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Surficial Deposits, Landforms, Glacial History and Potential for Granular Aggregate and Frac Sand: Maxhamish Lake Map Area (NTS 94O), British Columbia

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Surficial Deposits, Landforms, Glacial History and Potential for Granular Aggregate and Frac Sand: Maxhamish Lake Map Area (NTS 94O), British Columbia

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Abstract

As part of the Geo-mapping for Energy and Minerals Program Yukon and Liard Basin Project, the Geological Survey of Canada, in collaboration with the British Columbia Ministry of Energy Mines and Petroleum Resources is working to provide an inventory of terrain, landforms and geomorphic processes in the Maxhamish Lake map area (NTS 94O), British Columbia. This paper provides a preliminary interpretation of surficial geology from air photos, satellite imagery, field observations and digital elevation models; and provides new insight into the range of subglacial processes, patterns of ice flow, deglacial history, and associated sedimentary environments associated with the Late Wisconsinan Laurentide Ice Sheet. Our work provides government agencies, industry and the public access to reliable geoscience information with respect to surficial earth materials, geomorphic processes and the resource potential for granular aggregate and frac sand. The intent of this work is to attract new investment and reduce risks for exploration and development of natural resources in northern British Columbia.

Keywords

GEM-Energy, Yukon and Liard Basin Project, Maxhamish Lake, NTS 94O, Surficial Geology, Laurentide Ice Sheet, Glacial History, Glacial Lake, Granular Aggregate, Frac Sand, Landslides, Permafrost

INTRODUCTION

The Geological Survey of Canada (GSC) and British Columbia Ministry of Energy, Mines and Petroleum Resources (BCMEMPR) are collaborating to create an inventory of earth material, landforms and geomorphic processes in the Maxhamish Lake map area (NTS 94O), northeastern British Columbia (**Figures 1a, b**). This activity is part of the Geo-mapping for Energy and Minerals (GEM) Program, and falls under the GEM-Energy Yukon and Liard Basin.

Recent advances in petroleum drilling technology and completion methods have resulted in the economic development of organic-rich shale deposits that were not previously considered economically viable gas reservoirs. Consequently, the vast shale deposits in northeast British Columbia have attracted considerable attention in the natural gas industry, and the study area has seen record oil and gas land sale activity over the last two years (Adams, 2009). Exploration is mainly targeting Middle Devonian to Lower Mississippian strata, specifically Besa River Formation in Liard Basin and Muskwa/Otter Park and Exshaw formations in Horn River Basin and Cordova Embayment. As these basins mature, drilling activity, natural gas production and forest harvesting is expected to expand, resulting in increased demands for silica sand sources to facilitate hydro-fracturing in gas wells, and for quality infrastructure development (roads and pipelines) to ensure access to the land base.

Here, we present a preliminary interpretation of air photos, satellite imagery, terrain mapping, field observations and digital elevation models for the map area. This study will lead to a better understanding of the regional distribution of sediments, permafrost, landslides and other geomorphic processes. It will also improve our knowledge of the limits of glaciation, range of subglacial processes, patterns of ice flow, ice retreat, and history of glacial lakes. Current research builds on the knowledge of other regional studies and surficial mapping projects (e.g., Mathews, 1980; Rampton, 1987; Rutter et al., 1993; Lemmen et al., 1994; Duk-Rodkin and Lemmen, 2000, Smith, 2000, Bednarski and Smith, 2007; Bednarski, 2008; Hartman and Clague, 2008, Hickin et al., 2008; Trommelen and Levson, 2008).

Our work provides: a) essential regional scale geoscience data to help better define granular aggregate and frac sand resources in the map area; b) critical information for surface engineering (road design, well pad locations, pipeline routing); and c) baseline information for future land management decisions on resource development in the eastern Liard Basin and Fold Belt and northwest Fort Nelson / Northern Plains gas producing regions (Adams and Schwabe, 2009).

PHYSIOGRAPHY, GEOLOGY AND HYDROLOGY

The Maxhamish Lake map area encompasses the following physiographic regions: a) northwestern limits of Fort Nelson Lowland, generally lying below 530 m elevation; b) the western Etsho Plateau, between 600 to 740 m elevation; c) Maxhamish Escarpment (and Bovie Lake structure) ranging from 590 to 610 m elevation; d) Tsoo Tablelands, northernmost part of the Alberta Plateau, reaching elevations up to 820 m elevation; e) Liard, Fort Nelson and Petitot rivers, with active flood plains at elevations below 280 m elevation (**Figure 1a**).

The forms of major landscape elements are controlled by bedrock characteristics and geological structures, and modified by geomorphic processes over time. Lowland regions are underlain by shallow dipping shale, siltstone and sandstone (Upper Cretaceous Kotaneelee Formation overlying Lower Cretaceous Fort St. John Group rocks). Folded and fault-bounded Lower Carboniferous (Mississippian) sandstone, shale (Mattson Formation) and limestone (Flett Formation), and Upper Cretaceous conglomerate, sandstone, carbonaceous shale and coal (Dunvegan and Wapati formations) form escarpments, tablelands and plateaux (**Figure 1b**; Stott and Taylor 1968).

Topography and drainage patterns were greatly modified during the last glaciation: the underfit Fort Nelson and Petitot rivers occupy Late Pleistocene glacial spillways that drained northwest into the Liard River basin (Bednarski, 2008). Maxhamish Lake and numerous smaller basins were excavated when continental (Laurentide) ice and subglacial meltwater scoured older glacial deposits and weak bedrock. During the deglaciation, and into the Holocene, changes in regional base-level led to episodes of channel incision and aggradation, resulting in the formation of terraces along most stream and river valleys. Forest fires are a key trigger for landslide activity on slopes. Stream networks in lowland watershed are prone to disruption by beavers, and to a lesser extent, humans.

EARTH MATERIALS AND LANDFORMS INVENTORY

Mapping a landscape that is a composite of different earth materials and landforms requires the use of a logical and easily understood set of terms and symbols that must be meaningful to non-geoscientists. **Figure 2** depicts common terrain assemblages using letter codes and on-site symbols to capture the distribution, extent and location of bedrock, earth materials and landforms. Much of the map area is covered in glacial drift dating to the Late Pleistocene (Late Wisconsinan glaciation >25 to 12 ka) and nonglacial Holocene deposits (10 ka to present).

Earth materials and landforms were interpreted from 1:60,000 scale black-and-white stereo-pair air photographs (15BCB97010 series), satellite imagery and digital elevation models (Landsat and Shuttle Radar Topography Mission) covering the map area. Earth materials were defined on the basis of landform associations, texture, sorting, fissility, colour, sedimentary structure, degree of consolidation, and contact relationships. Terrain polygons and on-site symbols were digitized using commercially available computer software packages (e.g., Global Mapper, ArcMap, ArcGIS) and edge-matched with published maps, reports and digital data (Smith, 2002; Bednarski, 2003a-c; 2005a,b; Clement et al., 2004). Reconnaissance fieldwork in 2009 was undertaken to verify pre-typed terrain polygons and check characteristics that could not be determined from air photos and satellite images (e.g., tone, texture, patterns, deposit thicknesses, geomorphic processes and vegetation).

