm of the horizon the upper side of the pebbles are coated with silt probably related to downward percolation of overlying silt, and the undersides have thick coatings of calcium carbonate. The silt and carbonate coating are judged to be secondary features, added to a Brunisolic Bm horizon which developed over an extended period before deposition of the overlying calcareous silt. Similar anomalous carbonate concentrations have been described from the upper part of paleosols in central Yukon (Tarnocai *et al.*, 1985). There the carbonate was derived from overlying loess of the last (McConnell) glaciation.

So far as can be determined without laboratory study, the paleosol is similar to Diversion Creek Paleosol, which is developed on deposits of the penultimate (Reid) glaciation of central Yukon (Tarnocai *et al.*, 1985; Smith *et al.*, 1986) and is consistent with the broad correlation of Mountain River Glaciation with Reid Glaciation on the basis of geomorphic criteria.

Weak soil development in the silt which overlies the paleosol suggests that the silt was deposited a short time before the site was drowned beneath a glacial lake impounded by the Laurentide Ice Sheet. The origin and significance of the silt, remain uncertain.

GAYNA RIVER GLACIATION

Gayna River Glaciation is the name here assigned to the last montane glaciation in the Mackenzie Mountains. The type locality is a well preserved terminal moraine complex in Gayna River Valley (Fig. 12).

1) *Degree of preservation*: The Gayna River glacial features are very well preserved and readily distinguished in the course of regional mapping from Mountain River glacial features by the relatively fresh appearance of moraine ridges and ice marginal channels. The moraine complex at the type locality (Fig. 12) comprises a series of narrow sharp-crested subparallel moraine ridges truncated by the river as well as hummocky moraines at the distal part. Although other large montane glaciers in valleys such as Keele, Stone Knife Valley and its branch, a western tributary of Arctic Red Valley and its branch, left well preserved frontal moraines and loops where they bulged into lateral valleys (such as the ones in Hay Creek), none left terminal moraines as completely preserved as the moraine complex in Gayna Valley. Gayna River glacial features are similar in the degree of preservation to those of McConnell age and presumed correlatives throughout Yukon (Hughes et *al.*, 1969).

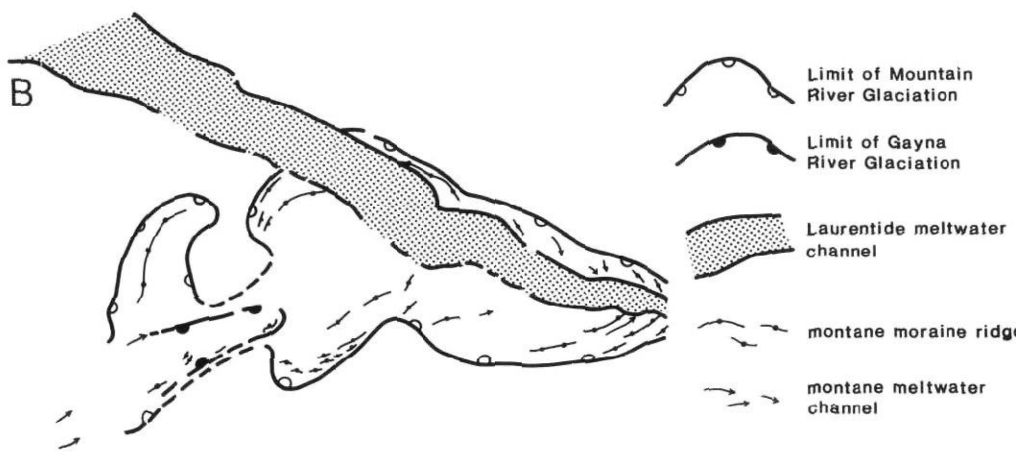


FIGURE 7. A. Moraine complex of Mountain River age cut by a meltwater channel of Laurentide origin. B. Glacial features of Mountain River and Gayna River that can be seen on A.

A. Complexe morainique datant de la Glaciation de Mountain River entaillé par un chenal de fonte d'origine laurentidienne; B. formes glaciaires des rivières Mountain et Gayna montrées en A.

