Article

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AGE RELATIONSHIPS OF LAURENTIDE AND MONTANE GLACIATIONS, MACKENZIE MOUNTAINS, NORTHWEST TERRITORIES

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ABSTRACT The Mackenzie Mountains were glaciated repeatedly by large valley glaciers that emanated from the Backbone Ranges, and by much smaller valley glaciers that emanated from peaks in the Canyon Ranges. During the Late Wisconsinan the Laurentide Ice Sheet reached its all-time maximum position. The ice sheet pressed against the Canyon Ranges and moved up major valleys causing the diversion of mountain waters and organizing a complex meltwater system that drained across mountain interfluve areas towards the northwest. Two ages of moraines deposited by montane glaciers occur widely in the Mackenzie Mountains. Near the mountain front certain of the older moraines have been truncated by the Laurentide Ice Sheet, and others have been incised by meltwater streams emanating from the Laurentide ice margin, indicating that these older moraines predate the maximum Laurentide advance. Locally, certain of the younger montane moraines breach moraines and other ice marginal features of the Laurentide maximum, indicating that the younger montane glaciation post-dated the Laurentide maximum. Some large montane glaciers extended out from the mountains to merge with the retreating Laurentide Ice Sheet. There are several localities that display the age relationships between montane and Laurentide glaciations such as Dark Rock Creek, Durkan-Lukas Valley, Little Bear River and Katherine Creek. The older of the local montane glaciations is correlated tentatively with Reid Glaciation (Illinoian?) of central Yukon, and the younger with the Late Wisconsinan McConnell Glaciation. The Laurentide Glaciation is correlated with Hungry Creek Glaciation of Bonnet Plume Depression, which probably culminated about 30,000 years ago or somewhat later.

RÉSUMÉ *Les liens chronologiques entre l'Inlandsis laurentidien et les glaciers alpins des monts Mackenzie, Territoires du Nord-Ouest.* Les monts Mackenzie ont souvent été envahis par de grands glaciers de vallée, en provenance des Backbone Ranges, et par de plus petits, qui venaient des sommets des Canyon Ranges. Pendant le Wisconsinien supérieur, l'Inlandsis laurentidien atteignait ses limites maximales. Appuyé contre les Canyon Ranges, l'Inlandsis a envahi les principales vallées, entraînant ainsi la dérivation des eaux et la mise en mouvement d'un important réseau d'eaux de fonte qui se drainaient vers le nord-ouest, à travers les interfluves. De nombreuses moraines déposées par les glaciers alpins dans les monts Mackenzie appartiennent à deux époques de mise en place. Près du front montagneux, certaines des plus anciennes moraines ont été tronquées par l'Inlandsis laurentidien, tandis que d'autres ont été incisées par les courants d'eaux de fonte en provenance des marges glaciaires laurentidiennes, démontrant ainsi que ces moraines précédaient l'optimum glaciaire laurentidien. Localement, certaines moraines plus récentes trouent d'autres moraines et reliefs de marge glaciaire datant de l'optimum laurentidien, révélant que la glaciation alpine la plus récente a suivi l'optimum laurentidien. Quelques grands glaciers alpins se sont étendus au point de se fusionner à l'Inlandsis laurentidien en retrait. Plusieurs sites témoignent des liens chronologiques entre l'Inlandsis laurentidien et les glaciers alpins comme Dark Rock Creek, Durkan-Lukas Valley, Little Bear River et Katherine Creek. À titre d'essai, on fait la corrélation entre les plus anciennes glaciations alpines locales et la Glaciation de Reid (Illinoien?) du centre du Yukon et entre la plus jeune, et la Glaciation de McConnell, du Wisconsinien supérieur. La Glaciation laurentidienne est corrélé à la Glaciation de Hungry Creek (Bonnet Plume Depression), qui a connu son optimum il y a environ 30 000 ans ou un peu plus tard.

ZUSAMMENFASSUNG *Chronologische Beziehungen zwischen laurentidischem Inlandeis und den alpinen Gletschern der Mackenzie Mountains, Northwest Territories.* Die Mackenzie Mountains wurden wiederholt durch breite Talgletscher vereist, die von den Backbone Ranges kamen, sowie durch viele kleinere Talgletscher, dir von den Gipfeln der Canyon Ranges kamen. Während des späten Wisconsiniums erreichte die laurentidische Eisdecke ihre maximale Ausdehnung aller Zeiten. Die Eisdecke drückte gegen die Canyon Ranges und bewegte sich durch die Haupttäler aufwärts. So lenkte sie die Bergwasser ab und bewirkte ein komplexes Schmelzwassersystem, das durch Berg-Riedel-Gebiete nach Nordwesten abfloss. Zwei Epochen von durch alpine Gletscher abgelagerten Moränen kommen in den Mackenzie Mountains vermehrt vor. In der Nähe der Bergfront sind einige von den älteren Moränen durch die laurentidische Eisdecke abgestumft worden, während andere durch die Schmelzwasserströme von dem laurentidischen Eissaum eingeschnitten worden sind, was darauf hinweist, dass diese älteren Moränen dem Hochstand des laurentidischen Vorstosses vorausgehen. Einige der jüngeren alpinen Moränen durchbrechen stellenweise Moränen und andere Ausformungen des Eissaums des laurentidischen Hochstands, was wiederum zeigt, dass die jüngere alpine Vereisung auf den laurentidischen Hochstand folgte. Einige Plätze zeigen die chronologischen Beziehungen zwischen den alpinen und laurentidischen Vereisungen wie z.B. Dark Rock Creek. Versuchsweise korreliert man die ältere der örtlichen alpinen Vereisungen mit der Reid-Vereisung (Illinoisch?) von Zentral-Yukon und die jüngere mit der Spät-Wisconsinium McConnell-Vereisung. Die Laurentidische Vereisung wird korreliert mit der Hungry Creek-Vereisung von Bonnet Plume Depression, welche ihren Höhepunkt wahrscheinlich vor etwa 30,000 Jahren oder etwas später erreichte.

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INTRODUCTION

Mackenzie Mountains are the northward continuation of Rocky Mountains. Beginning north of Liard River at about 59°30′N, they extend north and northwest in a great arc to south of Bonnet Plume Depression (Fig. 1). They are bordered to the east and northeast by Mackenzie Lowland and Peel Plateau and to the west by Selwyn Mountains. Mackenzie Mountains comprise two rather distinct parts, the Backbone Ranges on the west with peaks up to 2720 m, some of which support small glaciers, and the lower Landry and Canyon Ranges to the east and northeast.

The first systematic mapping of the surficial geology of the middle reaches of Mackenzie Valley and adjacent parts of Mackenzie Mountains was begun by Hughes in 1969 and 1970 as part of Operation Norman of Geological Survey of Canada and continued by Hughes and various others in 1971 to 1974 as part of a project that had as its main object the mapping of the surficial geology of Mackenzie Transportation Corridor. Open File maps resulting from the projects (Hughes, 1970; Hughes *et al.*, 1972a,b; Hughes and Pilon, 1973; Hanley and Hughes, 1973; Hanley *et al.*, 1975) emphasized areas bordering Mackenzie River, to the exclusion of Mackenzie Mountains, because of immediate need for terrain data in the lowlands, where pipelines and highways were being planned. A coherent picture of the glacial geology of Mackenzie Mountains did not emerge until mountainous parts of the relevant map areas were studied by Duk-Rodkin beginning in 1986.

The glacial history of Mackenzie Mountains is complex. Geomorphic and stratigraphic evidence indicates repeated advances of glaciers from three sources. Large montane glaciers originating in the high Backbone Ranges near the Yukon-Northwest Territories boundary moved northeasterly to northerly along major valleys such as Moose Horn, Keele, Mountain and Arctic Red, extending digitations into many tributary valleys. Much smaller glaciers advanced repeatedly from cirques in the highest peaks of the Canyon Ranges. Along the entire arc of the Mackenzie Mountain front, the Laurentide Ice Sheet pressed against the outermost ranges, extended tongues as much as 47 km up Keele, Mountain and other valleys, and diverted drainage to flow along valleys situated as much as 100 km back from the mountain front (Fig. 2, 3).

