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Surficial geology, geomorphology, granular resource evaluation and geohazard assessment for the Maxhamish Lake map area (NTS 94-O), northeastern British Columbia

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Abstract

As part of the Geo-mapping for Energy and Minerals Program (GEM-Energy) Yukon Basins Project, the Geological Survey of Canada (GSC) and British Columbia Ministry of Energy and Minerals (BCMEM) collaborated between 2009 and 2011 to produce a digital surficial geology and landform (geoscience) map and an accompanying geodatabase of field observations, terrain units, landforms and geomorphic processes in the Maxhamish Lake map area (NTS 94-O), British Columbia. In this paper, we present the distribution of surficial deposits and landforms; and describe the sedimentology, surface morphology and facies associations of major terrain units and landforms. This terrain inventory is evaluated to: a) better define the regional potential for granular aggregate and frac sand resources in the map area; b) identify key geohazards that could impact surface infrastructure (e.g., road design, well pad locations, pipeline routing); c) provide baseline information useful for future land management decisions on resource development in northeastern British Columbia. By providing government agencies, industry, communities and the public access to reliable geoscience information on surficial earth materials, geohazards and granular resource potential and groundwater, the risks for new investment, exploration and development of natural resources in northern British Columbia will be reduced.

KEYWORDS: Geo-Mapping for Energy and Minerals Program, Yukon and Liard Basin Project, Maxhamish Lake, NTS 94-O, surficial geology, data model, granular aggregate, frac sand, geohazards

Introduction

Sustainable economic investment in exploration and development of energy and mineral resources in northeastern British Columbia will require quality infrastructure development (e.g., roads and pipelines) to ensure access to the land base and reliable silica sand sources to facilitate hydro-fracturing in gas wells. To help address these needs, the Geological Survey of Canada (GSC) and British Columbia Ministry of Energy (BCMEM) are currently compiling regional-scale information on surficial deposits and landform processes in northeastern British Columbia as part of the Geo-Mapping for Energy and Minerals (GEM-Energy) Program, Yukon Basins Project (Huntley, 2010a, b, c; Huntley and Hickin, 2010; Huntley and Sidwell, 2010; Huntley and Hickin, 2011; Hickin and Huntley, 2011; Huntley et al., 2011; Ferri et al., 2011a; 2011b).

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, Bednarski and Smith, 2007; Bednarski, 2008; Hartman and Clague, 2008, Hickin et al., 2008; Trommelen and Levson, 2008; Demchuck, 2010a, b; Hickin et al. 2010).

The terrain model presented here conforms to the science language for the data management component of the GSC GEM geological map flow process (cf. Huntley and Sidwell, 2010; Deblonde et al., in prep.). Desktop terrain classification and digital mapping, combined with benchmarking field-based studies have led to a better understanding of the regional distribution of surficial deposits, permafrost, landslides and other geomorphic processes. Our work is also improving our knowledge of the limits of glaciation, the range of subglacial processes, the patterns of ice flow, and the history of ice retreat and glacial lake formation during a dynamic period of climate change and geomorphic adjustment. This new geoscience information is critical for a preliminary evaluation of the potential for granular aggregate, possible frac sand sources, and baseline assessment of geohazards in the study area (**Figure 1a, b**).

Location, physiography and geology

This paper focuses on the surficial geology units and landforms mapped and classified on the Maxhamish Lake map sheet (NTS 94-O): an area some 12,641 km^2 in northeastern British Columbia (**Figure 1, Figure 2**). The Maxhamish Lake map area encompasses the following physiographic regions (Bostock, 1970): a) the northwestern limits of the Fort Nelson Lowland, generally lying below 530 m elevation; b) the western Etsho Plateau, between 600 and 740 m elevation; c) the Maxhamish Escarpment (and Bovie Lake structure) ranging from 590 to 610 m elevation; d) the Tsoo Tablelands, the northernmost part of the Alberta Plateau, reaching elevations up to 820 m elevation; and e) the Liard, Fort Nelson and Petitot rivers are incised into the landscape with active flood plains below 280 m elevation (**Figure 1a, Figure 2**).