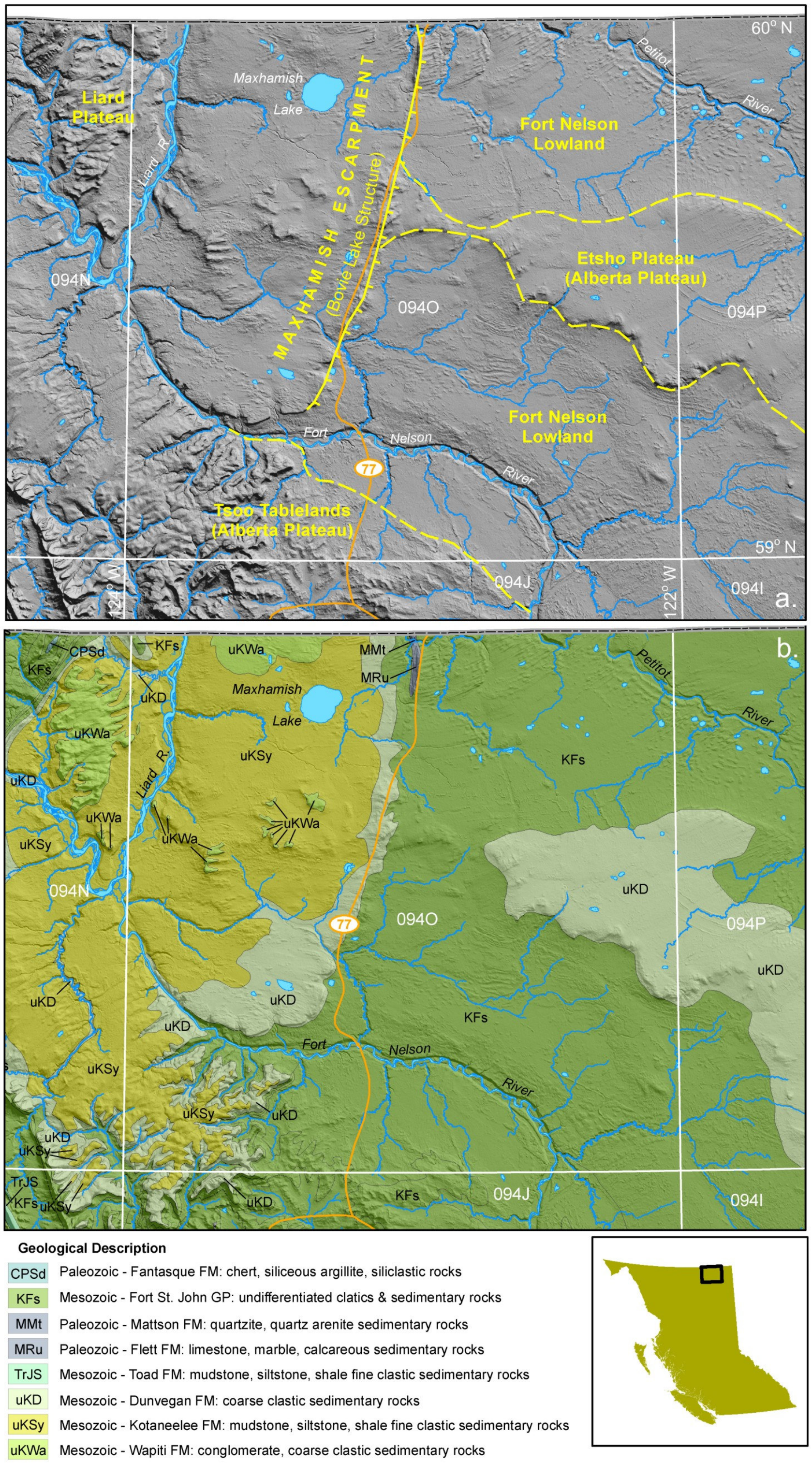

Figure 1 Limits of the Maxhamish Lake map area (NTS 94O), showing: a) major physiographic regions and hydrology (after Bostock, 1970); b) bedrock geology, modified after Stott and Taylor (1968)

