# Glacial history of the Mackenzie region

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**Abstract:** The present landscape of the Mackenzie valley is primarily a result of the last continental glaciation which covered most of the area about thirty thousand years ago (30 ka BP). This glaciation resulted in rearrangement of the preglacial drainage system, including redirection of much of the Mackenzie River drainage to the Arctic Ocean. Meltwater channels established along the edge of the retreating ice sheet became parts of present Mackenzie River tributaries. Lakes were impounded by the ice as it retreated rapidly into the present Mackenzie valley area about 13 ka BP. These glacial lakes received silt and clay accumulating to thicknesses of several tens of metres. Today these sediments include some of the more problematic ice-rich materials with which engineers and construction personnel must deal. By 10 ka BP, the Mackenzie valley was ice-free. Northward tilting of the land continuing to empty and shrink the remaining glacial lakes to their present size.

**Résumé :** Le paysage actuel de la vallée du Mackenzie a été principalement façonné au cours de la dernière glaciation continentale, au moment où les glaces ont recouvert presque toute la région il y a quelque 30 000 ans (30 ka). Cette glaciation a réorganisé le réseau hydrographique préglaciaire en redirigeant notamment une grande partie du réseau du fleuve Mackenzie vers l'océan Arctique. Les chenaux d'eau de fonte qui se sont formés en bordure de l'inlandsis en retrait sont devenus des affluents du fleuve Mackenzie actuel. Des lacs ont été créés vers 13 ka par la retenue des eaux de fonte dans l'actuelle vallée du Mackenzie, au front des glaces en retrait rapide. Dans le fond de ces lacs glaciaires, du silt et de l'argile se sont accumulés sur plusieurs dizaines de mètres d'épaisseur. Ce sont ces sédiments qui constituent les matériaux riches en glace qui causent le plus de soucis aux ingénieurs et aux constructeurs. Avant 10 ka, la vallée du Mackenzie était totalement dépourvue de glaces. L'inclinaison vers le nord de la surface du sol a permis la vidange des lacs glaciaires et leur rétrécissement jusqu'à leur taille actuelle.

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## INTRODUCTION

The landscape of the Mackenzie region is largely the result of glacial activity. Since the Late Pliocene, northwestern Canada has been affected by several montane and continental glaciations. (The term ‘montane’ glaciation/glaciers is used here to refer to valley glaciers that occupied the Mackenzie Mountains, and is distinct from the ‘Cordilleran Ice Sheet’ which refers to the continuous carapace of ice that occupied the Selwyn Mountains on the western side of the continental divide.) Montane glaciers extended to the foothills as piedmont lobes, except during the last glaciation when only valley glaciers were present. The earliest montane glaciation of the region, recorded in the Mackenzie Mountains (Fig. 1), is considered to be of Late Pliocene age (Duk-Rodkin et al., 1996). Deposits of the montane glaciations were truncated by the Late Wisconsinan Laurentide Ice Sheet. There is no clear record of how many times continental (Laurentide) ice

