



# Surficial Geology and Quaternary History of the High Prairie Area (NTS 83N/SE)

# **Surficial Geology and Quaternary History of the High Prairie Area (NTS 83N/SE)**

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## Abstract

This report describes the distribution, character and origin of surficial materials in the High Prairie map area (NTS 83N/SE) and discusses the Quaternary history of the region. The High Prairie map area is located west of Lesser Slave Lake, and comprises the Swan Hills Upland (up to 1000 m asl) in the south and the broad lowlands of the Sturgeon, Falher and High Prairie plains (450–750 m asl) in the north.

Widespread till and associated streamlined landforms document the southward advance of the Laurentide Ice Sheet across the High Prairie area during Late Wisconsinan glaciation. This advance covered the High Prairie region, including local uplands, and deposited two major till facies and associated landforms across much of the map area. These sediment-landform associations document former ice sheet dynamics, and provide further insight into regional stratigraphy and landscape evolution.

During regional deglaciation, the Laurentide Ice Sheet retreated from the High Prairie area at ca. 12 ka BP, exposing the broad lowland basin in the northern part of the map area. This basin subsequently captured subaerial and glacial meltwater drainage that converged towards the ice margin, forming the eastern part of a regional proglacial lake termed ‘Glacial Lake Peace.’ This lake is now demarcated by glaciolacustrine sediments that cover the northern High Prairie area, up to about 630 m asl. These glaciolacustrine sediments correlate with a larger expanse of proglacial lake sediments deposited throughout the Peace River lowlands at the end of the last glaciation. Glacial Lake Peace drained from the High Prairie area as the retreating Laurentide Ice Sheet exposed a major outlet along the Lesser Slave Lake–Athabasca River valley to the east of the map area. Following glacial lake drainage, fluvial sediments transported by the East and West Prairie rivers aggraded across parts of the High Prairie lowlands, draping till and glaciolacustrine sediments with a veneer of fine sand and silt.

## 1 Introduction

As part of a multiyear initiative, Alberta Geological Survey (AGS) continued its surficial mapping program, focusing on the High Prairie area in the southeast quadrant of the 1:250 000 Winagami map area (NTS 83N/SE; Figure 1). This work was released in 2008 as AGS Surficial Geology Map 421 (Atkinson, 2008).

The mapping objectives were to describe the distribution of surficial materials in the High Prairie area and determine the Quaternary history of the region. This report complements AGS Map 421 (Atkinson, 2008) and provides a more detailed description of the spatial distribution and character of these surficial materials. The report also discusses the Quaternary history of the High Prairie area, focusing particularly on the role of the Laurentide Ice Sheet in regional landscape evolution.

The surficial geology map of the High Prairie area was based on the interpretation of 1:60 000 aerial photographs, augmented by georeferenced digital data and remote sensing techniques. Field mapping was conducted in the summer of 2007 and provided 180 site descriptions to constrain the airphoto interpretation. Four-wheel-drive trucks provided access along gravelled roads and trails, and a helicopter was used to access more remote areas. The interpreted airphotos were scanned and georeferenced, and the boundaries of the interpreted surficial units were vectorized using ArcInfo™. The final map products were prepared following review and editing.

## 2 Physiography

The High Prairie map area occupies about 3500 km<sup>2</sup> and straddles the Northern Alberta Lowlands and the Southern Alberta Uplands of the Interior Plains of Canada, south of the town of High Prairie (Figures 1 and 2; Pettapiece, 1986). It is bounded by latitudes 55°00'N and 55°30'N, and longitudes 116°W and 117°W. The region is characterized by flat to gently undulating terrain that formed initially during Late Tertiary fluvial incision and was later modified by Quaternary glaciation. The major physiographic features include the broad lowlands of the Sturgeon, Falher and High Prairie plains (450–750 m asl) in the northern part of the map area. These plains occupy the eastern part of the regionally extensive Peace River Lowland. The Swan Hills Upland extends to the south of the map area, and contains the local high relief of the Blue and Brush mountains (960–1000 m asl). Less prominent features include Horizon Hill and a smaller unnamed hill that sites the Enilda fire tower, in the eastern part of the map area (Figure 2). Surface drainage radiates from these uplands and is captured by tributaries of the northward-flowing East and West Prairie rivers. These supply the South Heart River, which flows east into Lesser Slave Lake.

## 3 Bedrock Geology

The map area is located in the north-central part of the Western Canada Sedimentary Basin (Mossop and Shetsen, 1994). It is underlain by Late Cretaceous clastic rocks deposited along the transition between marine and nonmarine environments that resulted from the regression of an interior seaway, termed the 'Pakowki Sea,' after around 83 Ma (Dawson et al., 1994; Hamilton et al., 1999; Figure 3). The Smoky Group subcrops in the north-central part of the map area, and comprises thinly bedded, dark grey, fossiliferous marine shale that was deposited within this seaway. The Smoky Group is conformably overlain by the nonmarine Wapiti Formation, which subcrops in a southeast-trending band across the map area. This formed part of a prograding clastic wedge that was supplied by rivers flowing eastwards from the emergent Rocky Mountains into the Pakowki Sea. The lower Wapiti Formation consists of grey to greenish grey feldspathic sandstone and grey, clayey siltstone. Lower Wapiti sandstone is exposed along the East Prairie River in the southern portion of the map area. The lower Wapiti Formation is conformably overlain by grey, feldspathic, clayey sandstone and bentonitic mudstone of the upper Wapiti Formation that subcrops along the southwestern part of the map area.

## 4 Vegetation

The High Prairie area straddles two natural regions: the Boreal Forest in the north and the Foothills in the south (Downing and Pettapiece, 2006). The Boreal Forest region comprises two subregions. The Dry Mixedwood subregion occurs across the flat terrain of the northern Sturgeon Plain and is characterized by abundant cultivated land in the northeastern part of the map area, with occasional mixed stands, together with bogs and fens in low-lying or poorly drained areas in the northwest. The Central Mixedwood

