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QUATERNARY GEOLOGY OF NORTHEASTERN ALBERTA

J.M. Bednarski

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Cover illustration

A photograph of the gravel pit near Myers Lake showing a cross-section through the Slave moraine. Note the coarse glacial diamicton and interbedded gravel lenses steeply dipping to the southwest. Glaciolacustrine varves overlie the gravel in the upper right of the photograph. Photograph by J. Bednarski. GSC 1998-073A

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CONTENTS

Illustrations

QUATERNARY GEOLOGY OF NORTHEASTERN ALBERTA

Abstract

The Kazan upland, the only surface exposure of Precambrian shield in Alberta, was extensively scoured by the Laurentide Ice Sheet during the last glaciation and is now sparsely covered by glacial deposits. In contrast, areas underlain by Paleozoic sedimentary rocks west of the Slave River are covered by widespread glacial, deltaic, and lacustrine sediments.

The ice sheet flowed southwestward over the area during the last glacial maximum, but the pattern of ice flow changed during deglaciation when two distinct lobes developed. A westward-flowing ice lobe, occupying the Lake Athabasca basin, converged with southwesterly flowing ice north of it. The lateral contact between the two lobes is marked by converging striae and a broad east-west band of glacial outwash and lake sediments.

As the ice sheet retreated eastward, the Slave River lowland and Lake Athabasca basin were flooded from the north by glacial Lake McConnell. The ice sheet formed an extensive ice dam along the western edge of the Kazan upland and glacial Lake McConnell reached about 305 m a.s.l. near present-day Lake Athabasca. The Slave moraine marks the position of this ice front and is correlative with the 10 ka BP Cree Lake moraine of northeastern Saskatchewan.

As glacial Lake McConnell drained, a large delta formed in the Slave River lowland depositing sand over the glaciolacustrine mud. The delta was at its largest when Lake Athabasca separated from glacial Lake McConnell between 9 and 8 ka BP. Later, in the Holocene, the Peace and Slave rivers incised the older deltaic sediments, forming the modern Peace River–Athabasca River delta.

Résumé

Les hautes terres de Kazan, qui renferment les seuls affleurements du bouclier précambrien en Alberta, ont été soumises à un vaste décapage par l'Inlandsis laurentidien au cours de la dernière glaciation. Actuellement, elles sont parsemées de dépôts glaciaires. À l'opposé, les régions de roches sédimentaires paléozoïques à l'ouest de la rivière Slave sont recouvertes par des sédiments glaciaires, deltaïques et lacustres répandus.

Au cours du dernier pléniglaciaire, l'inlandsis s'est écoulé vers le sud-ouest sur l'ensemble de la région, mais la configuration de l'écoulement glaciaire s'est modifiée au cours de la déglaciation alors que deux lobes glaciaires distincts se sont développés. Un lobe à écoulement vers l'ouest, qui remplissait le bassin du lac Athabasca, a convergé vers des glaces au nord du lobe qui s'écoulaient vers le sud-ouest. Le contact latéral entre les deux lobes est marqué par des stries convergentes et par une large bande de direction est-ouest de dépôts d'épandage fluvioglaciaire et de sédiments lacustres.

Au fur et à mesure que l'inlandsis a reculé vers l'est, les basses-terres de la rivière Slave et le bassin du lac Athabasca ont été inondés à partir du nord par le Lac glaciaire McConnell. L'inlandsis a formé une vaste barrière de glace le long de la bordure occidentale des hautes terres de Kazan et le niveau du Lac glaciaire McConnell s'est élevé à environ 305 m au-dessus du niveau de la mer à proximité de l'actuel lac Athabasca. La moraine de Slave marque la position du front glaciaire et peut être mise en corrélation avec la moraine de Cree Lake de 10 ka située dans le nord-est de la Saskatchewan.

Le Lac glaciaire McConnell s'est vidé et un grand delta s'est constitué dans les basses terres de la rivière Slave, déposant du sable sur les boues glaciolacustres. Le delta a atteint sa superficie maximale au moment où le lac Athabasca s'est séparé du Lac glaciaire McConnell il y a entre 9 et 8 ka. Par la suite, au cours de l'Holocène, la rivière de la Paix et la rivière Slave ont incisé les sédiments deltaïques plus anciens, ce qui a engendré la formation de l'actuel delta de la rivière de la Paix et de la rivière Athabasca.

SUMMARY

The surficial geology of northeastern Alberta was mapped in detail as part of the Canada-Alberta Mineral Development Agreement. The project resulted in five 1:100 000 scale maps and GSC reports on till geochemistry. This report describes the surficial deposits in detail and provides an interpretation of the Quaternary history.

The maps cover the area between 58°40′N and 60°N and 110°W and 112°W, about 15 200 km², and include the only portion of the Canadian Shield exposed in Alberta, the southern Kazan upland. The shield is bounded to the south by Lake Athabasca and to the west by lowlands underlain by flat-lying Paleozoic rocks along the Peace and Slave rivers. These lowlands, part of the southern Great Slave plain, are covered by the Peace River–Athabasca River delta, a flat expanse of Pleistocene to Holocene deltaic and lacustrine sediment deposited into glacial Lake McConnell. The Athabasca plain, the third major physiographic element in the map area, forms a large embayment into the western part of the Kazan upland. This part of the Precambrian shield is composed of thick, unmetamorphosed Middle Proterozoic sedimentary rocks (Athabasca Group) that unconformably overlie the basement. Lake Athabasca (8080 km² at 210 m a.s.l.) lies along the northern margin of the Athabasca plain and defines the southern limit of the map area. The topographic depression that contains Lake Athabasca is probably a glacially eroded trough.

Surficial deposits have been divided according to age, genesis, and type of depositional environment. Generally, most surficial materials derived from the shield and the Athabasca Group are very sandy which complicates genetic interpretations. This is particularly problematic where extensive reworking by fluvial and eolian processes occurred during deglaciation. Till and ice-contact glaciofluvial sediment were deposited during the Late Wisconsinan and early Holocene in glacial environments. Nonetheless, most of the glacial materials were reworked during deglaciation and deposited in proglacial environments peripheral to the ice sheet. The dominant materials deposited in proglacial environments were glacial outwash, lake sediment, and to a lesser extent, eolian sediment. Proglacial sediments generally decrease in age eastward because the proglacial zone followed the eastward retreat of the ice front.

Till cover is sparse on the Kazan upland and is usually only found on the lee side of prominent outcrops. In large areas it forms a thin (<1 m thick) discontinuous veneer of unconsolidated drift, comprising a coarse sandy matrix with erratics and striated clasts. Although most of the material was derived only a few kilometres upstream, some volcanic erratics originate several hundred kilometres to the northeast. Thicker, siltier till is more common over the Paleozoic rocks west of the Slave River.

SOMMAIRE

Les dépôts superficiels du nord-est de l’Alberta ont été cartographiés systématiquement dans le cadre de l’entente entre le Canada et l’Alberta sur l’exploitation minérale. Le projet a permis à la CGC de réaliser cinq cartes à l’échelle du 1/100 000 et des rapports sur la géochimie du till. Le présent bulletin décrit en détail les dépôts superficiels et propose une interprétation du Quaternaire.

Les cartes portent sur la région d’environ 15 200 km² entre 58° 40′ et 60° de latitude N. et entre 110° et 112° de longitude W., incluant la seule portion du Bouclier canadien qui affleure en Alberta, soit la partie méridionale des hautes terres de Kazan. Le bouclier est limité au sud par le lac Athabasca et à l’ouest par les basses terres de roches planes paléozoïques le long de la rivière de la Paix et de la rivière Slave. Ces basses terres, qui font partie de la portion méridionale de la plaine du Grand lac des Esclaves, sont recouvertes par le delta de la rivière de la Paix et de la rivière Athabasca, étendue plane de sédiments deltaïques et lacustres qui s’échelonnent du Pléistocène à l’Holocène et qui se sont déposés dans le Lac glaciaire McConnell. La plaine d’Athabasca, le troisième élément géomorphologique important de la région cartographique, forme une grande baie dans la partie occidentale des hautes terres de Kazan. Cette portion du bouclier précambrien comporte des roches sédimentaires épaisses non métamorphisées du Protérozoïque moyen (Groupe d’Athabasca) qui reposent en discordance sur le socle. Le lac Athabasca (8 080 km² à 210 m au-dessus du niveau de la mer) se trouve le long de la bordure septentrionale de la plaine d’Athabasca et constitue la limite méridionale de la région cartographique. La dépression qui contient le lac Athabasca serait une cuvette érodée par les glaces.

Les dépôts superficiels ont été regroupés selon leur âge, leur genèse et le type de milieu de sédimentation. En règle générale, la plupart des matériaux superficiels dérivés du bouclier et du Groupe d’Athabasca sont très sableux, ce qui rend les interprétations génétiques difficiles, tout particulièrement là où les processus fluviatiles et éoliens ont provoqué de vastes remaniements au cours de la déglaciation. Le till et les sédiments fluvioglaciaires de contact glaciaire se sont déposés dans des milieux glaciaires au cours du Wisconsinien supérieur et de l’Holocène inférieur. Néanmoins, la plupart des matériaux glaciaires ont été remaniés au cours de la déglaciation et se sont déposés dans des milieux proglaciaires à la périphérie de l’inlandsis. Les matériaux prédominants déposés dans les milieux proglaciaires sont des dépôts d’épandage fluvioglaciaire, des sédiments lacustres et dans, une mesure moindre, des sédiments éoliens. L’âge des sédiments proglaciaires décroît généralement vers l’est, car la zone proglaciaire a suivi le recul du front glaciaire vers cette même direction.

La couverture de till est éparse sur les hautes terres de Kazan, ne se rencontrant généralement qu’en aval des affleurements proéminents. Dans de vastes régions, elle forme un placage (<1 m d’épaisseur) discontinu de sédiments glaciaires meubles comprenant une matrice sableuse à grain grossier, des blocs erratiques et des clastes striés. Bien que la plupart des matériaux proviennent d’une région située à quelques kilomètres en amont, certains blocs erratiques volcaniques sont originaires d’une région située à plusieurs centaines de kilomètres au nord-est. Du till plus épais de contenu silteux plus important se rencontre plus fréquemment sur les roches paléozoïques à l’ouest de la rivière Slave.

Glacial meltwater extensively reworked till on the Kazan upland and glacial diamictons are commonly found interbedded with glaciofluvial gravels along former ice margins. The Slave moraine is a good example. This extensive moraine formed during deglaciation when the Laurentide Ice Sheet stabilized along the western margin of the Kazan upland. The Slave moraine formed in a subaqueous environment because glacial Lake McConnell was in contact with the ice margin at this time. The Slave moraine is thought to be the northern extension of the Cree Lake moraine of northern Saskatchewan which dates about 10 ka BP. Subsequent, rapid retreat of the ice sheet is marked by De Geer moraines in lowlands north of Lake Athabasca.

Glaciofluvial sediment was deposited by meltwater streams either in an ice-contact environment or as proglacial outwash. Coarse glaciofluvial deposits on the Kazan upland can be up to 40 m thick and generally contain subrounded to well rounded pebbles to boulders with rudimentary bedding. Some of the outwash is pitted with kettles indicating meltout of buried glacial ice. In places meltwater channels flowed into lakes forming glaciofluvial deltas. The largest volume of glaciofluvial sediment is found in a zone extending from Colin Lake to Bocquene Lake, within the Colin Lake interlobate moraine, and along the north shore of Lake Athabasca, northeast of Fort Chipewyan. The Colin Lake interlobate moraine was formed along the lateral margin of two lobes within the Laurentide Ice Sheet during the waning phase of glaciation.

Glaciolacustrine sediments were deposited in ice-dammed lakes along the margin of the Laurentide Ice Sheet. Glacial lake sediments on the Kazan upland in the eastern part of the map area have little clay and are mostly unlaminated fine sand and silt confined to valley bottoms and depressions. In places they are similar to outwash sand, except with an absence of pebbles and a slight increase in silt content. The greatest volume of glaciolacustrine sediment is found on the Great Slave plain and underlying the Peace River–Athabasca River delta, where it forms flat, poorly drained ground. Most of this sediment was deposited in glacial Lake McConnell shortly after deglaciation of the Slave River lowland. Glacial Lake McConnell reached a maximum level of about 305 m a.s.l. along present Lake Athabasca at about 10 ka BP. During this time it extended northward to Great Bear Lake basin, reaching more than 215 000 km^2. The lake was short lived at this size because of rapid glacio-isostatic rebound. Glaciolacustrine varves suggest that glacial Lake McConnell did not remain at its maximum for much more than 50 a and drained from the area within 200 a.

When glacial Lake McConnell separated into Great Slave Lake and Lake Athabasca, a large volume of deltaic sand was deposited over glaciolacustrine sediment on the Great Slave plain. Younger alluvium and delta sediment have been inset into the older delta by the Peace and Slave rivers. As glacial Lake McConnell drained, large plains of lacustrine and deltaic material

Les eaux de fonte ont remanié considérablement le till des hautes terres de Kazan et des diamictons glaciaires sont souvent interstratifiés dans des graviers fluvioglaciaires le long d'anciennes marges glaciaires. La moraine de Slave en est un bon exemple. Cette vaste moraine a vu le jour au cours de la déglaciation lorsque l'Inlandsis laurentidien s'est stabilisé le long de la bordure occidentale des hautes terres de Kazan. Elle s'est formée dans un milieu subaquatique parce qu'à cette époque, le Lac glaciaire McConnell était en contact avec la marge glaciaire. Elle correspondrait à la prolongation septentrionale de la moraine de Cree Lake, dans le nord de la Saskatchewan, dont l'âge se situe à environ 10 ka. Le recul rapide et ultérieur de l'inlandsis est marqué par la présence de moraines de De Geer dans les basses terres au nord du lac Athabasca.

Des cours d'eau de fonte ont déposé des sédiments fluvioglaciaires soit dans un milieu de contact glaciaire, soit sous forme de dépôts proglaciaires. Sur les hautes terres de Kazan, les dépôts fluvioglaciaires à grain grossier, dont l'épaisseur peut atteindre 40 m, renferment généralement des galets et jusqu'à des blocs subarrondis à bien arrondis qui montrent un litage rudimentaire. Certains dépôts d'épandage fluvioglaciaire sont criblés de kettles, indicateurs de fonte de glace glaciaire enfouie. Par endroits, les chenaux d'eau de fonte se sont versés dans des lacs pour former des deltas fluvioglaciaires. Le volume le plus important de sédiments fluvioglaciaires se rencontre dans une zone s'étendant du lac Colin au lac Bocquene, à l'intérieur de la moraine interlobaire de Colin Lake et le long de la rive septentrionale du lac Athabasca, au nord-est de Fort Chipewyan. La moraine interlobaire de Colin Lake s'est constituée le long de la bordure latérale de deux lobes au sein de l'Inlandsis laurentidien, au cours de la phase d'amaigrissement des glaces.

Les sédiments glaciolacustres se sont déposés dans des lacs de barrage glaciaire en bordure de l'Inlandsis laurentidien. Sur les hautes terres de Kazan, les sédiments de lac glaciaire dans la partie est de la région cartographique contiennent peu d'argile et se composent principalement de sable fin et de silt non stratifiés confinés dans les fonds de vallée et les cuvettes. Par endroits, ils sont semblables à des sables d'épandage fluvioglaciaire, sauf qu'ils sont dépourvus de galets et contiennent un peu plus de silt. Le volume de sédiments glaciolacustres le plus important se rencontre dans la plaine du Grand lac des Esclaves et sous le delta de la rivière de la Paix et de la rivière Athabasca où ils forment un terrain plat mal drainé. La plus grande partie de ces sédiments s'est déposée dans le Lac glaciaire McConnell peu après la déglaciation des basses terres de la rivière Slave. Le Lac glaciaire McConnell a atteint son niveau maximal d'environ 305 m au-dessus du niveau de la mer le long de l'actuel lac Athabasca il y a environ 10 ka. Au cours de cette période, il se prolongeait vers le nord jusqu'au bassin du Grand lac de l'Ours pour atteindre une superficie de plus de 215 000 km^2. En raison d'un rapide relèvement isostatique, il a conservé cette superficie maximale peu longtemps, sans doute pas plus de 50 ans, comme semble l'indiquer la présence de varves glaciolacustres, et il se serait retiré de la région en moins de 200 ans.

Lorsque le Lac glaciaire McConnell s'est dédoublé pour former le Grand lac des Esclaves et le lac Athabasca, de vastes quantités de sable deltaïque se sont déposées sur les sédiments glaciolacustres de la plaine du Grand lac des Esclaves. La rivière de la Paix et la rivière Slave ont transporté des alluvions et des sédiments deltaïques plus récents dans le delta plus ancien. Au fur et à mesure que le Lac glaciaire McConnell s'est vidé, de grandes plaines de were exposed to intense wind erosion. Eolian deposits including sheets of windblown sand and dune fields are common throughout the area. The western edge of the map area includes the Wood Buffalo sand hills, an area of particularly large dunes up to 30 m high, formed because of the readily available sand from the Pleistocene delta. Parabolic dunes on the Kazan upland are common northwest of Hooker Lake and south of Woodman Lake, within the zone of the Colin Lake interlobate moraine. Most of the dunes in the map area have a predominant elongation to the northwest implying strong surface winds from the southeast. This is diametrically opposite to the predominant present-day winds that blow out of the northwest. This suggests that the dunes date from early postglacial time when a persistent anticyclone was centred over the Laurentide Ice Sheet and dominated the regional circulation.

Under nonglacial conditions that prevailed during the latter part of the Holocene, large volumes of sediment were deposited by the Peace River prograding into Lake Athabasca. Historically, the delta flooded seasonally depositing large volumes of silt and fine-grained sand. Nonetheless, over the last few decades the flow of the Peace River has been controlled and reduced discharge has caused large areas of the delta to dry out. Modern littoral processes are most prevalent along the north shore of Lake Athabasca particularly where thick drift provides much sandy sediment. The shoreline is affected by wind-driven currents from both the northeast and southwest, forming prominent beaches and spits. Fluvial deposition is restricted to narrow flood-plain deposits along the Peace and Slave rivers and some tributaries.