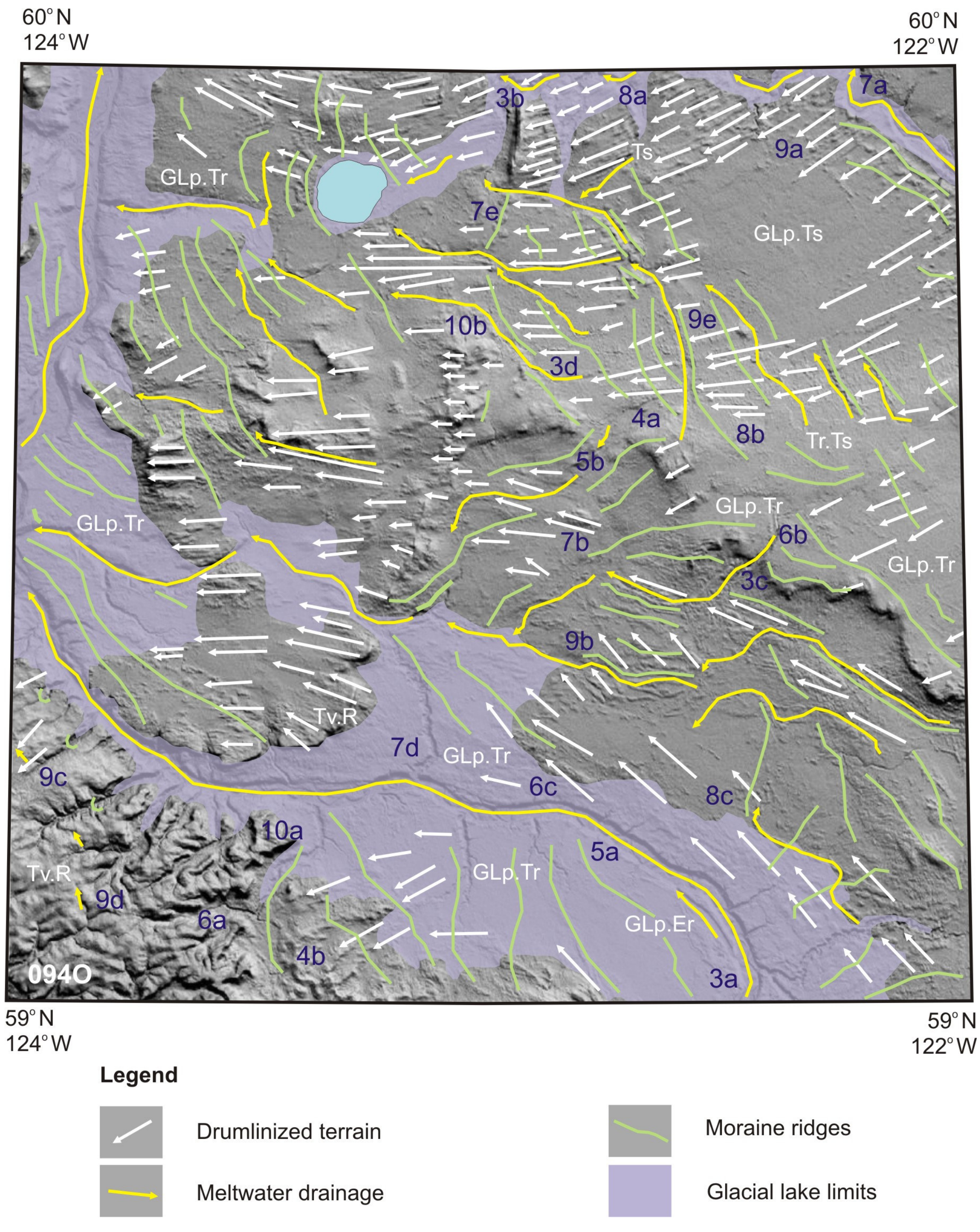

Figure 2 Simplified preliminary surficial geology of Maxhamish Lake map area (NTS 94O). Legend: Er – Eolian dunes; Tr – till ridges and moraines; Ts – streamlined till; Tb – till blanket > 2 m thick; Tv – till veneer < 2 m thick; GLp – glaciolacustrine plain; R – bedrock; GLp.Tr – component 1 in greater abundance than component 2; dark blue number-letter symbols indicate location of photographs in **Figures 3** to **10**

Holocene

Alluvial deposits (Ap, At, Af)

Alluvial sediments include boulders, gravel, sand and silt transported and deposited by modern rivers, streams and creeks (**Figures 3a-d**). Deposits are confined to deltas and fans (Af), valley-side terraces (At), bedrock channels, point bars and floodplains (Ap); all of which are subject to periodic flooding. Generally, alluvial deposits are well sorted and stratified, greater than 2 m thick, and may contain interbedded debris flows and buried organic material (e.g., trees, driftwood, charcoal and anthropogenic material). Alluvial sediments are a potential source of aggregate. However, gravel extraction may produce significant changes in stream courses or downstream changes in stream conditions, and have impact of fish and wildlife resources.

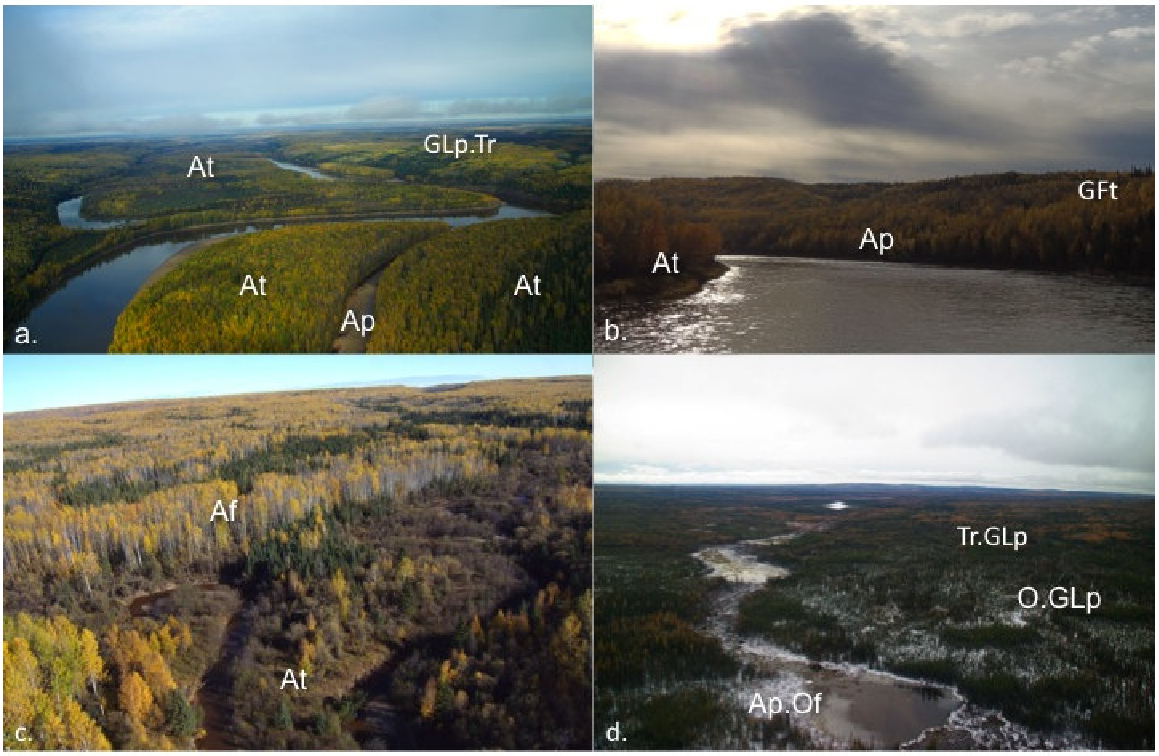

Figure 3 Alluvial deposits: a) underfit Fort Nelson River occupying NW-trending meltwater spillway (At, Ap); b) alluvial and glaciofluvial terraces, and flood plain along the Petitot River (GFt.At, Ap); c) alluvial channels incising alluvial fan deposits below the Etsho Plateau (Af, At); d) beaver-dammed stream occupying meltwater channel on the Fort Nelson Lowland (Ap.Of)

Organic deposits (O, Op, Of)

Undifferentiated muskeg (O), peat bogs (Op) and fens (Of) are formed by the accumulation of organic matter in poorly-drained depressions or level areas (**Figures 4a-b**). Typically, they are treeless or with scattered black spruce and tamarack. Lichens commonly account for greater than 50% of the vegetated surface. In vertical profile, organic deposits comprise sedge and woody sedge overlain by *Sphagnum* peat. Permafrost is observed sporadically at depths of less than 1 m throughout the map area, especially where peat overlies glacial lake sediments. Peat in wet depressions is thawed to depths greater than 1 m.

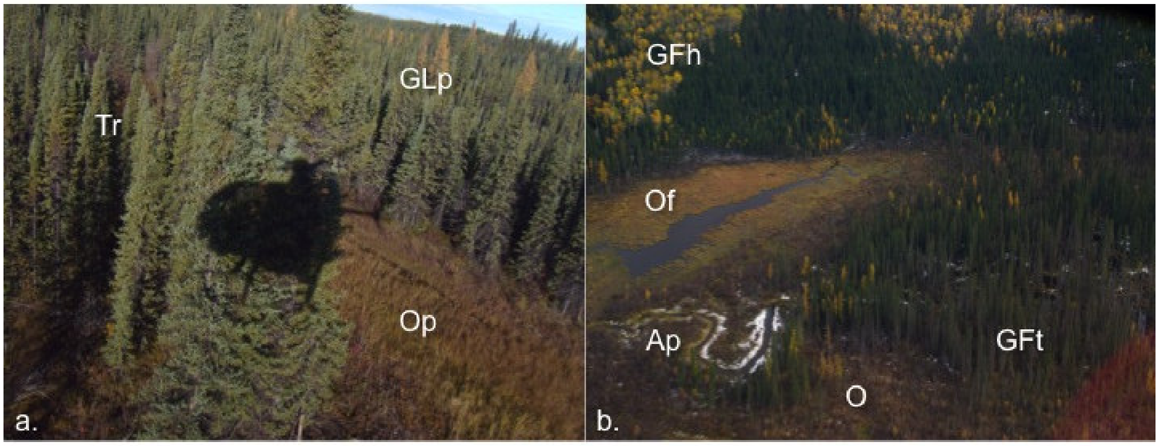

Figure 4 Organic deposits: a) hummocky bogs with sphagnum and forest peat (Op) are formed in wet, ombrotrophic environments, usually treeless or sparsely treed with a cover of ericaceous herbs; b) fen peat (Of) derived from sedges and shrubs in a relatively open eutrophic environment with a mineral rich water table that persists seasonally near the surface

Late Pleistocene to Holocene

Eolian (Loess) Deposits (Ev, Er)

Eolian deposits range from discontinuous veneers (Ev) to dunes (Er) of silt and sand derived from deflation of glacial lake sediments, outwash, till and alluvial sediments, then transported and deposited by wind action (**Figures 5a-b**). Loess deposits are generally less than a metre in thickness, display cross-, ripple- or massive bedding, and contain little to no ground ice. Quartz-rich eolian deposits may be potential frac sand sources.