2) *Extent*: An abundance of well defined lateral moraines, ice marginal channels and terminal moraines permit delineation of the former extent of large montane glaciers in all of the major drainages of the region. This reconstruction shows that there was a shift from independent glaciers occupying single drainages in the northwest, to increasingly complex anastomosing glacier systems (transection glaciers) in the south. In general, the distance from source area to terminus increases southward, the more northerly glaciers terminating short of the mountain front, and the more southerly extending to and beyond the mountain front (Fig. 13). In this respect the glacier in Arctic Red valley, which extended beyond the mountain front to form a lobate terminus on Peel Plateau, is anomalous. It is possible that ice accumulation in the headwaters region was augmented by outflow from the northern margin of the Cordilleran Ice Sheet. The glacier in Gayna River, on the other hand, was relatively short, undoubtedly because its headwaters, although in the Backbone Ranges, do not extend to the continental divide, as do the others.

The flow pattern of ice emanating from the headwaters of the Mountain River during Gayna River Glaciation was complicated, with tongues extending laterally into intermontane valleys. One such tongue extended southeastward into a valley occupied in part by Hay Creek. Another tongue followed the northwestward continuation of the same valley, to join another

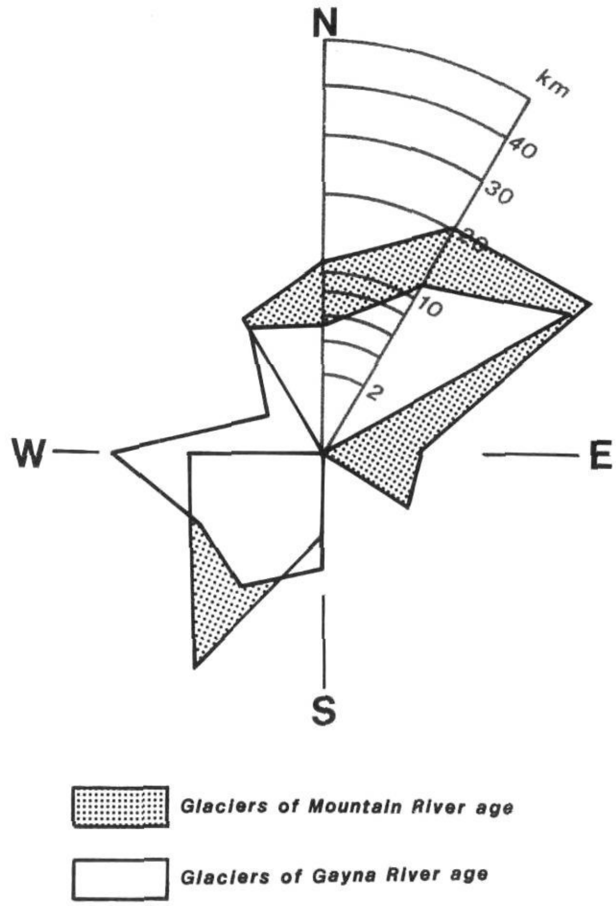


FIGURE 8. Rose diagram depicting length and aspect of local glaciers of the outer ranges.

Diagramme circulaire qui donne l'aspect et la longueur des glaciers locaux issus des chaînes externes.