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 Mississippian sandstone and shale (Mattson Formation) and limestone (Flett Formation), and Upper Cretaceous conglomerate, sandstone, carbonaceous shale and coal (Dunvegan and Wapiti formations) form escarpments, tablelands and plateaux (**Figure 1b, Figure 2**; Stott and Taylor 1968). Exploration is targeting gas-bearing Middle Devonian to lower Mississippian strata in the Liard and Horn River basins (Ferri et al., 2011a; 2011b). Much of the map area is covered in glacial drift dating to the Late Pleistocene (Late Wisconsinan, >25 to 10 ka) and non-glacial Holocene (10 ka to present) deposits (Huntley and Hickin, 2010).

Approach to surficial geology mapping

Mapping of surficial earth materials and landforms was based on the interpretation of 1:60 000 scale black-and-white stereo-pair aerial photographs (15BCB97010 series), Landsat 7 satellite imagery and digital elevation models from the Shuttle Radar Topography Mission (free online data sources downloaded using Global Mapper® software). The base map was generated from CANVEC shape files (http://geogratis.cgdi.gc.ca/geogratis/ [URL 2011]; Huntley and Sidwell, 2010). Terrain polygons and on-site symbols were digitized using commercially available computer software packages (Global Mapper® and ArcGIS®) and edge-matched with published maps, reports and digital data (Bednarski, 2003a-c; Bednarski, 2005a-b; Clement et al., 2004).

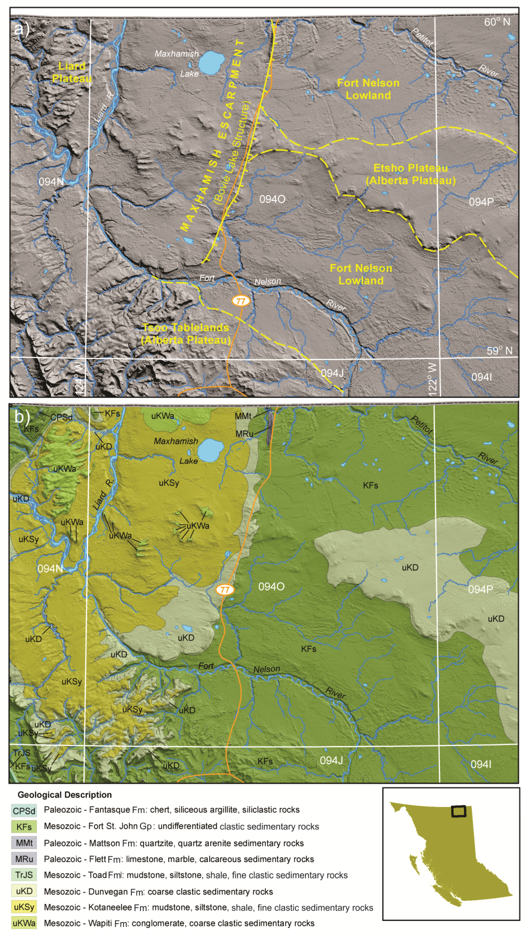

Figure 1 Limits of the Maxhamish Lake map area (NTS 94-O), northeastern British Columbia: a) major physiographic regions and hydrology (after Bostock, 1970); b) bedrock geology modified after Stott and Taylor (1968).

Reconnaissance fieldwork was undertaken in 2009 and 2010 to verify the interpreted aerial photographs and satellite imagery with surficial geology polygons and to check characteristics that could not be determined remotely. Earth materials were defined on the basis of landform associations, texture, sorting, colour, sedimentary structures, degree of consolidation, and stratigraphic contact relationships at 553 field stations and remote observations from helicopters and trucks (**Figure 3**). Approximately 12% of polygons have been ground-checked, which is a survey intensity level appropriate for regional-scale reconnaissance terrain mapping (Resource Inventory Committee, 1996).

Figure 2 Maxhamish Lakescape (2003): original 5 x 7 inches, acrylic on cotton, private collection; this art work depicts the major physiographic elements of the map area described in the text (see also Huntley, 2010a, b). In the foreground, a beaver-dammed meltwater channel incises morainal deposits with a forest cover of trembling aspen and white spruce. Mid-ground, the painting is transected by fens and peat lands. This terrain gives way to the tablelands, upland plateau, and foothills to thrust-and-folded mountains.