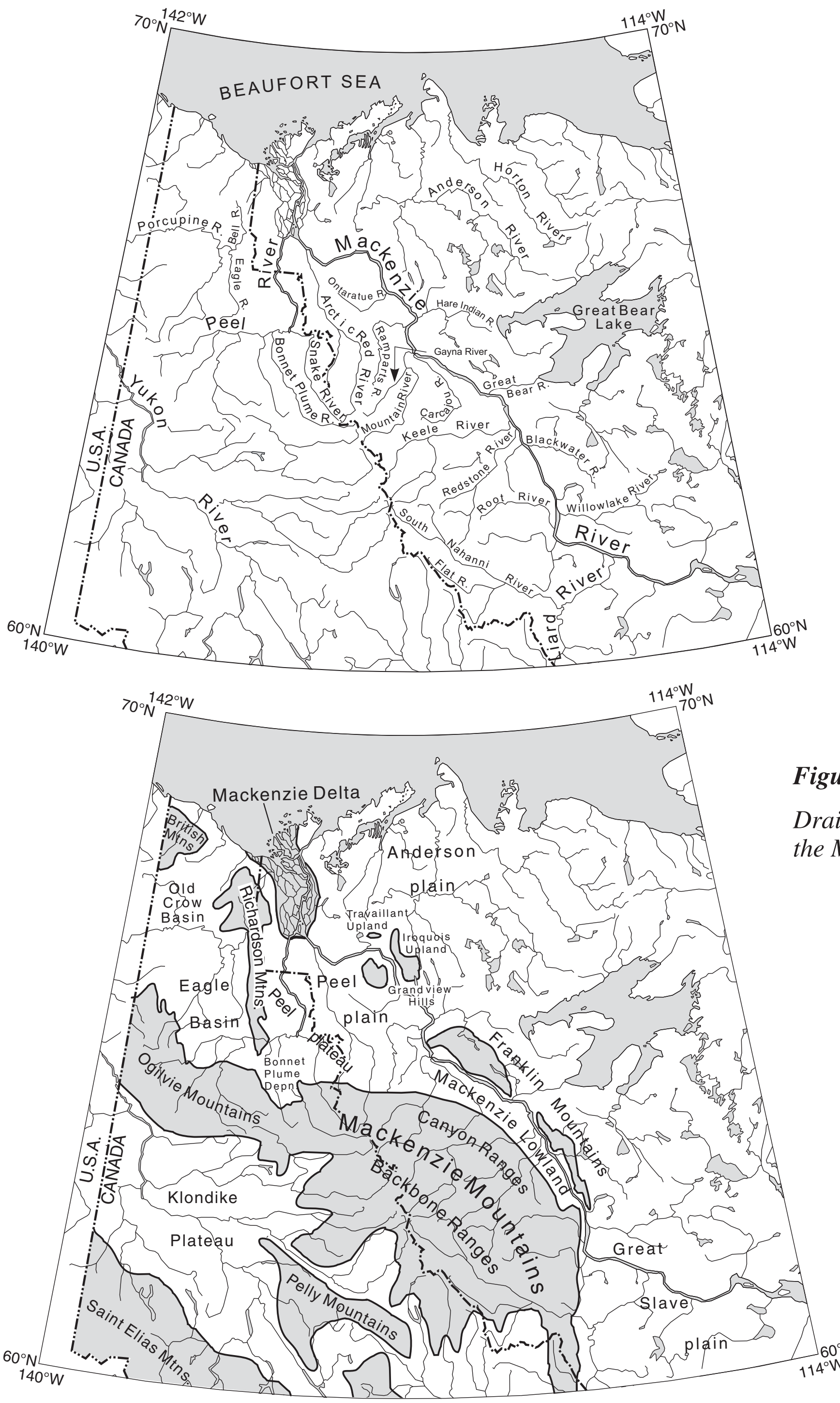


***Figure 1.***

*Drainage and major physiographic features of the Mackenzie region.*

advanced over the Canadian northwest, although at least five glaciations are recorded on Banks Island (Barendregt et al., 1998). The stratigraphic and geomorphic records of the Richardson and Mackenzie mountains indicate that the Late Wisconsinan Laurentide Ice Sheet was the only continental glacier to reach these areas. Prior to glaciation, the Mackenzie River valley had a very different landscape.

During the Late Wisconsinan, continental and montane glacier advances were not synchronous. The Laurentide Ice Sheet reached its maximum about 30 ka BP (thousands of radiocarbon years before present) while montane ice was building near the continental divide in the Backbone Ranges of the Mackenzie Mountains (Fig. 1). The Laurentide Ice Sheet was already retreating when montane glaciers reached their maximum extent; although at a few localities the two coalesced. The glaciers in the mountains retreated rapidly, and by 9 ka BP occupied approximately the same areas as modern glaciers while the margin of the Laurentide Ice Sheet still lay near the eastern boundary of the northern Interior Plains.

## PREGLACIAL DRAINAGE

In preglacial time, drainage extended from the mountains eastward across the entire northern Interior Plains. The modern Mackenzie River formed much later, primarily as a result of glacial erosion and drainage diversion. The region presently drained by the Mackenzie River formerly contributed to two major drainage systems: one entering the north Atlantic (the Bell River system; Fig. 2), the other entering the Arctic Ocean (Porcupine River and Anderson River; Duk-Rodkin and Hughes (1994)). The Porcupine River drained across the Richardson Mountains to the Mackenzie Delta area starting in the Early Eocene (Duk-Rodkin and Hughes, 1994). River terraces in the mountains (Duk-Rodkin and Hughes, 1992) are correlative with alluvial deposits on the eastern side of the delta. The Peel and Snake rivers were tributaries to the Anderson River as indicated by topographic reconstruction of the region, as well as by clasts found in the Anderson River Tertiary deltaic sediments.

Advance of the Late Wisconsinan Laurentide Ice Sheet diverted these preglacial drainage systems. The Porcupine River was directed to the Pacific Ocean via the Yukon River. Drainage as far south as the Athabasca and Peace rivers was diverted northwestward into the Arctic Ocean. A series of ice-marginal and proglacial channels associated with retreat of the Late Wisconsinan Laurentide Ice Sheet integrated drainages to form the Mackenzie River. Most of the rivers occupying the foothills and plains of the Mackenzie region (e.g. Peel, Snake, Ramparts, Mountain, Carcajou, and others) follow former ice-marginal channels for at least part of their modern courses. Hence the Mackenzie River, Canada’s largest drainage system, is entirely postglacial in age and the present interglacial is unique in terms of the amount of fresh water delivered to the Arctic Ocean from North America.