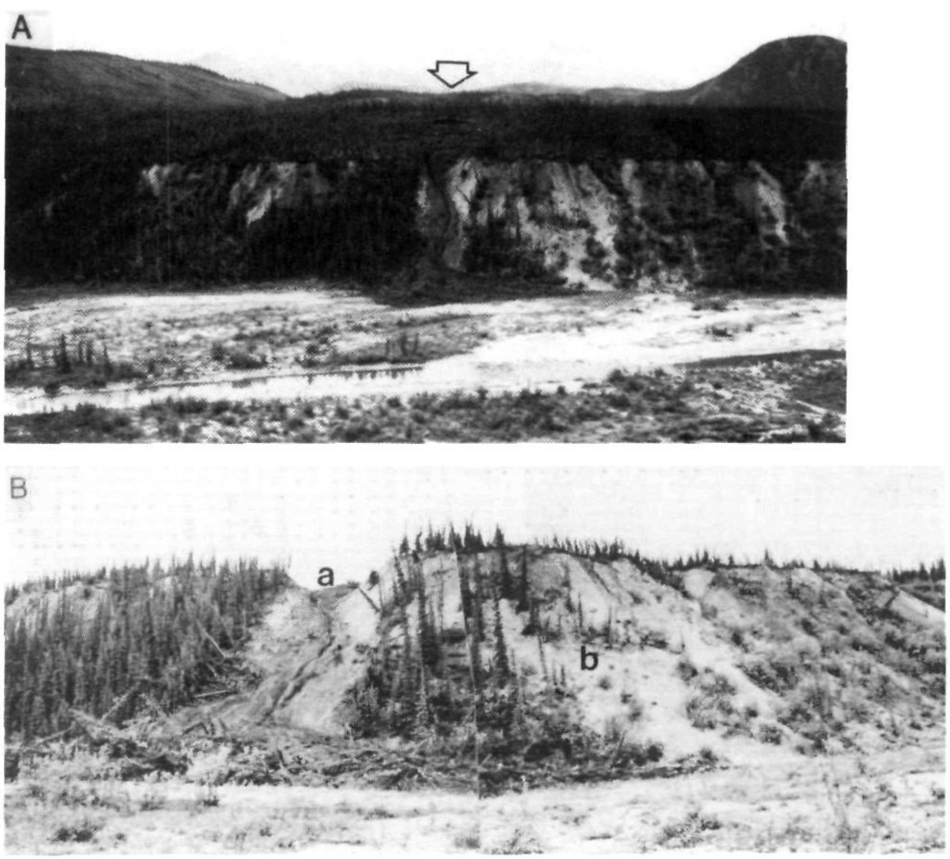


FIGURE 9. A. Panoramic view of the type locality section for Mountain River Glaciation. Note the retrogressive thaw flow slide head wall developed in ice rich silt and clay. B. Close view of section in A: a) retrogressive thaw flow slide; b) 30 m of outwash gravels.

Vue panoramique de la coupe de référence de la Glaciation de Mountain River. Noter la niche d'arrachement, résultant d'un glissement rétrogressif de liquéfaction, formée en substrat limono-argileux renfermant de la glace. B. Gros plan de la coupe en A: a) glissement rétrogressif de liquéfaction; b) 30 m de graviers fluvioglaciaires.

FIGURE 10. Top of Mountain River section: a) glaciolacustrine deposit; b) 50 cm of loess; c) paleosol in gravels; d) gravel parental material.

Partie supérieure de la coupe de Mountain River; a) dépôts glaciolacustres; b) 50 cm de loess; c) paléosols sur graviers; d) gravier de matériel parental.

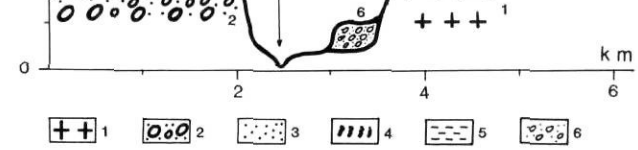


FIGURE 11. Schematic cross section, type locality for Mountain River Glaciation: 1) bedrock; 2) glaciofluvial gravel, Mountain River Glaciation; 3) glaciofluvial sand; 4) paleosol; 5) glaciolacustrine sediments; 6) glaciofluvial gravel, Gayna River Glaciation.

Coupe schématique au site de référence pour la Glaciation de Mountain River: 1) substratum; 2) gravier fluvioglaciaire (Glaciation de Mountain River); 3) sable fluvioglaciaire; 4) paléosol; 5) sédiments glaciolacustres; 6) gravier fluvioglaciaire (Glaciation de Gayna River).

glacier in Stone Knife Valley. The terminal deposits in Mountain River valley, which occur 30 km upstream from the terminus of Mountain River age, are blanketed by debris of a large rockslide. Pitting on the debris surface suggests that ice remained at the terminus when the slide took place. In a segment of Mountain River valley about 5 km upstream from this terminal zone, upper ice marginal features of Mountain River age lie about 150 m higher on the valley side than those of Gayna River age, providing a direct measure of the greater thickness of ice during Mountain River Glaciation.

Ice from the headwaters of Keele River flowed eastward to Delthore Mountain, then northwestward to Twitya Valley, part extending eastward 15 to 20 km, the rest turning westward as indicated by a moraine on the south side of Twitya Valley that declines westward, to merge with ice that was moving down Twitya Valley. White horblende biotite granites from O'Grady Batholith or from one of the plutons located along the upper reaches of Keele and Twitya rivers (R. G. Anderson, personal communication) were found in the lateral moraine described above. The merged glaciers then extended northwestward into the broad intermontane valley now occupied in part by Hay Creek, the flow opposing but not merging with, the ice tongue from Mountain River.

Only limited photo interpretation has been undertaken in the Landry Ranges in the southern-most part of the study area. There glacial features of Gayna River age indicate equally complicated flow patterns as ice from the Backbone Ranges moved eastward via Natla, Moose Horn, Ravens Throat and Silverberry valleys (Fig. 4).