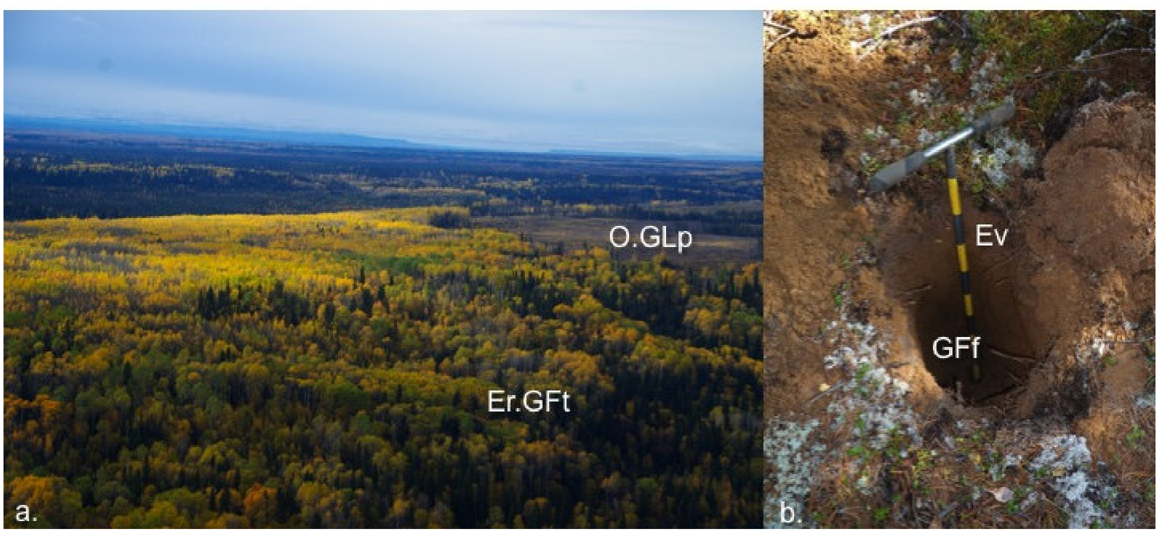

Figure 5 Eolian deposits: a) dune field (Er.GFt) formed by eolian re-working of outwash and glacial lake sediments (O.GLp), paleo-wind direction to northwest; b) eolian veneer of silty fine sand (Ev) overlying glaciofluvial pebbly sand (GFf)

Colluvial deposits (Cv, Cb)

Colluvial deposits are a product of the weathering and down-slope movement of earth materials by gravitational processes (mass wasting). Massive to stratified, clast-supported diamictons form a veneer (Cv) or blanket (Cb) on bedrock and debris-covered slopes. Mass wasting processes include retrogressive rotational slides in glaciolacustrine sediments and outwash in lowland valleys; rock falls, topples, rock slides and debris flows occur where shale, sandstone and carbonate strata is exposed at or close to the surface (**Figures 6a-c**). Earth materials on slopes above 10-15^{o}, with greater than 5 m relief, are prone to remobilization by landslides and debris flows. In areas underlain by glaciolacustrine deposits with discontinuous permafrost, debris slides and flows occur on slopes less than 5^{o}. Slope instability could present major problems for construction in some areas (e.g., south flank of the Etsho Plateau, Fort Nelson and Petitot river valleys).