Distribution of surficial geology units and landforms

The landscape is a composite of different earth materials and landforms that must be spatially represented in terms that will be meaningful to professionals and non-geoscientists. **Figure 4** depicts the *provisional* distribution, extent and location of bedrock, earth materials and landforms of the Maxhamish Lake map area. Terrain codes and symbols used in **Figure 5** are derived from mapping conventions used by the Geological Survey of Canada and terrain analysts in British Columbia and the Yukon (Resource Inventory Committee, 1996; Howes and Kenk, 1997; Bednarski, 2003a-c; 2005a, b; Clement et al., 2004). The surficial geology data model conforms to the science language for the data management component of the GSC GEM geological map flow process (cf. Deblonde et al., in prep.).

Map units are distinguishable from surrounding terrain on the basis of earth material genesis, environment of deposition, sedimentology, morphology, thickness, physical limits, geological age and other distinguishing characteristics. Map unit (terrain) polygons are delimited so that their positions represent a particular characteristic of the landscape (**Figure 4a**). Map units in **Figure 5a** are presented chronostratigraphically, and include organic deposits, alluvial sediments, colluvium, eolian deposits, glaciolacustrine sediments, glaciofluvial deposits, tills and bedrock. The distribution of glacial and non-glacial landforms is depicted on **Figure 4b**, with the working legend shown in **Figure 5b**.

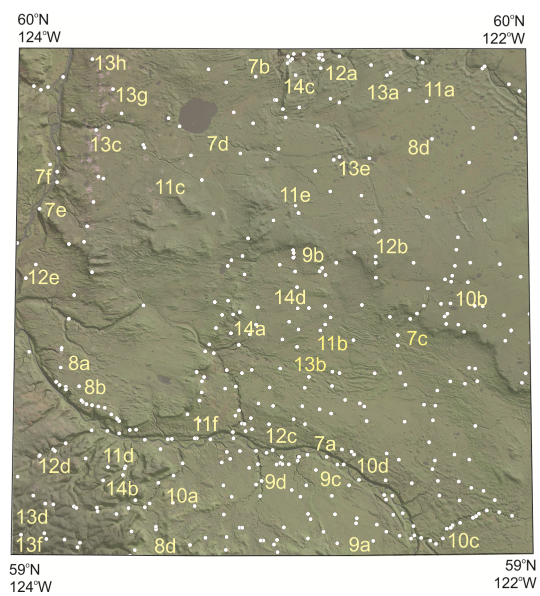

Figure 3 Location of benchmarking field observations in the Maxhamish Lake map area from 2003 to 2010; also showing location of photographs in **Figures 7** to **14**.

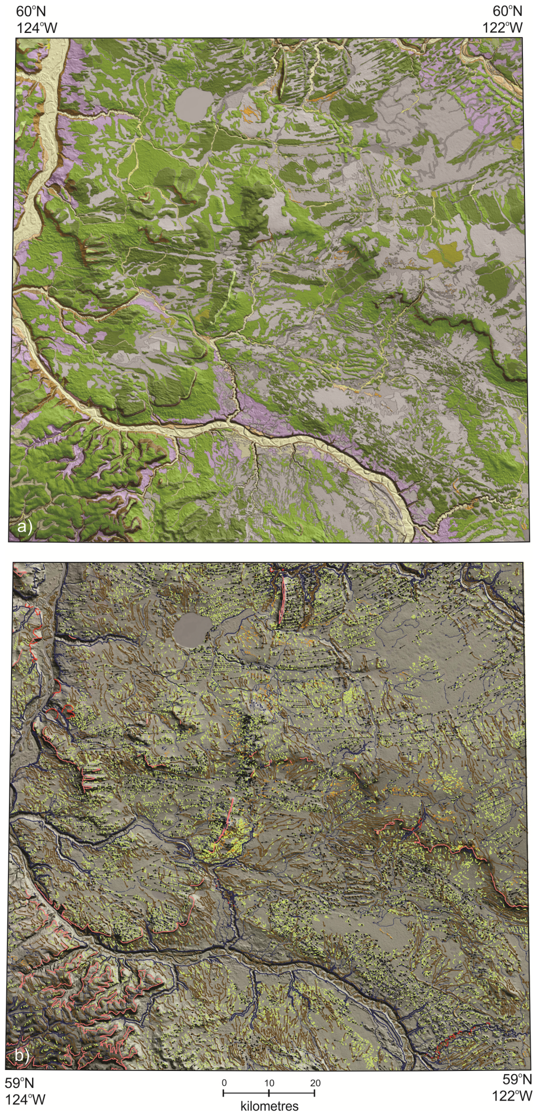

Figure 4 Surficial geology of the Maxhamish Lake map area (NTS 94-O): a) surficial deposits; b) landforms. See **Figure 5** for map legends.