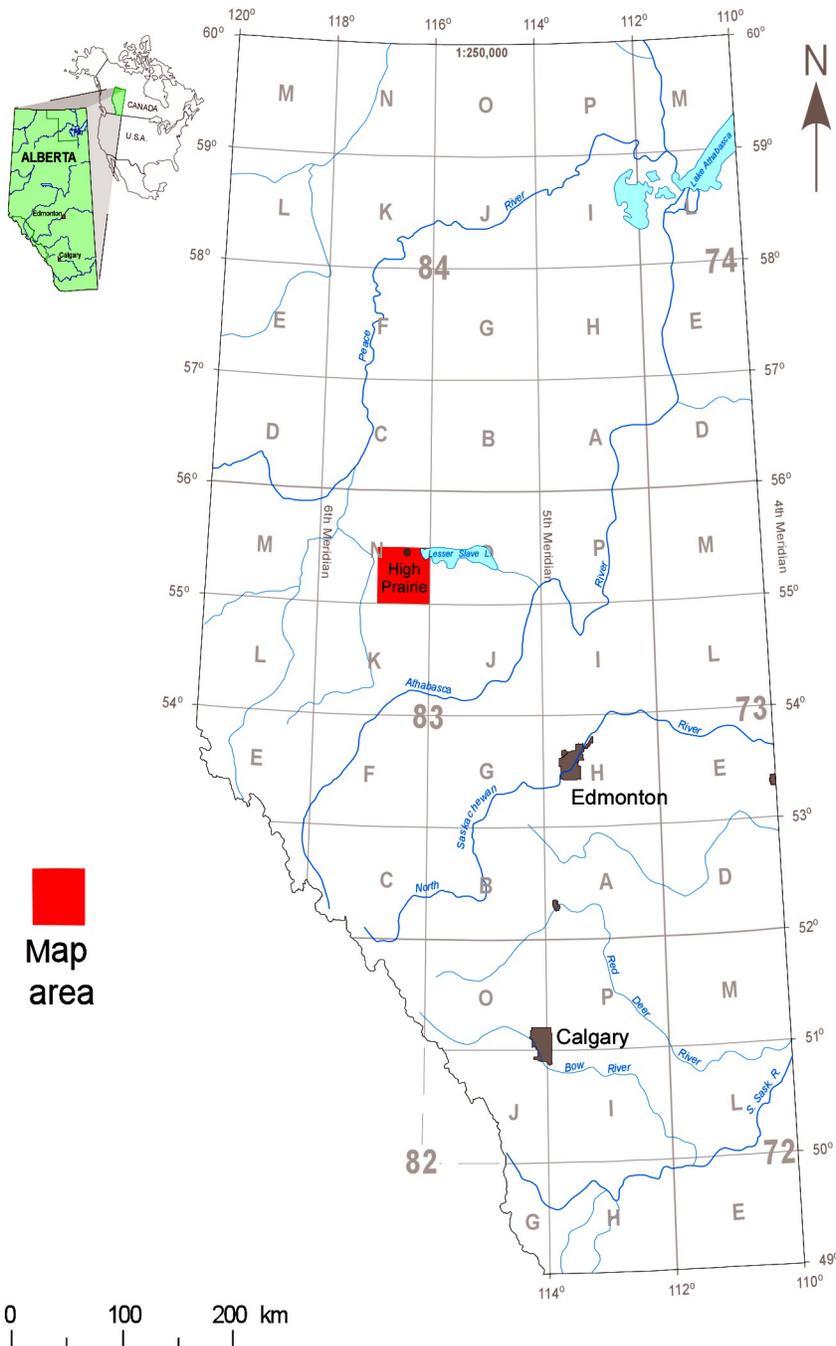


Figure 1. Location of the High Prairie map area, north-central Alberta.

subregion occupies the gently undulating terrain of the southern Sturgeon Plain and comprises less agricultural land and a mosaic of mixed conifer and deciduous stands, with extensive treed fens developed across poorly drained areas. The Foothills region comprises a number of subregions, including the Lower Foothills subregion that occurs across the Swan Hills Upland in the southern part of the map area. The

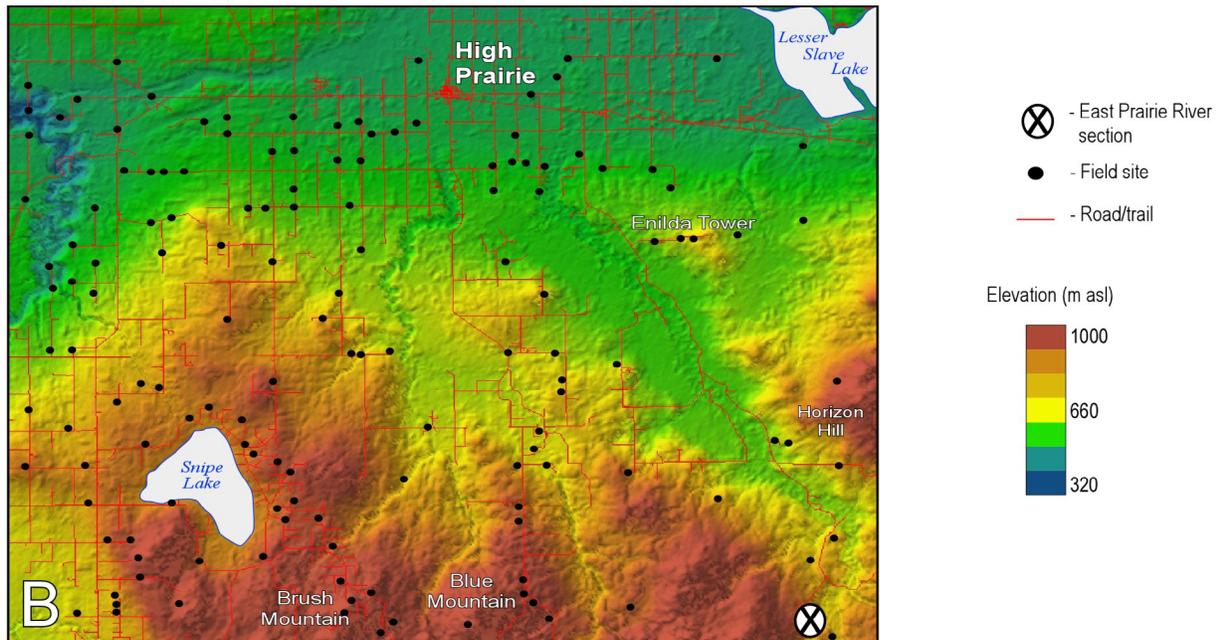
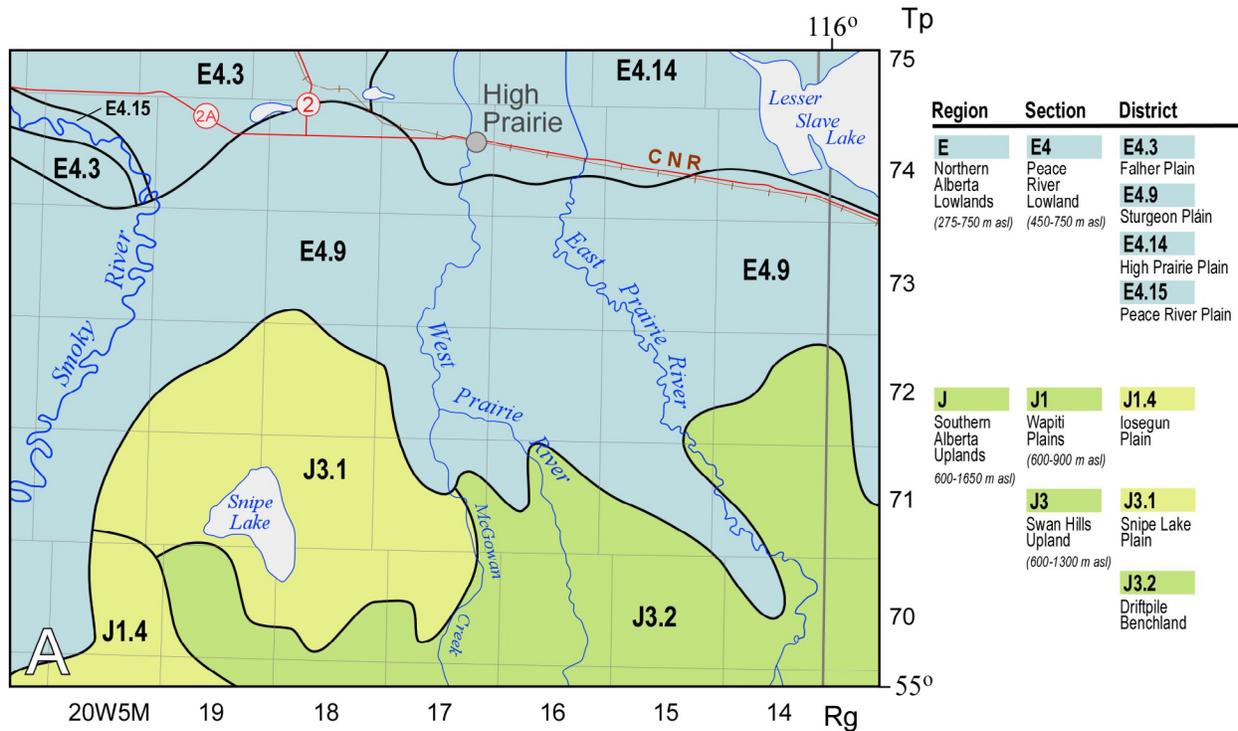