Deposits produced by mass wasting occur mostly along cutbanks of the Peace and Slave rivers. A particularly large landslide is found at Carlson Landing on the Peace River. Other large slumps occur on the west shore of Slave River, north of Fitzgerald. In each case, sliding was enhanced by an impermeable silt and clay layer underlying thick deltaic sediments.

Organic deposits are usually found as layers overlying lacustrine silt and clay in poorly drained areas. Poorly drained depressions abound on the Kazan upland but the largest areas of organic terrain occupy the lowlands west of the Slave River. This part of Alberta lies within the zone of discontinuous permafrost and sufficiently thick organic layers of peat provide an effective insulative layer so that ground ice persists throughout the summer. The growth of ground ice produces landforms such as peat plateaus and palsas which are common on the Kazan upland. Areas underlain by permafrost are very sensitive to disturbance. Where the insulative layer is disrupted, the surface rapidly subsides as the ground ice melts.

The association of surficial deposits and stratigraphy show that the Quaternary record of northeastern Alberta covers a relatively short period (ca. 30 ka to 8.5 ka BP),

matériaux lacustres et deltaïques ont été soumises à une intense érosion éolienne. Des dépôts éoliens, notamment des nappes de sable éolien et des champs de dunes, sont fréquents dans l'ensemble de la région. La bordure occidentale de la région cartographique englobe les dunes de Wood Buffalo, région où des dunes particulièrement grandes, allant jusqu'à 30 m de hauteur, se sont érigées en raison de la disponibilité immédiate de sable en provenance du delta pléistocène. Sur les hautes terres de Kazan, des dunes paraboliques sont présentes au nord-ouest du lac Hooker et au sud du lac Woodman, à l'intérieur de la zone renfermant la moraine interlobaire de Colin Lake. Dans la région cartographique, la plupart des dunes sont allongées principalement vers le nord-ouest, ce qui laisse supposer que des vents forts de surface soufflaient du sud-est, soit une direction diamétralement opposée aux vents du nord-ouest qui prédominent de nos jours. Par conséquent, les dunes se seraient formées au début du postglaciaire alors qu'un anticyclone persistant était centré sur l'Inlandsis laurentidien et dominait la circulation atmosphérique régionale.

Lorsque des conditions non glaciaires dominaient au cours de la dernière partie de l'Holocène, d'importants volumes de sédiments ont été déposés par la rivière de la Paix en progradation dans le lac Athabasca. D'un point de vue historique, le delta était soumis à des inondations saisonnières et a déposé d'importants volumes de silt et de sable fin. Cependant, au cours des dernières décennies, on a contrôlé l'écoulement de la rivière de la Paix et réduit son débit, ce qui a asséché de vastes étendues du delta. De nos jours, les processus littoraux prédominent le long de la rive septentrionale du lac Athabasca, particulièrement là où des dépôts glaciaires épais fournissent des sédiments sableux en abondance. Le rivage est soumis à des courants provoqués par des vents soufflant du nord-est et du sud-ouest, ce qui entraîne la formation de plages et de flèches proéminentes. La sédimentation fluviatile est confinée à des dépôts étroits de plaine d'inondation le long de la rivière de la Paix, de la rivière Slave et de certains affluents.

Les dépôts engendrés par des mouvements de masse se rencontrent principalement le long des berges hautes de la rivière de la Paix et de la rivière Slave. On peut observer un glissement de terrain particulièrement important à Carlson Landing, sur la rivière de la Paix. D'autres glissements d'envergure se sont produits sur la rive occidentale de la rivière Slave, au nord de Fitzgerald. Dans tous les cas, le glissement a été facilité par la présence d'une couche de silt et d'argile imperméable reposant sous des sédiments deltaïques épais.

Des dépôts organiques forment généralement des couches susjacentes aux silts et argiles lacustres dans les régions mal drainées. Des cuvettes mal drainées foisonnent sur les hautes terres de Kazan, mais les régions de sol organique les plus étendues occupent les basses terres situées à l'ouest de la rivière Slave. Cette partie de l'Alberta se trouve dans la zone de pergélisol discontinu. Les couches organiques de tourbe sont suffisamment épaisses pour constituer une isolation efficace permettant aux glaces de sol de persister tout au long de l'été. La croissance de ces glaces donne lieu à des modelés tels que des plateaux palsiques et des palses qui sont fréquents dans les hautes terres de Kazan. Les régions pergélisolées sont très sensibles aux perturbations. Aux endroits où la couche isolante est interrompue, la surface s'enfonce rapidement au fur et à mesure que fond la glace de sol.

L'association des dépôts superficiels et la stratigraphie montrent que, dans le nord-est de l'Alberta, le Quaternaire couvre une période relativement courte (environ 30 à 8,5 ka) liée à l'avancée de related to the advance of the Laurentide Ice Sheet during Late Wisconsinan glaciation. At the height of glaciation, the dominant glacial flow was from the northeast and major erosion and dispersal of the underlying bedrock occurred. Till is very sparse on the Kazan upland, nevertheless, during ice retreat, large volumes of glacial drift were concentrated as glaciofluvial sediment along ice margins and in proglacial lakes. Much of this sediment was redeposited during postglacial time as proglacial lakes emptied and integrated drainage networks developed. Further dispersal of sediment took place by intense southeast winds sweeping the barren postglacial landscape. In contrast, areas underlain by Paleozoic sedimentary rocks west of the Slave River are covered by widespread glacial, deltaic, and lacustrine sediments.

During the last glacial maximum, the Keewatin sector of the Laurentide Ice Sheet flowed southwestward on a regional scale, relatively independent of local topography. However, during deglaciation, when the ice thinned, distinct lobes developed in the ice sheet changing the flow pattern. A westward-flowing ice lobe, occupying the Lake Athabasca basin, converged laterally with southwesterly flowing ice north of it. This lateral contact is marked by converging striae and a broad east-west band of glacial outwash and lake sediments.

Glacial Lake McConnell, occupying the isostatic depression left by the retreating Laurentide Ice Sheet, was in contact with the northwestern margin of the ice sheet. Consequently, the Slave River lowland and Lake Athabasca basin were flooded from the north when the ice retreated onto the Kazan upland. The Laurentide Ice Sheet formed an extensive dam along the western edge of the Kazan upland when glacial Lake McConnell reached about 305 m a.s.l. near present-day Lake Athabasca. The position of the ice sheet during this time is recorded by the north-trending Slave moraine. The Slave moraine is correlative with the 10 ka BP Cree Lake moraine of northeastern Saskatchewan and marks a regional stillstand in the retreat of the Laurentide Ice Sheet. Subsequently, as the ice sheet retreated farther eastward, large volumes of meltwater were diverted across the shield. Glacial drift was extensively redistributed and many ephemeral lakes were created which subsequently drained during the Holocene. With crustal rebound, glacial Lake McConnell drained and a large delta formed in the Slave River lowland, depositing sand over the glaciolacustrine mud. The delta had its greatest extent when it separated Lake Athabasca from glacial Lake McConnell between 9 ka and 8 ka BP. Later, during the Holocene, the Peace and Slave rivers incised the older delta forming the modern Peace River–Athabasca River delta which currently progrades into Lake Athabasca.

l'Inlandsis laurentidien au cours de la glaciation du Wisconsinien supérieur. Lorsque la glaciation a atteint son apogée, l'écoulement glaciaire prédominant venait du nord-est et le substratum rocheux sous-jacent a été soumis à une érosion et un dispersion importantes. Le till est très épars sur les hautes terres de Kazan. Cependant, au cours du recul glaciaire, d'importants volumes de dépôts glaciaires se sont concentrés sous forme de sédiments fluvioglaciaires le long des marges glaciaires et dans des lacs proglaciaires. Une grande partie de ces sédiments se sont redéposés au cours du postglaciaire au fur et à mesure que les lacs proglaciaires se sont vidés et que des réseaux hydrographiques intégrés se sont développés. Les sédiments ont été davantage dispersés par des vents forts soufflant du sud-est qui ont balayé sur leur passage le paysage postglaciaire stérile. Par contraste, les régions de roches sédimentaires paléozoïques à l'ouest de la rivière Slave sont recouvertes par des sédiments glaciaires, deltaïques et lacustres répandus.

Au cours du dernier pléniglaciaire, les glaces du secteur de Keewatin de l'Inlandsis laurentidien s'écoulaient vers le sud-ouest à l'échelle régionale, plus ou moins indépendamment de la topographie locale. Toutefois, au cours de la déglaciation, des lobes distincts se sont constitués dans l'inlandsis lorsque la glace s'est amincie, ce qui a modifié la configuration de l'écoulement. Un lobe glaciaire à écoulement vers l'ouest qui remplissait le bassin du lac Athabasca a convergé latéralement vers les glaces au nord qui s'écoulaient vers le sud-ouest. Ce contact latéral est marqué par des stries convergentes et par une large bande de direction est-ouest de dépôts d'épandage fluvioglaciaire et de sédiments lacustres.

Le Lac glaciaire McConnell, qui occupait la dépression isostatique créée par le retrait de l'Inlandsis laurentidien, était en contact avec la bordure nord-ouest de l'inlandsis. Par conséquent, les basses terres de la rivière Slave et le bassin du lac Athabasca ont été inondés à partir du nord lorsque les glaces ont reculé sur les hautes terres de Kazan. L'Inlandsis laurentidien a érigé un vaste barrage le long de la bordure occidentale des hautes terres de Kazan quand le niveau du Lac glaciaire McConnell a atteint environ 305 m audessus du niveau de la mer à proximité de l'actuel lac Athabasca. La position de l'inlandsis au cours de cette période est indiquée par la moraine de Slave de direction nord. Cette moraine peut être mise en corrélation avec la moraine de Cree Lake de 10 ka située dans le nord-est de la Saskatchewan et marque une période de halte régionale dans le retrait de l'Inlandsis laurentidien. Par la suite, au fur et à mesure que l'inlandsis a reculé davantage vers l'est, de grands volumes d'eau de fonte se sont déversés sur l'ensemble du bouclier. Les sédiments glaciaires ont été l'objet d'une vaste redistribution et de nombreux lacs temporaires se sont créés, puis se sont vidés au cours de l'Holocène. Lors du relèvement de la croûte, le Lac glaciaire McConnell s'est vidé et un vaste delta s'est formé dans les basses terres de la rivière Slave, déposant du sable sur les boues glaciolacustres. Le delta a atteint sa superficie maximale lorsqu'il séparait le lac Athabasca et le Lac glaciaire McConnell il y a entre 9 et 8 ka. Par la suite, au cours de l'Holocène, la rivière de la Paix et la rivière Slave ont incisé le delta plus ancien pour former l'actuel delta de la rivière de la Paix et de la rivière Athabasca en progradation actuellement dans le lac Athabasca.

INTRODUCTION

This is the final report on the Quaternary geology of the northeastern corner of Alberta, a project sponsored by the Canada-Alberta Mineral Development Agreement (1992–1995). The glacial geology is based on five 1:100 000 scale surficial geology maps covering NTS 74 M and part of 74 L (Fig. 1). The objective of the project was to stimulate mineral exploration in the region by providing detailed information on the genesis and distribution of surficial materials, including chemical and mineral variations within the glacial deposits. In addition to the mapping, 336 bulk samples of glacial drift where analyzed for geochemistry. These results were presented in GSC open files (Bednarski, 1993a, b, 1995a, b, 1996) and a preliminary synthesis in a GSC bulletin (Bednarski, 1997).

The research procedure involved airphoto interpretation followed by ground verification and field mapping conducted during the summers of 1992, 1993, and 1994. Till and other surficial materials were retrieved by float plane, boat, and foot traverses, giving an average density of one sample per 30 km². The greatest sampling density was around the larger lakes (Fig. 2). All information was entered into digital databases and compiled onto digital maps. The surficial geology is presented on five 1:100 000 A-series maps compiled from 1:50 000 digital bases (Maps 1937A, 1938A, 1939A, 1940A, 1941A, in pocket).

Pre-Quaternary physiography and bedrock geology

The mapped area lies between 58°40′N and 60°N and 110°W and 112°W, about 15 200 km², and includes the only portion of the Canadian Shield exposed in Alberta (map unit R). The shield is bounded to the south by Lake Athabasca and to the west by lowlands underlain by Paleozoic rocks along the Peace and Slave rivers (map unit R1).

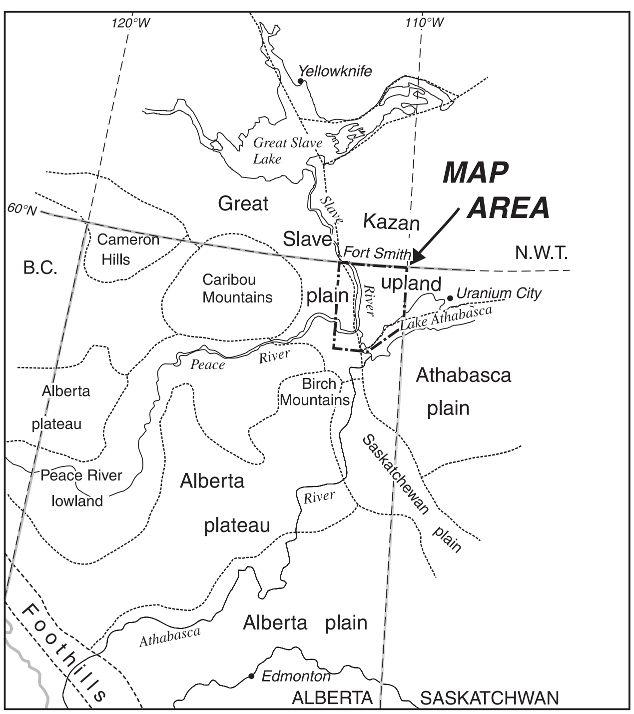

Figure 1. *Location of the map area and physiographic regions of Alberta; the Kazan upland and Athabasca and Great Slave plains (after Bostock, 1970).*

The preglacial physiography influenced the Quaternary history of northeast Alberta by affecting glacial flow and ice retreat of the Laurentide Ice Sheet. Bostock (1970) defined three physiographic regions in the area based on elements of regional topography and underlying bedrock structure (Fig. 1). Most of the study area is part of the Kazan upland, the exposed shield of crystalline Precambrian basement, consisting of volcanic and sedimentary rocks of Archean and Early Proterozoic age (Godfrey, 1986; McDonough, 1997). The broadly rolling upland rises gently from about 215 m a.s.l. along the Slave River, to more than 400 m a.s.l. along the Saskatchewan border. Its surface is etched by ridges, valleys, and shallow basins controlled by folding and fracturing of the rock and by differential erosion of various bedrock units. The structures produce a general northeast topographic trend, with local relief usually less than 100 m.

Surficial cover over the Kazan upland is very thin and drainage patterns are strongly influenced by the bedrock structure. The main streams parallel the structure, whereas, crosscutting joints and weaknesses in the bedrock are exploited by secondary channels that intersect the main streams at sharp angles. Similarly, larger lakes also have angular shorelines defined by the bedrock structure. Smaller depressions are poorly drained and perched lakes and bogs abound. Currently, the Kazan upland drains south and east, into Lake Athabasca, and west directly into the Slave River. A small amount of runoff in the northeast drains northward into Great Slave Lake via the Tethul–Taltson river system (Fig. 3). Drainage patterns during retreat phases of the Laurentide Ice Sheet were significantly different from those of the present.