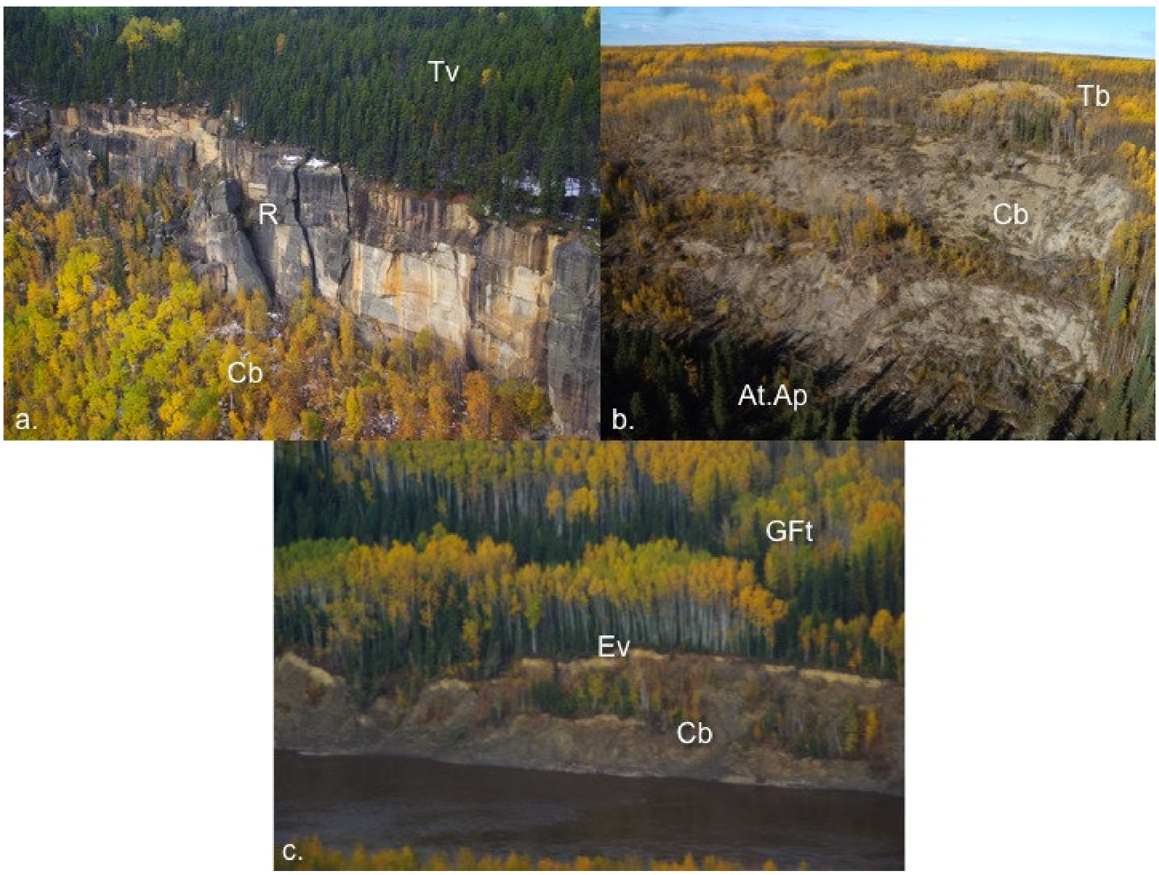

Figure 6 Colluvial deposits: a) Tsoo Tablelands, conglomerate and sandstone escarpment (Dunvegan Formation, R) prone to toppling, rock slides, failure along de-buttressing fractures sub-parallel to escarpment face (Cb); b) Etsho Plateau, complex retrogressive, rotational-translational bedrock-debris slide, incorporating shale, sandstone and siltstone (Fort St. John Group) and Pleistocene glacial deposits, landslide triggered by post-glacial incision of plateau escarpment (Cb); c) rotational debris slide (Cb) triggered by cutbank erosion along the Fort Nelson River, failure is confined to glaciofluvial terraces (GFt) draped with an eolian veneer (Ev)

Late Pleistocene

Glaciofluvial deposits (GFr, GFt, GFp, GFf, GFh)

Glaciofluvial sediments include boulders, cobbles, pebble-gravel, sand, silt and diamicton deposited by rivers and streams flowing from, or in contact with glacial ice. Glaciofluvial deposits are generally massive to stratified, and greater than 2 m thick. Landforms include eskers (GFr), kames, terraces (GFt), spillways, outwash plains (GFp), and fan deltas (GFf) (**Figure 7a-e**). Evidence for ice collapse including slumping, kettles and irregular topography is also observed (GFh). Glaciofluvial sediments are a potential source of granular aggregate when material is gravel-rich. Eskers and fan-deltas may be frac sand sources if quartz-rich.

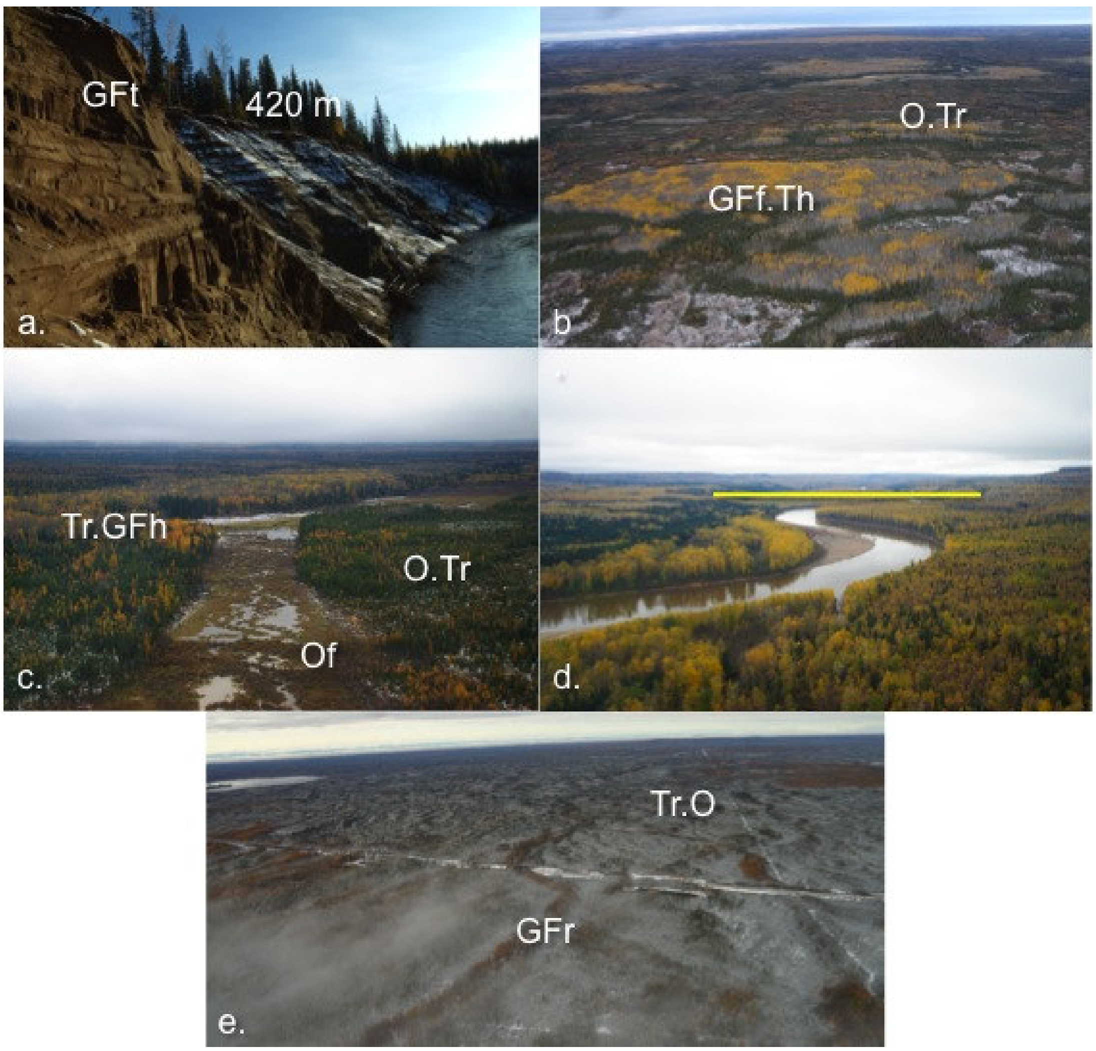

Figure 7 Glaciofluvial deposits: a) terraced retreat-phase glaciodeltaic outwash (GFt) graded to a glacial lake surface elevation ca. 420 m, Petitot River; b) ice-contact fan-delta constructed of pebbly sand (GFf) and diamicton (Th), Fort Nelson Lowland; c) organic-filled meltwater tunnel channel (Of) incised into fine-grained till (Tr) and sandy ice-contact glaciofluvial deposits (GFh); d) Fort Nelson River occupies a broad meltwater channel (orange bar = channel width); e) sinuous esker ridge (GFr) composed of pebbly sand and diamicton, formed in association with crevasse fill ridges and minor (recessional) moraines

Glaciolacustrine deposits (GLb, GLp, GLt, GLh)

Glaciolacustrine deposits (**Figures 8a-c**) include massive or rhythmically interbedded silt and clay, with subordinate sand, gravel and diamicton. Sediments are deposited by subaqueous gravity flows and thermal melting of ice and reworked by wave action in lakes adjacent to glaciers and along shorelines. Glacial lake deposits are generally thicker than a metre (GLb) and typically form plains (GLp) or terraces (GLt). Slump structures, irregular topography and kettles (GLh) indicative of collapse from melting of buried ice may be locally present. Where permafrost is, or was present, glaciolacustrine deposits may be subject to thermokarst processes and slopes less than 5^{o} are potentially unstable and prone to debris slides and flows.