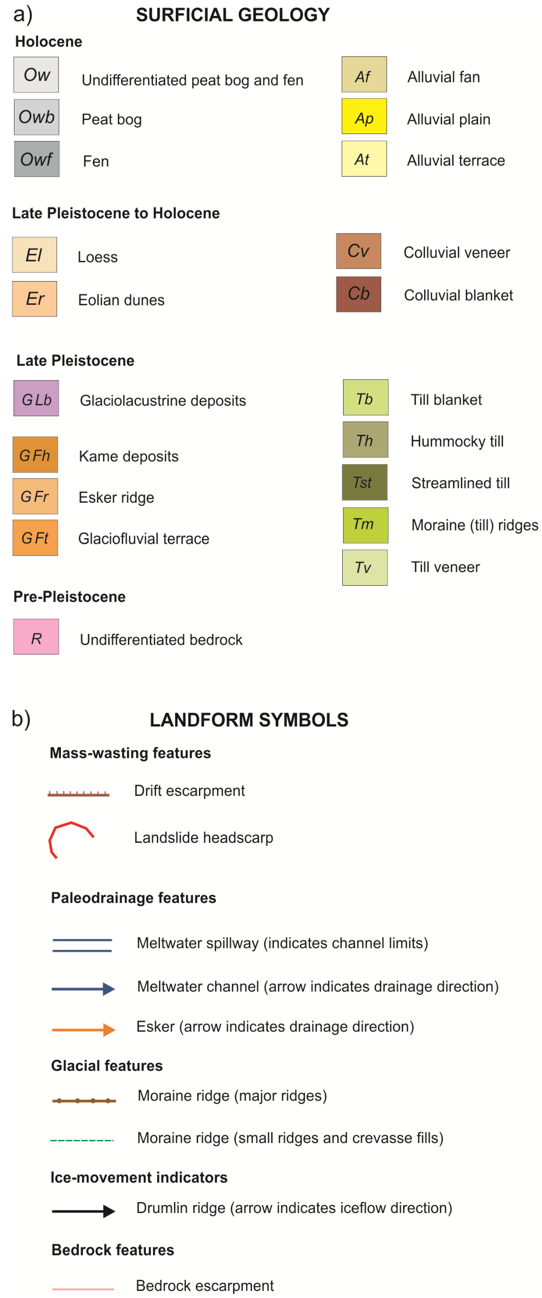

Figure 5 Legend for **Figure 4**: a) surficial deposits; b) landforms.

Surficial earth materials and landform inventory

The number of units mapped (n = 4506 terrain polygons) is graphically summarized in **Figure 6a**. Polygons most frequently contain tills as dominant terrain units (n = 1785) and organic deposits (n = 1745). Glaciolacustrine deposits (n = 265), alluvial sediments (n = 215), and colluvium (n = 189) are less frequent. Terrain polygons mapped with glaciofluvial sediments (n = 198), bedrock (n = 46) and eolian deposits (n = 63) are least common (**Figure 6a**).

Areal extent (km^2) of surficial units is shown in **Figure 6b**. The most extensive surficial units are tills (covering 5965 km^2 or 50% of the map area) and organic deposits (covering 4068 km^2 or 32% of the mapped area). Glaciolacustrine deposits (771 km^2 or 6%), alluvial sediments (723 km^2 or 6%), and colluvium (536 km^2 or 4%) cover much of the remaining map area. Glaciofluvial (109 km^2 or 0.8%), bedrock (48 km^2 or 0.4%), and eolian deposits (107 km^2 or 0.8%) are the least areally extensive (**Figure 6b**).