Small montane glaciers of Gayna River age developed in the numerous cirques along north facing slopes of the outer ranges, whereas many of the cirques on south facing slopes were inactive. The best example of this irregular distribution can be seen in the interfluve between Carcajou River-Etagochile Creek Valley and Little Keele-Sheep Lick Creek Valley (Fig. 4). Here numerous cirques on the north facing slopes supported montane glaciers during both Mountain River and Gayna River glaciations, while on the south facing slopes only a few cirques were active during Mountain River glaciation, and only one during Gayna River Glaciation (Fig. 8). The average length of glaciers on north facing slopes was 10 km compared with 5.5 km for glaciers on to the south facing slopes. Small valley glaciers west of Arctic Red River at the mountain front had an unusually large extent (up to 25 km), with their termini extending out onto Peel Plateau, the same as the Arctic Red Valley glacier (Fig. 14).

3) *Stratigraphy:* At the type locality, terminal deposits of Gayna River Glaciation are exposed intermittently in a scarp on the left side of Gayna River for a distance of 4 km (Fig. 12). Fairly well exposed sequences of glaciofluvial and till deposits occur at two sites along the scarp. The first is located in the upstream part of the section where the core of one of those moraine ridges is exposed. The second site is exposed intermittently downstream at a distance of 1.7 km where hummocky moraine deposits are exposed.

At the *first site* bedrock (quartzite of Proterozoic Katherine Group) is overlain by 1 m of fluvial gravels (unit 1) followed by 7.30 m of

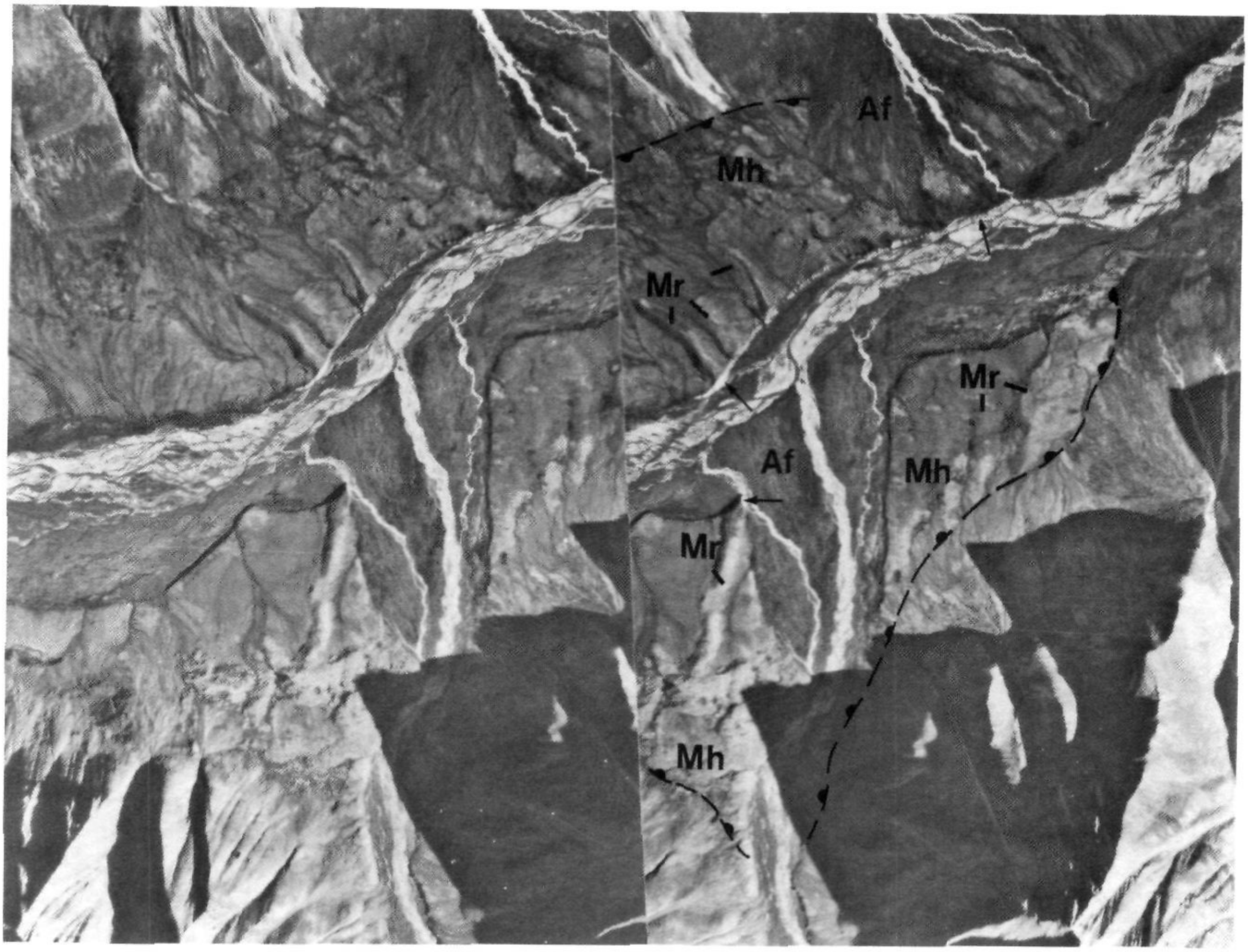
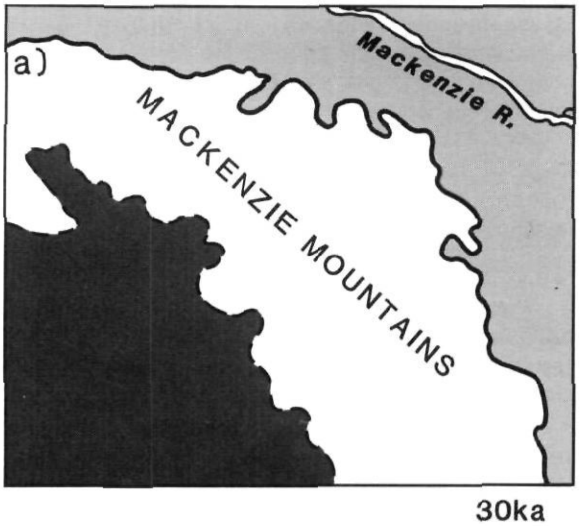