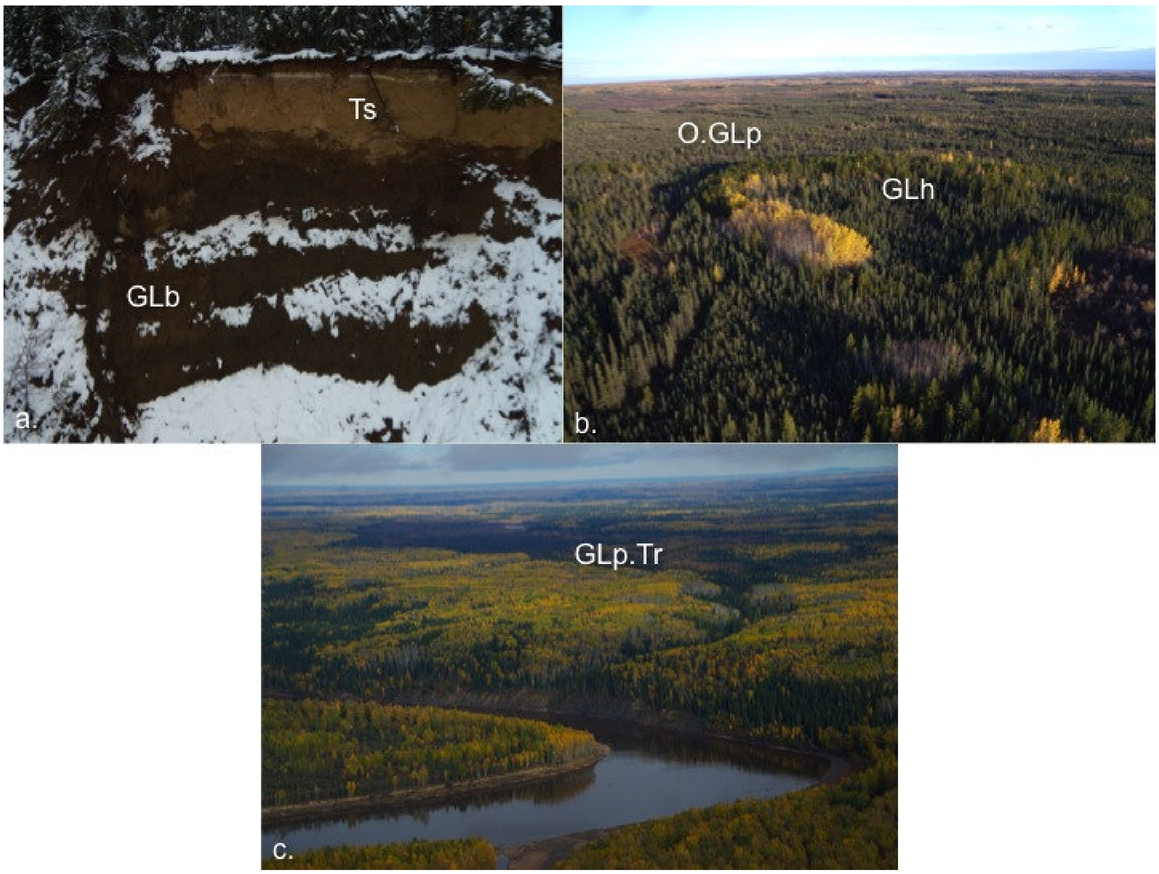

Figure 8 Glaciolacustrine deposits: a) advance phase glaciolacustrine sand, silt and clay (GLb), truncated, deformed and overlain by streamlined lodgement till (Ts), Petitot River valley; b) hummocky glaciolacustrine terrain (GLh, O.GLp) around 610 m elevation, associated with proglacial lakes confined to flanks of the Etsho Plateau and Maxhamish Escarpment; c) glaciolacustrine plain with end moraines (GLp.Tr), incised by Fort Nelson River, ice lobe margins were graded to a proglacial lake surface elevation ca. 420-460 m in the Liard, Fort Nelson and Petitot river valleys

Till deposits (Tb, Tv, Ts, Tr, Th)

Deposits of massive, matrix-supported diamictons are interpreted as tills formed directly by lodgement, basal meltout, glacial deformation and *in situ* melting from stagnant ice. Till containing sub-rounded granitic erratic boulders with sources on the Canadian Shield are interpreted as deposited by the Laurentide Ice Sheet (**Figures 9a-e**). Landforms include till blankets (Tb), veneers and boulder lags (Tv), crag-and-tails, drumlins, fluted ridges (Ts), till ridges (Tr) and hummocky ground moraine with kettle depressions (Th).