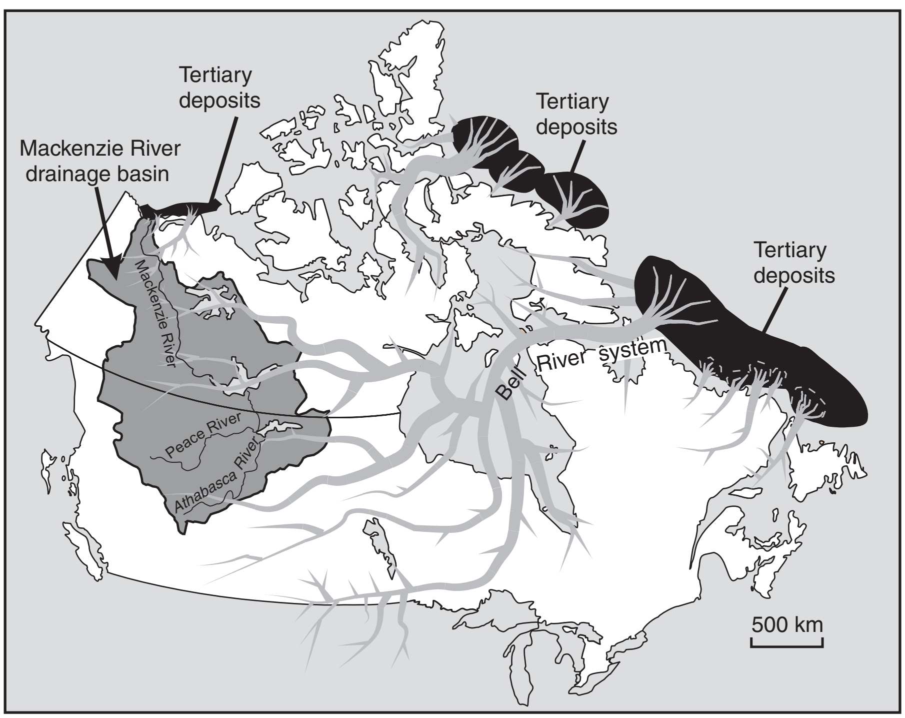


***Figure 2.*** *Late Pliocene to Pleistocene drainage systems (Duk-Rodkin and Hughes, 1994). The modern Mackenzie River flows perpendicular to this drainage, and is a product of glacial diversion.*


***Figure 3.*** *Late Wisconsinan Laurentide maximum, 30–25 ka BP: glacial lakes Old Crow and Hughes at maximum draining via Porcupine River into Alaska; glacial Lake Nahanni forming.*

### *The Laurentide maximum (ca. 30 ka BP)*

During the last glaciation, the Laurentide Ice Sheet moved west and northwest from the Canadian Shield and reached its maximum extent about 30 ka BP (Fig. 3). The ice sheet covered the Mackenzie and Peel plains and abutted the Mackenzie and Richardson mountains, with ice tongues extending up to 50 km up valleys such as those of the Keele, Mountain, Gayna, and Arctic Red rivers. In the Mackenzie Mountains, ice blocked pre-existing drainage and created a complex system of lakes and channels that drained to the northwest. This drainage system crossed the front of the Canyon Ranges and followed the edge of the ice sheet upon reaching Bonnet Plume Depression, where glacial Lake Hughes was formed by damming of the Peel River (Duk-Rodkin and Hughes, 1995). Glacial Lake Hughes spilled northward via the Eagle River outlet channel into glacial Lake Old Crow, formed in the Bell, Old Crow, and Bluefish basins by ice-sheet damming of the eastward-flowing Porcupine River. The outlet of glacial Lake Old Crow cut a canyon that permitted the water to drain westward into the Yukon River drainage system. At this time, montane glaciers formed only an ice cap on the Backbone Ranges of the Mackenzie Mountains.

Glacial lakes were also formed in most Mackenzie and Wernecke mountain drainages that were impounded by the ice sheet. The most important of these was glacial Lake Nahanni which occupied the South Nahanni and Flat river valleys. Thick lacustrine deposits (>30 m) occur in valleys along the southern boundary of the central Mackenzie Corridor (e.g. Mountain, Gayna, Arctic Red rivers).