The flow of glaciers in those valleys in the past left clear evidence of their former presence. Well defined and preserved glacial features clearly depict the degree of complexity of the relationships between the former glaciers. Moraines and other ice marginal features that mark the limits of the last montane glaciation in the area, and those marking the all time limit and retreatal positions of the Laurentide Ice Sheet (fig. 2, 4) are well preserved. Those of the penultimate montane glaciation are subdued but still recognizable. Further, most of the features are above tree-line, so the spatial and hence relative age relationships between the various features can be determined readily from airphotos. From those features can be inferred a complex network of large and small montane glaciers.

Certain of the moraine sets are truncated by ice marginal features that mark the Laurentide maximum, or are cut by meltwater channels that flowed from the Laurentide ice margin, and hence are older than the Laurentide maximum. Other moraine sets extend onto surfaces formerly covered by the Laurentide Ice Sheet, and hence are younger than the Laurentide maximum. In general this age difference is reflected by better preservation of the younger moraines.

Some moraine sets formed by the late advance of small montane glaciers from Canyon Ranges are truncated by ice marginal features that mark a readvance of the Laurentide Ice Sheet, indicating that the glaciers had advanced and retreated prior to the Laurentide readvance. The large valley glaciers that emanated from the Backbone Ranges reached their maximum positions later, perhaps about the time of the Laurentide readvance.

The spatial relationships relationships of montane and Laurentide ice-marginal features are mostly displayed at Dark Rock Creek, with others displayed at Durkhan-Lukas valley, Little Bear River and Katherine Creek.

REGIONAL QUATERNARY GEOLOGY

Quaternary chronologies have been developed for three areas that are contiguous with the present study area: Selwyn Mountains and much of Yukon Plateau (Fig. 1,3), which were glaciated repeatedly by the Cordilleran Ice Sheet; Southern Ogilvie Mountains, where there were three or more advances of montane glaciers; and an area embracing the western extremity of Mackenzie Mountains, the northern edge of Southern Ogilvie Mountains and Northern Ogilvie Mountains, where Laurentide Glaciation, as well as multiple montane glaciations, is recorded.

Bostock (1966) inferred four advances of the Cordilleran Ice Sheet in central Yukon: Nansen (oldest), Klaza, Reid and McConnell (Fig. 2), with each successive glaciation less extensive than the previous one. Well-preserved moraines and other ice-marginal features mark the digitate former limit of McConnell Glaciation, allowing the limit to be traced throughout central and southwestern Yukon (Hughes *et al.*, 1969). Features of Reid age are subdued but are likewise traceable throughout central and southwestern Yukon. Glacial landforms of Nansen and Klaza age are much subdued, so that the all-time limit of the Cordilleran Ice Sheet can be determined only on the ground from the distribution of foreign rock types in the surficial deposits. Deposits of the two older glaciations have been differentiated only in the area described by Bostock (1966).

Deposits of McConnell, Reid and pre-Reid glaciations are further distinguished by major differences in soil development (Tarnocai *et al.*, 1985; Smith *et al.*, 1986). Drift of McConnell age typically has a thin brunisolic soil. Diversion Creek paleosol, developed on drift of Reid age, is a much thicker brunisol and Wounded Moose paleosol, developed on pre-Reid drift, is a very thick luvisol. These differences in soil development are not generally evident, however, where the respective deposits lie above regional tree line. There, pervasive cryoturbation seems to have destroyed whatever distinctions there may have been between soils on the different ages of drift.

In Southern Ogilvie Mountains, there were at least three episodes of montane glaciation, termed last, intermediate and old

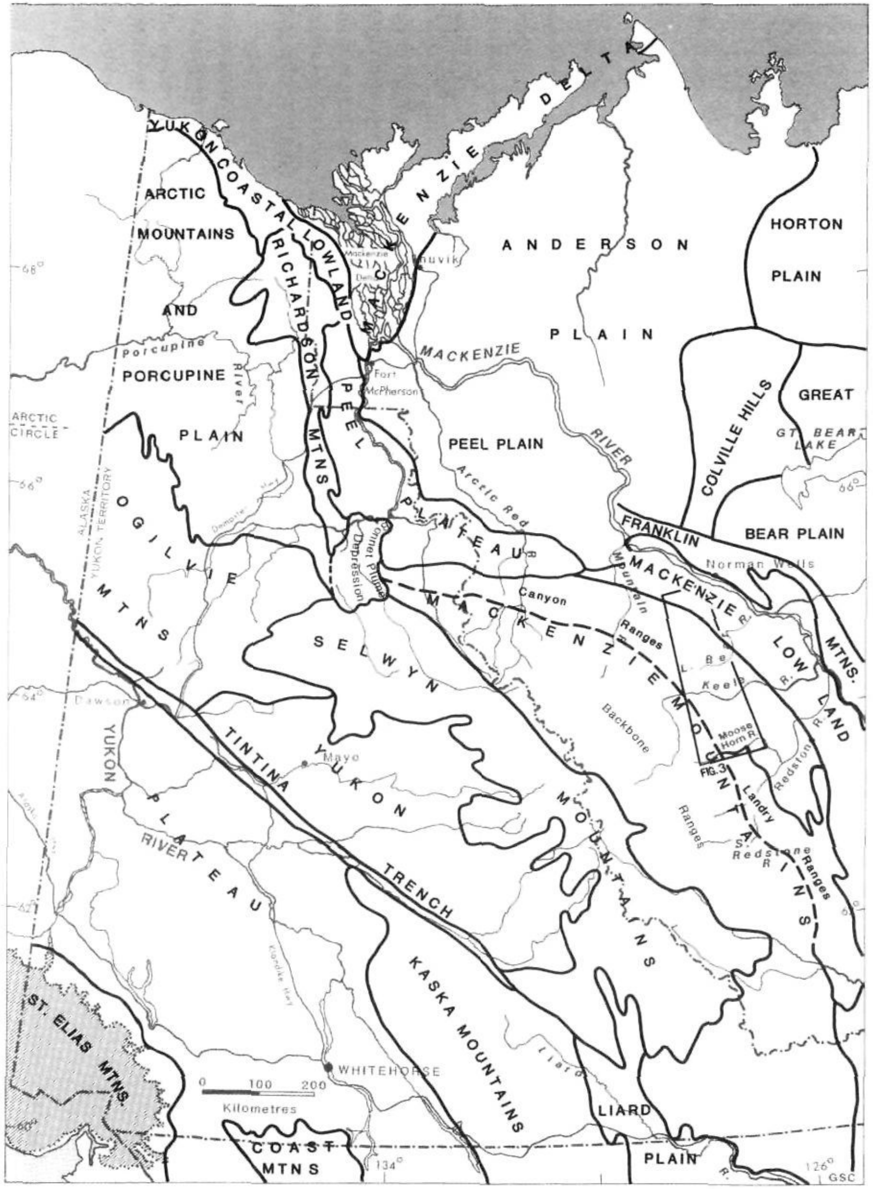


FIGURE 1. Physiography of Yukon and western District of Mackenzie.
La physiographie du Yukon et de l'ouest du district de Mackenzie.