The Athabasca plain, the second major physiographic element in the study area, forms a large embayment into the western part of the Kazan upland. This part of the Precambrian shield is composed of thick, unmetamorphosed Middle Proterozoic sedimentary rocks (Athabasca Group) that unconformably overlie the basement. Nearly flat-lying conglomerate and sandstone units, with clay and silt interbeds, comprise the base of the group which outcrops along the northern shore of Lake Athabasca (Wilson, 1985). Lake Athabasca (8080 km² at 210 m a.s.l.) lies along the northern margin of the Athabasca plain and defines the southern limit of the study area. Before glaciation, the Athabasca Group probably extended farther north over the crystalline basement, but the rocks were eroded back by continental glaciation. Large volumes of glacially transported sand throughout the study area probably were derived from these recessive rocks. The topographic depression that contains Lake Athabasca is probably a glacially eroded trough, however, Lake Athabasca has a maximum depth of only 124 m in Saskatchewan which is atypical of glacial overdeepening. Westward, in Alberta, the maximum depth is only about 16 m, shallowing to a few metres in the west adjacent to the modern delta. The thickness of Quaternary fill within the lake is unknown but may be significant given the recessive nature of the Athabasca Group. In contrast, glacial erosion was extensive in the eastern bays of

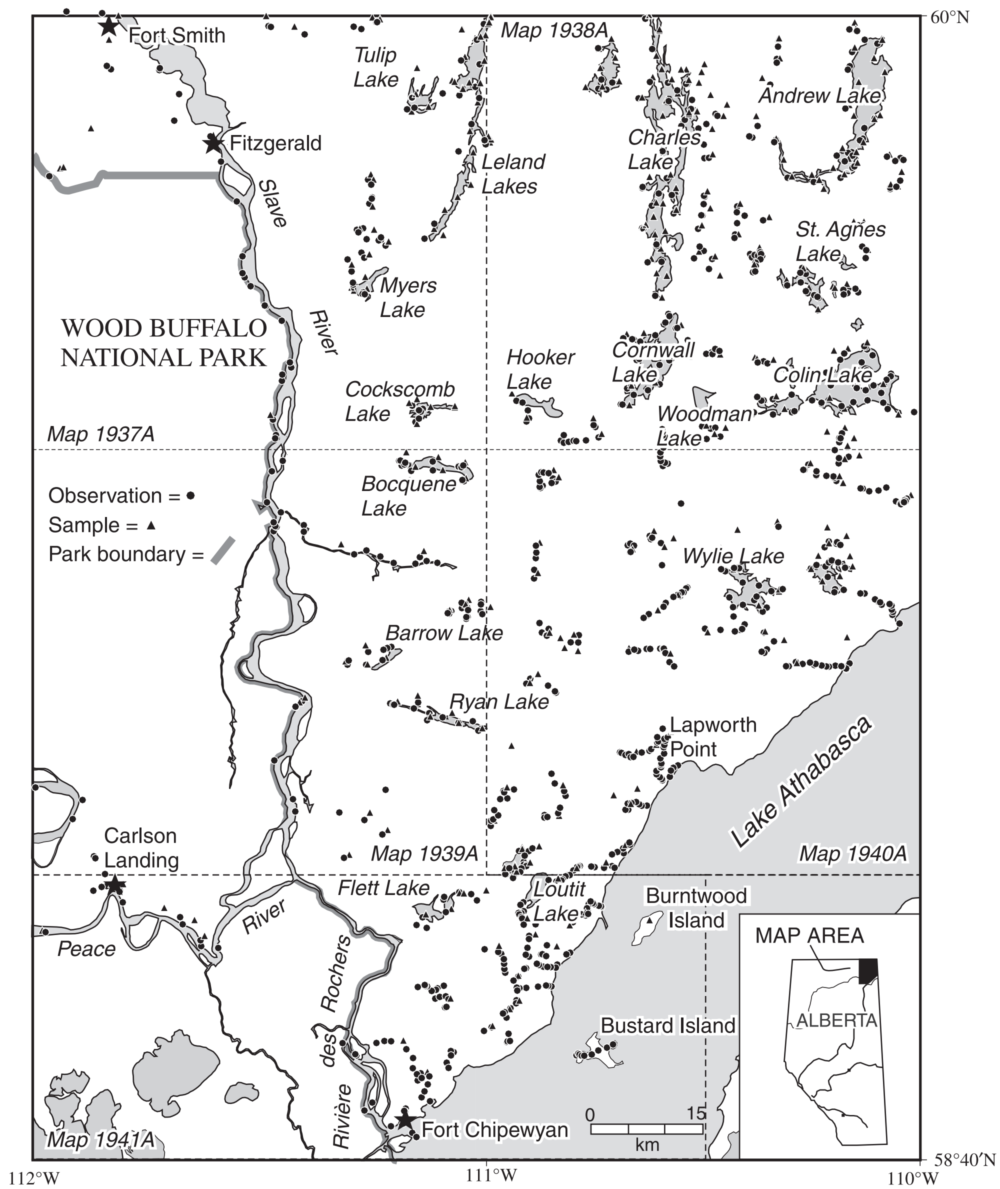

Figure 2. *Demarcation of the five 1:100 000 scale surficial geology maps and place names and locations of observation and sample points.*

Great Slave Lake, found to the north in the Northwest Territories. Erosional troughs in Great Slave Lake are greater than 700 m deep, more than 550 m below sea level.

Kazan upland is bounded to the west by the Great Slave plain where the Precambrian basement is covered by flat-lying Middle Devonian rocks, forming a lowland not greater than about 245 m a.s.l. Slave River flows northward into Great Slave Lake (156 m a.s.l.) along this Paleozoic–Precambrian contact. The Chenal des Quatre Fourches and the Rivière des Rochers drain Lake Athabasca and join the Peace River to form the Slave River. The southern part of the Great Slave plain is covered by the Peace River–Athabasca River delta, a flat expanse of Pleistocene to Holocene deltaic and lacustrine sediment. West of the Slave River, the drainage of the Great Slave plain is poorly integrated, and swampy and muskeg-covered terrain is common. Local relief is only 15–20 m along sandy beach ridges and dunes. The southwest part of the area, north of Peace River, is covered by part of the Wood Buffalo sand hills, an extensive stabilized dune field (David, 1977). Karst topography and salt pans are common in the extreme western parts of the study area (Bayrock, 1972b; Tsui and Cruden, 1984).

Beyond the map area, the Great Slave plain is bounded by the Caribou Mountains to the west and Birch Mountains to the southeast (Fig. 1). These uplands controlled the pattern of deglaciation and directed glacial meltwater diversion within the region. Great Slave plain forms a contiguous lowland with the Peace River lowland in the west. Together these lowlands channelled large volumes of nonglacial runoff and meltwater which flowed into the study area from the west.

Figure 3.

The present-day drainage basins are shown for the map area. Only the watershed in the north-east corner drains into the Tethul River–Taltson River system and not into either Lake Athabasca or Slave River.

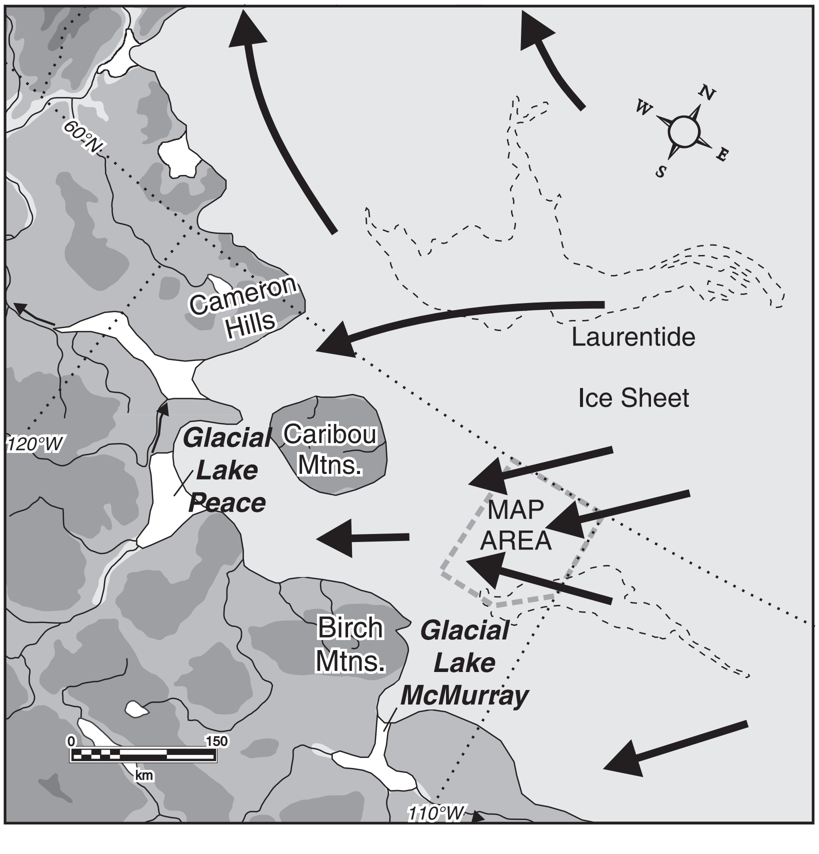

Figure 4.

The regional glacial cover at ca. 11 ka BP. Note the meltwater diversions and ponded lakes along the margin of the Laurentide Ice Sheet. Darker shading represents higher ground. Arrows on the ice show major directions of glacial flow (modified from Lemmen et al., 1994, Fig. 4e).

Overview of the Quaternary history of northern Alberta

Although observations on the glacial history of regions north and west of Lake Athabasca were made as early as the late nineteenth century (Tyrrell and Dowling, 1897), the surficial geology of the area remained largely unmapped. Bayrock (1972a, b) published two maps on the general surficial geology of Fort Chipewyan (NTS 74 L) and Peace Point and Fitzgerald west of 111°20′W (NTS 84 P, 74 M) at 1:250 000 scale. Godfrey (1984a, b, c, 1986) included some glacial features in his bedrock maps and provided brief descriptions.

Northeastern Alberta was probably overridden by continental glaciers more than once during the Pleistocene but evidence of this was obscured by the last glaciation (Late Wisconsinan; Fulton, 1989). The onset of the last glaciation, which began about 30 ka BP, was marked by the growth of several independent ice caps over the Canadian Shield that eventually coalesced to form the Laurentide Ice Sheet (Dyke and Prest, 1987). At the height of glaciation (ca. 18 ka BP), the ice sheet consisted of a complex of ice domes, saddles, and lobes, advancing against the regional slope in places. The shield of northern Alberta was scoured by southwestward-flowing ice out of the Keewatin ice divide. The ice crossed the

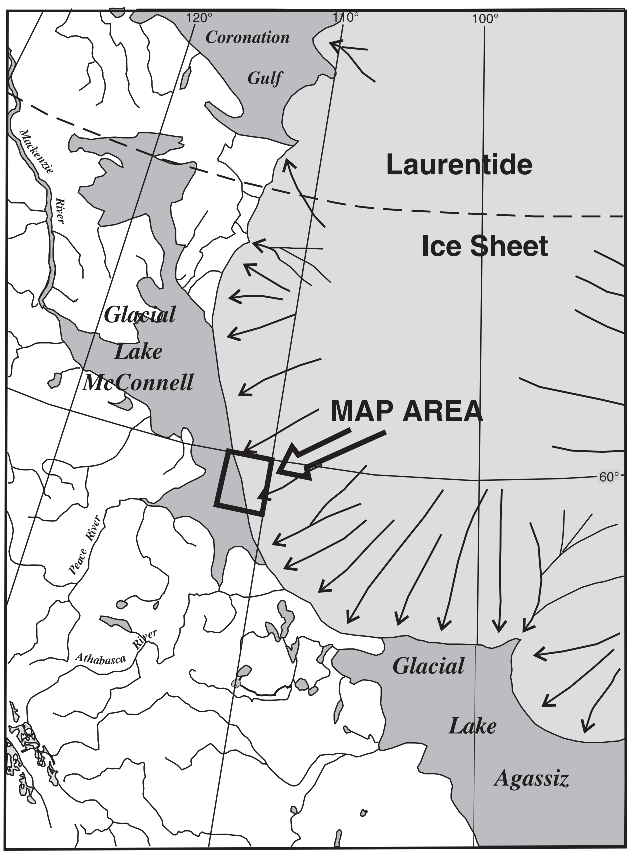

Figure 5. The paleogeography of the Laurentide Ice Sheet at ca. 10 ka BP when glacial Lake McConnell attained its greatest size (>215 000 km^2). The lake dominates the margin of the ice sheet in the study area (information from Dyke and Prest, 1987).

Interior Plains until it met the eastward-flowing Cordilleran Ice Sheet in northeastern British Columbia, causing major diversions in drainage (Mathews, 1980). Nonetheless, it has been suggested that the two ice sheets may not have coalesced during the Late Wisconsinan but during earlier glaciation (cf. Bobrowsky and Rutter, 1992).

During deglaciation, large proglacial lakes formed along the margin as the ice retreated northeastward (Lemmen et al., 1994; Fig. 4). As the ice sheet thinned, the underlying topography asserted greater control on ice-flow patterns resulting in pronounced lobes along its margin. At ca. 11 ka BP a lobe of Laurentide ice extending down the Peace River lowland was flanked by ice-free uplands: the Caribou Mountains to the north and Birch Mountains to the south (Fig. 4). Farther west, a late phase of glacial Lake Peace contacted the front of the lobe within the lowland (Dyke and Prest, 1987), whereas glacial Lake McMurray occupied the Athabasca River valley to the south (Lake Tyrrell, Taylor, 1960; Fisher, 1993). In the far north, the retreating ice front led to the development of an early phase of glacial Lake McConnell that occupied part of present Great Bear Lake (Lemmen et al., 1994).

A chronology of ice retreat reconstructed from radiocarbon dates on postglacial organic matter and correlation of former lake levels shows that from 11 ka BP to ca. 9 ka BP the Laurentide ice front retreated eastward across the entire map area. During this time, glacial Lake Peace expanded into the Lake Athabasca basin, forming glacial Lake Athabasca (Schreiner, 1984), also called Lake Tyrrell by Taylor (1960). Concurrently in the north, glacial Lake McConnell expanded southward into Great Slave Lake basin and down Great Slave plain. Radiocarbon dates suggest that, before 10 ka BP, glacial Lake McConnell coalesced with Lake Tyrrell. At its height, glacial Lake McConnell covered more than 215 000 km² and was the second largest Pleistocene lake in North America (Fig. 5; Lemmen et al., 1994). Glacial Lake McConnell reached this size because it occupied an extensive glacio-isostatic depression along the margin of the Laurentide Ice Sheet (Craig, 1965). Consequently, the lake was short lived because postglacial rebound continuously decanted the lake out the Mackenzie River system once the ice load was removed. Lake levels fell rapidly and by ca. 8.5 ka BP glacial Lake McConnell separated into present-day Great Bear Lake, Great Slave Lake, and Lake Athabasca.

In summary, the recorded Quaternary history of the map area is thought to cover a short period (ca. 30 – 8.5 ka BP) related to Late Wisconsinan glaciation. Major erosion and dispersal of the underlying bedrock occurred during this time but deposition of till was very sparse on the resistant Kazan upland. Nevertheless, during retreat of the ice sheet, large volumes of glacial drift concentrated as glaciofluvial sediment along the ice margins and in proglacial lakes. Much of this sediment was redeposited during postglacial time as proglacial lakes emptied and integrated drainage networks developed. Further dispersal of sediment took place by intense southeast winds sweeping the barren postglacial landscape. The following sections detail the pattern of ice retreat, glacial sedimentation, and drainage evolution that resulted in the landform assemblage and pattern of surficial materials found on the 1: 100 000 maps (Maps 1937A, 1938A, 1939A, 1940A, 1941A). The surficial geology of the area is generalized in Figure 6.

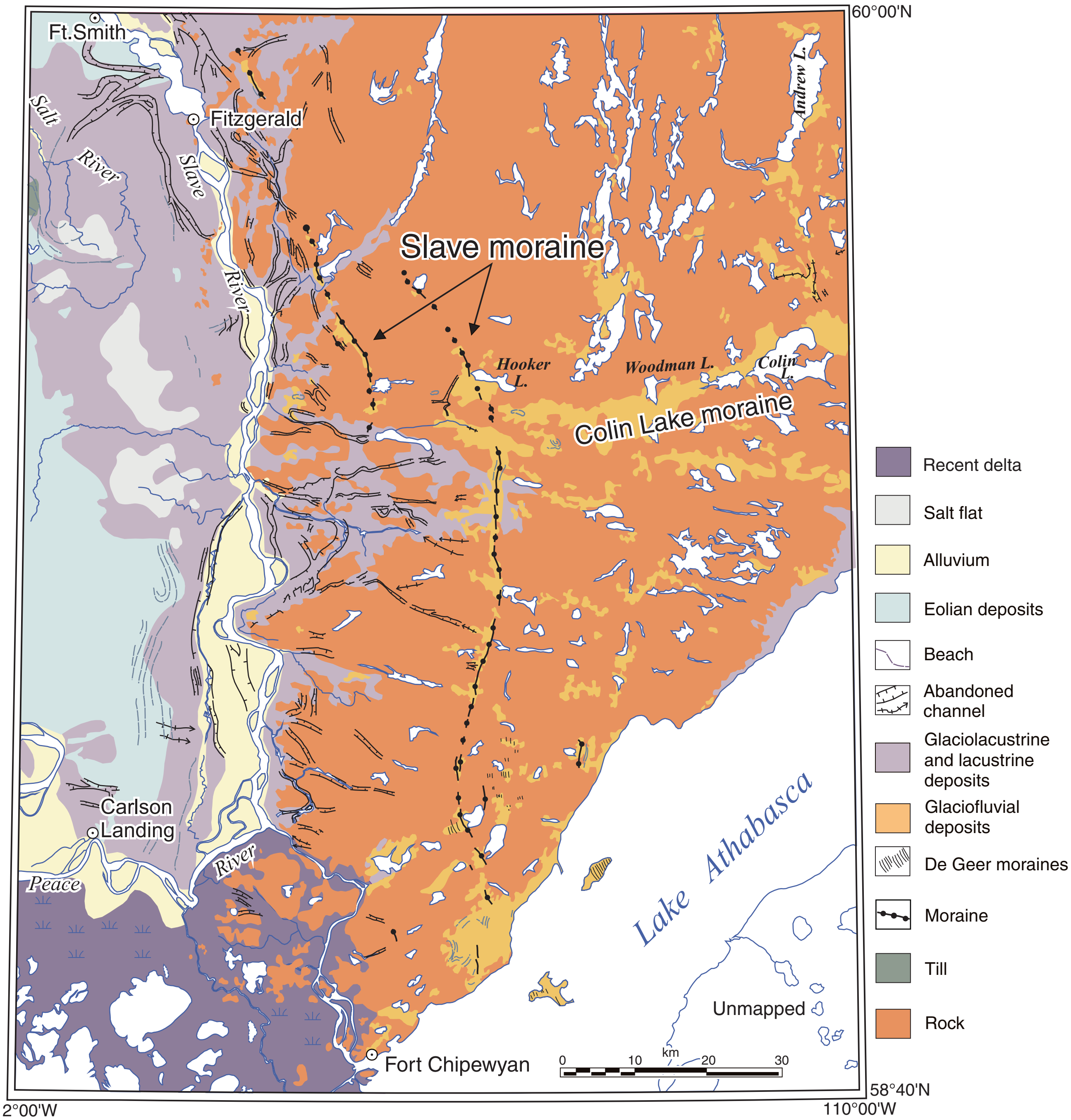

Figure 6. The generalized surficial geology of the study area. Note the sparse surficial cover overlying the Kazan upland, the extensive moraine system east of the Slave River marking a major stillstand of the retreating Laurentide Ice Sheet (Slave moraine), and the accumulation of thick glacial drift along an east-west belt marking the Colin Lake interlobate moraine. The Great Slave plain, west of Slave River, is covered by thick glaciolacustrine and glaciodeltaic sediment, and recent deltaic sediment south of Peace River. Prominent raised beaches mark the regression of glacial Lake McConnell. Thick till is limited to the northwest part of the study area near Salt River.