### *Katherine Creek phase (ca. 22 ka BP)*

By ca. 22 ka BP, the Laurentide Ice Sheet had retreated from its maximum position and readvanced to within less than 200 m of its maximum elevation (Fig. 4). This position records the limit of ice during the Katherine Creek phase of the Laurentide Ice Sheet, and is recorded by ice-marginal channels extending from the southern Mackenzie Mountains to the Richardson Mountains (Lemmen et al., 1994). A readvance is demonstrated in two localities where moraines of the Laurentide Ice Sheet truncate moraines of montane glaciers, which in turn crosscut the slightly higher Laurentide maximum. By this time, the Porcupine River had already been integrated as part of the Yukon River basin, and did not revert to its eastward drainage with the retreat of the Laurentide Ice Sheet. A fluctuating glacier margin in the Bonnet Plume Depression (Hughes et al., 1981) resulted in periodic

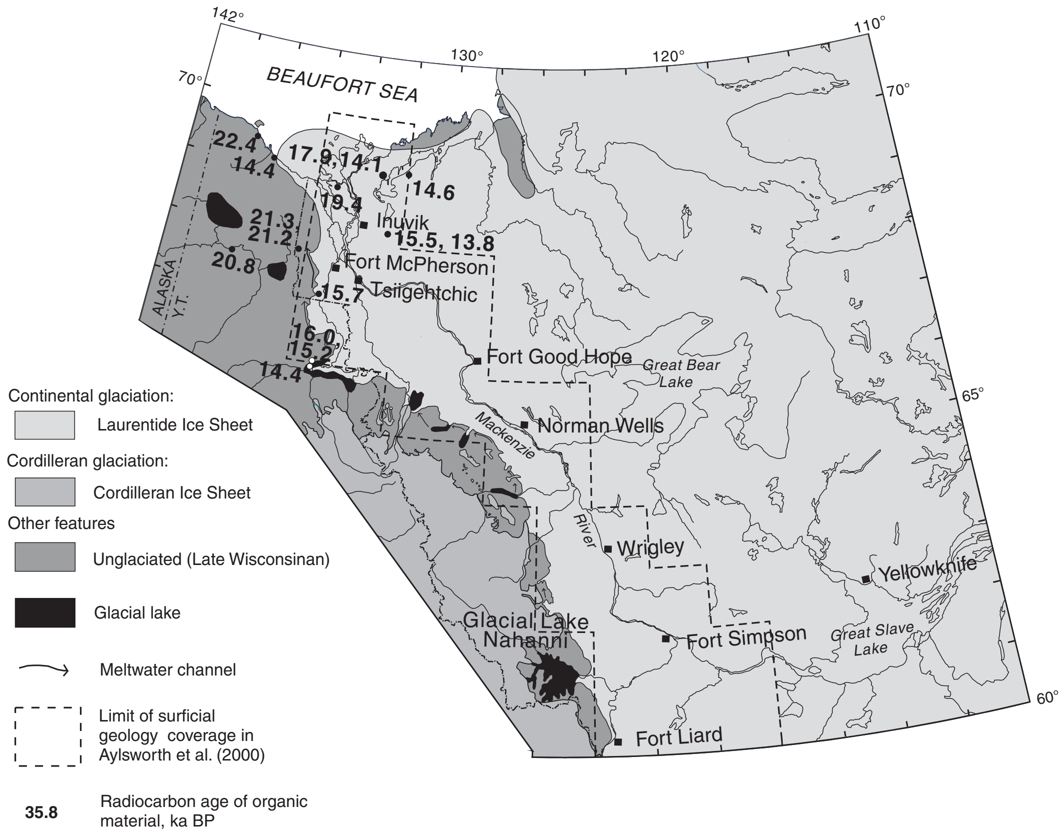


***Figure 4.*** *Katherine Creek phase, 22–18 ka BP: Late Wisconsinan Cordilleran maximum; coalescence of Cordilleran ice with retreating Laurentide Ice Sheet; glacial Lake Nahanni at maximum.*

diversion of the Peel River drainage into Bell Basin. Montane glaciers in the Mackenzie Mountains (there were no glaciers in Richardson Mountains) had advanced to their maxima and contacted the Laurentide Ice Sheet in the Bonnet Plume, Arctic Red and Redstone river valleys. At the Arctic Red River, montane glaciers overrode stagnant Laurentide ice, producing loops of hummocky terrain (Duk-Rodkin and Hughes, 1991).

Glacial Lake Nahanni drained northward along the mountain front at this time, and remained dammed by the ice sheet until ca. 11 ka BP (Lemmen et al., 1994). Locally, the ice sheet impounded drainage, forming temporary glacial lakes on rolling moraine terrain along Peel plateau. Extensive ponding associated with this phase also occurred along the foothills between the Arctic Red River and the Bonnet Plume Depression.