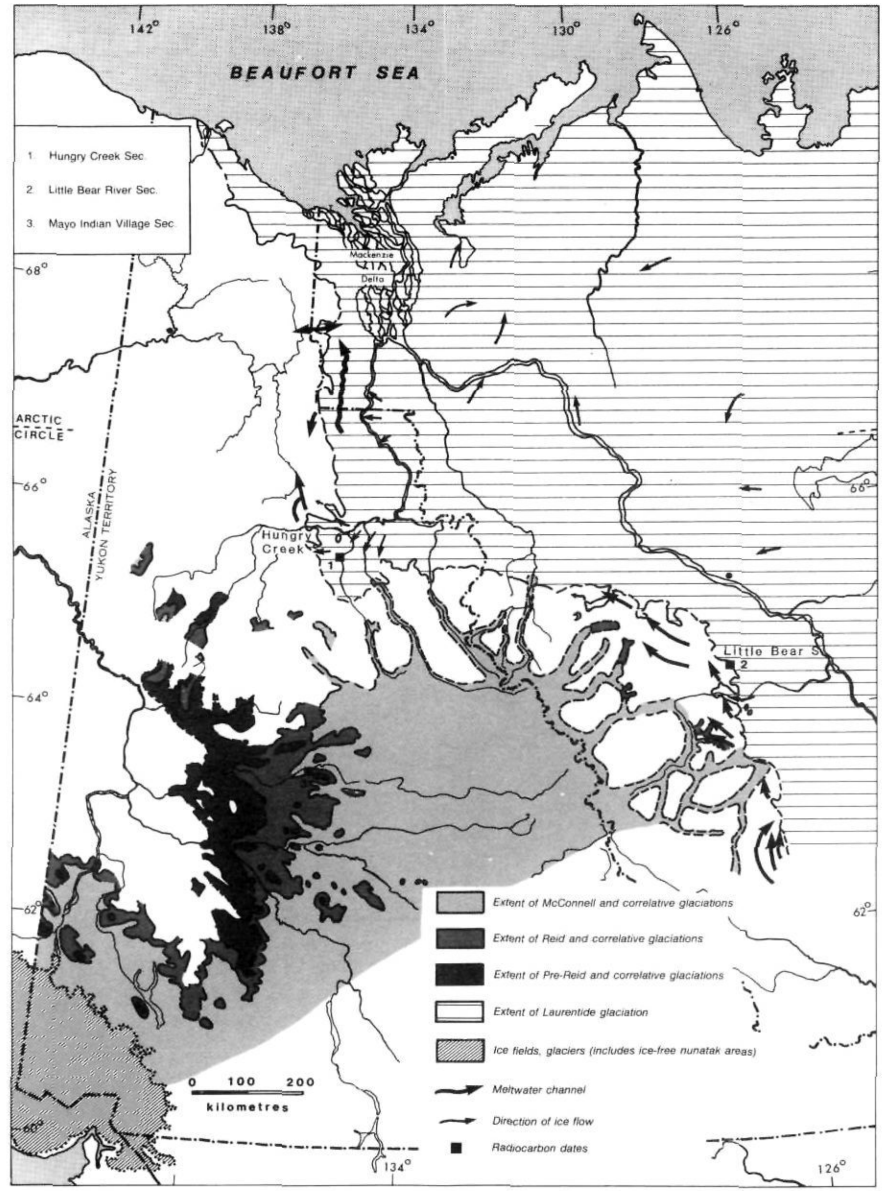


FIGURE 2. Glaciations in Yukon and western District of Mackenzie (after Hughes *et al.*, 1968; Hughes, 1987, with additional data for Mackenzie Mountains by authors of this paper).

Les glaciations au Yukon et dans l'ouest du district de Mackenzie (selon Hughes et al., *1968; Hughes, 1987, et données supplémentaires sur les monts Mackenzie par les auteurs).*

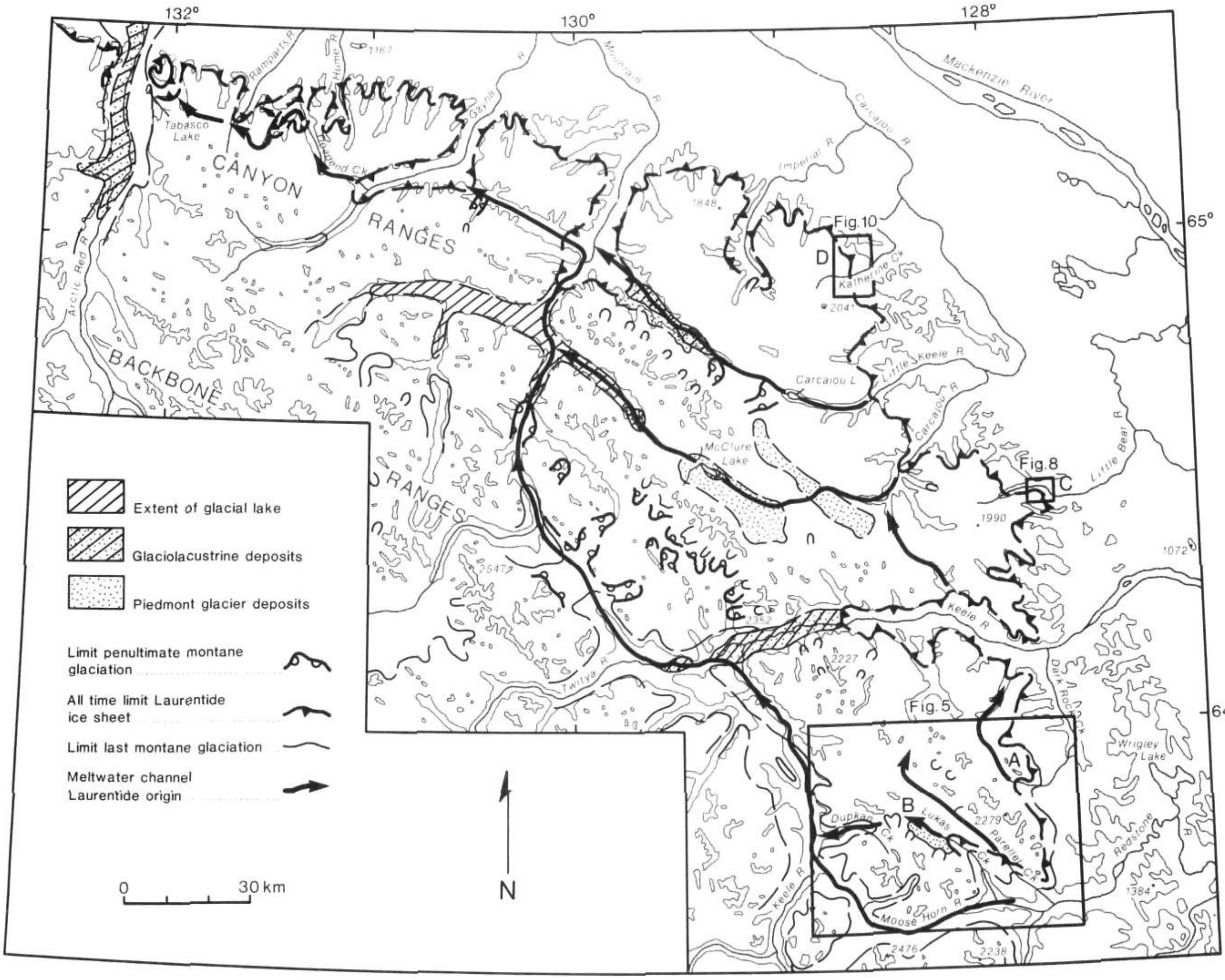


FIGURE 3. Limits of montane and Laurentide glaciations at the Mackenzie Mountains front between Moose Horn and Arctic Red valleys.

Limites des glaciations alpines et laurentidienne au front des monts Mackenzie, entre les vallées de Moose Horn et d'Arctic Red.

FIGURE 4. Ice marginal channels marking the upper limit of the Laurentide Ice Sheet.

Chenaux glaciaires marginaux qui constituent la limite supérieure de l'Inlandsis laurentidien.

(Vernon and Hughes, 1966). Moraines of the last and intermediate glaciations are comparable in degree of preservation to those of McConnell and Reid glaciations, respectively. As with landforms of Nansen and Klaza age, those of the old glaciation(s) are much subdued. Soil developed on montane moraines of intermediate age is similar to the Diversion Creek paleosol which is developed on deposits of Reid age. Similarly, soil developed on deposits of the oldest montane glaciation are similar to the Wounded Moose paleosol which is developed on deposits of pre-Reid age (Nansen and Klaza, undivided) (Tarnocai *et al.*, 1985; Smith *et al.*, 1986).