FIGURE 12. Gayna River moraine complex. Mh: humocky moraine, Mr: moraine ridge, Af: alluvial fan; discontinuous line with black semi-circles indicates limit of Gayna Valley glacier during Gayna River Glaciation. Arrows mark upstream and downstream ends of a line of discontinuous exposure.

Complexe morainique de Gayna River, Mh: moraine mamelonnée, Mr: crête morainique, Af: cône de déjection; la ligne brisée avec demi-cercles noirs montre la limite du glacier de la vallée de Gayna pendant la Glaciation de Gayna River. Les flèches identifient les limites aval et amont d'un affleurement discontinu.



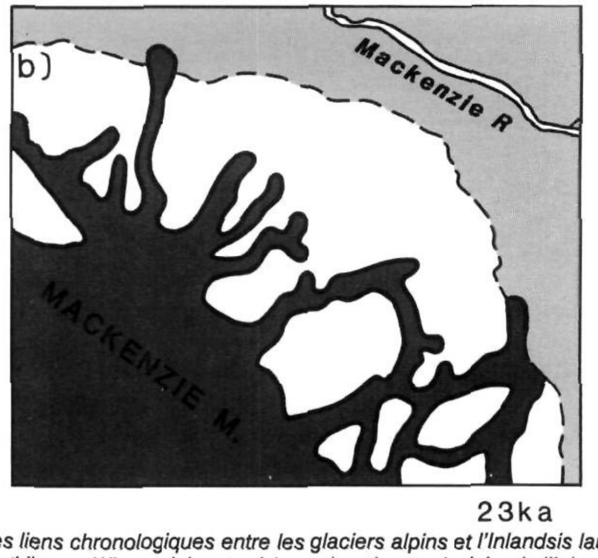


FIGURE 13. Age relationships between montane and Laurentide glaciations during Late Wisconsinan: a) Laurentide maximum and advance of montane valley glaciers; b) montane glacial maximum and retreat of the Laurentide Ice Sheet.

Les liens chronologiques entre les glaciers alpins et l'Inlandsis laurentidien au Wisconsinien supérieur; a) optimum glaciaire de l'Inlandsis laurentidien et avancée des glaciers de vallée; b) optimum des glaciers alpins et retrait de l'Inlandsis laurentidien.

glaciofluvial sands and gravels (unit 2), 7.6 m of debris flow deposits (unit 3), 7.7 m of till and 0.45 m of clayey silt (unit 4) (Fig. 15).

• Unit 1: 20 cm of normally graded well sorted open work gravel with clasts to 15 cm at the base, decreasing upward to 1 cm followed by 50 cm of structurless well sorted gravels with clasts 2 to 5 cm, occasionally 20 cm diameter intercalated with coarse sand.