SURFICIAL DEPOSITS

The following is a more detailed description of the geological units and features on the legend accompanying the surficial geology maps. Surficial units are divided according to age, genesis, and type of depositional environment. Generally, most surficial materials derived from the shield are very sandy (Fig. 7); moreover, sediments derived from the Athabasca Group (Wilson, 1985) are all texturally similar, complicating genetic interpretations, especially where extensive reworking by fluvial and eolian processes occurred during deglaciation. Examples of significant landforms comprising certain units and stratigraphy are described.

Postglacial or Late Wisconsinan proglacial and glacial environments

Deposition in glacial environments is represented by till and ice-contact glaciofluvial sediment deposited during the Late Wisconsinan and early Holocene. Nonetheless, most of the glacial materials were reworked during deglaciation and deposited in proglacial environments peripheral to the ice sheet. Proglacial environments were dominated by deposition of glacial outwash, lake sediment, and eolian sediment to a lesser extent. Proglacial sediments generally decrease in age eastward because the proglacial zone followed the eastward retreat of the ice front.

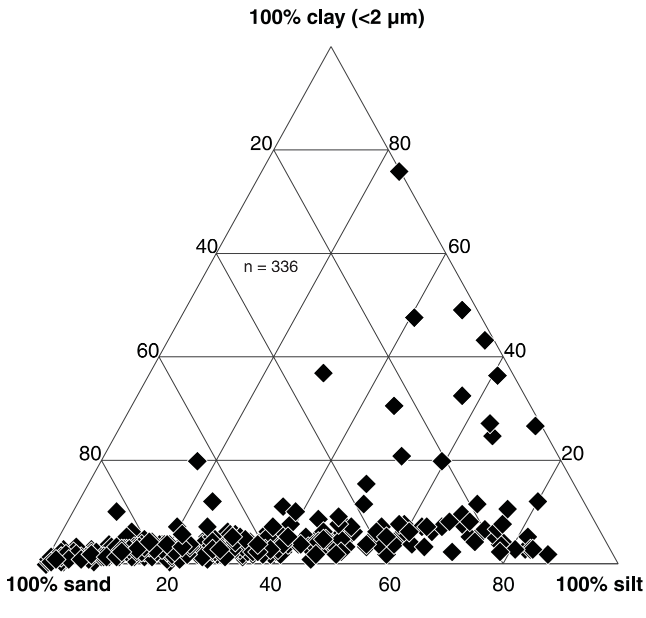

Figure 7. *Sand, silt, and clay ratios for 336 glacial drift samples. Grain-size analysis was by sieving and sedimentation into: greater than 2 mm, sand (2 mm to 63 µm), silt (2 µm to <63 µm), and clay (<2 µm) fractions. Although most surficial units have a similar matrix, tills and glaciofluvial gravels have an abundance of cobbles and boulders.*

Till (map units T, Tv)

Till (map unit T), is material that was deposited directly by glacial melting, or by lodgement at the base of the ice. The latter produces the densest till with a strong clast fabric oriented in the direction of former glacial flow (cf. Dreimanis, 1990). Lodgement till is uncommon in the map area because glacial erosion dominated the Kazan upland. However, in places, basal till is found on the lee side of prominent outcrops. Locally, the till forms a tapered tail on the downstream side of a bedrock knob (crag-and-tail features). Streamlined drift features such as drumlins or flutings are rare in the area.

Till on the Kazan upland generally forms a thin (<1 m thick) discontinuous veneer of unconsolidated drift with a coarse sandy matrix (map unit Tv). The sediment characteristics indicate an ablation till facies laid down during stagnant ice wastage. The till has a very similar texture to colluvium or diamicton units of coarse outwash; however, it can be distinguished by the relative abundance of erratics and striated clasts. The crystalline basement of the Kazan upland was resistant to glacial erosion. In contrast, glacial ice was effective in eroding the sediments of the Athabasca Group. Sandstone erratics, several metres in diameter, and thick bodies of unconsolidated sand are common several kilometres north of the contact along Lake Athabasca. Glacial erosion was also more effective on the Paleozoic substrate underlying the Great Slave plain. A few exposures show a till blanket overlying the bedrock.

Sand-sized grains dominate the composition of local till derived from basement rocks (Fig. 7). These till units contain angular to subangular igneous and metamorphic clasts and multimodal grain size. In the southern part of the study area, till derived from the Athabasca Group is very sandy, with uniform matrix and pinkish colour. Pebble analysis of 150 till samples reflects the diversity of lithologies on the shield, but no clear distinctions of provenance could be made. The bulk of basal till is usually transported less than 10 km from its source (Puranen, 1988), however, far-travelled lithologies are also present. For example, a volcanic erratic from the District of Keewatin (Pitz Formation) found in till north of Bocquene Lake (Fig. 2), shows a transport distance of approximately 800 km from the northeast. In the southern parts of the Kazan upland, large sandstone erratics are common 10–20 km north of the basement contact. West of the Slave River, till derived from the Paleozoic bedrock is more indurated and has a silty matrix with carbonate clasts in addition to the shield lithologies. Dilution of glacial sediment derived from the shield occurred over a very short distance as the ice sheet flowed off the Kazan upland and onto the carbonate terrain. Good exposures of till derived from Paleozoic rocks are found along the Salt River in the northwest part of the area (Fig. 6).

Glacial meltwater extensively reworked most of the till on the Kazan upland and glacial diamicton units are commonly found interbedded with glaciofluvial gravel along former ice margins (map unit G). The Slave moraine is a good example of this (Fig. 8). The best exposure of till on the Kazan upland is found in the Myers Lake section but the till is discontinuous and interbedded with glaciofluvial material (Fig. 9).

Glaciofluvial deposits (map units G, Gi, Gt, Gd, Gv)

Glaciofluvial sediment is material that has been worked and deposited by meltwater streams. In the map area it consists of interbedded sand, gravel, and sandy diamicton subdivided into ice-contact glaciofluvial sediment (map unit Gi) and proglacial outwash deposited away from the immediate ice front (map unit G). Because of the 1:100 000 map scale, many areas were collectively mapped as unit G because ice-contact glaciofluvial sediments commonly grade into proglacial outwash or were extensively reworked by subsequent meltwater as the ice front receded (e.g. Slave moraine, *see* below). Coarse glaciofluvial deposits on the Kazan upland can be up to 40 m thick and generally contain subrounded to well rounded pebbles to boulders with rudimentary bedding (Fig. 8, 10). Map unit Gt describes terraces of

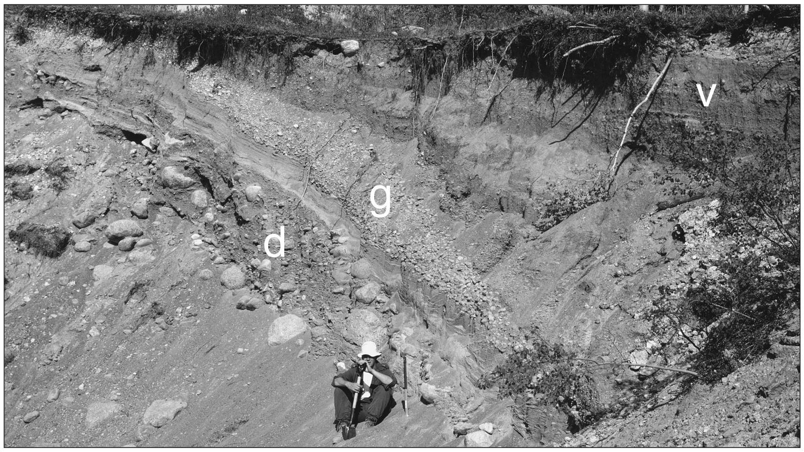

Figure 8.

A photograph of the gravel pit near Myers Lake showing a cross-section through the Slave moraine. Note the coarse glacial diamicton (d) and interbedded gravel (g) lenses steeply dipping to the southwest. Glaciolacustrine varves (v) overlie the gravel in the upper right of the photograph. Photograph by J. Bednarski. GSC 19998-073B

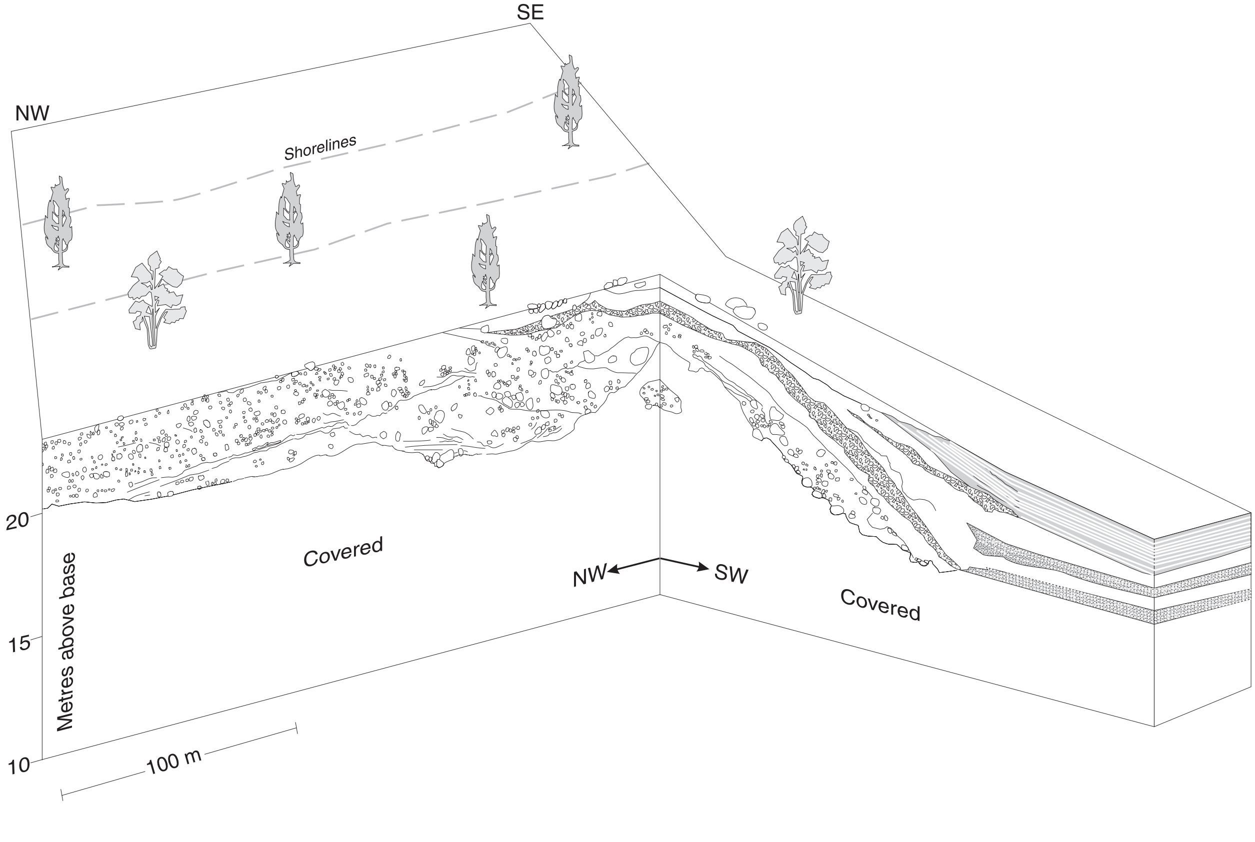

Figure 9. *This drawing shows the composition of the Slave moraine in three dimensions, based on a gravel pit near Myers Lake. The right hand face is shown in Figure 8. Stratified sand and gravel is interbedded with bouldery diamicton that forms tongues dipping southwest at 20–30°E. Clasts of many lithologies, including well rounded quartzite boulders, are supported in a sandy matrix. Slump structures also show movement to the west. The gravel-diamicton succession fines upward and is overlain by varved glaciolacustrine mud from glacial Lake McConnell. Regression of the lake is marked by distinct beaches on either side of the moraine.*

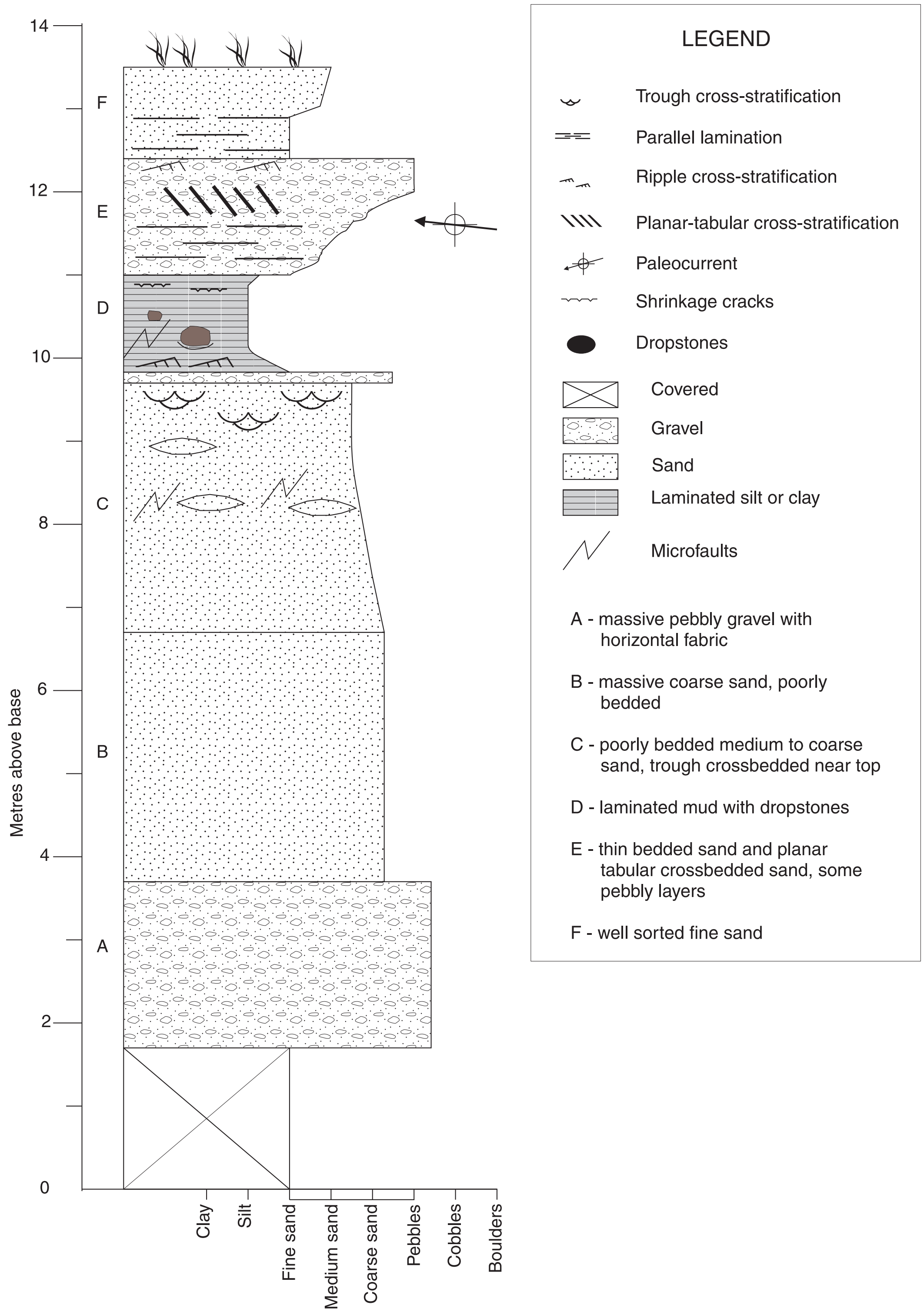

Figure 10. *The exposed stratigraphic section in a gravel pit near the Fort Chipewyan airport showing thick glaciofluvial gravels overlain by glaciolacustrine deposits. Massive gravels at the base of the section were laid down by proximal high-energy meltwater issuing from the retreating ice sheet. Near the top of the section, the meltwater flows diminish as fines, including varves from glacial Lake McConnell, were laid down. The glaciolacustrine sediments are overlain by current-bedded sands and gravels related to regression of the lake.*

glaciofluvial sediment found on valley slopes. In places meltwater channels flowed into lakes forming glaciofluvial deltas (map unit Gd) that formed distinct terraces (map unit Gdt; Fig. 11).

The largest volumes of glaciofluvial sediment are found in a zone extending from Colin Lake (Fig. 6) to Bocquene Lake, within the Colin Lake interlobate moraine, described in the next section. Another large glaciofluvial body lies along Lake Athabasca, northeast of Fort Chipewyan (Fig. 6).

Steep-sided kettles occur on some glaciofluvial deposits suggesting that isolated remnants of buried glacial ice had subsequently melted out. In places the kettles are elongated and aligned along faults in the bedrock. These faults were probably scoured out by glacial ice and later in-filled by glaciofluvial material. Stagnant blocks of ice probably remained in parts of the troughs to form the kettles.

Kame terraces are usually perched above lowlands on the side of a hill. The terraces accumulated subaerially along the hillslope when glacier ice occupied the lowlands. Some terrace surfaces are pitted with kettles indicating formerly buried glacial ice.