### *Tutsieta Lake phase (ca. 13 ka BP)*

The retreat of both the Laurentide Ice Sheet and montane glaciers occurred after ca. 22 ka BP (Fig. 5). The margin of the Laurentide Ice Sheet just prior to ca. 13 ka BP is recorded by the limit of the Tutsieta Lake phase (Hughes, 1987). At this time, meltwater drained freely along an ice-marginal channel, parts of which are occupied by the modern Hume, Ramparts, Arctic Red, Snake, and Peel rivers (Fig. 1). The Peel River incised the Peel plateau, draining parallel to the mountains and creating a new base level for the drainage of the Richardson Mountains between Bonnet Plume Basin and the Aklavik Range. Meltwater along the north and northeast sides of the ice sheet drained across the Anderson plains.

Local ice-damming of drainages formed temporary lakes, producing a discontinuous blanket of lake sediments that is most extensive on the rolling moraine of the Peel plateau. Postglacial stream incision of up to 500 m has produced spectacular canyons on the Peel plateau.

### *Glacial Lake Travaillant, Mackenzie River outlet, and Arctic Red River meltwater channel phase (ca. 12.5 ka BP)*

Continued southward retreat of the Laurentide Ice Sheet and exposure of a drainage divide resulted in cessation of northward meltwater drainage across the Anderson plain at ca. 12.5 ka BP (Fig. 6). Instead, water flowed south towards the ice sheet and into glacial Lake Travaillant, which occupied the low area between Grandview Hills, and the Iroquois and Travaillant uplands. At its highest level, the lake spilled northward towards the Anderson plain, but later a westward outlet was


***Figure 5.*** *Tutsieta Lake phase, 13 ka BP: retreat of Cordilleran Ice Sheet; drainage across Anderson plain; Cordilleran drainage exiting via Peel River.*


***Figure 6.*** *Glacial Lake Travaillant phase, ca. 12.5 ka BP: formation of proglacial Lake Travaillant in Mackenzie valley; Cordilleran drainage exiting via Arctic Red River.*


***Figure 7.*** *Glacial Lake Ontaratue stage, ca. 12.2 ka BP: formation of proglacial Lake Ontaratue; draining of glacial Lake Travaillant. Cordilleran drainage exiting through Ramparts River.*

established via the Rengleng River, a few kilometres north of the modern Mackenzie River. With further ice retreat, the Mackenzie River became the outlet for glacial Lake Travaillant. An extensive glacial lake occupied upper Arctic Red River valley and drained via an ice-marginal channel that defines the modern route of lower Arctic Red River.

Both the Mackenzie and Arctic Red rivers cross extensive plains (approximately 3500 km$^2$) blanketed by glaciolacustrine sediments (3–30 m thick) deposited in glacial lakes during this stage.

### *Glacial Lake Ontaratue phase (12.2 ka BP)*

Further retreat of the Laurentide Ice Sheet resulted in mountain waters flowing to the ice-sheet margin via the lower Ramparts River. The water was impounded against the slopes of a low interfluve forming glacial Lake Ontaratue. At its maximum level, the lake drained towards the Arctic Red River, but with continued ice retreat a second outlet (Ontaratue River) was established to the northeast with drainage entering the receding glacial Lake Travaillant (Fig. 7). By this time, the Mackenzie River had cut a canyon through bedrock at Tsiigehtchic (formerly Arctic Red River), establishing a permanent channel for meltwater originating from both sides of the ice sheet located upvalley.

Glacial lake sediments associated with this stage cover approximately 3000 km$^2$ with an average thickness of 15 m.

### *Early glacial Lake Mackenzie and Kelly Lake phase (12–11.5 ka BP)*

Glacial Lake Ontaratue extended southward with retreat of the ice sheet, establishing the early stages of glacial Lake Mackenzie (Fig. 8). The northwest extension of glacial Lake Ontaratue was abandoned, with Ontaratue River serving as the lake outlet during surges of the retreating ice sheet (Duk-Rodkin and Hughes, 1995). The outlet of glacial Lake Mackenzie into the Mackenzie River was established at The Ramparts. At that time the ice sheet occupied the vicinity of Norman Wells around Kelly Lake and extended as far north as the Mountain River. The lower Mountain River served as the collector of meltwater drainage from the Mackenzie Mountains, and deposited an extensive deltaic complex into glacial Lake Mackenzie that extended from the mountain front to a few kilometres north of the confluence with the Mackenzie River. An ice-marginal channel along the slope of the Canyon Ranges was the major tributary to the Mountain River and carried waters from as far south as the Keele River.