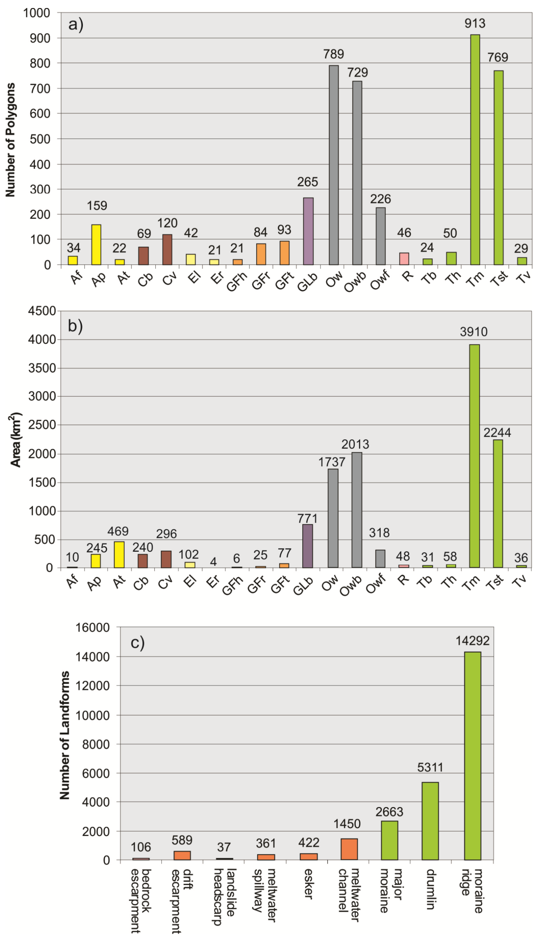

Figure 6 Summary statistics for surficial map units and landforms: a) number of polygons per map unit; b) areal extent of map units (km^2); and c) number of landforms. Note colours are generalized in relation to the map legend (see **Figure 5**).

Figure 6c shows that the dominant landforms in the map area are minor moraine ridges (n = 14,294), drumlins and flutes (n = 5311), major moraine (n = 2664) and meltwater channels (n = 1452). Less common are drift escarpments (n = 589), eskers (n = 422), meltwater spillways (n = 362), and bedrock escarpments (n = 106).

Holocene earth materials and landforms

Organic deposits include undifferentiated muskeg (Ow), peat bogs (Owb) and fens (Owf) formed by the accumulation of organic matter in depressions or level areas underlain by poorly drained till or glaciolacustrine sediments (**Figures 7a-7d**). Typically, wetlands 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. In 2003, discontinuous permafrost was observed sporadically at depths of less than 1 m throughout the southeast part of the map area, especially where peat blanketed glacial lake sediments. In wet depressions, peat was thawed to depths greater than 1 m (Clement et al., 2004).

Alluvial deposits include boulders, gravel, sand and silt transported and deposited by modern rivers, streams and creeks (**Figures 8a-8f**). 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 and other land use activities (e.g., road construction, pipeline crossings and logging) that adversely affect stream courses or conditions, which impact fish and wildlife resources.

Late Pleistocene to Holocene earth materials and landforms

Eolian (loess) deposits include discontinuous veneers and blankets (El) and parabolic dunes (Er) of silt and sand derived from the deflation of glacial lake sediments, outwash, till and alluvial sediments, then transported and deposited by wind action (**Figures 9a-9d**). Loess deposits are generally less than 1 m 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.

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 10a-10d**). 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).