Eskers, glaciofluvial sediments deposited along conduits within or on top of the ice sheet, are rare in the study area and restricted to short segments in some valley bottoms. The lack of coherent esker networks in the map area implies that glacial retreat was too rapid for their development. A major esker zone lies about 75 km northwest of the study area, in the Northwest Territories (Prest et al., 1968; Aylsworth and Shilts, 1989). The eskers record radial outflow of meltwater from the Keewatin Ice Divide along an orientation subparallel to the ice-flow direction, and clearly show a large influx of glacial meltwater to the study area from hundreds of kilometres away. Schreiner (1984) felt that the eskers in northern Saskatchewan formed when the ice mass was bounded by the

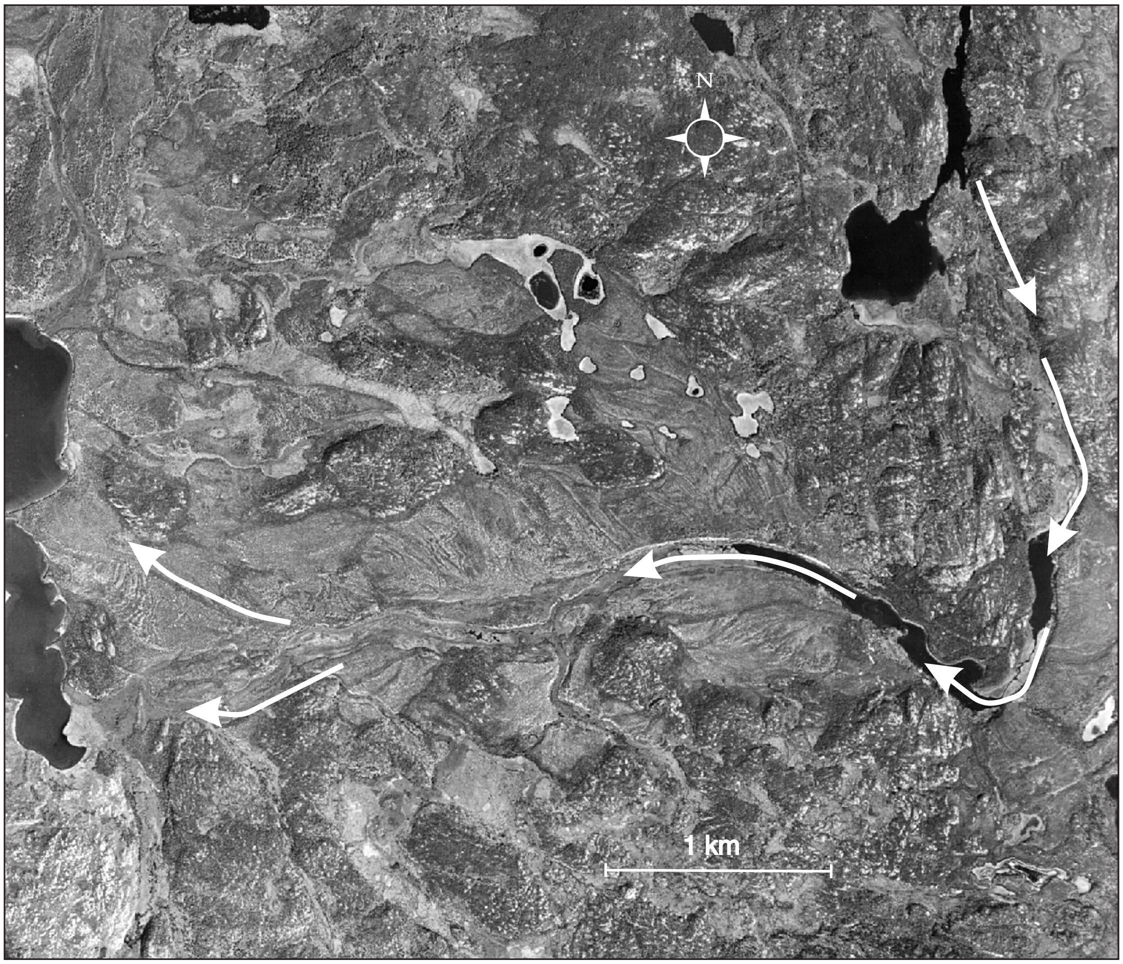

Figure 11. *An aerial photograph of a large braided delta east of St. Agnes Lake (far left centre) on the Kazan upland. The glaciofluvial gravels show a strong outflow of meltwater to the west, which is opposite to the present drainage direction. The natural southward drainage was blocked by the ice margin, which still covered the land to the south. Farther upstream, the meltwater channel is cut into the Precambrian bedrock. NAPL 15152-160*

Cree Lake moraine, and that most of the esker formation occurred when the ice front retreated 35–40 km north from the moraine.

In summary, most of the glaciofluvial sediments were deposited in proglacial environments that generally decrease in age eastward. Glaciofluvial sediment was deposited laterally along the ice margin, within spillways, and as coarse deltaic material prograded into glacial lakes. Continuous rearrangement of the drainage network took place as the ice front retreated eastward. The result is that outwash is now found throughout the area at various elevations relating to distinctly different base levels and drainage directions. The material is composed of unconsolidated, coarse sand and gravel, containing many lithologies. Bedding is rarely visible. The interlobate zone from Colin Lake to Hooker Lake (Fig. 6) contains large volumes of proglacial outwash in close association with ice-contact material. In the northeastern part of the study area large spillways record southward-flowing rivers diverted to the west by glacial ice that persisted in the south. One channel can be traced for more than 15 km to a prominent braided, outwash delta east of St. Agnes Lake (Fig. 11). A second prominent outwash delta lies east of Andrew Lake (Fig. 6). Both deltas record lake levels of more than 320 m a.s.l. Braid patterns on the outwash show that the direction of outflow was to the west, despite the southern regional slope of the land.

Glacial landforms

Extensive moraines formed at the margin of the retreating Laurentide Ice Sheet are the most prominent glacial landforms in the map area. These moraines are described and informally named here.

Colin Lake interlobate moraine

The ‘Quaternary history’ section describes the formation of two lobes within the Laurentide Ice Sheet during the waning phase of glaciation. In brief, southwesterly flowing ice over the Kazan upland converged with the westward-flowing Athabasca lobe. The lobes formed a lateral contact zone of thick glacial drift extending from Colin Lake to Bocquene Lake (Fig. 2, 12), the greatest concentration of glaciogenic sediments on the Kazan upland (Fig. 6). Colin Lake interlobate moraine is used as a collective term to describe the suite of sediments deposited along this lateral contact zone. Morphologically this zone consists of extensive kame terraces forming a broad east-west band. The terraces are most common around Colin Lake and south of Woodman Lake coinciding with the band of glaciofluvial sediments shown in Figure 6. Kame terraces in the area are very sandy and can be tens of metres thick. Because all known exposures in the area show either glaciofluvial gravel or glaciolacustrine sand, it is

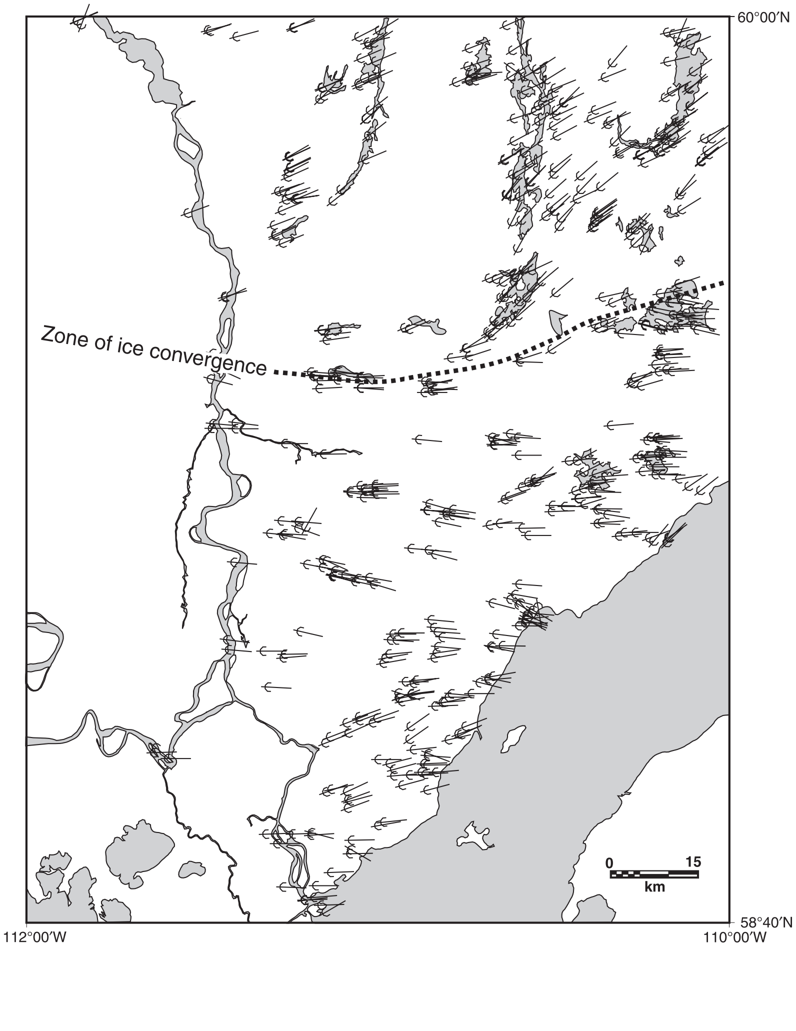

Figure 12.

Glacial striations in the study area. Note the dominant flow from the northeast converging with predominantly westward flow in the southern part of the area.

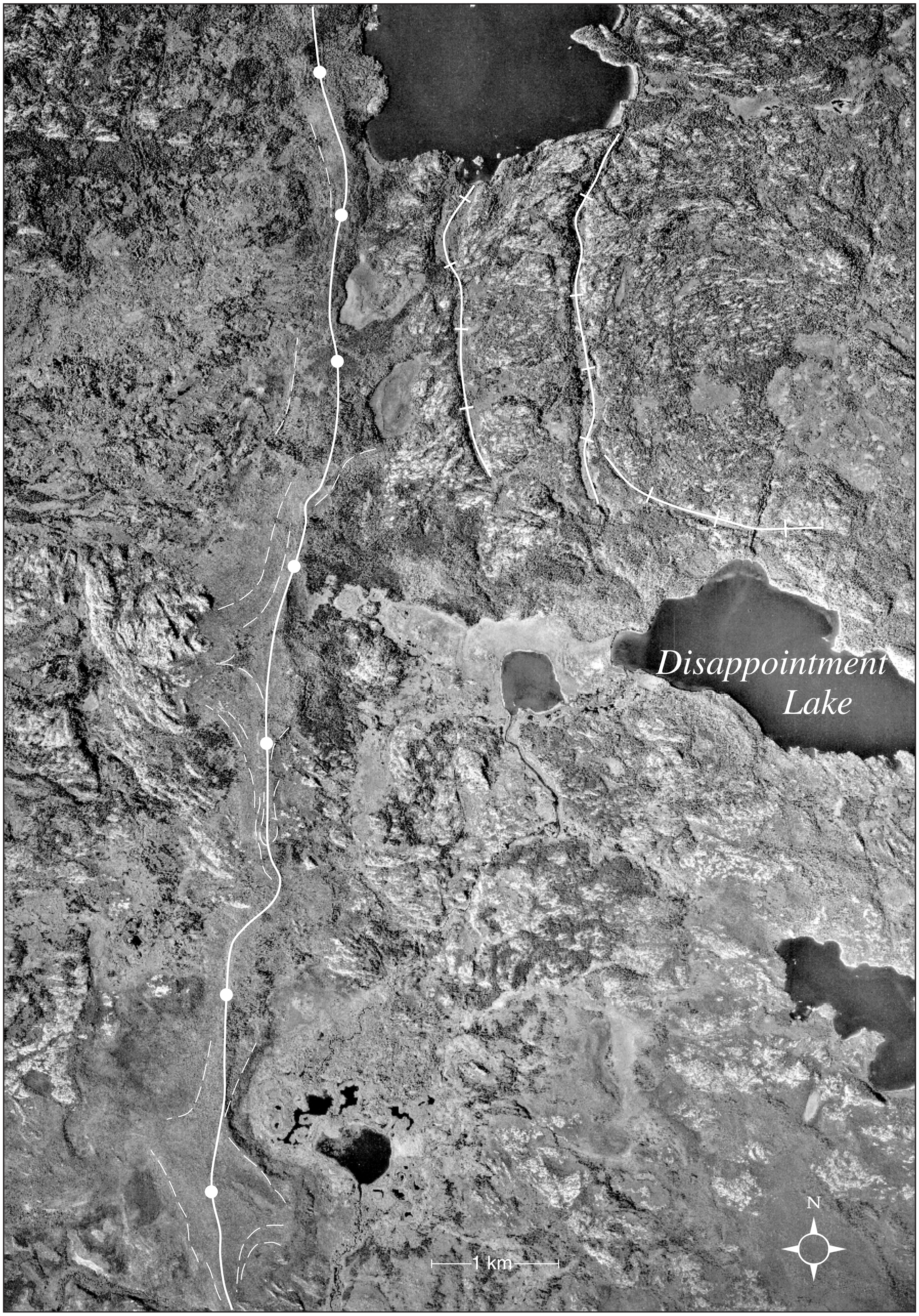

Figure 13. *An aerial photograph of a segment of the Slave moraine (dotted line) west of Disappointment Lake. The moraine dams the natural westward drainage forming many lakes in the area. Glacial Lake McConnell shorelines (dashed lines) were constructed on either side of the moraine. As the ice front retreated eastward, meltwaters flowing along the margin cut lateral channels (line with ticks) trending parallel to the moraine. NAPL 15154-55*

not known how much of the Colin Lake interlobate moraine contains till. Nonetheless, bouldery gravel on the sides of many kettles suggests deposition by glacial ablation.

Slave moraine

When the Laurentide Ice Sheet retreated eastward out of the Slave River lowlands onto the Kazan upland, it temporarily stabilized or experienced minor readvances into glacial Lake McConnell. Till and ice-contact gravel units accumulated along the ice margin forming narrow ridges of sediment over the bedrock. The most prominent ridge on the Kazan upland is the Slave moraine. The moraine is sharp-crested and typically 50 m high and 500 m wide. It is found from 35 km to 7 km east of Slave River and can be traced for 120 km, from Lake Athabasca to southeast of Fort Smith (Fig. 6). North of Bocquene Lake, the moraine forms two parallel segments about 12 km apart, suggesting two closely spaced still stands. The Slave moraine frequently dams westward-trending valleys forming lakes such as Myers Lake. However, it is occasionally breached by former spillways and modern streams (Fig. 13). In places the Slave moraine infills crosscutting meltwater channels, suggesting that the channels were initially subglacial in origin. Distinct strandlines are common on either flank of the Slave moraine (Fig. 6).

A gravel excavation near Myers Lake provides an excellent three-dimensional exposure of the distal side of the Slave moraine (Fig. 8, 9). The stratigraphic succession revealed is probably typical of the moraine. The 22 m section shows stratified sand and gravel interbedded with bouldery diamicton. The thick diamicton units form lenses dipping southwest at 20–30°. Clasts of many lithologies are supported in a sandy matrix and have a strong fabric bearing 239°. Some material has been transported great distances, for example, very resistant quartzitic boulders found throughout have no immediate provenance. The boulders are well rounded with many percussion marks indicative of high flows. Common structures in the coarse interstratified material indicate slumping in a westward direction. Generally, clast size decreases upward in the section and sorting improves. The gravel-diamicton succession fines upward into stratified gravel which is overlain by glaciolacustrine mud, at least 1 m thick, comprising more than 50 varves (Fig. 14). The glaciolacustrine unit is, in turn, overlain by littoral gravel related to the regression of glacial Lake McConnell.

Interpretation of the Myers Lake section shows that the Slave moraine was deposited in a subaqueous environment at the grounding line of the Laurentide Ice Sheet. As the moraine accreted, tongues of debris sloughed off the ice margin in a southwest to westward direction. Finer grained sediment was laid down when the ice margin receded further to the east and glacial Lake McConnell inundated the proximal side of the moraine. As will be discussed in a following section, the Slave moraine lies below the maximum elevation of glacial Lake McConnell. Distinct strandlines formed on either side of the Slave moraine.

The Slave moraine is thought to be the northern extension of the Cree Lake moraine of northern Saskatchewan. The Cree Lake moraine was traced to the southern shore of Lake Athabasca (Prest et al., 1968; Dyke and Prest, 1987) and is also associated with glaciofluvial complexes (Schreiner, 1984). The Cree Lake moraine is dated ca. 10 ka BP (Schreiner, 1984; Dyke and Prest, 1987) and it is likely that the Slave moraine also dates from this time.

Figure 14. *Glaciolacustrine varves deposited in glacial Lake McConnell. The photograph shows more than 50 coarse-fine couplets deposited on the Slave moraine near Myers Lake. Photograph by J. Bednarski. GSC 1998-073C*

Minor moraines

Several short end moraine segments, with similar characteristics to the Slave moraine, are found throughout the Kazan upland. These likely represent local pauses in recession of the ice front as deglaciation continued eastward. A second type of moraine is restricted to low-lying areas near Lake Athabasca. Generally, they form short parallel ridges of glaciofluvial gravel and boulders and are no more than a few tens to hundreds of metres long. The spacing is very regular, usually about 150 m, with a maximum of about 5 m in relief (Fig. 15). These moraines were described as crevasse fillings by Bayrock (1972a), who mapped tens of square kilometres of them south of Lake Athabasca. Schreiner (1984) mapped them as De Geer moraines (*see* below), an interpretation supported by this study. De Geer moraines form along a calving ice-front when the ice sheet is retreating in a depth of water approaching the buoyancy level of the ice. The moraines form cyclically when the ice front becomes buoyant and fractures. This may occur annually each time the ice front thins during the ablation season. De Geer moraines mapped in the area are found on either side of the Slave moraine immediately north of Lake Athabasca and are associated with glacial Lake McConnell. They are especially prominent on the down ice-flow side of a bedrock ridge extending for 15 km northwest of Loutit Lake and on Burntwood Island on Lake Athabasca (Fig. 6).

Glaciolacustrine deposits (map units L, Lv, Lvh, Lh, Ld, Ldt, Lr)

In the map area glaciolacustrine sediments were deposited in ice-dammed lakes along the margin of the Laurentide Ice Sheet. Rhythmically bedded lake bottom mud was deposited throughout the Slave River lowlands from glacial Lake McConnell. Glacial lake sediments on the Kazan upland in the eastern part of the map area have little clay and are mostly unlaminated fine sand and silt. In places, they are similar to outwash sand, except with an absence of pebbles and a slight increase in silt content. Discontinuous glaciolacustrine deposits less than 1 m thick are mapped as unit Lv. Glaciolacustrine sediments west of the Slave River display a hummocky topography that probably reflects the underlying bedrock (map unit Lh).