With respect to montane glaciation, the third area is an extension of Southern Ogilvie Mountains, with moraines divisible into the same three age categories. It is useful, however, to distinguish between large glaciers in valleys such as Snake, Bonnet Plume and Wind that originated in the relatively high mountains of the Yukon-Mackenzie divide, from smaller glaciers that originated in cirques of the lower outer ranges. In addition to the glacial deposits of montane origin, there are moraines and other deposits of the Laurentide Ice Sheet, which pushed westward and southward across Bonnet Plume Depression and impinged against the mountain front (Hughes, 1972; Fig. 2, this paper).

At a point 11 km west of Snake River, the all-time Laurentide limit, sharply defined by an ice-marginal channel, truncates the moraine of a small montane glacier which has the form of moraines of intermediate (= Reid) age in Southern Ogilvie Mountains. A large glacier that flowed northward in Bonnet Plume Valley (in effect an outlet glacier from the north side of the Cordilleran Ice Sheet, augmented by montane glaciers) appears from geomorphic evidence to have extended northward to cross and destroy moraines deposited earlier at the all-time limit of Laurentide Glaciation.

THE LAURENTIDE ICE SHEET

The all-time limit of the Laurentide Ice Sheet in the Mackenzie Mountains is well defined. Ice marginal features and shield erratics can be observed all along the Mackenzie Mountain front. The features descend in elevation at an approximate rate of 1.2 m/km towards Bonnet Plume Depression and the Arctic Ocean. Good markers are located in the Landry Ranges (south of Keele River) as high as 1550 m and in the Canyon Ranges (north of Keele River) as high as 1430 m where the upper limit is marked by small ice marginal channels and shield erratics (Fig. 4). The small size of the channels suggests they formed near the equilibrium line and mark the upper edge of the ice sheet. Markers occur at lower elevations along Katherine Creek (1280 m) and along the slopes west of Arctic Red River at the mountain front (1100 m) where the upper limit is marked by segments of moraine ridges and shield erratics.

The ice sheet pressed against the Mackenzie Mountain front, and tongues moved up major valleys such as Moose Horn, Keele, Mountain, Gayna and Arctic Red, and minor valleys such as Carcajou, Little Bear, Little Keele, Imperial, Hume, Ramparts and others as it was diverted down the Mackenzie Valley (Fig. 3).

When the Laurentide Ice Sheet occupied the lower reaches of mountain valleys it caused the diversion of mountain drainage which together with meltwater formed a complex system of major channels. The main channel drained to the northwest and collected the waters from a series of Laurentide meltwater channels and drained through parts of Keele, Twitya, Hay and Mountain valleys. Two of the most important meltwater channels head in Carcajou (1100 m) and McClure (1240 m) lakes (Fig. 3). They are in remnants of meltwater channels related to Laurentide ice tongues in the lower mountain reaches of Little Keele, Carcajou and Keele valleys. The two channels were cut across the divide and joined Mountain River channel when the Laurentide Ice Sheet blocked eastward flow of Little Keele, Carcajou and Keele rivers. The channel system, developed into one channel that forms a deep canyon across the interfluve between Mountain and Gayna valleys. This channel system does not appear to be large enough to carry the modern day flow of all the drainages that were blocked and diverted by the Laurentide Ice Sheet. This could have been due mainly to large net accumulation of ice in the montane glaciers forming in the Backbone Ranges. The channel was also diverted across the divide between the valley of Gayna River and Deadend Creek (1010 m) and continued to the Ramparts Valley and thence into Arctic Red Valley in the vicinity of Tabasco Lake (Fig. 3). Where the drainage continued beyond this locality is not clear as the Laurentide Ice Sheet was blocking the lower mountain reaches of Arctic Red Valley. If the channel crossed the interfluve towards Snake Valley, all evidence was obliterated by montane valley glaciers that filled the valleys after the maximum advance of the Laurentide Ice Sheet.

Moraines of valley and piedmont glaciers were incised by this channel system in many places in the Mackenzie Mountains. Piedmont glacier deposits were cut by McClure Lake meltwater channel; moraine ridges and piedmont glacier deposits were incised by Carcajou Lake meltwater channel; moraine ridges from a local montane glacier were truncated by the Mountain-Gayna valleys part of the channel. Hence these montane glacier deposits clearly predate the Laurentide maximum advance.

Short-lived glacial lakes were formed along the channels and mountain valleys that were blocked by Laurentide ice at its maximum or during retreat (Fig. 3). Thick glaciolacustrine sediments can be observed along the valley sides in the vicinity of the Keele-Twytia confluence, along Carcajou and McClure lakes meltwater channels, along the valley sides of the lower mountain reaches of Mountain, Gayna, Hume, Ramparts and Arctic Red rivers as well as in almost all valleys occupied by the small creeks that flow out to the plains.

The retreating Laurentide ice left numerous channels and moraine ridges on the slopes along the mountain front. Moraine systems and associated meltwater channels mark several significant readvances or major stillstands of the Laurentide Ice Sheet following attainment of the Laurentide maximum (Sabine phase and Sitidgi stade of Rampton, 1982 and 1988; Tutsieta and Kelly lakes phases of Hughes, 1987; Katherine Creek phase, this paper).

MONTANE-LAURENTIDE AGE RELATIONSHIPS, MACKENZIE MOUNTAINS

The pattern of montane glaciation in Mackenzie Mountains is generally similar to that seen in Southern Ogilvie Mountains and in Wernecke and Northern Ogilvie Mountains to the north. The relationships of moraines and other ice-marginal features of montane origin to those of Laurentide origin are generally similar to those described immediately above for the Wernecke Mountains-Northern Ogilvie Mountains area. Selected localities in Mackenzie Mountains allow us, however, to amplify as well as verify the relationships seen in the former area. Those localites are Dark Rock Creek (Fig. 3, A; Fig. 5), a valley occupied by Durkan and Lucas creeks, herein called Durkan-Lucas Valley (Fig. 3, B; Fig. 5), Little Bear River (Fig. 3, C; Fig. 8), and Katherine Creek (Fig. 3, D; Fig. 10).

DARK ROCK CREEK

Salient glacial features of the Dark Rock Creek locality (Fig. 5, 6), in order of formation as inferred from photo-interpretation of geomorphic relations are (1) lateral moraines