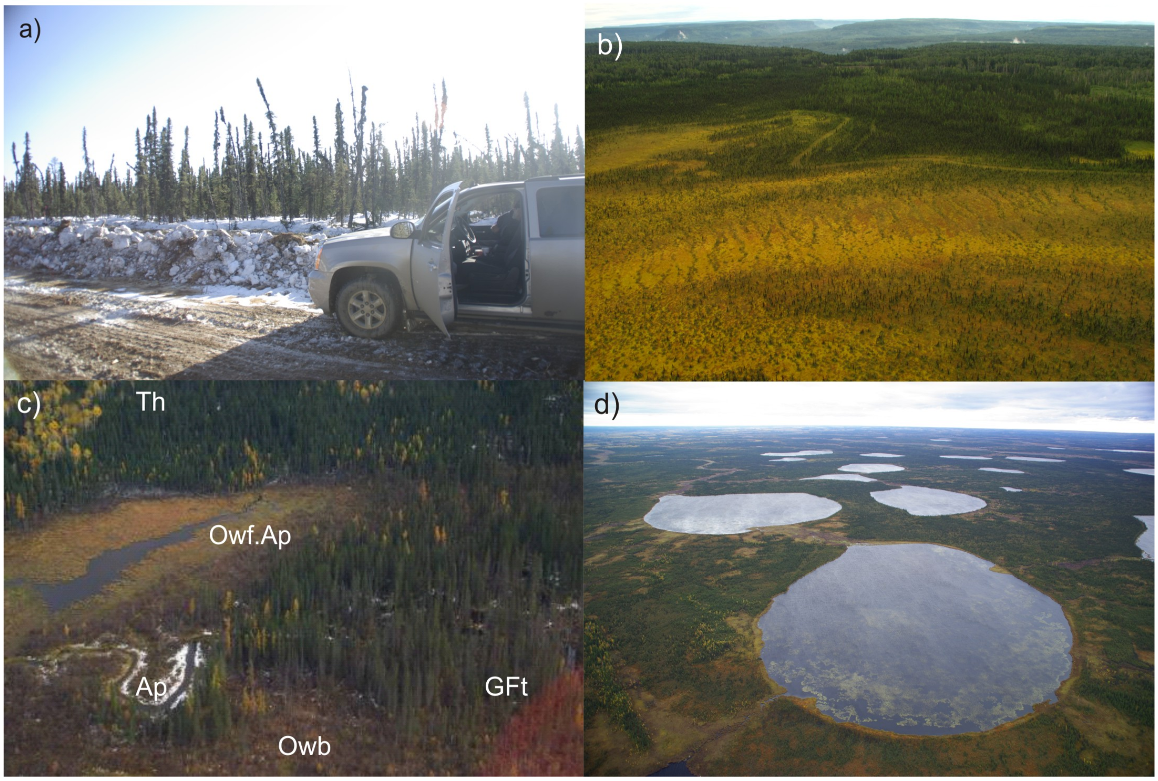

Figure 7 Organic deposits: a) hummocky bogs with sphagnum and forest peat (Owb) are formed in wet environments, usually treeless or with a cover of black spruce and ericaceous herbs; b) ribbed fen peat (Owf) are derived from sedges and shrubs in a relatively open environment with a mineral rich water table that persists seasonally near the surface; c) fenland developed over alluvial plain (Ap) in response to beaver-damming of meltwater channel, d) undifferentiated organic deposits (Ow) with thermokarst lakes indicate presence of sporadically discontinuous permafrost.

Figure 8 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 moraine deposits below the Etsho Plateau (At.Ap); d) beaver-dammed stream occupying meltwater channel on the Fort Nelson Lowland (Ap.Owf); e) Liard River looking south to confluence with Fort Nelson River; f) Alluvial terrace (At), in-channel bar on the Liard River comprising massive, planar and cross-bedded silt, sand and rare gravel.

Figure 9 Eolian deposits: a) loess field (El) formed by eolian re-working of outwash (GFt) and glacial lake sediments (Ow.GLb); b) eolian veneer of silty fine sand (Ev) overlying glaciofluvial pebbly sand (GFf); c) fine to medium-grained quartz and feldspar-rich eolian sand exposed in parabolic dune (Er); d) parabolic dunes (Er) formed over organic (Ow) and glacial lake deposits (GLb), paleowind direction to southeast.