• Unit 2: The upper 3.8 m of this unit is mostly concealed though some horizontal stratification is visible.

Subunit 2a: 1.8 m thick. Pebbles and boulders (2 to 40 cm) in a coarse sandy matrix. The boulders tend to form clusters enclosing poorly sorted smaller clasts. A sharp horizontal contact with subunit a is marked by a layer of structureless silty sand of 3 to 8 cm thick.

Subunit 2b: 0.58 m thick. Coarse sand with foresets crudly defined by pebble-rich layers. Clast diameter 1 to 7 cm.

Subunit 2c: 0.2-0.3 m thick. Massive fine sand with small pebbles (up to 5 cm) and granules.

Subunit 2d: 1.25 m thick. Layers (5 to 15 cm thick) of fine sand with granules and pebbles up to 8 cm alternating with coarse to medium sand with pebbles up to 4.5 cm.

• Unit 3: 7.6 m thick. This unit is separated from unit 2 below by a sharp contact of openwork gravels. Clast supported structureless diamicton with a fine sandy matrix; there is no prefered orientation of clasts. Clasts up to 40 cm in size.

• Unit 4: 7.2 m thick. It is a sandy silty matrix-supported till with about 25 to 30% clasts from granules to boulders 35 cm in diameter, subangular to subrounded.

• Unit 5: 45 cm of clayey silt that correspond to a small lake that was formed between two moraine ridges.

Unit 1 is judged to be fluvial gravel deposited before onset of Gayna River Glaciation. Unit 2 is glaciofluvial gravel deposited immediately before the site was overridden by an advancing glacier, and unit 3 is probably part of a debris flow derived from the glacier snout. The till of Unit 4 forms a prominent moraine ridge exposed at the upstream end of the scarp face (Fig. 12).

At the second site the river has incised into bedrock exposing three main glacial units:

• Unit 1: 10.5 m of glaciofluvial gravel and sand overlies 1.8 m of quartzite (exposed thickness). The unit is poorly exposed but shows alternation of gravel and sand with both of reverse and normal grading where visible.

• Unit 2: 0.7 m of stratified sand in sharp contact with the underlying unit 1. This unit comprises beds 3 to 15 cm thick of silty sand with minor coarse sand and pebbles (0.5 to 3.5 cm). The unit could have been deposited either subaerially or subglacially.

• Unit 3: 11.7 m of matrix supported crudely stratified ablation till with about 25% coarse clasts. The upper part of the unit is covered. The crude stratification is produced by alternation of the matrix between silty clay and silty sand.