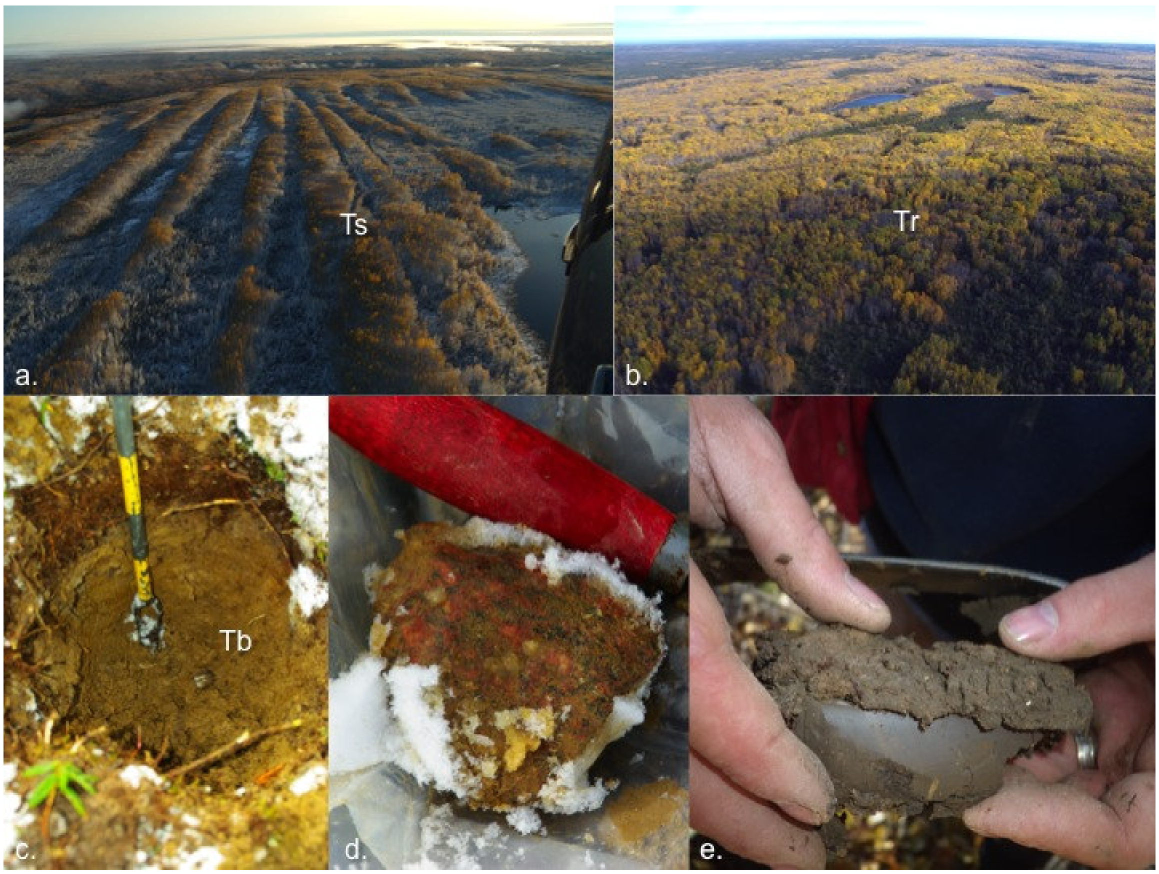

Figure 9 Till deposits: a) glacially streamlined till (Ts) indicating paleoiceflow to the southwest, Petitot River; b) ice-marginal moraine ridges (Tr), Fort Nelson Lowland; c) observation pit exposing >1 m of massive, matrix-supported diamicton interpreted as Laurentide till, Tsoo Tablelands; d) granitic erratic with a Canadian Shield provenance recovered from till, Tsoo Tablelands; e) Laurentide till, massive matrix-supported diamicton with a silt-clay matrix and clast content < 8 %, Fort Nelson Lowland

Pre-Quaternary

Bedrock (R)

Sedimentary bedrock (R) comprising Paleozoic to Mesozoic strata is exposed in steep cliffs along the Liard, Fort Nelson and Petitot rivers, Maxhamish Escarpment and Tsoo Tablelands (**Figures 10a-b**). South of the Petitot River, limestone exposed along the Maxhamish Escarpment is quarried as a source of crushed granular aggregate.

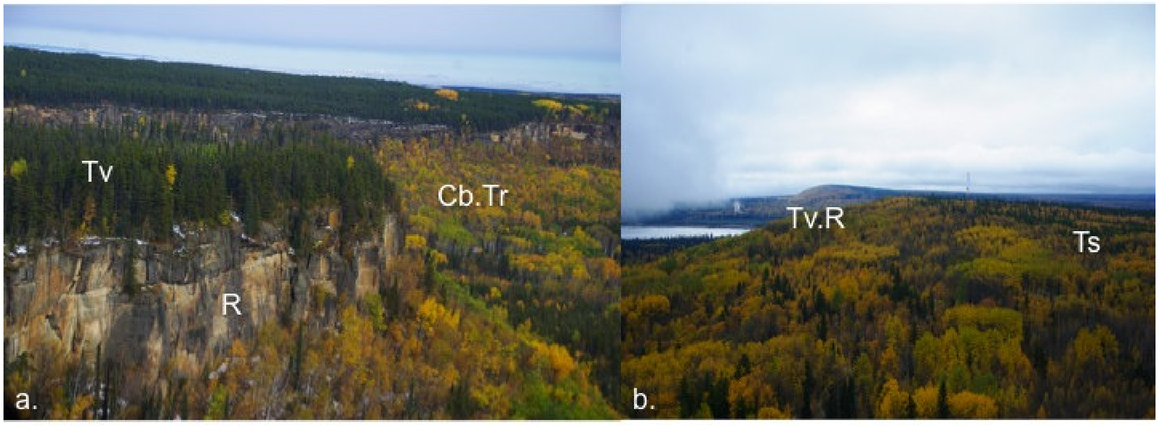

Figure 10 Bedrock: a) exposed conglomerate and sandstone (R, Dunvegan Formation) forming escarpment of the Tsoo Tablelands; b) till veneer (Tv) overlying glacially streamlined conglomerate, sandstone and shale (R, Dunvegan Formation)

GLACIAL HISTORY

Pre-glacial (=Tertiary) topography and drainage patterns were significantly rearranged during Quaternary glaciations. At the onset of the last glaciation, equivalent to the Fraser Glaciation in British Columbia and the McConnell Glaciation in Yukon, the Maxhamish Escarpment formed a barrier to westward meltwater drainage as continental ice advanced into the region. As a result, a proglacial lake was impounded in a paleovalley east of the escarpment, into which were deposited sand and gravel outwash (**Figure 8a**). Advance phase deposits were subsequently overridden and deformed by the Laurentide Ice Sheet at the glacial maximum (ca. 25 to 18 ka).

Bedrock had an important influence on the iceflow dynamics: the presence of weak siliciclastic bedrock would have resulted in deformable, lubricated conditions at the glacier sole (Mathews, 1974; Boulton, 1987; Fisher *et al.*, 1995; Stokes and Clark, 2001; van der Meer *et al.*, 2003). Drift thicknesses in excess of 5 m are observed in major valleys and it is suspected that similar drift thicknesses blanket bedrock across the area (cf. Smith and Lesk-Winfield, in press). Tills contain proximally derived Cretaceous siliciclastic sedimentary rocks; but also distal exotic igneous and metamorphic clasts from the Canadian Shield exposed hundreds of kilometres to the northeast (**Figure 9d**). Glacially sculpted landforms up to several kilometres in length (drumlins, fluted till ridges and furrows) indicate tills were deposited beneath an active, wet-based Laurentide Ice Sheet. Ice flowed in from the northeast and southeast, and then continued westward into the Liard River basin, and southwest over the Tsoo Tablelands toward the Northern Rockies (**Figure 2**). Drumlinized terrain is most pronounced south of the Petitot River and west of the Maxhamish Escarpment where ice flowed uphill and thick accumulations of till were deposited over soft bedrock and advance-phase sediments (**Figure 9a**).

Numerous small ridges drape streamlined bedforms in crosscutting patterns (**Figure 7b**). These features are interpreted as crevasse fillings and minor moraines deposited shortly after drumlinization ended or as ice retreated from the map area (cf. Bednarski, 2008). Their mapped distribution implies that ice margins receded to the northeast in the Petitot valley, and to the southeast in the Fort Nelson valley. Subglacial meltwater channels, esker systems and numerous kettle lakes on either side of the Maxhamish Escarpment and Etsho Plateau suggest that stagnant glacier ice remained in lowland areas (**Figure 2**). Eskers are composed of till and glaciofluvial sand and minor gravel, and likely exploited pre-existing crevasse patterns beneath the ice sheet (**Figure 7e**). Eastward retreating Laurentide ice and stagnant ice masses blocked regional drainage during deglaciation. As a result, an extensive system of proglacial lakes was created in the Laird, Fort Nelson and Petitot valleys, linked by channel outlets that drained meltwater northward into the Mackenzie River basin (**Figures 7c-d**; cf. Bednarski, 2008).

Glaciolacustrine deposits draping till and bedrock indicate lakes had surface elevations of ~610 m and 420 m (**Figures 8b-c**).

During the Holocene (<10 ka), slopes and stream networks were modified by forest fires, beavers and eventually human activity. Pulses of fluvial terrace building followed initial valley incision by the Liard, Fort Nelson and Petitot rivers. Most streams and rivers have alluvial terraces <5 m above active floodplains consisting of gravel

overlain by silt and sand (**Figures 3a-d**); charcoal is observed in dug pits, suggesting forest fires may have contributed to periods of local fluvial aggradation (Clement et al., 2004). Landslides are common where bedrock outcrops form escarpments, or where shale or fine-grained glacial deposits are exposed along steep cutbanks (**Figures 6a-c**). Poorly drained clay-rich till on the plateaux and glaciolacustrine sediments in lowland areas are covered by extensive peatlands and fens (**Figures 4a-b**).