Figure 2. A) Physiographic regions (modified from Pettapiece, 1986) and B) Digital elevation model (DEM), generated by the Shuttle Radar Topography Mission (SRTM), of the High Prairie map area, showing place names referred to in the text.

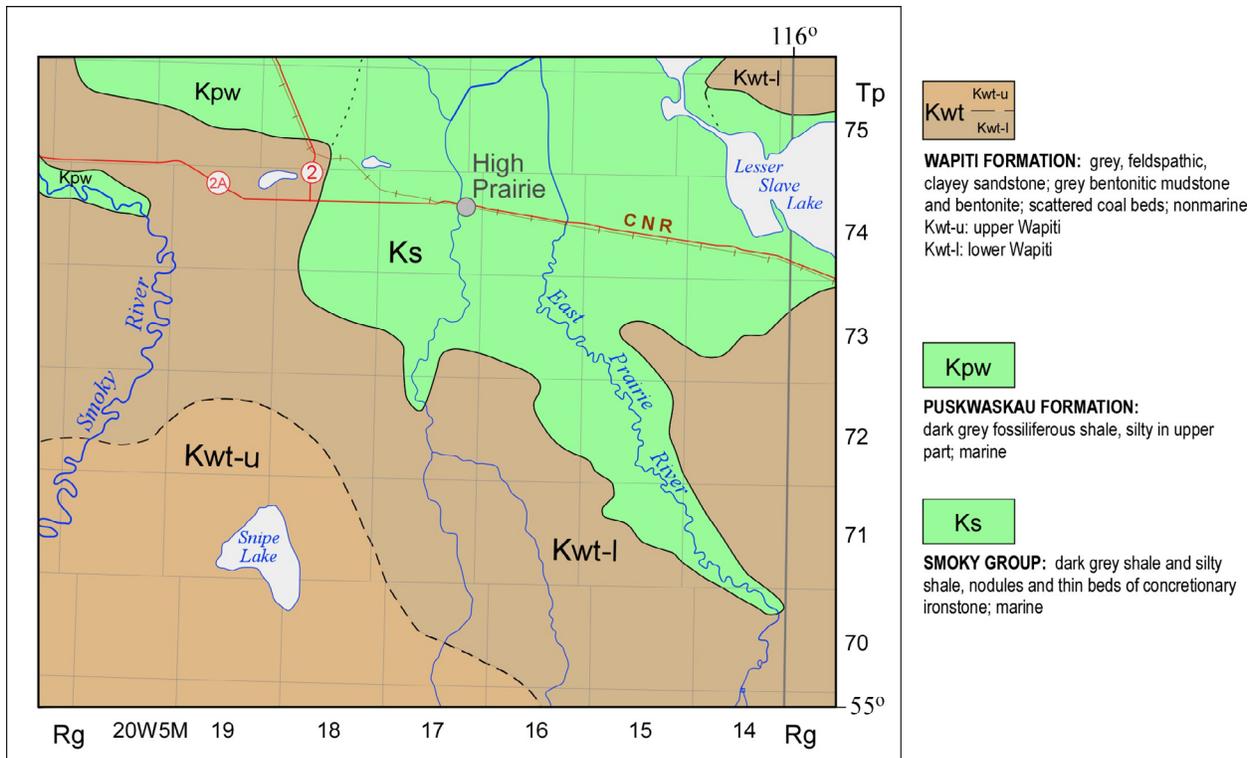


Figure 3. Bedrock geology of the High Prairie map area (modified from Hamilton et al., 1999).

foothills subregion is dominated by pine and spruce, with occasional birch stands at lower elevations. There is energy development and logging activity in this subregion, with only minor cultivation.

## 5 Surficial Geology

The surficial geology map of the region shows the distribution of seven genetic types of surface materials (Atkinson, 2008). These materials and their associated landforms are discussed below, in the order in which they appear in the legend of AGS Map 421 (Atkinson, 2008), which reflects their relative ages (Figure 4). Their significance in relation to the Quaternary history of the map area is discussed in Section 7.

### 5.1 Moraine (Units M, MS, MT, MF)

Moraine, herein described synonymously as till, is the predominant Quaternary material described in this report, covering about 75% of the map area (Figure 4). Moraine veneer (Mv) is mapped wherever till is insufficient to obscure the relief of the underlying units (<2 m thick). Areas of till veneer occur mainly in the southern part of the map area, between Blue and Brush mountains, and on the eastern uplands between the Enilda fire tower and Horizon Hill. Till veneer is rarely streamlined, although a narrow tract (<2.5 km wide) of southerly oriented flutings occur at the head of a gap between Blue and Brush mountains. Till thickness diminishes across areas of greater relief, either because higher parts of the glacier bed extended into cleaner ice, or because these areas experienced enhanced erosion (cf. Dyke et al., 1992). Moraine plain (Mp) is mapped wherever till masks the underlying bedrock ( $\geq 2$  m thick) and occurs primarily in the lowlands to the north of Blue and Brush mountains. In places, this till plain is fluted and streamlined. Individual flutes are up to 1.5 km long, exhibit a southerly orientation ranging from 130° to 195°, with local divergence around physiographic highs, and occur within distinct tracts between 1 and 7 km wide (Figure 5).