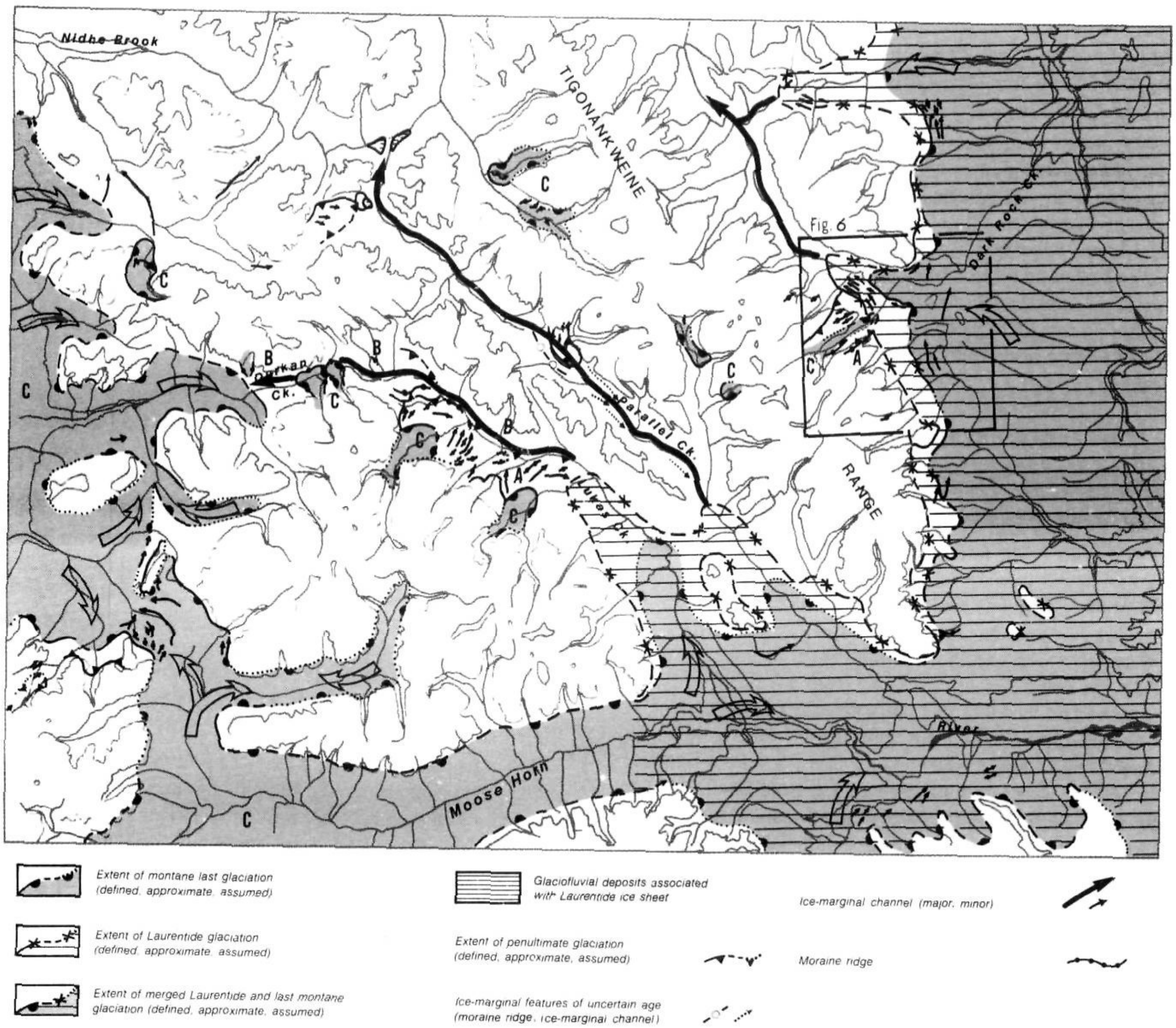


FIGURE 5. Relationships between montane and Laurentide glaciations in Tigonankweine Range.

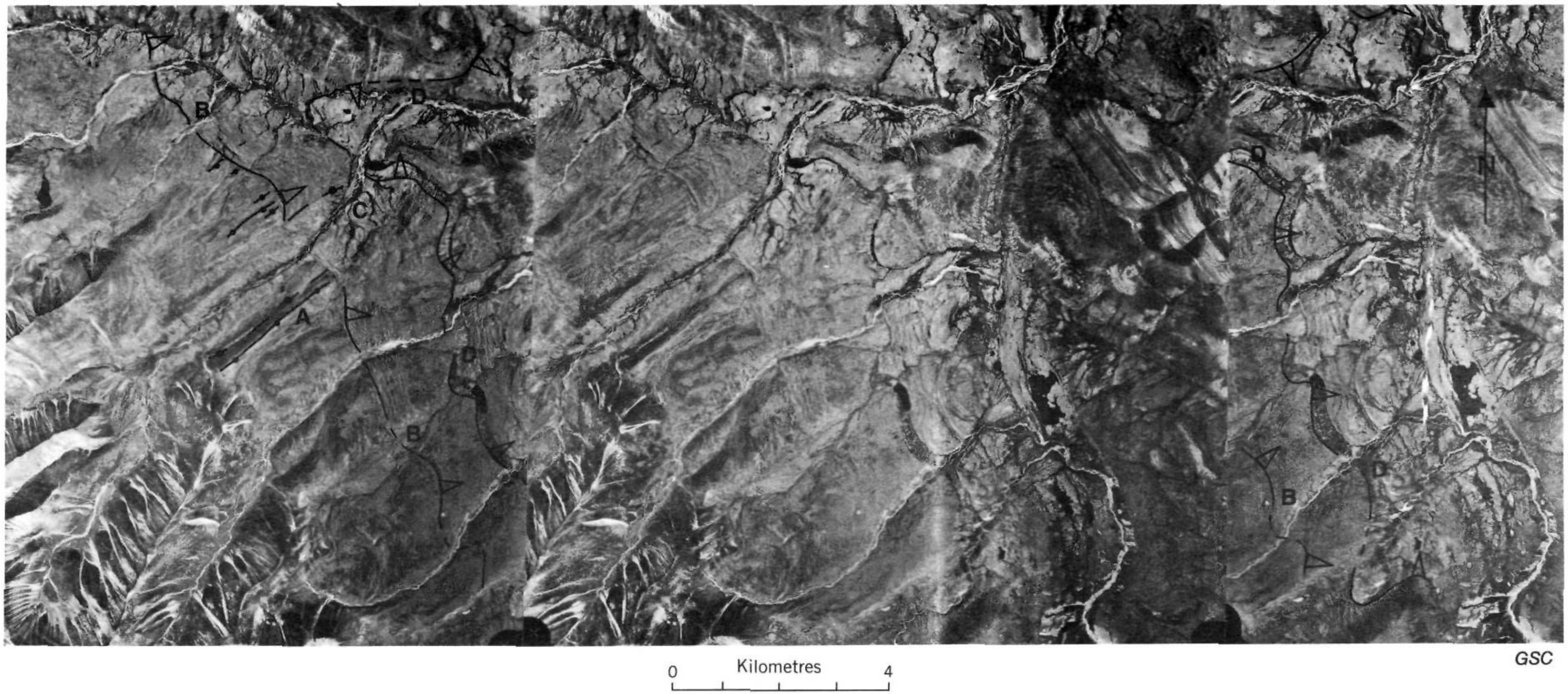
Liens entre les glaciations alpine et laurentidienne dans la chaîne Tigonankweine.

(Fig. 6, A) that indicate one or more advances of a small montane glacier along the southwest fork of Dark Rock Creek from a cirque a few kilometres to the southwest in Tigonankweine Range; (2) the all-time upper limit of Laurentide Glaciation, defined by a sharp upper limit of ice-marginal channels (Fig. 6, B) and a sharp upslope limit to glacial erratics of Shield origin; (3) weakly developed moraines that mark the limit of a later montane glaciation that extended downslope beyond the all-time Laurentide limit. (Fig. 6, C); and (4) kames and ice-marginal channels some 120 m below the all-time Laurentide limit that define an ice-marginal position when a large valley glacier emanating from Moose Horn valley had merged with the Laurentide Ice Sheet (Fig. 6, D).

The core of one of the montane moraine ridges at A is exposed in a gully where the ridge is truncated by a channel that marks the Laurentide limit. Till forming the ridge is very coarse, consisting mainly of subangular to subrounded clasts of quartzite of Tigonankweine Formation which occupies much of the source area (Gabrielse *et al.*, 1973).

The sharply defined limit of Laurentide Glaciation (Fig. 6, B) lies at about 1480 m. The limit is marked by an ice-marginal channel, with a series of subparallel moraine ridges and ice-marginal channels extending downslope. Glacial erratics of Shield origin are common in drift at and below the limit, but are lacking upslope, indicating that the set of ice-marginal features marks the all-time limit of Laurentide Glaciation. The features clearly truncate the montane lateral moraines described above, and are therefore younger than those moraines. Any terminal moraines that might have been associated with the lateral moraines would have been erased during the Laurentide advance.

The proportion of clasts of Shield origin in coarser fractions of the drift at the Laurentide limit has not been determined. Typical values are probably less than 0.5%, but pink granites



A. *Lateral moraines of a montane glacier during penultimate glaciation.*

B. *Upper limit (all time) of the Laurentide ice sheet.*

C. *Lateral and terminal moraines of a montane glacier during the last glaciation.*

D. *Ice-marginal features that mark the margin of merged montane and Laurentide ice.*

FIGURE 6. Relationships between montane and Laurentide glacial limits, southwest Dark Rock Creek area.

Relations entre les limites des glaciers alpins et l'Inlandsis laurentidien dans le sud de la région de Dark Rock Creek.

and gneisses, the most common of the erratics, are conspicuous amongst the quartzites of montane origin, making them seem more abundant.