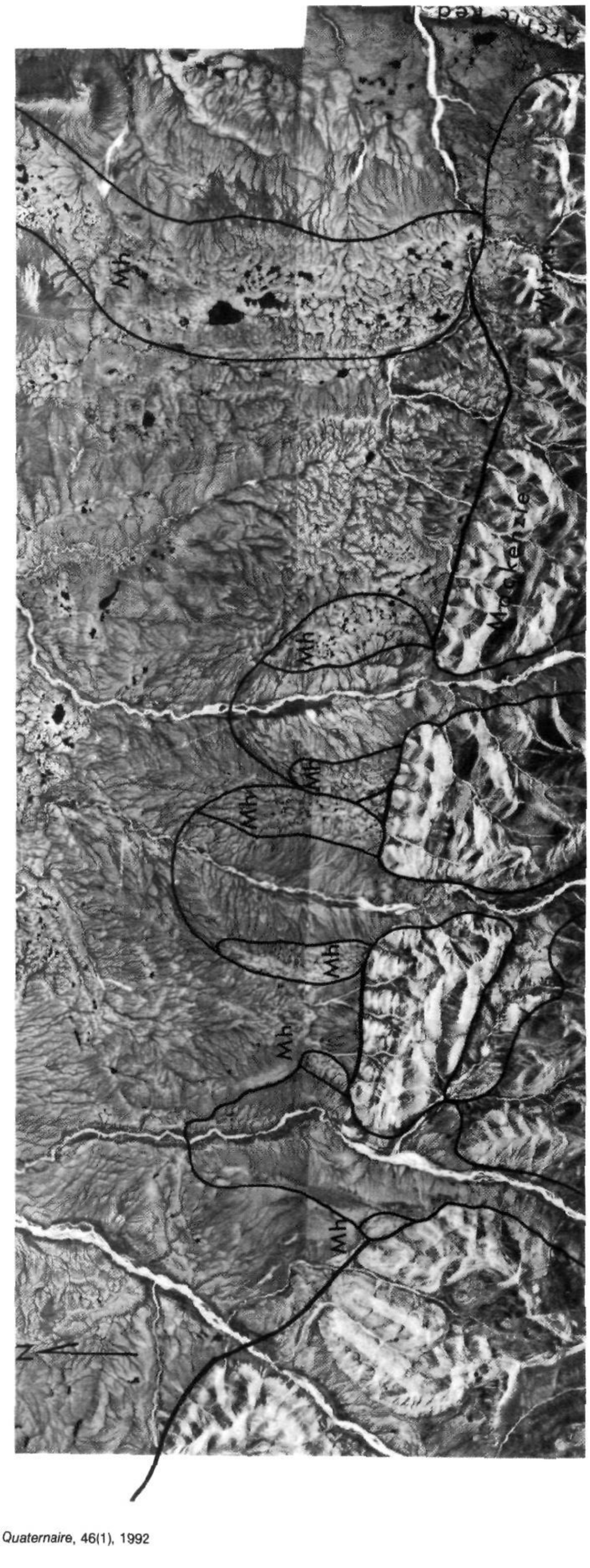


FIGURE 14. Loops of hummocky moraines marking the limits of glaciers that extended beyond the Mackenzie Mountain front onto Peel Plateau during Gayna River Glaciation. Decease outward in clarity and definition of moraine topography suggests that the outermost parts of the montane glaciers rested on stagnant Laurentide ice.

Boucles de moraine mamelonnée marquant la limite des glaciers qui se sont étendus au-delà du front des monts Mackenzie vers le plateau Peel, au cours de la Glaciation de Gayna River. La moindre clarté de la topographie morainique vers l'extérieur laisse croire que les extrémités des glaciers alpins reposaient sur des glaces laurentidiennes stagnantes.

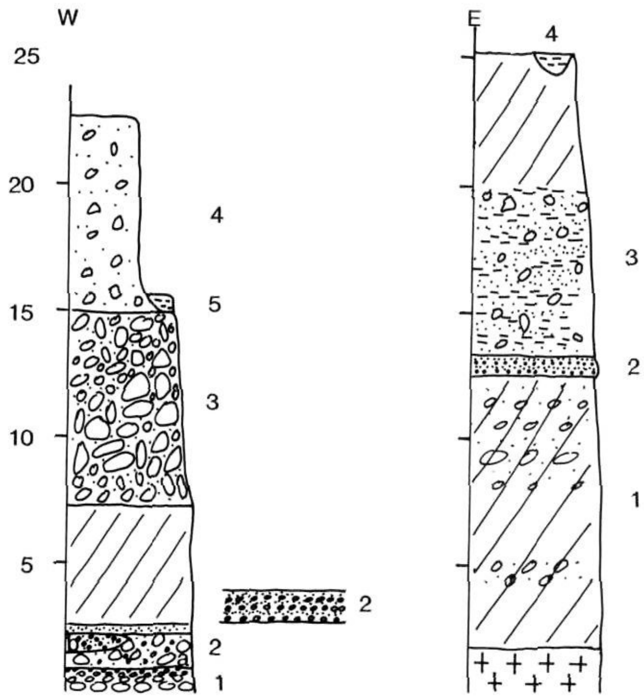


FIGURE 15. Stratigraphic sections at the type locality for Gayna River Glaciation (see text for description of units).

Coupes stratigraphiques au site de référence pour la Glaciation de Gayna.

• Unit 4: 1 m of silty clay. This deposit lies in a small kettle on the hummocky terrain surface behind the scarp face, and was examined using a soil auger.

The gravel at this site is judged to be proximal glaciofluvial gravel deposited immediately before advance of a glacier over the site. The ablation till forms the hummocky moraine at the outer margin of the moraine complex (Fig. 12, Unit Mh)

THE LAURENTIDE ICE SHEET

Another age criterion is the relationship of montane glacial features and deposits to glacial features and deposits of Laurentide origin. These relationships were described and interpreted by Duk-Rodkin and Hughes (1991). Briefly, during the Late Wisconsinan, the Laurentide Ice Sheet pressed against the Mackenzie Mountains reaching its all time limit approximately 30 ka ago. It left moraines, ice-marginal channels and erratics of Shield origin by which the former limits of Laurentide ice can be reconstructed in considerable detail. Ice tongues projected up major river valleys, blocking and diverting the drainage from the mountains and initiating a complex of drainage channels that followed intermontane valleys northwestward for great distances before reemerging at the mountain front (Fig. 4). Glacial lakes were impounded locally beyond the ice tongues. During this time montane glaciers had not yet reached their maximum extent (Fig. 13a).