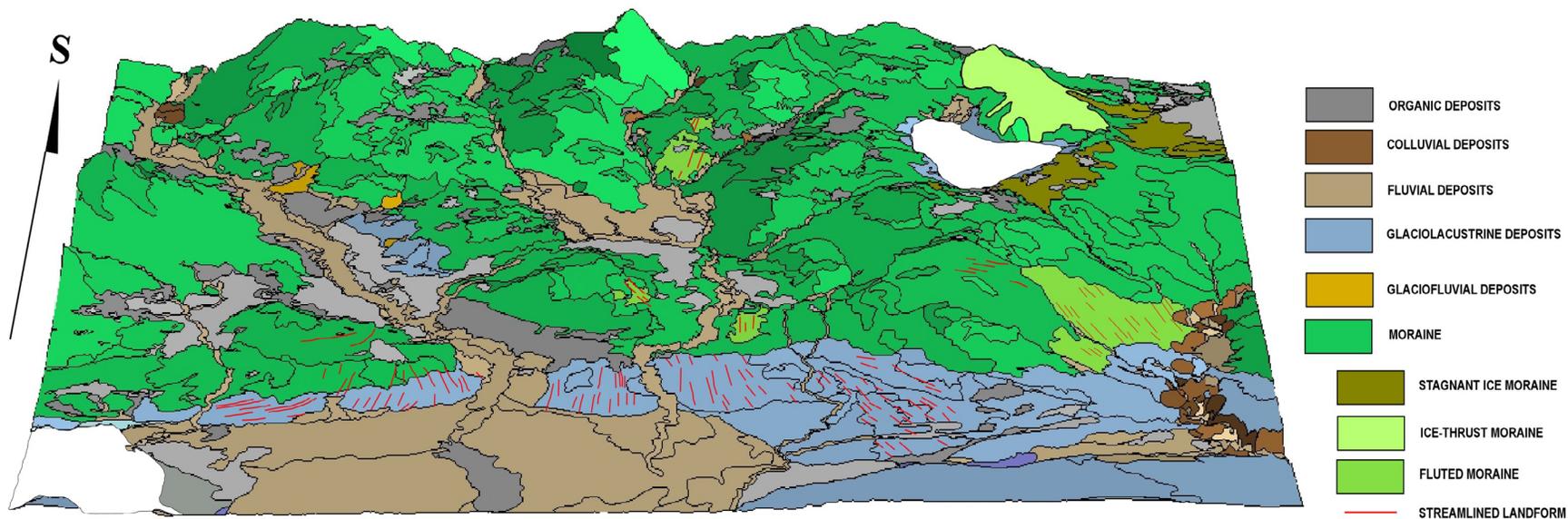


Figure 4. Simplified surficial geology of the High Prairie map area, draped on a hill-shaded SRTM DEM with a 15x vertical exaggeration and a western light source.



**Figure 5. Tract of fluted till plain east of the Little Smoky River. Lines indicate axes of flutes.**

Till veneers and plains commonly exhibit a suite of irregular mounds and ridges that document the stagnation of the Laurentide Ice Sheet margin during regional deglaciation and the subsequent melt-out of buried ice. These include areas where actively flowing ice abutted a stagnant ice margin, producing buried and stranded ice blocks that slowly melted on the landscape, producing kettled and pitted terrain, as well as areas of hummocky moraine that resulted from the melt-out of debris-mantled ice (Evans et al., 2006b). Areas of hummocky moraine are frequently associated with dissected and gullied moraine, likely resulting from erosion and reworking by glacial meltwater and by the modern drainage of ephemeral streams during spring snowmelt.

### **5.1.1 Till composition and Distribution**

A qualitative assessment of till characteristics based on field examination demonstrates that two major till facies occur across the map area (Figure 6). The first lithofacies comprises a black to very dark grey, matrix-supported, clayey silt diamict. Clast content, which includes Cretaceous, Paleozoic and Canadian Shield rock types, is typically 2%–10% and comprises mainly subangular granules, with occasional subrounded pebbles. The second lithofacies is a very dark grey-brown to olive brown, matrix-supported, sandy silt diamict. Clast content in this lithofacies is generally 2%–5% and includes Cretaceous, Paleozoic and Canadian Shield rock types as subrounded to rounded pebbles to cobbles, with occasional subangular granules. These lithofacies occur in lowland and upland settings, indicating that their distribution does not reflect physiographic control. However, it was noted that the very dark grey diamict occurs primarily in areas of till veneer, whereas the very dark grey-brown to olive brown diamict is mainly associated with till plains.



Figure 6. The two till facies that characterize the High Prairie map area: olive brown, sandy silt till (left) and clay-rich, black to dark grey till (right).

### 5.1.2 Till Stratigraphy

Two major and one minor lithofacies associations (LFA) have been identified in the High Prairie map area, based on stratigraphic sequences examined at two sections exposed along the East Prairie River (Figures 2 and 7). Due to the lack of datable material, the chronostratigraphy of these sediments remains uncertain. However, their stratigraphy and genesis are inferred to be consistent with a single, Late Wisconsinan glaciogenic sequence.

The lowest lithofacies exposed along the East Prairie River constitutes <5% of the logged section and consists of a southward-tapering, wedge-shaped sequence of massive, poorly sorted, clast-supported diamict (LFA 1; Figure 8). This diamict consists of a chaotic assemblage of sub- to well-rounded quartzite cobbles and boulders in a sandy to muddy matrix. No Canadian Shield rock types were observed in this diamict. There were no surface exposures of this minor lithofacies observed in the map area; therefore, it is not depicted on Map 421 (Atkinson, 2008).

Lithofacies association 1 is overlain by a black to very dark grey, massive, matrix-supported clayey silt diamict, which represents the second major lithofacies exposed along the East Prairie River (LFA 2). The contact between LFA 1 and LFA 2 has a sharp ice-distal (southern) slope and diffuse ice-proximal slope, which exhibits a shear amalgamation zone, whereby the overlying clayey silt diamict has ingested cobbles from LFA 1 (cf. Stea and Finck, 2001; Figure 8). Clast content within LFA 2, which includes both local and Shield rock types, is approximately 2%, consisting predominantly of subangular granules with occasional subrounded and glacially faceted pebbles. This diamict has high bulk density and exhibits a fissile and platy structure, characterized by subhorizontal concave fractures that are crossed by well-developed subvertical dilation joints (Figure 9).



Figure 7. Sections on the A) west and B) east banks of the East Prairie River. Person circled for scale. Section A is located 3 km north of Section B (see Figure 2 for location).



Figure 8. Massive, poorly sorted, clast-supported diamict (lithofacies association 1) overlain by clay-rich diamict (lithofacies association 2) within the section shown in Figure 7A. Note the erosional ice-distal (southern) contact, and the diffuse ice-proximal (northern) contact (dashed line).