Moraine ridges and associated ice-marginal channels (Fig. 6, C) mark the terminal and retreatal positions of the latest montane glaciation. There are no exposures of the materials that form the moraines, but scattered shield erratics occur among dominantly quartzite boulders on the moraine surfaces, indicating that the advancing montane ice picked up and redeposited earlier deposits of Laurentide origin.

At 1360 m and below there is a set of kame terraces and ice-marginal channels that lie parallel with the all-time Laurentide limit. No erratics of shield origin were noted at the upper margin of this set of features, and only sparse shield lithology was found at lower levels. The most conspicuous rock type in gravel of the kames and in a till exposure is green siltstone, the nearest source of which is found in Rapitan Group in Moose Horne Valley. The evidence suggests that the kame gravel and till were deposited by a large montane glacier that flowed eastward through Moose Horn Valley. For such a glacier to have flowed northward along the mountain front rather than following the continuation of the valley eastward, would require that it be deflected by some barrier (Fig. 7). The only possible barrier would be the margin of the Laurentide Ice Sheet, the margin having retreated some distance to the east before the montane glacier expanded downvalley to merge with the Laurentide ice. The proposed relationship is similar to that inferred by Stalker (1956) to explain an erratics train in the Foothills of Alberta. There, a large valley glacier emanating from Athabasca Valley and carrying large blocks of distinctive quartzite of the Cavell Formation (now Gog Group) (Mountjoy, 1958) was diverted southward along the mountain front by Laurentide ice, ultimately leaving behind a train of blocks known as the Foothills erratics train, that extends southward almost to the United States border.

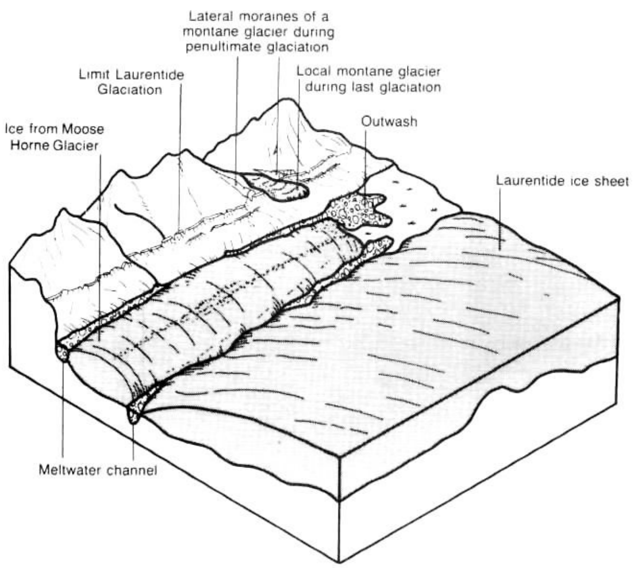


FIGURE 7. Block diagram depicting Moose Horn Glacier being deflected northward by the Laurentide Ice Sheet, at Dark Rock Creek.

Bloc-diagramme montrant le glacier Moose Horn dévié vers le nord par l'Inlandsis laurentidien, à Dark Rock Creek.

DURKAN-LUKAS VALLEY

The principal features of Durkan-Lukas Valley are 1) moraines that record an advance of local montane glaciers from the mountainous upland south of the valley (Fig. 5, A); 2) a large abandoned glacial meltwater channel that formerly drained westward to Keele River (Fig. 5, B) (the channel is incised into the moraines and clearly post-dates them); 3) moraines that record a later advance of local montane glaciers (Fig. 5, C). Two of the moraines extend across and interupt the channel, indicating that they post-date occupation of the channel.

The form of the moraines of the penultimate glaciation of the area indicates that small montane glaciers, emanating from cirques in the mountainous upland south of Durkan-Lucas Valley, merged to form a piedmont glacier that extended across the valley floor. The morainic landforms are subdued, similar to those of the penultimate glaciation in contiguous areas. The channel is part of a system by which Mackenzie Mountain drainage, blocked from access to Mackenzie River by the presence of the Laurentide Ice Sheet, was diverted northwestward through mountain valleys, reaching the mountain front some 200 km to the northwest (Fig. 2).

The exact position of the Laurentide ice margin during the time the channel was active is not apparent on airphotos, and the limits of shield erratics have not been determined in the field. Projection southward of the well defined ice margin in the Dark Rock Creek area indicates that Laurentide ice should have stood above 1500 m at the south end of the ridge that terminates near the confluence of Moose horn River and Parallel Creek. From there, an ice tongue should have extended far up Moose Horn Valley, with secondary tongues extending up Lukas and Parallel creeks, forcing discharge westward in Durkan-Lukas Valley and northward along Parallel Creek. Drainage from the upper part of Moose Horn River would have been diverted westward through a low pass at about 1080 m to Natla River and thence to Keele River.

Moraines of the last glaciation that occur in the middle part of the valley were deposited by glaciers that headed in cirques south of the valley. Two of the moraines extend across and disrupt the meltwater discharge channel. The channel terminates abruptly to the west against a moraine loop that was formed by an ice tongue that extended into the west end of the valley from a major glacier in Keele Valley. The moraines have preservation comparable with that of moraines of the last glaciation in contiguous areas. The relationship of the moraines to the channel indicate that advance of the small montane glaciers and the much larger glacier in Keele Valley culminated after Laurentide source meltwater discharge ceased.

The relationship of penultimate and last local montane glaciations to the discharge channel in Durkan-Lukas Valley repeats the relationship of those glaciations to the all-time Laurentide limit at Dark Rock Creek. In summary, the penultimate glaciation was followed by the Laurentide maximum, during which meltwater discharged westward through Durkan-Lukas Valley. Following retreat of the Laurentide Ice Sheet to a level that meltwater discharge ceased, local montane glaciers readvanced, some of them crossing the abandoned meltwater channel. A large montane glacier in Keele Valley also advanced, blocking the west end of the channel, but there is no evidence as to relative timing of advances of the local and the much larger montane glaciers.

LITTLE BEAR RIVER

The relationships of ice marginal features of Laurentide and montane origin are similar to those described from Dark Rock and Katherine creeks.

Important geomorphic features of the area are 1) an upper limit of glacial erratics of Shield origin and small meltwater channels that mark the all-time limit of Laurentide Glaciation (Fig. 8, A); 2) lateral moraine ridges formed by a local montane glacier that extended downvalley into the area previously occupied by the Laurentide Ice Sheet (Fig. 8, B); and 3) a lower Laurentide limit that appears to truncate the montane moraines (Fig. 8, C). A major meltwater channel (Fig. 8, D, 9) leads northwestward from that lower limit. The channel was probably initiated, however, during the initial advance of the Laurentide Ice Sheet to its maximum position and subsequent retreat from that position.

The all-time Laurentide limit drops rather steeply northwestward from 1260 to 1120 m on slopes south of Little Bear River. Such steep gradients are characteristic of minor ice tongues that extended from the Laurentide Ice Sheet into narrow valleys along the Mackenzie Mountain front. The local montane glacier that succeeded the Laurentide Ice Sheet emanated from cirques in the headwaters of Little Bear River, about 20 km up valley. Lateral moraines built by the glacier are best developed, or perhaps best preserved, on the right side of the valley, where they lie about 160 m below the limit of Laurentide glaciation. Large quartzite boulders derived from Tigonankweine Formation in the upper valley are the most conspicuous component of the moraines. Other rocks derived from up-valley include dolomite and argillite of Proterozoic to Cambrian age (Aitken and Cook, 1974). There are also scattered pink granites and other erratics of Shield origin, incorporated from the earlier deposited Laurentide drift.