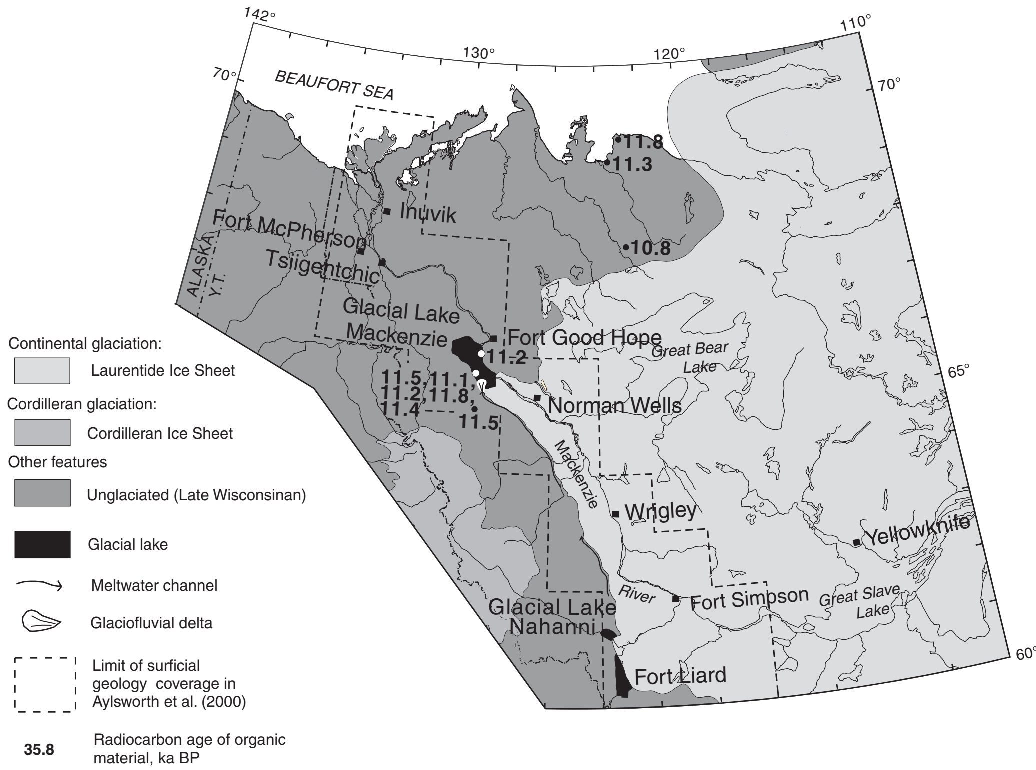


*Figure 8. Early glacial Lake Mackenzie, 12–11.5 ka BP: further downwasting of Cordilleran Ice Sheet, formation of glacial Lake Mackenzie; draining of glacial Lake Nahanni. Cordilleran drainage exiting via Mountain River.*