Figure 9. Fissile structure of lithofacies association 2 within the section shown in Figure 7A. Note the subhorizontal concave fractures crossed by well-developed subvertical dilation joints.

Lithofacies association 2 contains several intrabeds of well-sorted medium sand that have undergone varying degrees of deformation but retain their primary sedimentary structures. Individual sand intrabeds occur either as isolated, strongly deformed and attenuated pods or as moderately deformed lenses. A stack of three northward-dipping, imbricate sand lenses, each up to 2.5 m wide and 0.75 m thick, occurs in the central part of the section (Figure 10). The base of these lenses is planar and dips at a shallow angle to the north, whereas the upper surface is convex upward, with a gentle northern slope and a steeper southern slope. Flame structures resulting from the diapiric intrusion of highly dilated/fluidized diamict are common along the southern edges of the sand intraclasts, between which are streaks and augens of sand enveloped by diamict (Figure 10). This lithofacies is considered to correlate with the black to very dark grey, matrix-supported, clayey silt diamict that forms till veneer throughout the High Prairie area.

Lithofacies association 2 is overlain by a grey-brown to olive brown, massive, matrix-supported, sandy silt diamict that represents the third lithofacies exposed along the East Prairie River (LFA 3). Clast content in LFA 3 is 2%–5% and includes Cretaceous, Paleozoic and Canadian Shield rock types as subrounded to rounded pebbles to cobbles, with occasional subangular granules. Although this diamict has a lower bulk density than LFA 2, vertical dilation joints are common and are preferentially eroded to produce minor hoodoos (Figure 11). Where visible, the boundary between LFA 2 and LFA 3 is diffuse; elsewhere it is obscured by colluvium. However, at one exposure along the East Prairie River, LFA 2 and LFA 3 are separated by several moderately deformed interbeds of laminated fine sand and silt. These include a 0.5–1 m thick, laterally discontinuous, lenticular interbed with a concave base and a planar upper contact (Figure 12) that contains boudinaged and overturned laminations (Figure 13). The upper contact between this fine sand interbed and LFA 3 exhibits distinct horizontal banding, which likely resulted from part of the interbed being incorporated into a 10–20 cm thick shear amalgamation zone of the newly accreting diamict. This lithofacies is considered to correlate with the very dark grey-brown to olive brown, matrix-supported, sandy silt diamict that has been mapped within till plains throughout the area (Figure 6).

## **5.2 Glaciofluvial Deposits (Unit FG)**

Glaciofluvial sediment is a minor unit in the High Prairie map area, comprising sand veneer overlying till along the western flank of the East Prairie River. These sand deposits are perched up to about 50 m above the modern floodplain, and likely resulted from the progradation of proglacial outwash that emanated from a suite of northeasterly oriented glacial meltwater channels incised within the northern slope of the Swan Hills Upland.

### **5.2.1 Meltwater Channels**

A number of valleys in the map area exhibit anomalous overdeepening and/or overwidening relative to the size of the active channels that currently occupy them. Consequently, it is inferred that these valleys were eroded by discharges of glacial meltwater during regional deglaciation. These include minor meltwater channels, which commonly occur as nested, subparallel incisions comprising relatively short (1–3 km), narrow (<100 m), shallow (<20 m) and discontinuous segments. The East and West Prairie rivers currently occupy relatively small channels that meander through wide (up to ~1.5 km), flat-floored misfit valleys that likely originated as major meltwater channels (Figure 14). The East Prairie River is incised into till and bedrock, exposing the stratigraphic sections discussed in Section 5.1.2.

## **5.3 Glaciolacustrine Deposits (Units LG, LGL)**

Glaciolacustrine sediment is the dominant surficial material in the northern part of the map area, covering the Falher and High Prairie plains and extending south across part of the Sturgeon Plain, where it onlaps till up to ~630 m asl. These deposits comprise massive to horizontally laminated, rhythmically bedded, fine sandy silt and clay with occasional dropstones (Figure 15). Individual sandy silt–clay couplets vary



Figure 10. Deformed and attenuated intratill sand lenses within lithofacies association 2 at the section shown in Figure 7A. Diffuse or obscured contact is shown by the dashed line.



Figure 11. Vertical dilation joints within lithofacies association 3 at the section shown in Figure 7B.



Figure 12. Lenticular sand interbed between lithofacies associations 2 and 3 at the section shown in Figure 7B. Pick (circled) for scale. Diffuse or obscured contact is shown by the dashed line.



Figure 13. A) Fine sand interbed between lithofacies associations 2 and 3 at the section shown in Figure 7B. Pick (65 cm long) for scale. B) Detailed view of this interbed, showing boudinaged and overturned laminations (Canadian five-cent coin for scale).



Figure 14. View north along a major meltwater channel occupied by the East Prairie River where it flows across A) the Swan Hills Upland, and B) Sturgeon Plain.

in thickness from 1 to 2.5 cm. Clay laminae range from 0.5 to 2 cm thick, whereas the thickness of the sandy silt component of the couplet is more variable, ranging from <0.5 cm at the base of the deposit to 1.5 cm towards to top. These couplets record ice-distal sedimentation within the deeper parts of a former lake basin, although the incremental thickening of sandy silt laminae toward the top of the unit suggests that sedimentation occurred within a progressively shallowing basin. These glaciolacustrine deposits typically blanket the underlying till, forming extensive plains. Much of this unit has a hummocky relief, likely due to melting of stranded ice blocks, as well as differential melting and collapse of massive ground-ice inclusions (cf. Dyke et al., 1992).

Along the western flank of the East Prairie River, a veneer of glaciolacustrine sediment mantles till up to 660 m asl (Figure 4). These deposits comprise horizontally laminated couplets of fine sandy silt diamict (~15 cm thick) and silty clay (<1 cm thick) with isolated dropstones (Figure 16). These rhythmites likely document ice-proximal sedimentation into a shallow former lake basin. Much of the southern margin of the mapped glaciolacustrine sediments is fluted and streamlined. Individual flutes are up to 2 km long and occur within a broad, lobate tract (~32 km wide), with flute orientations ranging from 140° in the west to 195° in the east.

### **5.3.1 Iceberg Scours**

Iceberg scours have been mapped across glaciolacustrine sediment on the Sturgeon Plain in the northwestern portion of the map area. These straight to curvilinear scours are up to 800 m long and extend subparallel to the southwest-trending lineaments in the adjacent fluting tract, although they exhibit more variable orientations (105°–190°) as well as localized crosscutting.

## **5.4 Lacustrine Deposits (Unit L)**

Holocene lacustrine sediments are minor units in the High Prairie map area, comprising sand, silt and small amounts of fine gravel along the margins of Lesser Slave Lake and Snipe Lake. These sediments exhibit modification by recent littoral processes, producing a suite of landforms that includes beach berms, bars and spits.