GRANULAR AGGREGATE AND FRAC SAND RESOURCE ASSESSMENT

Important objectives of our work are the regional mapping and assessment of the nature and genesis of known surficial deposits (GSC), and the recognition and description of new and/or potential granular aggregate and frac sand deposits (BCMEMPR)

Proven aggregate sources observed in the map area include: a) crushed limestone (Flett Formation) quarried at the northern end of the Maxhamish Escarpment (**Figure 11, site a**);

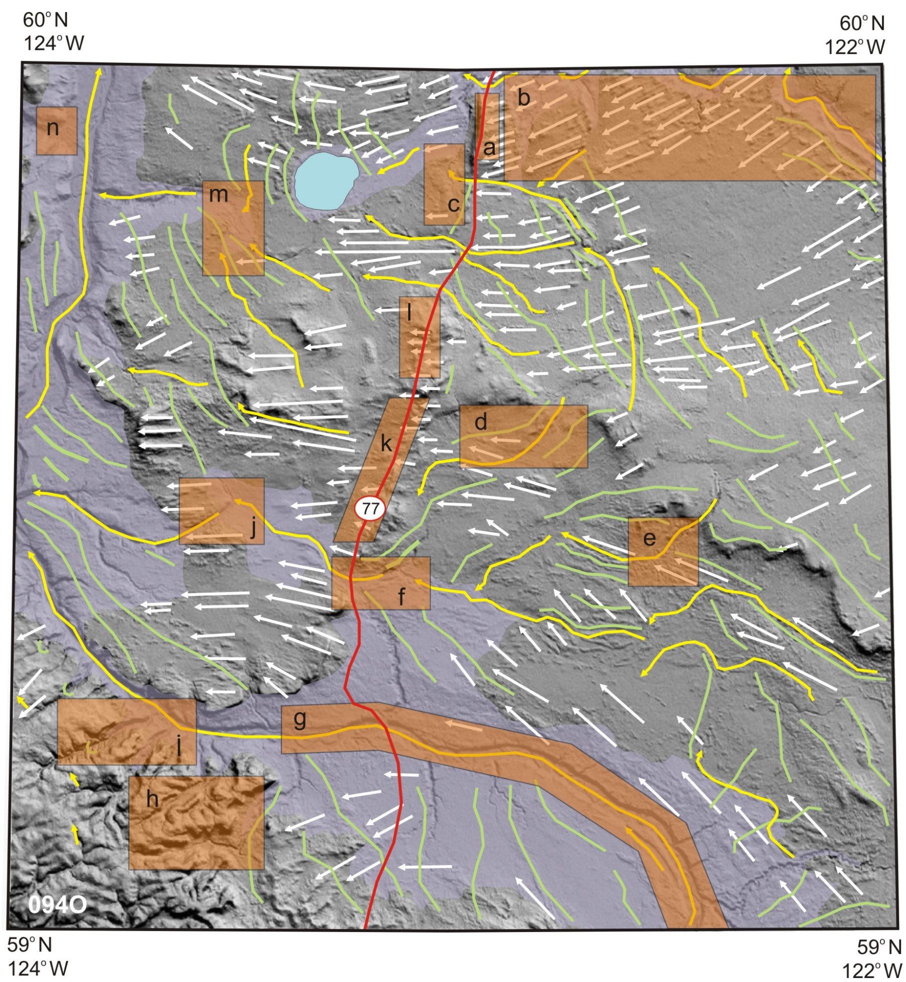

Figure 11 Granular aggregate and frac sand exploration target areas for Maxhamish Lake map area (NTS 94O)

b) borrow pits in till and outwash along the highway and all-season access roads (**Figure 11, sites k, l**); and c) glaciofluvial terraces with access via cutlines, winter trails and access roads along the Fort Nelson and Petitot Rivers and their tributaries (**Figure 11, sites b, g, n**). There are no known frac sand sources in the map area.

Glaciofluvial deposits visited during the 2009 field season were assessed as having low (to moderate) potential as granular aggregate sources. Although volumetrically favourable, most surface features in the Fort Nelson Lowland are constructed of silt-rich sands with only a minor pebble and cobble fraction (< 20%) (**Figure 11, sites c, d, e, f, j, m**); sand and gravel beds (up to 5 m thick) were also observed underlying > 3 m of clay-rich till in the Petitot valley (**Figure 8a**, **Figure 11, site b**). These sites need to be re-evaluated for their frac sand potential.

The most favourable granular aggregate targets identified by our work are glaciofluvial landforms (fan-deltas, terraces, kames, eskers and meltwater channels) graded to glacial lakes with surface elevations around 610 m and 420 m (**Figure 11, sites c, d, e, f, j, m**). Deeply incised valleys and lower colluvial slopes of escarpments in the Tsoo Tablelands are potential sources of sandstone and conglomerate (Dunvegan Formation) for crushed aggregate (**Figure 11, sites h, i**). Flat-lying terrain, thick till blankets and extensive bog and fen cover may obscure other deposits.

Possible frac sand targets include eolian deposits along the Fort Nelson River (**Figure 11, site g**) and sand-rich glaciofluvial features (**Figure 11, sites b, c, d, e, f, j, m**).

SUMMARY

The glacial and deglacial history presented here supports the proposed sequence of events described by other workers (e.g., Mathews, 1980; Rutter et al., 1993; Lemmen et al., 1994; Duk-Rodkin and Lemmen, 2000; Smith, 2000, Bednarski and Smith, 2007; Bednarski, 2008, Hartman and Clague, 2008).

Collaboration between the GSC and BCMEMPR and other agencies is ongoing. Collectively, our work is providing descriptive information and quantitative data about surficial sediments, their distribution, and providing insight into their geologic history, the nature of geohazards and resource potential. Further field studies in the Maxhamish Lake map area (NTS 94O) are required to better define the regional resource potential for granular aggregate and frac sands, and to evaluate the impact of climate change and land use on the distribution of unstable terrain and discontinuous permafrost.

These essential baseline geomorphic data are relevant for a range of potential end-users, including resource explorationists, geotechnical engineers, land-use managers, terrestrial ecologists, archaeologists and geoscientists. Project outputs over the coming years will include GSC Open File Reports and CD-ROM maps that can be used in mineral and energy resource evaluations, environmental assessments, and for drift geochemical exploration.

Possible future outcomes of our work include the attraction of new investment and reduction of risks for exploration and development of natural resources in northeastern British Columbia. Terrain maps, released as part of the project, will be valuable tools to identify and classify potential granular aggregate and frac sources, especially if combined with other methods of exploration (e.g., LIDAR, seismic shothole records, petrophysical logs, auger drilling, test-pitting, ground-penetrating radar, airborne electromagnetic survey; Best et al., 2004; Levson et al., 2004; Smith et al., 2006, Hickin et al., 2008; Smith and Lesk-Winfield, 2009).

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