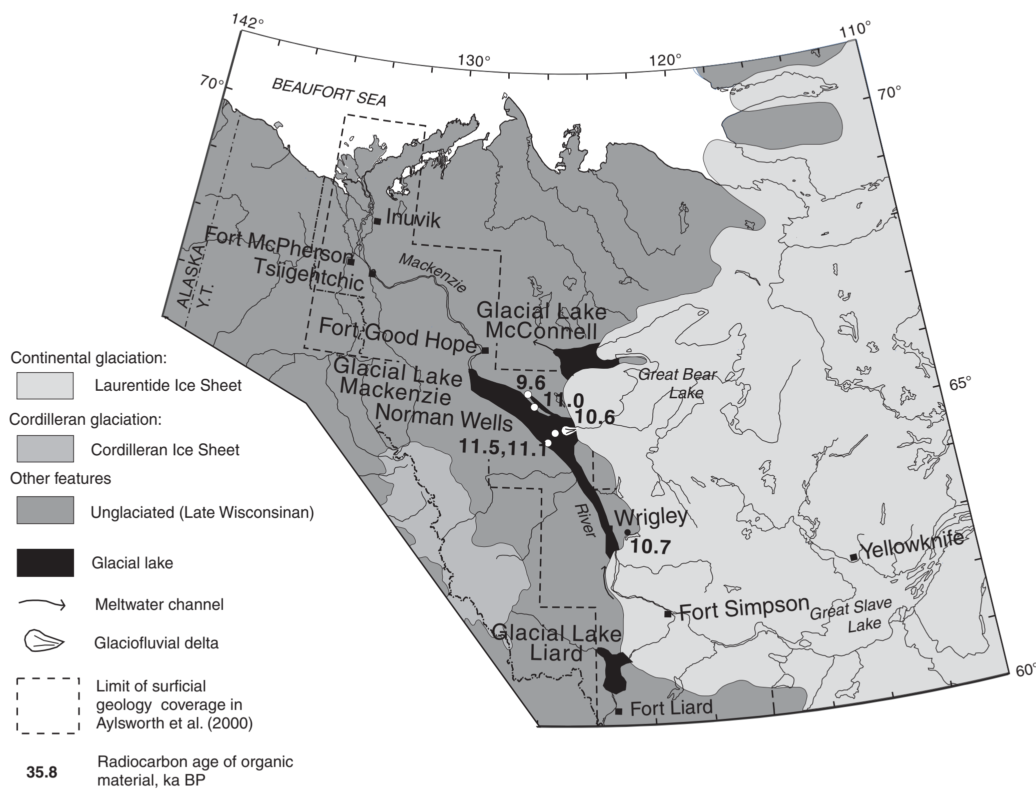


*Figure 9. Middle glacial Lake Mackenzie and early glacial Lake McConnell, 11.0 ka BP: glacial Lake Mackenzie occupying Mackenzie Lowland; early state of glacial Lake McConnell occupying Smith Arm of Great Bear Lake.*

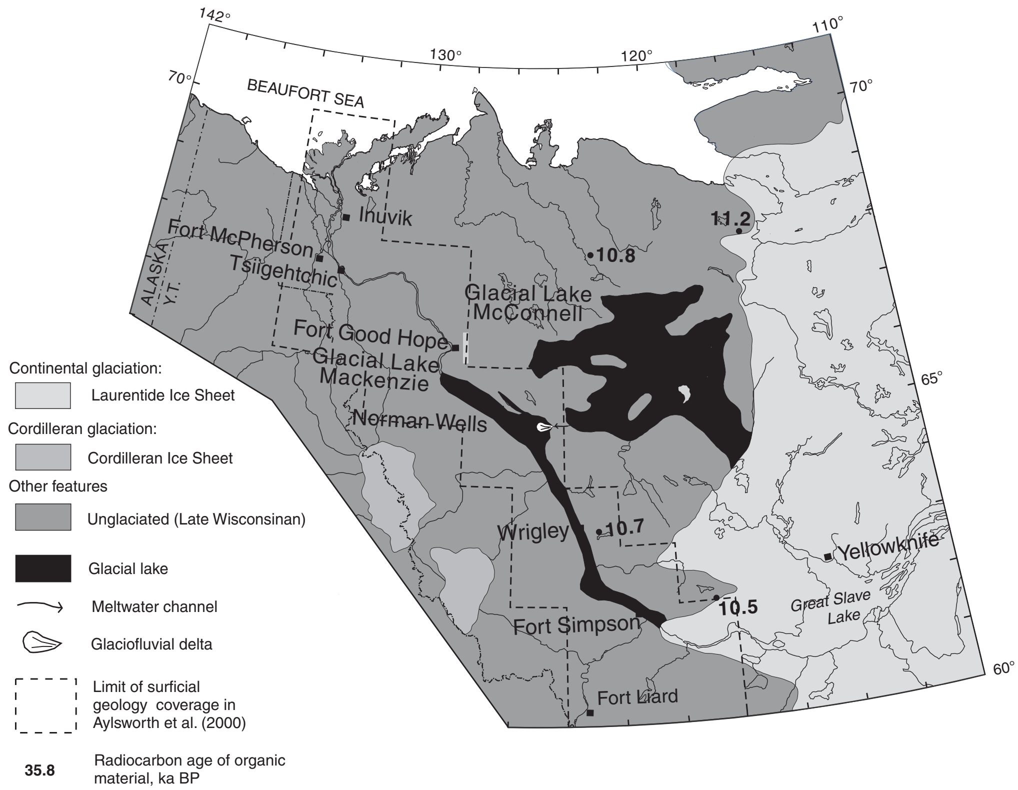


***Figure 10.*** *Late glacial Lake Mackenzie and early glacial Lake McConnell 11–10.5 ka BP: glacial Lake Mackenzie at maximum; glacial Lake McConnell occupying Great Bear Depression; glacial Lake Liard draining into glacial Lake Mackenzie.*