## **5.5 Fluvial Deposits (Unit F)**

Alluvium is a major surficial material in the map area and is divided into two types, depending on whether the sediment is being actively modified by modern fluvial processes or is presently inactive. Active alluvium occurs primarily along the East and West Prairie rivers and consists of sand and cobbles within the modern flood zone, which is bisected by meandering channels <30 m wide (Figure 17). The remaining sand and gravel in the East and West Prairie rivers is categorized as inactive alluvium, occurring in paired and unpaired terraces along the margins of these channels. These terraces are dissected by meandering paleochannels and are separated from the modern flood zone by a distinct bluff ≤3 m high (Figure 18). Two major alluvial plains occur in the map area. North of Blue Mountain, the West Prairie River and McGowan Creek emerge into a broad, till-floored basin, infilled with inactive alluvium, that in places contains abandoned meandering channels (Figures 2 and 4). McGowan Creek and the West Prairie River occupy former meltwater channels along the margins of this plain and have exposed up to 3 m of horizontally bedded fine sand and silt. Large areas of the Sturgeon and High Prairie plains in the northeastern portion of the map area are mantled by inactive alluvium, which contains numerous meandering paleochannels. Ongoing incision of these plains by the East and West Prairie rivers has exposed up to about 6 m of horizontally bedded, well-sorted, fine sand and silt deposited over glaciolacustrine sediment (Figure 19).



Figure 15. Rhythmically bedded glaciolacustrine sediments showing fine sandy silt and clay couplets in A) a soil probe, and B) a section.



Figure 16. Horizontally bedded couplets of sandy silt diamict and clay, containing dropstones, overlying sandy silt till.

## 5.6 Colluvial Deposits (Unit C)

Colluvium is a locally significant surficial unit resulting from the downward movement of slope-forming materials, including till, glaciolacustrine sediment and bedrock. These movements are the product of surface run-off and/or groundwater conditions, structural weakness within these materials, or fluvial erosion at the base of the slope. Colluvium mantles the slopes of a number of streams and rivers in the map area, and includes minor slumps as well as large, deep-seated landslides. The most extensive area of colluvium occurs along the Little Smoky River (Figure 4). Here, the moderate-wavelength, high-amplitude meanders of active and abandoned channels are associated with retrogressive rotational landslides that form multiple arcuate blocks. The heads of these stacked blocks are frequently back-tilted, forming depressions in which narrow, crescentic sag ponds have accumulated.

## 5.7 Organic Deposits (Units O, OB, OF)

Most wetlands, and therefore peatlands, overlie fine-grained till and glaciolacustrine sediments. These sediments are more heavily vegetated than the surrounding terrain and include small, isolated shrub or sedge bogs occupying areas ranging from poorly drained basins scattered across the irregular, till-covered terrain of the Swan Hills Upland to large tracts (up to 40 km<sup>2</sup>) overlying till on the Sturgeon Plain along the East Prairie River.



Figure 17. Active alluvium within A) the modern channel of the East Prairie River, comprising B) sand and imbricated gravel bars (flow is from left to right).



**Figure 18. Inactive alluvial terrace, containing a meandering paleochannel, perched above the modern channel of the East Prairie River.**



**Figure 19. Horizontally bedded alluvium within part of the Sturgeon Plain, exposed along the East Prairie River.**

## 6 Economic and Engineering Geology

Till, excavated locally from borrow pits, is a widely used construction material in the southern part of the map area, providing roadbase for well pads and access roads. Till in this part of the map area consists mainly of LFA 2, which presents some engineering challenges because of its high clay content. When wet, trafficability along these roads deteriorates markedly and they quickly become ridged and gullied, requiring ongoing regrading.

Unconsolidated sediments in formerly glaciated landscapes comprise bedrock derivatives that reflect the processes of bedrock erosion, as well as glacial and nonglacial processes that transport and deposit these derivatives (Shilts, 1993). Compositional trends in the dispersal of these derivatives, which include heavy minerals, can be determined by sampling higher order sediments such as till. The distribution of landforms associated with the two major till types described in this report are shown in AGS Map 421 (Atkinson, 2008). For reasons discussed in Section 7.1, LFA 3 (sandy silt diamict) is considered to have a stronger regional dispersal signal than LFA 2 (clayey silt diamict).

The High Prairie surficial geology map (Atkinson, 2008) shows a number of glacial meltwater channels in the Swan Hills Upland. A number of localized glaciofluvial deposits are associated with these channels, but the proportion of gravel within these sediments is unknown.

## 7 Quaternary History

### 7.1 Glacial History, Ice-Sheet Dynamics and Till Genesis

The distribution and character of many of the surficial sediments and associated landforms described in this report document the influence of the Laurentide Ice Sheet on the erosional and depositional history of the High Prairie map area during the last glaciation.

Ice-sheet motion is a fundamental control on the evolution, character and distribution of glaciogenic materials across formerly glaciated landscapes. Ice flow is driven by a range of processes, including ice deformation, deformation of the underlying substrate and sliding at the ice-bed interface, that act independently or in combination with one another (Benn and Evans, 1998). The degree of resistance to ice flow is controlled by a group of interacting factors that includes basal ice temperature, which dictates whether the ice is warm or cold based; debris content of the ice; bed roughness; and basal water pressure. Collectively, the interplay between driving and resisting forces dictates ice sheet dynamics, which in turn influences the rate and style of subglacial erosion and deposition, as well as the nature of subglacial sediment transport (Boulton, 1974, 1975; Hallet, 1979).

The quartzite cobble diamict (LFA 1) described in Section 5.1.2 is inferred to be the oldest Quaternary sediment described in this report. This lithofacies is typical of proglacial outwash found in the forelands of modern glaciers (Maizels, 1993; Evans, 2000) and likely resulted from the influx of hyperconcentrated meltwater outflows during an initial glacial advance into the region. The absence of Canadian Shield rock types from this diamict suggests it originated as proglacial outwash from a local ice lobe advancing northwards along the East Prairie River from a dispersal centre within the Swan Hills. This outwash was subsequently overridden and reworked by the Laurentide Ice Sheet that advanced southwards across the region, depositing LFAs 2 and 3 and associated morainal landforms described in this report.

Lithofacies associations 2 and 3 form a glaciotectonically disturbed, bipartite stratigraphy along the East Prairie River. This stratigraphy is consistent with widely reported, commonly occurring subglacial sequences and is interpreted as the product of vertical accretion of deforming till due to spatial and temporal variations in subglacial hydrology, basal ice deformation and substrate rheology (cf. Boulton and Hindmarsh, 1987; Clark and Walder, 1994; Benn and Evans, 1996; Evans, 2000; Evans et al., 2006a).