Glacial Lake McConnell

The greatest volume of glaciolacustrine sediment is found on the Great Slave plain and underlying the Peace River–Athabasca River delta where it forms flat, poorly drained ground (*see* section 'Pleistocene delta', below). Most of this sediment was deposited in glacial Lake McConnell when the ice margin was in contact with the Slave moraine. Glacial Lake McConnell sediments are distinctly varved and onlap the western edge of the Kazan upland, thinning out on the proximal (east) side of the Slave moraine. As noted, at least a metre of varves onlap the Slave moraine at Myers Lake (Fig. 9, 14). Varves were also found on the proximal side of the Slave moraine, north of Lake

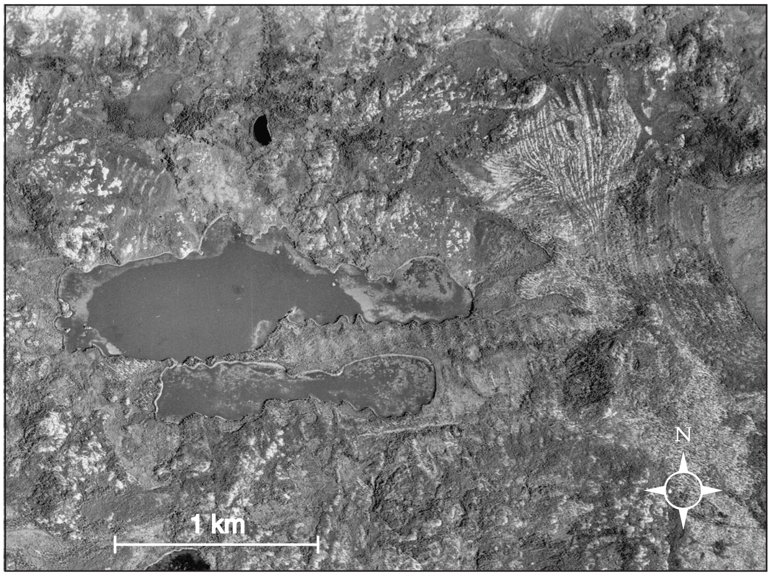

Figure 15.

The aerial photograph shows De Geer moraines draped across a glacial fluting near a small lake 10 km west of Lapworth Point, Lake Athabasca. The fluting forms a tail downstream of a bedrock knoll. Glacial flow was from right to left (east to west). The moraines show that rapid ice retreat took place by calving into a high lake level. Calving was probably enhanced by local thinning of the ice sheet as it flowed over a bedrock knoll. The fluting may have formed when basal sediment was forced into a subglacial cavity behind the knoll. Glacial Lake McConnell raised beaches form the fine berms on the right. NAPL 15157-77

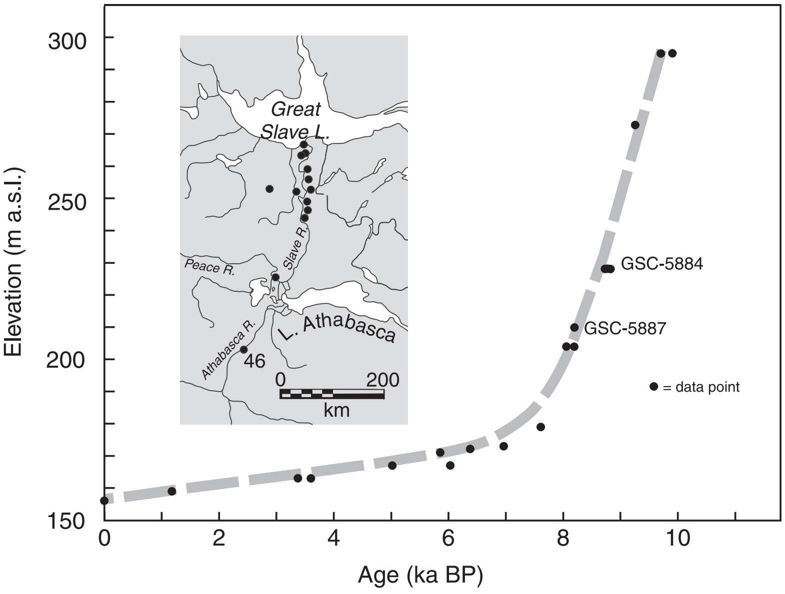

Figure 16.

Lake-level curve depicting the history of glacial Lake McConnell and Great Slave Lake along a transect following the Slave and Athabasca rivers (modified from Lemmen et al., 1994), with the addition of GSC-5884 (8720 ± 80 BP) and GSC-5887 (8070 ± 100 BP).

Athabasca west of Loutit Lake and near Fort Chipewyan (Fig. 2). At least 170 rhythmic couplets overlying glaciofluvial gravel were counted at the Fort Chipewyan site (Fig. 10). Farther east, glaciolacustrine sediment is discontinuous and confined to valley bottoms and depressions. Most of this sediment was deposited in small ephemeral lakes that formed along the retreating ice front, and not as part of glacial Lake McConnell. These lakes were at least 15 m higher in elevation than the maximum elevation of glacial Lake McConnell.

Successive strandlines marking the regression of glacial Lake McConnell are found throughout the western part of the area. West of the Slave River, northeast of Carlson Landing, coarse-sand berms, providing 15–20 m of relief, can be traced for 50 km at 221 to 244 m a.s.l. (Fig. 6). On the east side of the Slave River, flights of well developed beaches can be found on either side of the Slave moraine (Fig. 6). The beaches commonly extend to the crest of the Slave moraine showing that glacial Lake McConnell overtopped the moraine as the ice front withdrew eastward. The maximum elevation of beaches on the Slave moraine ranges from 244 m a.s.l., 25 km southeast of Fort Smith, to 305 m a.s.l. near Hooker Lake. The highest raised shorelines above Lake Athabasca attributed to glacial Lake McConnell are at least 305 m a.s.l. They usually consist of well sorted, pinkish sand derived from Athabasca Group lithologies. Schreiner (1984) suggested that glacial Lake Athabasca, the southeastern extension of glacial Lake McConnell, had an areal extent defined by the 305 m contour, including fluvial deltas near Uranium City, Saskatchewan, the easternmost part of the former lake. South of Great Slave Lake, northwest of the map area, the highest level of glacial Lake McConnell was about 310 m a.s.l. (Lemmen, 1990a, b). Although the maximum elevation of glacial Lake Athabasca was similar along its entire length, the maximum lake level must be time-transgressive because it took more than 1 ka for the ice sheet to vacate the lake basin completely (Dyke and Prest, 1987).

As noted, glacial Lake McConnell reached its maximum extent of more than 215 000 km^2 at 10 ka BP, shortly after deglaciation of the Slave River lowland (Lemmen et al., 1994). The lake did not exist very long because it occupied a glacio-isostatic depression that was rapidly uplifting after the ice load was removed. If the glaciolacustrine varves found throughout the area represent annual deposition, glacial Lake McConnell did not remain at its maximum for much more than 50 a and did not occupy the entire area for more than about 200 a.

Lemmen et al. (1994) reconstructed a lake-level curve describing the fall of glacial Lake McConnell throughout postglacial time (Fig. 16). It is based on the elevations of published radiocarbon dates along a transect from Great Slave Lake to the Peace River delta. The form of the curve is very similar to postglacial emergence curves from the Arctic that were caused by glacio-isostatic rebound (cf. Bednarski, 1995c). Two radiocarbon dates from wood buried in deltaic sediment complement the curve (*see* section below).

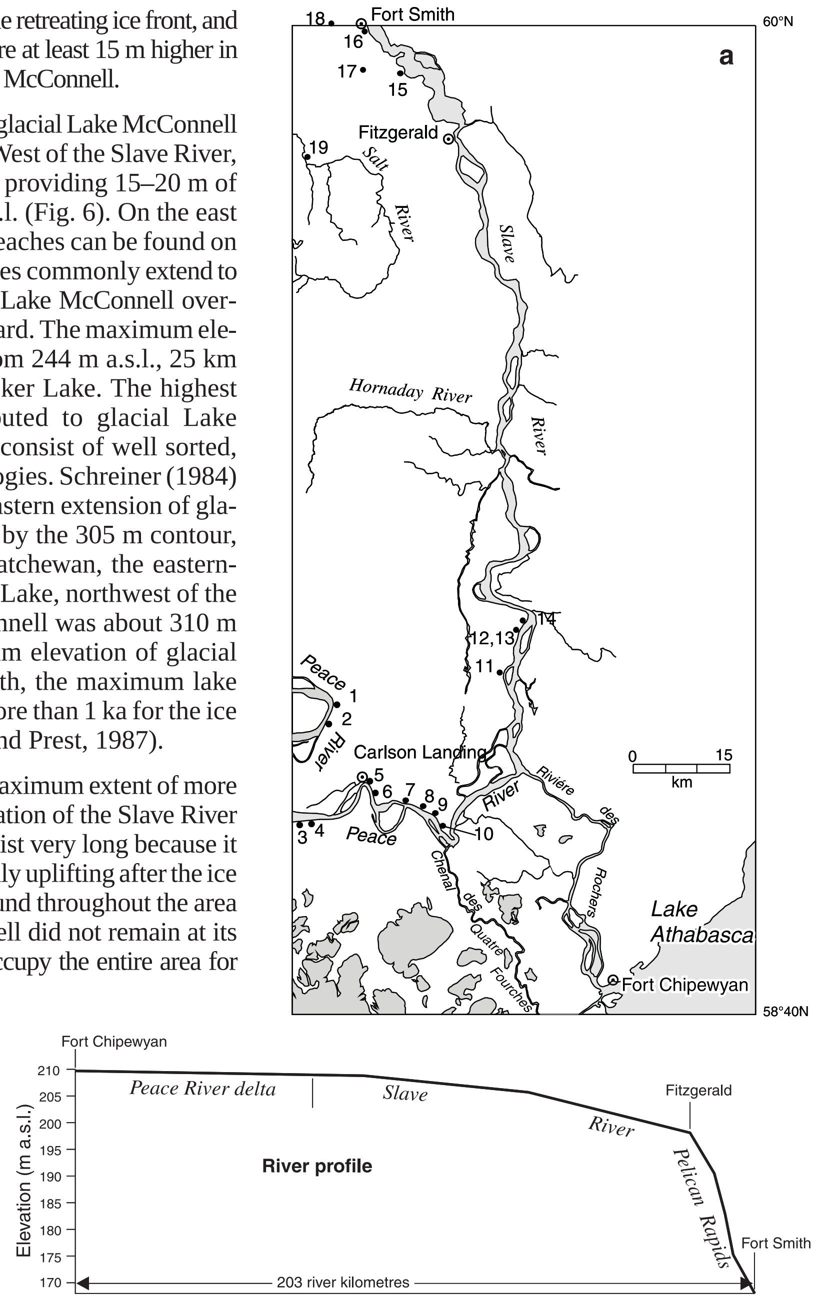

Figure 17. *Major stratigraphic sections in the western map area. Figure 17a shows the location of the sections and longitudinal river profile from Lake Athabasca near Fort Chipewyan, to Fort Smith, upstream of the Holocene Slave River delta built into Great Slave Lake. The profile was derived from topographic maps. Stratigraphic sections (1–10) through the glaciolacustrine delta along the Peace River are depicted in Figure 17b, and along the Slave River in sections 11 to 16 in Figure 17c. Sections 17 and 18 show recent cuts through sand dunes. Section 19 shows silty till, typical of the tills overlying the Paleozoic terrane, overlain by glaciolacustrine sediment.*

Pleistocene delta

When glacial Lake McConnell separated into Great Slave Lake and Lake Athabasca, a large volume of deltaic sand was deposited over glaciolacustrine sediment on the Great Slave plain (Fig. 1). Sections along the Peace and Slave rivers show deltaic sand (map unit Ldt) overlying dark clay and silt (Fig. 17a, b, c).

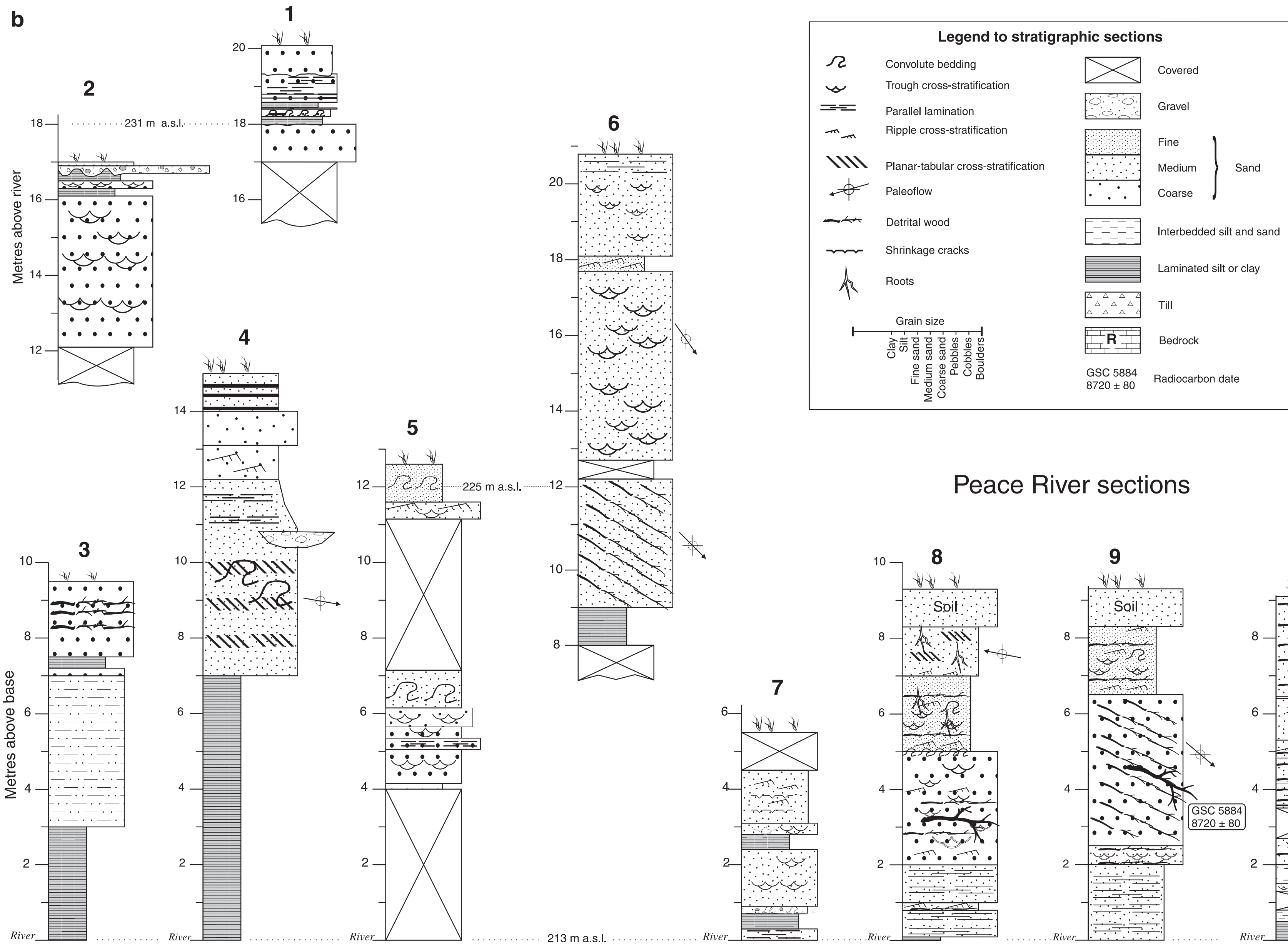
b
1
2
3
4
5
6
7
8
9
10
231 m a.s.l.
225 m a.s.l.
213 m a.s.l.
Metres above river
Metres above base
River
Soil
GSC 5884
8720 ± 80
Legend to stratigraphic sections
Convolute bedding
Trough cross-stratification
Parallel lamination
Ripple cross-stratification
Planar-tabular cross-stratification
Paleoflow
Detrital wood
Shrinkage cracks
Roots
Grain size
Clay
Silt
Fine sand
Medium sand
Coarse sand
Pebbles
Cobbles
Boulders
Covered
Gravel
Fine
Medium
Coarse
Sand
Interbedded silt and sand
Laminated silt or clay
Till
R
Bedrock
GSC 5884
8720 ± 80
Radiocarbon date
Peace River sections