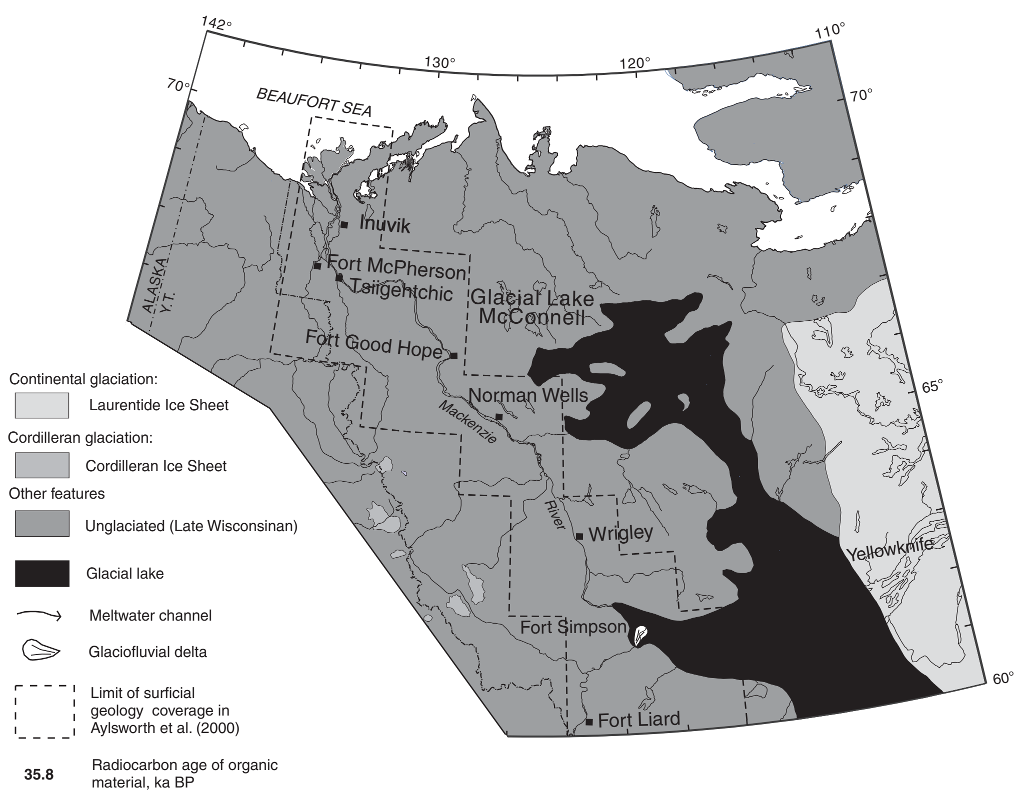


***Figure 11.*** *Glacial Lake McConnell, 10.0 ka BP: glacial Lake McConnell at maximum, occupying Great Bear and Great Slave basins.*

Glacial lake sediments extend along the Mackenzie River between the mouth of the Mountain River and Fort Good Hope (The Ramparts) and are up to 30 m thick.

### *Middle glacial Lake Mackenzie and early glacial Lake McConnell (11 ka BP)*

Glacial Lake Mackenzie expanded southward, occupying the Mackenzie Lowland, in association with continued ice-sheet retreat (Smith, 1992). At ca.11 ka BP, the ice sheet abutted the eastern and southern flanks of the McConnell Range and contacted the lake within the Mackenzie River valley (Lemmen et al., 1994; Fig. 9). Several meltwater channels contributed inflow to the eastern side of glacial Lake Mackenzie, constructing small deltas that indicate the lake reached a maximum elevation of 175 m a.s.l. In the southern Mackenzie Mountains, the Laurentide Ice Sheet still dammed glacial lakes in lower Liard and South Nahanni river valleys (Lemmen et al., 1994). Retreat of ice in the Great Bear Basin produced the earliest phase of glacial Lake McConnell, which drained via the Hare Indian River (Lemmen et al., 1994).

Lacustrine deposits related to this period form a discontinuous blanket along the lowlands of the Mackenzie River, which are more than 30 m thick in some locations south of the Great Bear River and north of the Redstone River.

### *Late glacial Lake Mackenzie and early glacial Lake McConnell (11–10.5 ka BP)*

Retreat of the Laurentide Ice Sheet to the eastern flanks of the Horn Plateau by ca.10.5 ka BP drained glacial lakes in the Liard and Nahanni river valleys, and resulted in the deposition of a large delta where Liard River entered glacial Lake Mackenzie (Lemmen et al., 1994; Fig. 10). At this time glacial Lake Mackenzie had expanded southeastward towards what would become the central basin of glacial Lake McConnell. Glacial Lake McConnell occupied an area slightly larger than present day Great Bear Lake, with its outlet via the route of Great Bear River which contributed to glacial Lake Mackenzie.

### *Glacial Lake McConnell (10 ka BP)*

Although the Mackenzie Corridor was free of ice by 10 ka BP, it was still affected by Lake McConnell, which had expanded to become the second-largest Pleistocene lake in North America, covering all of the modern Great Bear, Great Slave, and Athabasca basins (Lemmen et al., 1994; Fig. 11). It has also been proposed that glacial Lake Agassiz, occupying much of Manitoba and significant areas of northern Saskatchewan and northern Ontario, flowed northward into the Mackenzie Basin, beginning about 9.9 ka BP (Smith and Fisher, 1993). If this hydrological connection existed, it would have approximately doubled the size of the Mackenzie River drainage basin for about 400 years.

## ACKNOWLEDGMENTS

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