Accretion commenced during the advance of the Laurentide Ice Sheet into the region, which resulted in the horizontal transfer, or advection, of a thick sequence of clay-rich till across the map area. This till is likely an amalgam of Cretaceous bedrock and pre-existing materials, primarily advance-phase glaciolacustrine sediments that accumulated as the Laurentide Ice Sheet progressively impounded the eastward drainage of regional rivers, leading to the formation of large proglacial lakes (cf. Alley 1991; Smith et al., 2005). These glaciolacustrine sediments were subsequently overridden and advected downflow by subglacial deformation, contributing to the formation of the clay-rich till facies that occurs throughout the map area (cf. Alley, 1991). The base of this till along the East Prairie River section is marked by an erosional boundary, which in places forms a shear amalgamation zone within which cobbles from the underlying diamict (LFA 1) have been ingested into the overriding deforming layer. Subglacial shear is typically associated with an increase of pore-water pressure, which results in sediment expansion and a lowering of the cohesive and frictional strength of the till (Alley, 1991). Such dilation precludes the formation of a coherent till-matrix framework, which reduces ice-overburden pressure, thus facilitating further till dilation and thereby enhancing ice flow (Iverson et al., 2003). This relationship between till deformation and ice flow is reflected in the sediment-landform associations described in this report, since fluted moraine occurs primarily in areas of clay-rich till.

Despite evidence for widespread subglacial deformation of clay-rich till across the map area, sand lenses within LFA 2 at the East Prairie River section indicate that deformation was punctuated by intervals of basal sliding, since these sediments evidently resulted from glaciofluvial deposition at the ice-bed interface. Consequently, subglacial deformation across the map area likely coexisted with sliding and glaciofluvial sedimentation on a spatial and temporal continuum, depending on the predominant process at the time when these components of the glacial depositional system were switched on or off (Alley, 1992; Piotrowski and Kraus, 1997). Based on the morphology of these sand lenses, they were likely deposited within channels eroded into the underlying substrate (R-channels) along the ice-bed interface. Previous research has demonstrated that R-channels are only stable when the substrate is stiff or rigid (Walder and Fowler, 1994), suggesting that these lenses may reflect localized changes in the rheology of the clay-rich till due to periodic switching between dilatant and nondilatant (collapsed) states. This switching would have initiated dewatering and the development of the till-matrix framework, which would have enhanced intergranular contacts, thereby decreasing till porosity and increasing density. As till rigidity continued to increase, more grains would have contacted each other, giving the till greater frictional and cohesive strength. Previous studies have suggested that this process is particularly prevalent in clay-rich till (Benn and Evans, 1996; Evans et al., 2006a). Consequently, R-channels likely formed along rheological boundaries within LFA 2 due to increases in the subglacial hydraulic gradient. As till porosity decreased, less basal meltwater would have been discharged by Darcian flow, resulting in the formation of R-channels to drain the excess (Piotrowski, 1997). Moreover, R-channels would have captured pore water from the underlying till, resulting in its further dewatering and collapse. Framework collapse is commonly accommodated by clast readjustment, as well as the development of foliation, which is imparted by the segregation of clay minerals to form a plasmic fabric (Menziés et al., 2006). During unloading following ice retreat, this bedding-parallel fissility is reactivated, forming sub-horizontal fractures such as those described in LFA 2 (Figure 9). The preservation of primary sedimentary bedding within the intratill sand lenses indicates that, as more clay-rich till was accreted into the area, the base of the deforming layer migrated upward and deeper parts of LFA 2 became less mobile (Walder and Fowler, 1994). Consequently, these sand lenses are inferred to have acted as relatively stiff regions of the ice-sheet substrate that were tilted and deformed as they were rafted and partially ingested within the more rapidly deforming, clay-rich till.

The upper, sandy silt till (LFA 3) exhibits a different lithology and has a lower density and higher porosity than LFA 2. Collectively, these characteristics indicate that LFA 3 has a different provenance than LFA 2, likely due to the exhaustion of locally supplied, fine-grained proglacial sediment that had been inherited by LFA 2 during the initial advance of the Laurentide Ice Sheet into the area. In addition to

changing the dominant clast lithology, this change in provenance would have also caused textural variations in the till-matrix framework relative to LFA 2, thereby introducing a different rheology and deformation signature to the till sequence along the East Prairie River. Sandy diamict such as LFA 3, which is interpreted as part of a regionally dispersed sandy silt till facies (cf. Fenton, 2008), generally dilates more rapidly and is less likely to experience collapse and solidification than clay-rich diamict (Evans et al., 2006a). Moreover, sandier diamicts have a greater frictional strength and are more resilient to deformation. Nevertheless, boudinaged and overturned sand laminae within the sand interbed document minor deformation at the base of LFA 3 (Figure 12). Sediment-landform associations across the High Prairie area demonstrate that hummocky moraine occurs primarily in areas of this sandy silt till, suggesting that LFA 3 may also contain sediments that resulted from the melt-out of debris-rich ice.

Lithologically and rheologically distinct tills commonly display variable deformation signatures and may be separated by stratified interbeds that record changes in subglacial hydrology, bed rigidity and ice-till coupling (Walder and Fowler, 1994; Benn and Evans, 1996; Evans et al., 2006a). Consequently, the lenticular interbed between LFAs 2 and 3 that has a concave base and a planar upper contact may represent glaciofluvial sedimentation within a canal at the interface between ice and a dilated till. In contrast, the R-channel intrabeds within LFA 2 exhibit horizontal lower contacts and convex-upward upper contacts, and are considered to have been deposited at the interface between ice and relatively stiff, nondilated till.

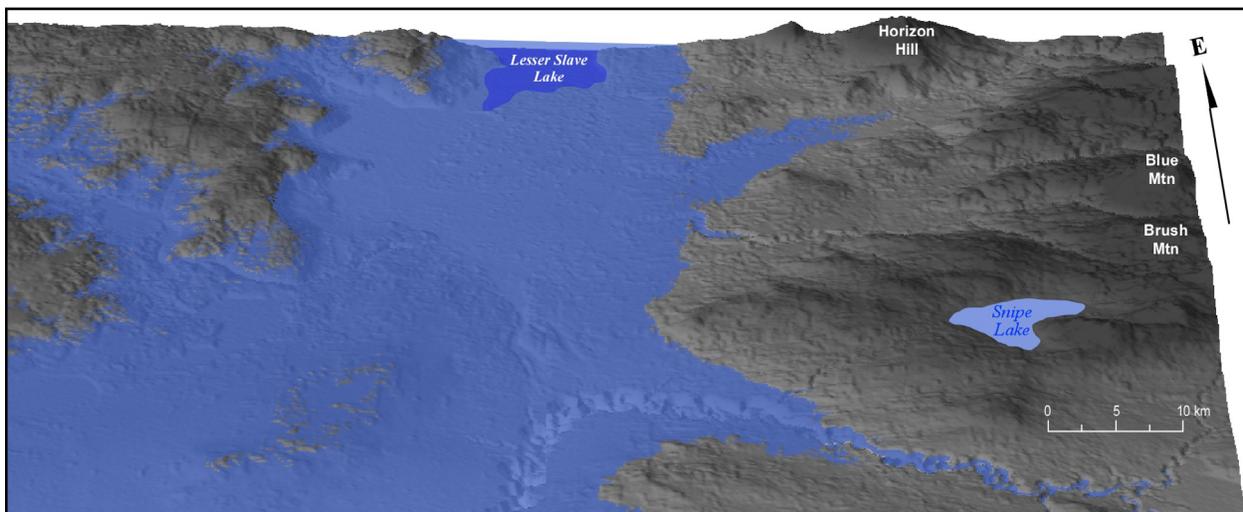
Consequently, the bipartite till sequence described along the East Prairie River is interpreted as a product of periodic switching between dilated and collapsed till zones, associated with spatial and temporal variations in substrate rheology, ice sheet dynamics and subglacial hydrology. These zones migrate through time, resulting in superposition of different processes and the stacking of different subglacial sediment types at any one site. The differences described in this report accord with studies of contemporary ice sheets, which contain juxtaposed deforming and nondeforming sediments that give rise to a mosaic of subglacial sediment types across former glacier beds (Piotrowski et al., 2004).