Figure 17b

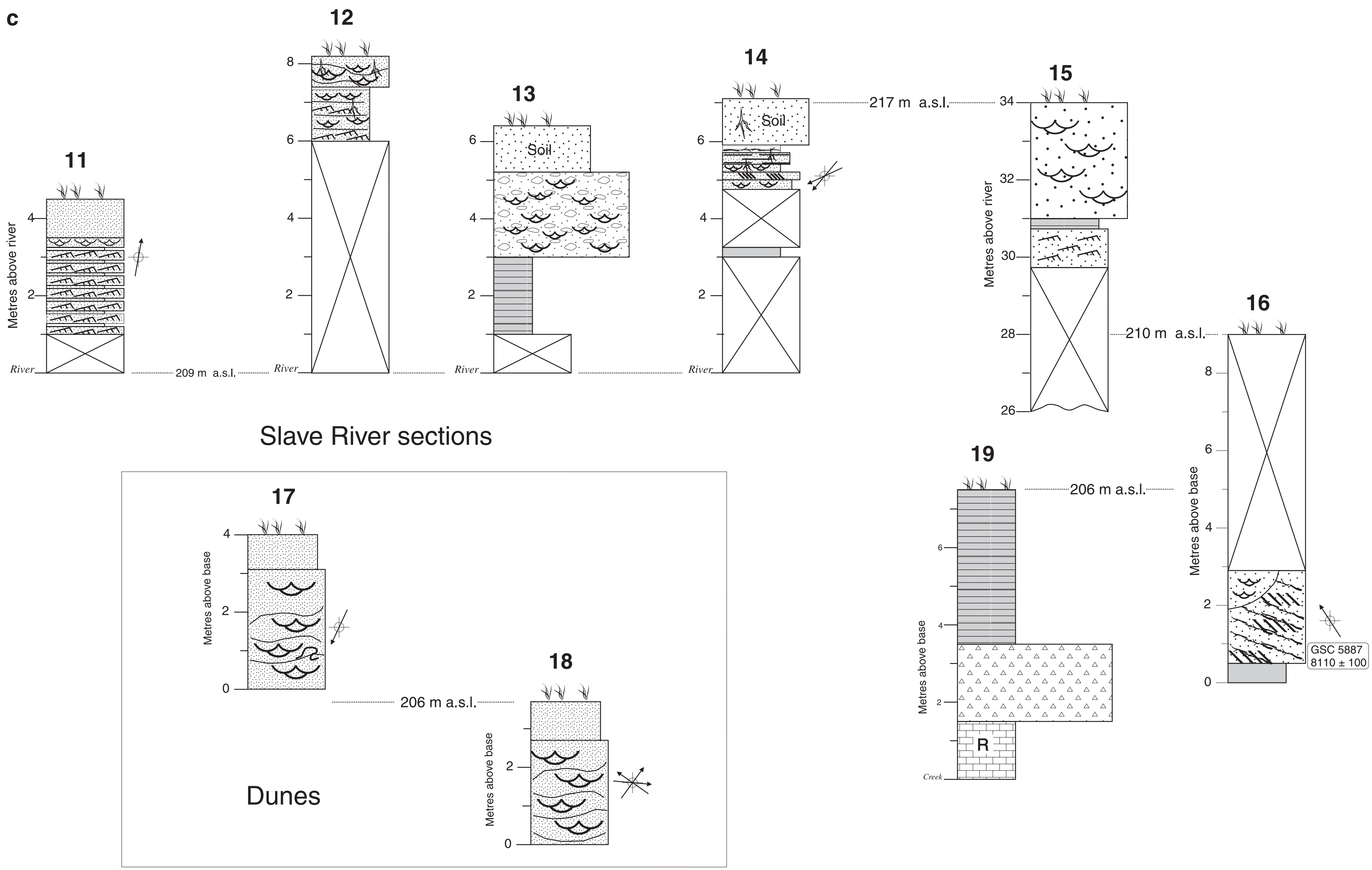
c
11
12
13
14
15
16
17
18
19
Metres above river
Metres above base
River
Soil
209 m a.s.l.
217 m a.s.l.
210 m a.s.l.
206 m a.s.l.
Slave River sections
Dunes
GSC 5887
8110 ± 100
R
Creek

Figure 17c

The deltaic plain extends to the Caribou Mountains in the west (Fig. 1) and to the east and south along the Slave and Peace rivers where more than 30 m of incision has taken place (Fig. 6). The sections show progradation of the delta with frequently shifting channels recorded by cut-and-fill sequences (Fig. 17b, c). Younger alluvium and delta sediment have been inset into the older delta by the Peace and Slave rivers. Several large channels were cut within the Slave River valley as lake drainage progressed. These channels are now abandoned or occupied by misfit streams (Fig. 6).

The age of deltaic progradation was determined by radiocarbon dating detrital organic matter deposited within the sediments. A spruce log extracted from organic-rich, foreset beds on the north shore of the Peace River yielded a date of 8720 ± 80 BP (GSC-5884; section 9, Fig. 17b). This gives the maximum age on deposition, and an age estimate on the approximately 215 m a.s.l. glacial Lake McConnell shoreline. The apparent age of this shoreline corresponds with the lake-level curve (Fig. 16) reconstructed by Lemmen et al. (1994). A second sample was collected from crossbedded sands at 210 m a.s.l., just south of the Fort Smith townsite at the base of a drainage canal (section 16, Fig. 17c). Twigs and wood fragments yielded a radiocarbon age of 8110 ± 100 BP (GSC-5887), giving an age estimate of the 210 m a.s.l. glacial Lake McConnell shoreline. This date also agrees with the lake-level curve (Fig. 16).

Nonglacial and proglacial environments

Eolian deposits (map units E, Er, Ev)

Eolian deposits including sheets of windblown sand and dune fields (map units E and Er) are common throughout the area. Extensive plains of lacustrine and deltaic sediments were exposed when proglacial lakes suddenly drained with ice retreat. This sediment was easily mobilized because of sparse vegetation and intense wind caused by the continued presence of the Laurentide Ice Sheet immediately to the east.

The western edge of the map area includes the Wood Buffalo sand hills, an area of particularly large dunes up to 30 m high (Fig. 6; David, 1977), formed from an abundance of Pleistocene delta sand. Recent excavations through smaller dunes in the northwest show several metres of trough crossbedded sand deposited from several wind directions (sections 17 and 18, Fig. 17c).

On the Kazan upland, deltaic and lacustrine sediment is more localized and eolian blankets are rare. Loess was deposited as 10–20 cm silt layers overlying till in many hollows on the upland. Most dunes on the Kazan upland are northwest of Hooker Lake and south of Woodman Lake, within the zone of the Colin Lake interlobate moraine (Fig. 6). These dunes are the parabolic type (Fig. 18; David, 1977), similar to the “Cree Lake” dune type (David, 1981). These dunes are usually elongated in a downwind direction because they advanced downwind as long as a source of sand was available.

On the Kazan upland, the dunes commonly advanced up to 3 km onto noneolian sediment or bedrock, extending beyond any apparent sediment source (Fig. 18). They form thin ridges up to 5 m in relief and are usually steeper on the north side. The shape and surface texture of the grains in the dune is not appreciably different from the source material. Most dunes seem stable and vegetated under the current environment, however, shallow blowouts occur on the tops of some ridges. Thin discontinuous sand covers some areas of wind-scoured bedrock (map unit Ev).

Most of the dunes in the map area have a predominant elongation to the northwest implying strong surface winds from the southeast. This is diametrically opposite to the predominant present-day winds that blow out of the northwest. This suggests that the dunes date from early postglacial time when a persistent anticyclone was centred over the Laurentide Ice Sheet and dominated the regional circulation (COHAP Members, 1988). Consequently, the age of the dunes can be constrained because they formed in a zone peripheral to the Laurentide Ice Sheet. The demise of the ice sheet allowed Arctic air masses to penetrate southward causing an abrupt shift in regional wind patterns. Rapid colonization by vegetation in the early Holocene (MacDonald, 1987) further stabilized the substrates. Under present conditions, only small blowouts remain active on the crests of a few shore dunes, on lacustrine deposits along Lake Athabasca, and on deltaic deposits west of Slave River. Modern deflation is predominantly to the southeast, directly opposite to the regional winds of the early Holocene.

Nonglacial environment

Lacustrine deposits (map units L1, L1d, L1r)

Typical of the shield, the Kazan upland has an abundance of lakes whose levels have fluctuated throughout the Holocene. The greatest changes occurred following the end of the large proglacial lakes and when new drainage networks became established. Most of the exposed lacustrine sediment (map unit L1) dates from early postglacial time when drainage systems were still blocked with glacial sediment or buried glacial ice. With time, the plugs were eroded and integrated drainage systems developed, dropping lake levels and exposing lacustrine sediment. Generally, this sediment is thin and indistinguishable from unvarved proglacial lake sediment deposited earlier (map unit L).

The greatest volume of lacustrine sediment was deposited by the Peace River prograding into Lake Athabasca (map unit L1d). The modern Peace River delta is usually 15 to 30 m below the level of the Pleistocene and/or early Holocene delta deposited into glacial Lake McConnell. The modern delta is etched by myriad constantly shifting channels and levees. Historically, the delta flooded seasonally depositing large volumes of silt and fine-grained sand. Nonetheless, over the last few decades, the flow of the Peace River has been controlled and reduced discharge has caused large areas of the delta to dry out. Most of the contemporary sedimentation occurs along distributary channels and smaller deltas within the overall deposit. Comparing airphotos from 1955, 1982, and 1984 clearly shows the changes.

Modern littoral processes are most prevalent along the north shore of Lake Athabasca (map unit L1r), particularly where thick drift provides much sandy sediment. The shoreline is affected by wind-driven currents from both the northeast and southwest, forming prominent beaches and spits. Large dunes, more than 10 m high, are often behind the beaches. Most of the dunes appear partly stabilized by vegetation, but active blowouts are common, as noted above. Some of these dunes were probably derived from pre-existing raised beaches, which are also common along the shore. In smaller lakes littoral processes are minor and are restricted to exposures of sandy drift or glaciofluvial material.

In places on the Kazan upland, high concentrations of erratic boulders line the lakeshores. The boulders can form prominent ridges of clast-supported material, but most are

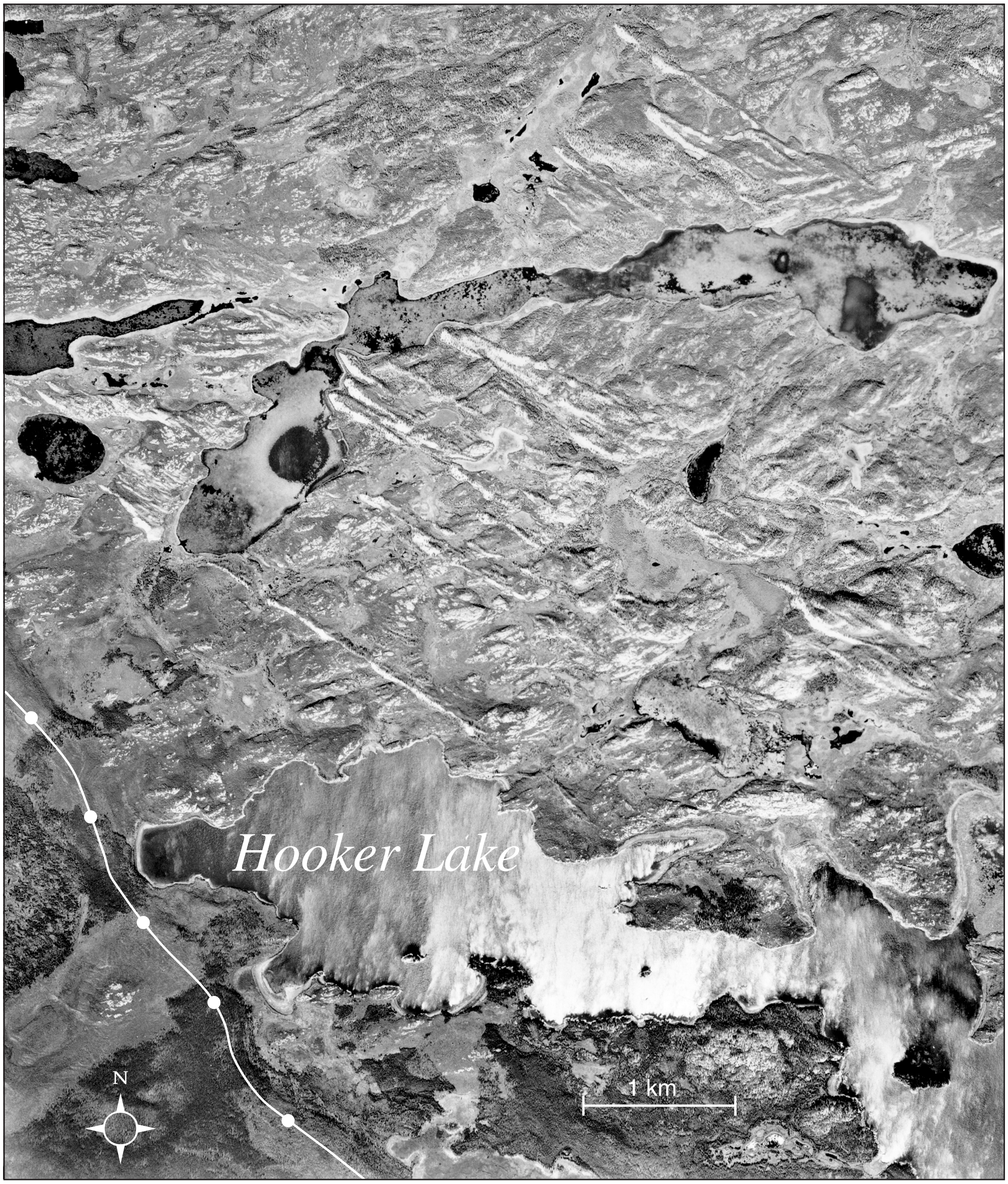

Figure 18. *Parabolic dunes north of Hooker Lake indicate strong winds from the southeast. The dunes form long thin ridges deposited over bare rock, several kilometres from their source areas of glaciolacustrine sand. The Slave moraine (dotted line), trending from north to south, dams Hooker Lake to the west (left). NAPL A15159-60*

submerged 1–2 m. For example, a bedrock island on the east side of Cornwall Lake (Fig. 2) is bordered by a boulder ridge, about 3 m above the lake. The boulders are typically angular, but some are subrounded and may be glaciofluvial deposits that winnowed out as the lake level fell. These features may have formed by the ploughing action of lake ice during periods of a colder climate. Ice-pushed ridges, called “boulder barricades”, are common along Arctic lake shores and coastlines (Bird, 1967).

Many larger lakes on the Kazan upland are bordered by prominent terraces up to 10 m above present levels (e.g. south end of Charles Lake, Fig. 2). The height of the terraces above the lakes is relatively constant but it is unlikely that these lakes are all responding to a common base-level change. This suggests that the lakes may have responded to some Holocene climatic change affecting the water balance.

In places, extensive lacustrine deposits in the northwest part of the map area are overlain by large salt flats (Fig. 6) in areas of ground water discharge. The salt is derived from Middle Devonian evaporite deposits.

Fluvial deposits (map units A, At, Al)

Development of contemporary drainage patterns followed the division of glacial Lake McConnell in the early Holocene. Without the influx of glacial meltwater, fluvial activity abated on the Kazan upland so that only minor redistribution of pre-existing glaciogenic sediment takes place today. Modern alluvium is restricted to narrow flood plain deposits along the Peace and Slave rivers and some tributaries (map unit A). In places, inactive terraces lie a few metres above the modern flood plains (map unit At). The alluvium consists of fine-grained sand and silt with small pockets of coarser gravel. Distinct scroll bars are commonly expressed on the surface (map unit Al). Beyond the major rivers, valleys throughout the area are occupied by misfit streams meandering through organic-rich sediments and no appreciable sediment is transported. Many large abandoned channels were formed by rivers draining high levels of Lake Athabasca when it separated from glacial Lake McConnell.

Colluvial deposits (map unit C)

Effective mass wasting occurs along cutbanks of the Peace and Slave rivers. A particularly large landslide is found at Carlson Landing on the Peace River involving at least a 30 m thickness of material. Other large slumps occur on the west shore of Slave River, north of Fitzgerald. In each case, sliding was enhanced by an impermeable silt and clay layer underlying thick deltaic sediments. In places, these slides are still active, as shown by groundwater seepage and freshly ruptured surfaces.

Rockfalls occur along brittle fault zones on the Kazan upland where significant relief is present. The rockfalls can involve angular granitic blocks, several metres in diameter. Glacial scour and meltwater action along the fault zones probably oversteepened them and subsequent unloading enhanced fracturing along joints (*see* section on ‘Glacial erosion’).

Organic deposits (map unit O)

Poorly drained lowlands in the map area are usually covered by a 1–2 m layer of organic matter that accumulated in swamps and bogs. The organic matter commonly overlies lacustrine silt and clay, and on the surficial geology maps, this is shown as a swamp pattern-fill over the lacustrine units (map units L or L1). Poorly drained depressions abound on the Kazan upland but the largest areas of organic terrain occupy the lowlands west of the Slave River.

A mat of organic peat is an effective insulator so that where the organic layer is 1 m or more thick, the substrate is often frozen throughout the summer. The map area lies within the zone of discontinuous permafrost (Brown, 1967). Landforms attributed to ground ice growth, such as peat plateaus and palsas, are common on the Kazan upland where the insulative layer is thick (Zoltai and Tarnocai, 1975). Peat plateaus, the larger of the two features, cover a few hundred square metres at most, and may be tree covered.

Areas underlain by permafrost are very sensitive to disturbance and when the insulative layer is disrupted, the surface rapidly subsides as the ground ice melts. Many peat plateaus may be degrading because during the summers of 1992, 1993, and 1994, the edges of the plateaus were slumping and surface trees had a ‘drunken’ appearance, tilting in every direction. This recent degradation has been reported on a regional scale and may signify recent climatic warming and resultant melting of ground ice (Vitt et al., 1994).

QUATERNARY HISTORY

Glacial erosion

The surface relief of the Kazan upland was enhanced by glacial scour that eroded the bedrock differentially. Generally, the recessive metasedimentary rocks coincide with the troughs, whereas, granitic rocks form the hills and mylonitic rocks form prominent ridges. The orientation of the bedrock structure to the direction of former glacial flow was also important. When glacial flow was parallel to the structural orientation, the ice flow accelerated within the troughs causing enhanced abrasion. Most of the larger lakes on the Kazan upland are straight-sided, glacially eroded troughs. Conversely, resistant ridges that lay across the direction of former ice flow underwent little glacial erosion.

Ice-flow indicators of varying scales are found on the Kazan upland. The most common are striations, formed by rock or mineral fragments being dragged along the sole of the glacier (Fig. 12). On a larger scale, rock drumlins, streamlined bedrock knolls with long axes oriented in the direction of ice movement are several hundreds of metres long. In many places the upstream side of ice-moulded bedrock protuberances are gently inclined, rounded, and striated, whereas the downstream sides are steep and blocky, the result of glacial plucking enhanced by subglacial freezing of meltwater. Streamlined bedrock forms are prevalent in the northeastern parts of the study area showing the strong glacial scour from the northeast.

Glacial meltwaters were also effective in eroding the bedrock by cutting subglacial and proglacial channels. The meltwaters effectively exploited weaknesses along bedrock lineaments on the Kazan upland. Glaciofluvial deposits in adjacent valleys are usually connected by these meltwater channels. Currently, many former channels are dry or occupied by misfit streams.