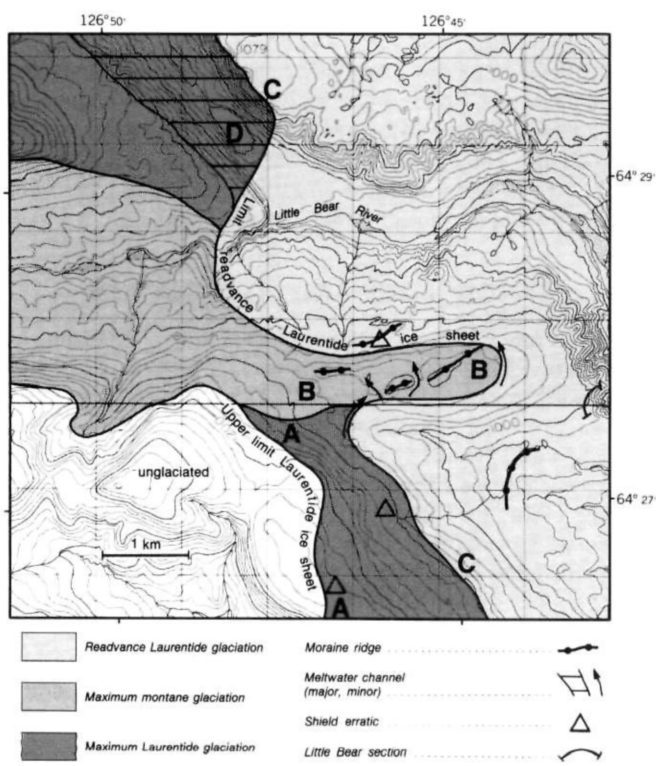


FIGURE 8. Relationships between montane and Laurentide glacial limits, Little Bear Valley.

Liens entre les limites des glaciers alpins et l'Inlandsis laurentidien, vallée de Little Bear.

The most prominent of the lateral moraines is sharply truncated by the lower Laurentide limit. The absence of any features that would suggest merging of montane and Laurentide ice, together with the absence of terminal moraine features in association with the lateral moraines, suggests that the Laurentide ice had retreated from the immediate area before the montane advance culminated. Any terminal features would have been erased by subsequent readvance of the Laurentide ice margin.

With readvance of the Laurentide ice margin, Little Bear River, augmented by meltwater, was again diverted northwestward through the meltwater channel. A paraglacial gravel fan was subsequently deposited in the approaches to the channel and in the channel proper.

The Little Bear River locality is of special interest because of a well exposed section in which five tills of montane origin, each with a paleosol, are overlain by boulder gravel of Laurentide origin (Hughes *et al.*, in preparation). The section will not be discussed here, but geomorphic features discussed above are important in inferring the age of the uppermost of the montane tills in the section.

KATHERINE CREEK

At this locality the principal glacial features are 1) an upper limit of erratics plus a moraine segment that marks the former maximum position of the Laurentide Ice Sheet (Fig. 10, A); 2) lateral moraine ridges that mark the former position of a local

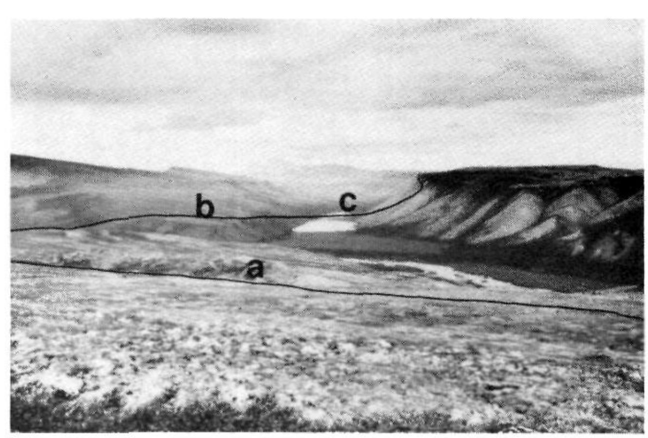


FIGURE 9. Limit of Laurentide readvance (in solid line), marked by a moraine ridge (a), outwash plain (b) and a meltwater channel (c).

Limite de la récurrence laurentidienne (ligne pleine), soulignée par une crête morainique (a), une plaine d'épandage (b) et un chenal d'eaux de fonte (c).

montane glacier that extended down-valley into the area previously covered by the Laurentide Ice Sheet (Fig. 10, B); and 3) a meltwater channel and prominent well preserved Laurentide moraines that truncate the lateral moraines of the montane glacier (Fig. 10, C).

The upper limit of Laurentide Glaciation, inferred from the upper limit of erratics of Shield origin, lies at about 1200 m at a point 5 km south of Katherine Creek and at 1160 m at a point 8 km northwest of Katherine Creek. Glacial erratics are sparse at the surface, so that it is possible that further search may extend the upper limit of Laurentide Glaciation by a few tens of metres. Sparseness of visible erratics may be due to local surface conditions (thick vegetation mat on gentle slopes, blocky bedrock detritus on steep slopes) but may indicate unusually thin Laurentide drift.

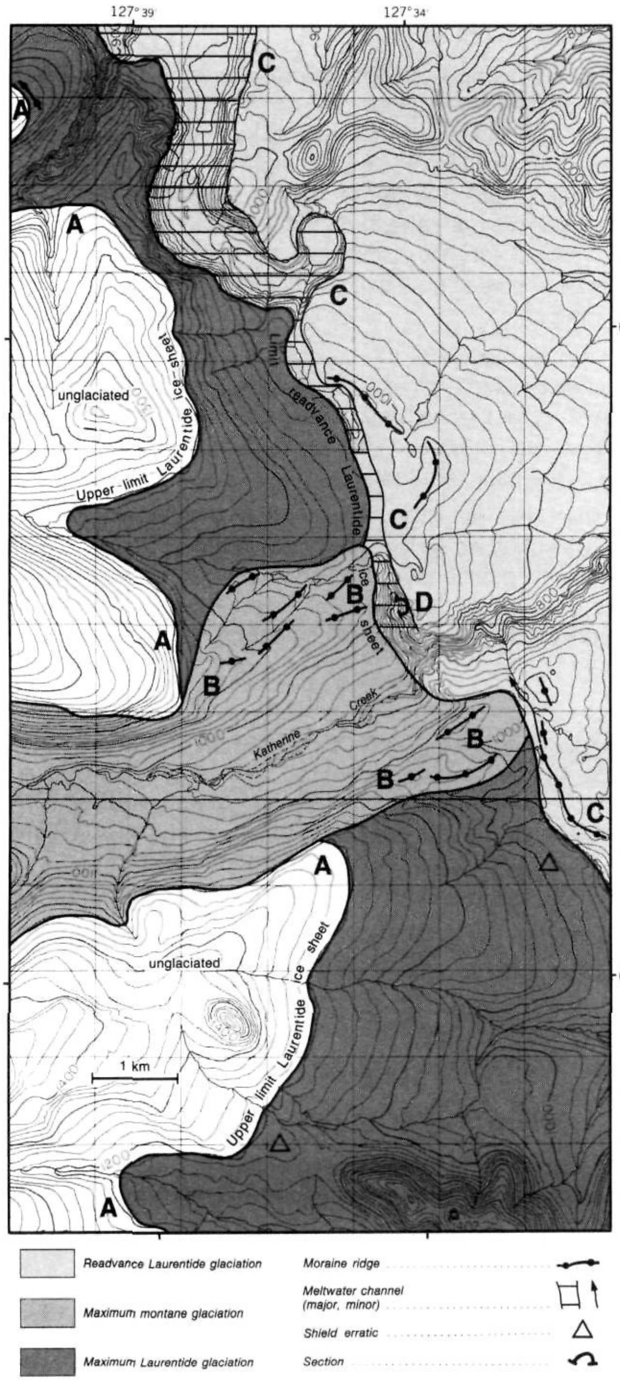


FIGURE 10. Relationships between montane and Laurentide glacial limits, Katherine Creek.

Liens entre les limites des glaciers alpins et l'Inlandsis laurentidien, Katherine Creek.

The montane glacier that produced the lateral moraines emanated from northeast-facing cirques in a prominent ridge with peaks to 2040 m, about 17 km southwest of the point where the moraines are truncated by a meltwater channel. Quartzite of Katherine Group, which occupies the headwaters of Katherine Creek (Aitken and Cook, 1974), dominates the lithology of till in the moraine ridges; minor siltstone is probably from the same source. Rare diabase may be of Shield origin, incorporated from previously deposited Laurentide drift; alternatively, it may be derived from a diabase sill within unmapped Tsezotene Formation, concealed beneath drift or colluvium in the upper part of the valley.