Pre-existing montane moraines and other deposits were affected in various ways. Those within the limits of the Laurentide Ice Sheet were truncated, or buried beneath Laurentide drift. Those lying beyond the ice margin in valleys utilized by the new drainage system were cut and partly eroded by the new channels (Fig. 7a, b). In the case of the type locality for Mountain River Glaciation, the terminal deposits (moraines and outwash plains) were inundated by a Laurentide ice-damned glacial lake and blanketed by glaciolacustrine sediments. The cross-cutting relationship demonstrates a pre-Laurentide maximum age for Mountain River Glaciation, and additionally corroborates assignments of moraines to Mountain River Glaciation that were based on moraine morphology and distance from source area. Such corroboration increases confidence in age assignment of moraines using the latter criteria alone.

At several localities, well preserved moraines of local montane glaciers cut across the Laurentide maximum position, or across channels that were occupied during the Laurentide maximum. The moraines are considered on the basis of degree of preservation and relative distance from source to be the product of Gayna River Glaciation, which must therefore post-date the Laurentide maximum.

Retreat following the Laurentide maximum was interrupted by a readvance during Katherine Creek Phase (Duk-Rodkin and Hughes, 1991). Some of the moraines that cut across the Laurentide maximum are truncated in turn by ice-marginal features of the Katherine Creek Phase of the Laurentide Ice Sheet. Local montane glaciers of Gayna River age therefore had reached their maximum positions, and had began to retreat, before the Katherine Creek readvance.

Within the study area, only two large montane glaciers extended far enough eastward during Gayna River time to interact with the Laurentide Ice Sheet (Fig. 13b). An ice tongue in Moose Horn Valley, part of an anastomosing glacier system emanating from the headwaters of Keele and Natla rivers, merged with the Laurentide ice and was deflected northward at a time when the latter lay at a well marked ice frontal position 100 m below the Laurentide maximum. The lower position is tentatively assigned to Katherine Creek Phase. If the assignment is correct, montane ice from Moose Horn Valley, derived ultimately from the Backbone Ranges, was active at the time when local montane glaciers of the outer ranges had retreated an undetermined distance up valley. A second large montane glacier in Arctic Red Valley extended beyond the mountain front to form a broad lobe (Fig. 14). The form of the resultant moraine suggests that the lobe of montane ice extended onto dead ice of the retreating Laurentide Ice Sheet, again suggesting late activity of large montane glaciers.

CONCLUSIONS AND COMMENTS

Criteria such as degree of preservation of glacial landforms, relative distances of terminal deposits from ice source, degree of soil development and locally, relationship to Laurentide ice marginal features and discharge channels, serve to separate deposits of the penultimate Mountain River Glaciation in the Mackenzie Mountains from those of the last, Gayna River Glaciation.

A division of moraines and other deposits of local montane glaciers into pre- and post-Laurentide categories according to their relationships to the maximum Laurentide limit and associated channel system and glacial lakes, is congruent with the division based on geomorphic preservation and pedologic criteria. The congruence attests to the reliability of these criteria in making broad age distinctions within Mackenzie Mountains and justifies extension of the criteria to adjacent regions.

The geomorphic and pedologic criteria that serve to separate landforms and deposits of Mountain River and Gayna River age, are the same as those used to separate those of Reid and McConnell age in central Yukon and those of the intermediate and last glaciations in Ogilvie and Wernecke mountains. These criteria are adequate for broad correlation, but are not sensitive enough to detect small differences in timing, such as that between large montane glaciers of Gayna River age and the small local glaciers.

There are no radiocarbon or other dates from the study area that serve to provide age limits for the glacial events described. Mountain River Glaciation is broadly correlated with Reid Glaciation of central Yukon, which culminated more than 80,000 years ago and is probably of Illinoian age (Hughes, 1989). The Laurentide maximum is considered to be correlative with the maximum of Hungry Creek Glaciation in Bonnet Plume Depression, which was probably attained about 30,000 years ago or somewhat later (Hughes *et al.*, 1981) possibly as late as 25,000 years ago (Morlan *et al.*, 1990, p. 85). Gayna River Glaciation is broadly correlated with McConnell Glaciation which culminated, sometime after 23,000 years ago (Matthews *et al.*, 1990).

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