Ice-sheet configuration and ice-flow patterns

Glacial features such as striae and rock drumlins unequivocally show the direction of ice flow and, therefore, put constraints on the former shape of the ice sheet when scouring took place. Unfortunately, directional features are not recorded everywhere, and commonly only the final flow pattern of the waning ice sheet is recorded.

When the Laurentide Ice Sheet covered the entire region during the last glacial maximum, the dominant ice flow was to the southwest from the Keewatin Ice Divide (Dyke and Prest, 1987). This ice-flow direction is widely recorded by scoured bedrock landforms and striae in the northern Kazan upland. However, the strongest flow recorded in the southern Kazan upland, north of Lake Athabasca, is east to west (Fig. 12). This flow is parallel to the Lake Athabasca trough and converges with the northern flow pattern along an east-west zone near the 59°30′N parallel.

The northern northeast to southwest flow progressively shifts westward as the southern zone of westward flow is approached (Fig. 12). This suggests that the northeast to southwest flow was deflected by westward-flowing ice in the south: two distinct lobes in the Laurentide Ice Sheet must have coexisted during deglaciation. As noted earlier, the zone of convergent flow coincided with a belt of thick surficial sediments, informally named the Colin Lake interlobate moraine, mapped along an east-west transect from Colin Lake, to south of Cornwall Lake, and then to Cockscomb Lake (Fig. 2).

As noted earlier, the southern lobe occupying the Lake Athabasca trough and southern Kazan upland probably developed during deglaciation when the Laurentide Ice Sheet thinned and became more influenced by the underlying topography. Initially the Athabasca lobe was probably the upstream part of a west-flowing lobe that developed in the Peace River lowland. This lobe formed when the ice sheet was channelled between the flanking Caribou and Birch mountains (Fig. 4).

Former meltwater channels on the northern Kazan upland commonly show that the natural drainage of meltwater flowing south was often diverted to the west (e.g. Fig. 11). This disruption of natural drainage could only occur if ice dammed the valleys to the south, and implies that the northern lobe must have retreated before the Athabasca lobe. Many proglacial lakes also formed during this time and it is possible that much of the glaciolacustrine sediment comprising the Colin Lake interlobate moraine was deposited then.

With further thinning of the ice sheet, the local topography imparted even greater control on the flow. Most of the later flows were aligned with valleys and along lakes. For example, sets of striae oriented along the north shore of Lake Athabasca crosscut the more dominant westerly flow (Fig. 12). Similarly, in the northern part of the study area, the dominant southwesterly striae are crosscut by secondary striae oriented along valley bottoms and elongate lakes.

Ice-flow patterns can be traced only as far west as the Precambrian–Paleozoic contact along the Slave River (Fig. 12). Outcrops west of the Slave River are rare and lithologies are not conducive to preservation of striae. Nonetheless, Tsui and Cruden (1984) reported striae bearing 210° along Salt River in the northwest. This implies that the prevailing flow pattern of the northern sector extended onto the Great Slave plain (Fig. 1). Lemmen (pers. comm., 1995) showed similar flow directions north of the study area, in the Northwest Territories.

Stratigraphy

The main stratigraphic exposures in the area were presented above. No stratigraphic sections had sediments that could be attributed to pre-Late Wisconsinan events although some black clays underlying the Pleistocene delta along the Peace River may be older than glacial Lake McConnell. On the Kazan upland sporadic deposition of till and few exposures make stratigraphic correlation of till impractical. The greatest difference occurs between sandy till on the shield exposed on the surface and in section at Myers Lake (Fig. 9) and calcareous till derived from Paleozoic rocks west of the Slave River (section 19, Fig. 17c). Natural sections of glaciofluvial sediments are also rare because of the loose nature of the sediment, although particularly good exposures are found in gravel pits near Myers Lake (Fig. 9) and near Fort Chipewyan (Fig. 10). A composite reconstruction of the stratigraphy in the western part of the map area has ice-contact glaciofluvial gravel overlain by glaciolacustrine fines, in turn, overlain by deltaic sand and regressive strandline deposits and dunes.

Conclusion

Late Wisconsinan glaciation was responsible for much of the glacial geomorphology and all of the glacial stratigraphy found in the map area. The glacial maximum was achieved after ca. 27 ka BP, based on the age of subtill organic material found southwest of the region (Liverman et al., 1989), and was maintained until ca. 18 ka BP (Dyke and Prest, 1987) when the Laurentide Ice Sheet inundated the area with strong flow from the northeast. Two convergent ice-flow patterns on the Kazan upland, north of Lake Athabasca, were formed by two lobes of ice emanating from the ice sheet. These lobes probably developed during deglaciation, ca. 11 ka BP, when uplands to the west and south emerged above the ice. The retreating ice front crossed the entire study area over a very short period, ca. 11–9 ka BP, but the effects of glaciation on meltwater drainage lasted for at least another 1 ka. As the ice margin withdrew, glacial Lake McConnell, an extensive ice-marginal lake, inundated all land below 305 m a.s.l., and extensive lake sediment was deposited over the lowlands in the west (Fig. 19).

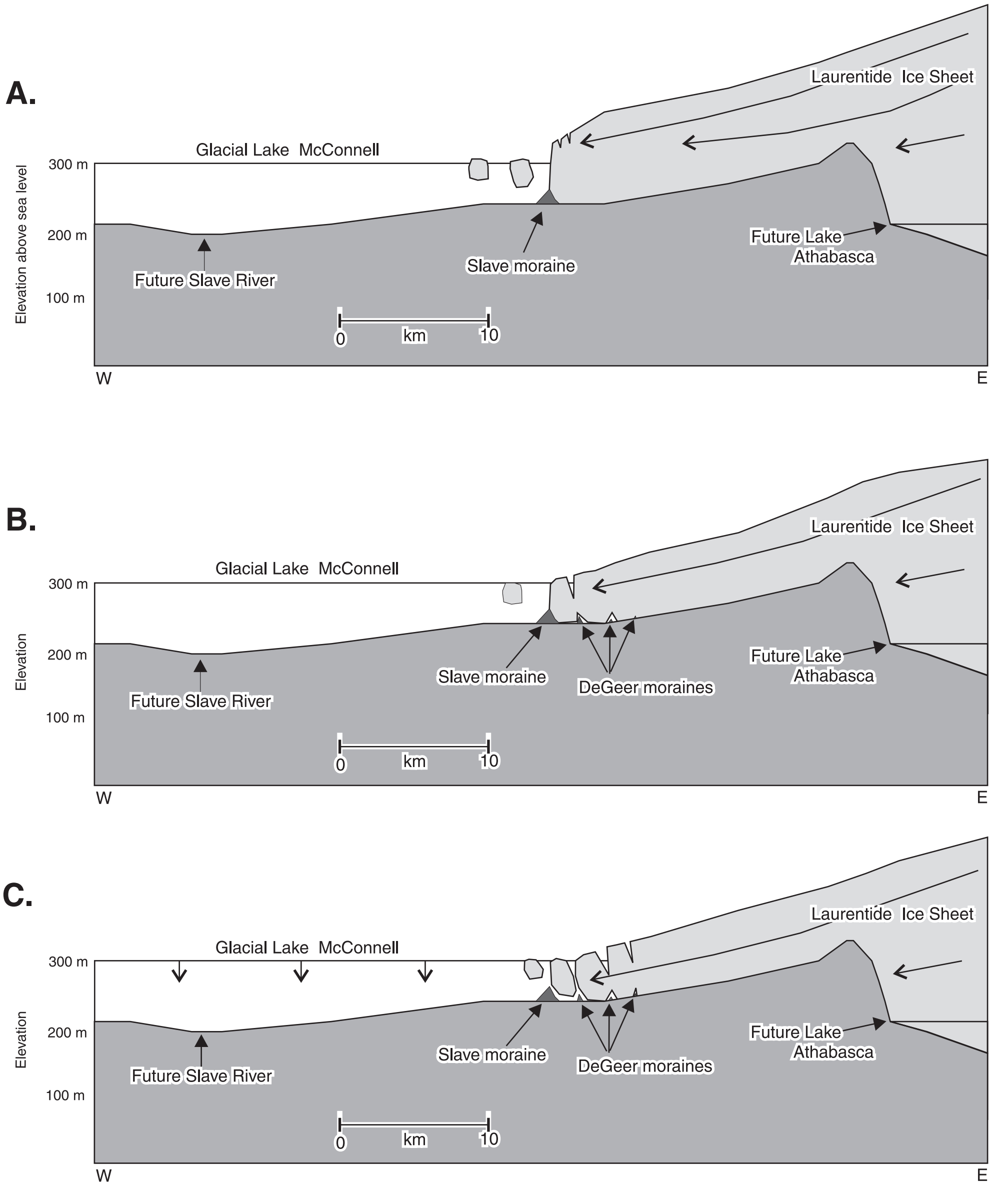

Figure 19. *Schematic profile of the Laurentide Ice Sheet and glacial Lake McConnell during deglaciation (about latitude 59°03′N).* ***A****) At 10 ka BP the ice margin built the Slave moraine subaqueously when glacial Lake McConnell inundated deglaciated lowlands below 305 m a.s.l.* ***B****) The ice sheet eventually thinned along the margin to the extent that ice-marginal crevasses formed and calving took place.* ***C****) The thinning margin became buoyant to the extent that very rapid retreat of the ice margin occurred and a series of De Geer moraines formed beneath the ice.* ***D****) Eventually the margin of the Laurentide Ice Sheet retreated from the Slave moraine and glacial Lake McConnell inundated the east (proximal) side of the moraine. Glacial Lake McConnell was rapidly dropping by this time and shorelines, marking the maximum lake level, were not recorded east of the Slave moraine.* ***E****) When the margin of the Laurentide Ice Sheet retreated within the Lake Athabasca trough, several lakes formed between the ice margin and higher ground to the north and west.*

The retreat of the ice margin was marked by stillstands or minor readvances recorded by local accumulations of glacial sediments. Two significant pauses in retreat occurred at ca. 10 ka BP, when the ice front was 10–30 km east of the Slave River, forming the 120 km long Slave moraine (Fig. 6). The Slave moraine is thought to be the northern extension of the Cree Lake moraine of northern Saskatchewan (Prest et al., 1968). The Cree Lake moraine marks a margin of the Laurentide Ice Sheet that extended across northern Saskatchewan to Manitoba. Because the Slave moraine was deposited subaqueously, subsequent retreat of the ice front caused glacial Lake McConnell to overtop the moraine and inundate proximal lowlands to the east. Rapid initial withdrawal of the ice front from the Slave moraine occurred in the Lake Athabasca basin where water depths were greatest and glacial calving took place forming De Geer moraines (Fig. 19). Glacial Lake McConnell fell rapidly because of glacio-isostatic rebound and free drainage through the Mackenzie River system. Consequently, extensive regressive shorelines were built on the Slave moraine and along the north shore of Lake Athabasca. If the glaciolacustrine varves found in the map area represent annual deposition, the maximum stage of glacial Lake McConnell probably did not last much more than 50 to 200 a. As glacial Lake McConnell fell, the Slave moraine blocked many westward-flowing valleys and many smaller lakes persisted until the moraine was breached by spillways. Several present-day lakes are still dammed by the Slave moraine.

Many ephemeral lakes were created when the ice front retreated eastward across the shield (Fig. 19). Impounded by ice-blocked drainage, these lakes were filled with sandy glaciolacustrine sediments and glaciofluvial deltas (Fig. 11). Elsewhere, meltwater scoured channels in bedrock. Thinning of the ice sheet exposed the Colin Lake interlobate moraine that formed when the northern and southern ice lobes converged. This interlobate zone accumulated thick glaciofluvial and glaciolacustrine sediment. Patterns of meltwater diversions suggest that after initial retreat of the ice front from the Slave moraine, the northern part of the map area became ice-free first. In the south, the Lake Athabasca lobe continued to occupy the Lake Athabasca trough and ponded meltwater along its margin on the Kazan upland where thick accumulations of glaciolacustrine sand were deposited. By the time the ice front retreated into Saskatchewan, most lakes drained and large expanses of sandy sediment were exposed to strong southeasterly winds forming extensive parabolic dunes. These winds were a late glacial feature caused by a strong anticyclone that persisted over the remnant Laurentide Ice Sheet.

By ca. 8.7 ka BP, the retreating Lake Athabasca lobe opened an embayment in glacial Lake McConnell. This embayment was first called glacial Lake Athabasca by Schreiner (1984). As lake levels dropped, the Peace River formed a delta over the Great Slave plain, and eventually, Lake Athabasca separated from glacial Lake McConnell along a prominent bedrock sill near Fort Smith (Craig, 1965). By ca. 8.2 ka BP, ancestral Great Slave Lake (a remnant of glacial Lake McConnell), receded north of Fort Smith to a level of about 204 m a.s.l. (Vanderburgh and Smith, 1988; Lemmen et al., 1994). The Slave River entrenched large channels into the plain as glacial Lake McConnell receded northward. On the Kazan upland, lake levels continued to decline throughout the Holocene as dams of glacial sediment were eroded and modern integrated drainage patterns developed.

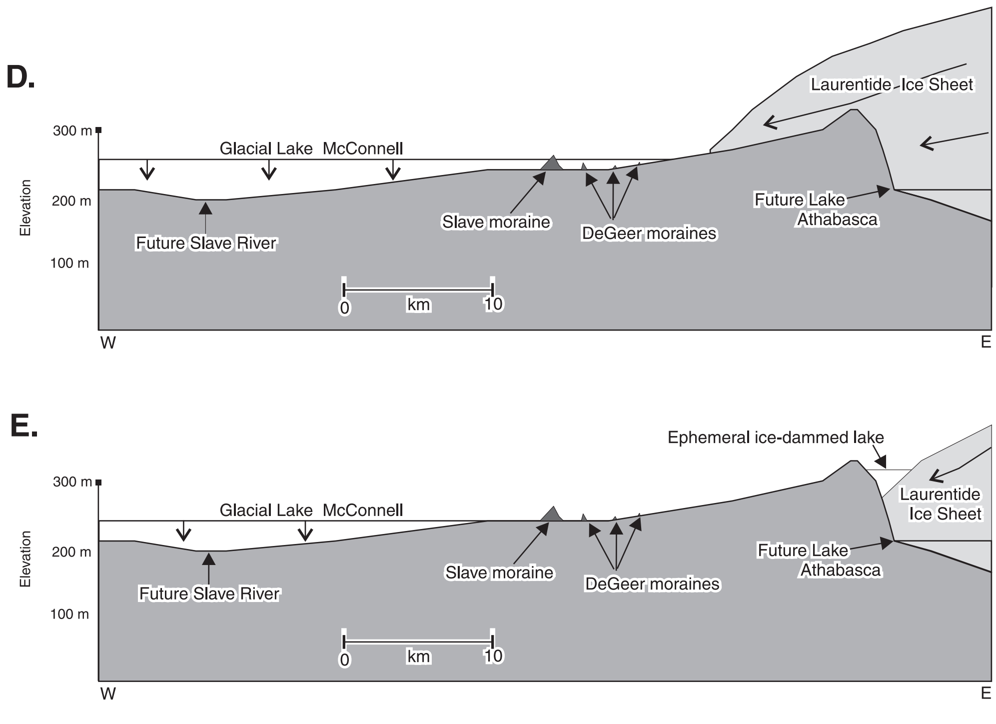

Figure 19 *(cont.)*

ECONOMIC AND ENGINEERING GEOLOGY

The surficial geology maps can be applied directly to land use and exploitation of mineral aggregate resources. Many unconsolidated deposits in the region have a sand to gravel texture (Fig. 7) with varying percentage of boulders. The quartzose sand composition of the glaciofluvial deposits (map unit G) provide the best construction materials but sorting in esker segments and especially the Slave moraine is generally restricted to discontinuous lenses (Fig. 9). Large glaciofluvial deposits near Fort Chipewyan and within the Colin Lake interlobate moraine (Fig. 6) have a more uniform sand composition. Sand dunes (map unit Er) also could provide a ready source of well sorted aggregate. Godfrey (1986) noted several potential quarry sites where quality building stone could be extracted from the glacially scoured granitoid rocks.

The Slave moraine forms a nearly continuous ridge for tens of kilometres and could provide a useful north-south transportation corridor above surrounding lowland filled with lacustrine mud. As with most glaciofluvial deposits in the area, the moraine is well drained, stable, and composed of hard inert rock with good load-bearing capacity. The shield is also very stable but has very irregular topography and is pitted by many poorly drained depressions.

Conversely, eolian deposits stabilized by vegetation and vegetated areas underlain by permafrost are very sensitive to disturbance. Once the vegetation is removed, the substrate is destabilized. As noted, the region is near the border of discontinuous permafrost (Brown, 1967) so that permafrost is present in areas in poorly drained organic terrain and absent on gravelly glaciofluvial terrain. Where ground ice is present, any disruption of the insulation cover can cause slumping that becomes self-perpetuating. Low areas mantled by lacustrine deposits often have tracts of continuous muskegs that have low density and little strength with very poor potential for transportation corridors.

The following highlights the results of the geochemical survey on glacial drift. Readers are referred to Bednarski (1996) for more detail.

1. Distributions of elements measured in the silt and clay fractions of glacial drift, indicate that many samples are enriched in the clay fraction. These anomalies were located by statistically derived contour maps. Some anomalies correspond with reported mineral showings (Godfrey, 1986; Langenberg et al., 1994) and anomalies recorded in lake sediments (McCurdy, 1997).

2. Heavy mineral analysis of 10 drift samples found one kimberlite indicator mineral from a glaciofluvial deposit near Colin Lake.

3. Gold anomalies west of Tulip Lake and east of the southern part of Andrew Lake are just west of gold anomalies discovered in sediment by McCurdy (1997) and gold mineralization zones identified by Salat et al. (1994). The anomalies reported here were probably displaced westward by glacial flow.

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