The moraine and associated meltwater channel that define the lower Laurentide limit of the locality are well defined beginning 3 km south of Katherine Creek and extend 4 km north of the creek (Fig. 10). This moraine segment is here named Katherine Creek moraine, and the readvance of the Laurentide Ice Sheet which culminated at the moraine is named Katherine Creek phase.

The moraine crest has elevations up to 1020 m, about 160 m below the all-time Laurentide limit. In a slumped exposure on the east side of a creek tributary to Katherine Creek (Fig. 10, D), bouldery Laurentide drift overlies bouldery drift of montane origin. Three or possibly four weathering zones are discernible in the montane drift, but these have not been examined closely. The evidence suggests that here, as at Little Bear River, there were several separate glaciations of upper Katherine Creek prior to arrival of Laurentide ice.

CHRONOLOGY AND CORRELATION

There are only two radiocarbon dates that relate to the glacial history of Mackenzie Mountains. At Little Bear River section, wood from an organic layer that lies below a till assigned to the penultimate montane glaciation yielded an age greater than 47 ka (GSC-1618). In an exposure in a gully 225 m north of the section, Laurentide drift overlies 5 m of sediment comprising clayey diamicton, cross-bedded sand and alternating cross-beds of sand and diamicton. The cross-bedded sand contains detrital coal, detrital wood and other organic material. A rounded fragment of spruce wood (identified by R. J. Mott) yielded an accelerator age of 44,420 ± 630 years (TO-195) (Hughes *et al.*, in preparation). The date should probably be treated as a minimum. Further, the wood is clearly detrital and may have been retransported from an older unit, in which case the date would have no relevance to glacial events in the area.

In the absence of limiting radiocarbon dates from Mackenzie Mountains, rough approximations of absolute ages of the glacial events can be obtained by correlation with other areas where at least partial dating control exists. The correlations are based, as discussed in the introduction, on the degree of preservation of ice-marginal features in the respective areas, in part supported by comparable soil development.

Reid and McConnell glaciations are now considered to be of Illinoian and Late Wisconsinan age, respectively, on the basis of radiocarbon and U/Th dates (Matthews *et al.*, 1990; Hughes, 1989; see locations of radiocarbon dates Fig. 2, this paper). Radiocarbon dating is inadequate to show whether the last montane glaciation in Southern Ogilvie Mountains was closely correlative or only generally correlative with McConnell Glaciation, and there are no limiting dates for either local or large montane glaciers in the area north of southern Ogilvie Mountains.

Ice-marginal features (Fig. 3) and glacial erratics of Shield origin that mark the all-time limit of the Laurentide Ice Sheet against Mackenzie Mountains can be traced around the west side of Bonnet Plume Depression where it coincides with the limit of Hungry Creek Glaciation (Hughes *et al.*, 1981; Hughes, 1989), and along the east side of Richardson Mountains into the limit of Buckland Glaciation on Yukon Coastal Plain (Rampton, 1982). The Laurentide Ice Sheet advanced over the site of Hungry Creek section sometime after 36,900 ± 300 years BP (GSC-2422). The ice sheet blocked previous eastward drainage of Porcupine River via McDougall Pass in Richardson Mountains, which led to impoundment of a glacial lake that inundated three basins in northern Yukon. Radiocarbon dates from beneath glaciolacustrine sediments in the basins suggest that the advance may have culminated as late as 25 ka ago (Schweger, 1989).

If the relationship between a large montane glacier in Wind Valley (essentially an outlet glacier of the Cordilleran Ice Sheet) and the Laurentide Ice Sheet has been correctly interpreted, then the Cordilleran Ice Sheet, like the large montane glaciers of Mackenzie Mountains, lagged behind the local montane glaciers in responding to climatic change.

Moraines and ice marginal channels correlative with Katherine Creek phase lie above the extrapolated level of Tutsieta Lake Phase (Hughes, 1987) and are judged to the older. The more extensive Sabine phase (Rampton, 1982) is a possible correlative of the Katherine phase.

CONCLUSIONS

Evidence from Dark Rock Creek and Durkan-Lukas Valley is consistent in demonstrating the following glacial sequence: 1) advance of local montane glaciers during a penultimate glaciation 2) advance of the Laurentide Ice Sheet to its all-time maximum position 3) retreat eastward of the Laurentide ice margin 4) a last advance of local montane glaciers (Fig. 11). A large montane glacier that emanated from the headwaters of Natla and Keele rivers pushed easterly along Moose Horn Valley to merge with the Laurentide Ice Sheet and flow northward along the mountain front. The timing of this advance with respect to the advance of small local montane glaciers is not evident at either Dark Rock Creek or Dukan-Lukas Valley. Nor is there evidence as to whether the Laurentide margin was still in retreat, stationary, or possibly readvancing.

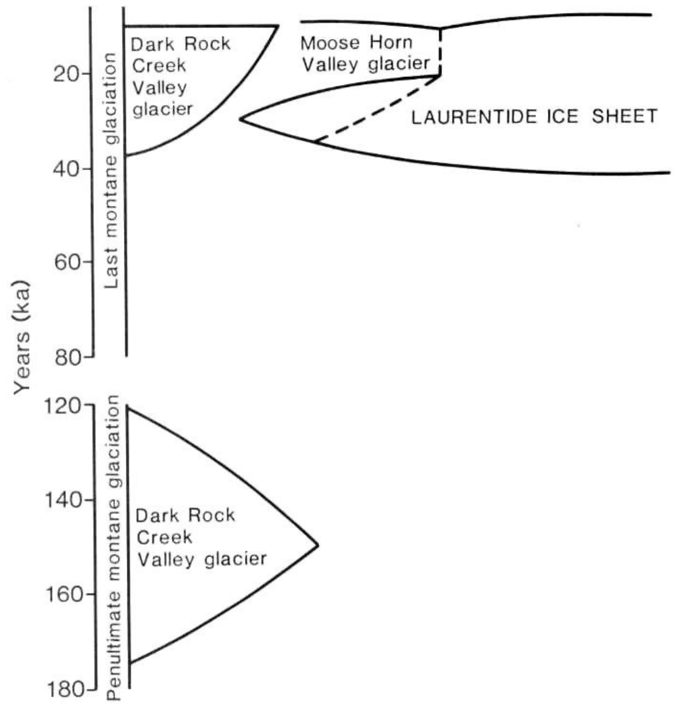


FIGURE 11. Schematic diagram showing inferred age and spatial relationships of montane glaciers and the Laurentide Ice Sheet.

Diagramme schématisé montrant l'âge estimé des glaciers alpins et de l'Inlandsis laurentidien et les liens entre eux.

At Little Bear River and Katherine Creek, although lateral moraines indicate a last montane glacier advance following retreat of the Laurentide ice margin, the moraines are truncated at prominent lower Laurentide ice-marginal positions. The geomorphic relationships imply that the Laurentide Ice Sheet readvanced to the prominent lower limit (Katherine Creek phase) after the local montane glaciers had retreated back up valley.

The merged montane and Laurentide ice at Dark Rock Creek lies 120 m below the all-time Laurentide limit, and the readvance positions at Little Bear River and Katherine Creek 160 m below. Similarity in the relative positions suggests (but does not prove) that the lower Laurentide positions of the three areas were synchronous, and suggest a readvance of the Laurentide ice along at least 150 km of its margin during Katherine Creek phase.

An important implication of assumed synchroniety of lower ice marginal positions is that whereas local montane glaciers had advanced and retreated before the Laurentide readvance, the large valley glacier that merged with Laurentide ice at Dark Rock Creek remained active. Possibly the local montane glaciers that extended on the order of 10 to 20 km from their sources in cirques were more responsive to climatic change than the large montane glacier that originated in icefields and cirques about 190 km away in the Backbone Ranges.

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