## 7.2 Deglaciation

The Late Wisconsinan retreat of the Laurentide Ice Sheet from the Interior Plains of Canada occurred across a surface that descends from 1200 m asl near the Rocky Mountain Front to 250 m asl at the edge of the Precambrian Shield (Klassen, 1989). This regional slope would have been augmented by glacioisostatic depression that increased northeastward towards a loading centre in Hudson Bay. Consequently, subaerial or glacial meltwater drainage systems that converged towards topographic basins abutting the ice margin would have formed short-lived proglacial lakes (cf. Teller and Kehew, 1994). The Laurentide Ice Sheet retreated from the High Prairie area ca. 12 ka BP (Dyke et al., 2003; Squires et al., 2006), exposing a broad basin presently occupied by the Falher, Sturgeon and High Prairie plains. This basin was subsequently filled by a proglacial lake that is now demarcated by the widespread glaciolacustrine sediments that cover the northern part of the map area up to ~630 m asl. These glaciolacustrine sediments form part of a larger expanse of proglacial lake sediments that were deposited within Glacial Lake Peace (Mathews, 1980).

Glacial Lake Peace is the collective term for a time-transgressive proglacial lake that formed when the Laurentide Ice Sheet exposed the Peace River valley during its retreat at the end of the last glaciation. Glacial Lake Peace occupied successive proglacial positions as the retreating Laurentide Ice Sheet exposed progressively lower outlets to the north and east. Previous paleoshoreline studies have suggested that the High Prairie area was inundated during the Clayhurst and Indian Creek stages (Fahler I equivalent; St-Onge, 1972) of Glacial Lake Peace (Mathews, 1980; Fenton, 2008a). During these stages, Glacial Lake Peace extended along the Peace River valley for 350 km west and 260 km north of the map area.

The highest glaciolacustrine sediments (660 m asl) described in this report occur along the East Prairie River and are interpreted to have been deposited as a Laurentide ice lobe retreated north along this valley, impounding local drainage and forming a narrow, short-lived proglacial lake. Regionally, a well-developed wave-cut scarp on the northern flank of the High Prairie Plain, in the adjoining McLennan map area (NTS 83N/NE; Fenton, 2008b) records a maximum Glacial Lake Peace shoreline of 680 m asl (Fenton, 2008a). This paleoshoreline correlates with the early Clayhurst stage of Mathews (1980) and has been mapped farther east, along the north shore of Lesser Slave Lake (Paulen et al., 2004). The highest regional paleoshoreline described in this report is inferred from the widespread distribution of glaciolacustrine sediments, which occur up to 630 m asl. Research of contemporaneous proglacial lakes elsewhere in central Alberta suggests that differential glacioisostatic rebound following the removal of the Laurentide ice load accounts for a northeasterly increase in shoreline elevation of ~1.2 m/km (Henderson, 1959). Consequently, when glacioisostatic tilting is taken into account, the 630 m asl paleoshoreline described in this report is contemporaneous with the early Clayhurst shoreline described by Fenton (2008a; Figure 20).



**Figure 20.** Paleogeographic reconstruction of the early Clayhurst stage of Glacial Lake Peace in the eastern half of NTS 83N. This lake level is based on the distribution of glaciolacustrine sediments and associated landforms draped on a hill-shaded SRTM DEM, using a northeasterly glacioisostatic correction of 1.2 m/km. Vertical exaggeration is 15x.

This paleogeographic reconstruction suggests that Glacial Lake Peace extended farther east during the Clayhurst stage than has been previously recognized (cf. Mathews, 1980). As the Laurentide Ice Sheet continued to retreat to the northeast, it exposed a major outlet along the Lesser Slave Lake–Athabasca River valley that was largely responsible for draining the Fahler I equivalents of Glacial Lake Peace (St-Onge, 1972).

Previous research has indicated that, following drainage of Glacial Lake Peace, the regional retreat of the Laurentide Ice Sheet was punctuated by readvances of localized ice lobes (Henderson, 1959). These lobes blocked drainage networks, re-establishing a series of short-lived proglacial lakes, including the Falher II equivalents of Glacial Lake Peace (St-Onge, 1972), which was impounded by the southward advance of the Peace River ice lobe along the Peace River valley immediately west of the study area (Henderson, 1959; Mathews, 1980; Paulen and McClenaghan, in press). Evidence of a southward readvance of a Laurentide ice lobe across glaciolacustrine sediments has been reported in the McLennan map area (Fenton, 2008a). The fluted and glaciotectionized glaciolacustrine sediments described in this report appear to have been part of a regional readvance that extended at least 40 km farther south, covering the High Prairie Plain and the northern Sturgeon Plain.

Following retreat of the Peace River ice lobe and final drainage of any residual proglacial lakes, well-sorted, fine-grained alluvium aggraded across the Sturgeon and High Prairie plains, mantling the glaciolacustrine sediment. Horizontal bedding of this alluvium suggests that it occupied the floodplain of the East and West Prairie rivers, which experienced periodic flooding and overbank sedimentation. This floodplain was likely also supplied by the South Heart River to the north of the map area. It remains uncertain whether these alluvial sediments are contemporaneous with those deposited upstream of the confluence of McGowan Creek and the West Prairie River, north of Blue Mountain (Figure 4). This inactive alluvium may have been deposited during regional deglaciation (ca. 12 ka BP; Dyke et al., 2003), when base levels were higher due to the inundation of the Northern Alberta Lowlands by Glacial Lake Peace. Alternatively, it may represent a younger deposit associated with periodic flooding of this upland basin during intervals when the combined discharge of these confluent rivers exceeded the downstream capacity of the West Prairie River, causing water to back up and inundate the upstream floodplain. The thickness and extent of inactive alluvium described across the Sturgeon and High Prairie plains suggests that, during the early Holocene, the East and West Prairie rivers produced significantly increased rates of sediment progradation and aggradation relative to their modern counterparts. This likely relates to increased meltwater discharge along these channels associated with the retreat of a residual ice cap towards the Swan Hills following regional deglaciation.

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