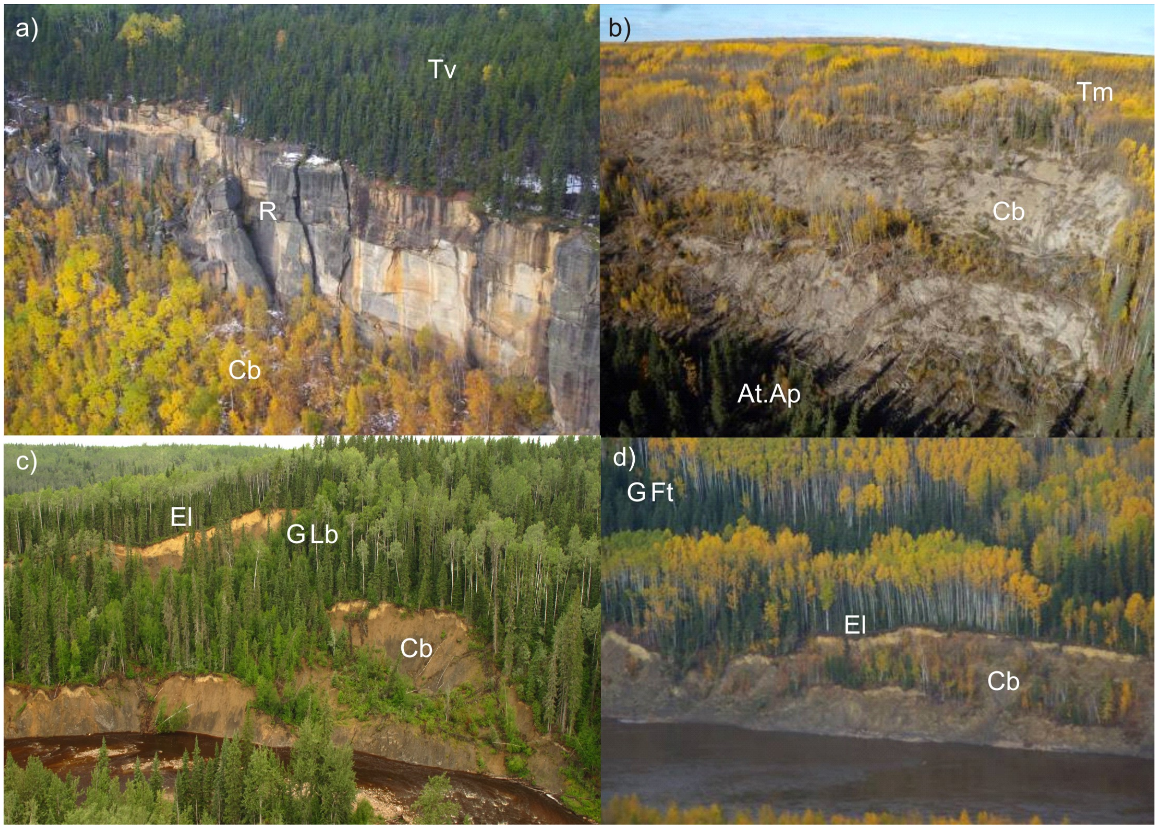

Figure 10 Colluvial deposits: a) Tsoo Tablelands, conglomerate and sandstone escarpment (Dunvegan Formation, R) prone to toppling, rock slides and failure along debuttressing fractures sub-parallel to escarpment face (Cb); b) Etsho Plateau, complex retrogressive, rotational-translational bedrock-debris slide (Cb) incorporating shale, sandstone and siltstone (Fort St. John Group) and Quaternary glacial deposits, landslide triggered by post-glacial incision of plateau escarpment; c) rotational debris slide (Cb) triggered by cutbank erosion along a tributary to the Fort Nelson River, failure is confined to glaciolacustrine deposits (GLb) draped with a discontinuous loess cover (El); d) rotational debris slide (Cb) triggered by cutbank erosion along the Fort Nelson River, failure is confined to glaciofluvial terraces (GFt) draped with a discontinuous loess cover (El).

Late Pleistocene earth materials and landforms

Glaciolacustrine deposits (**Figures 11a-11e**) 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 are reworked by wave action in lakes adjacent to glaciers and along shorelines. Glacial lake deposits are generally thicker than 1 m, blanketing other deposits (GLb). Slump structures, irregular topography and kettles indicative of collapse from the 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 landslides and debris flows.

Figure 11 Glaciolacustrine deposits: a) advance phase glaciolacustrine sand, silt and clay (GLb), truncated, deformed and overlain by streamlined lodgement till (Tst), Petitot River valley; b) organic, eolian-reworked till and glaciolacustrine terrain (Ow.GLb) around 610 m elevation, associated with proglacial lakes confined to flanks of the Etsho Plateau and Maxhamish Escarpment; c) glaciolacustrine plain with end moraines (GLb.Tm), incised by Fort Nelson River, ice lobe margins and meltwater features were graded to a proglacial lake surface elevation ca. 420 m in the Liard, Fort Nelson and Petitot river valleys; d) colluviated glaciolacustrine deposits (>50 m thick) confined to valleys in the Tsoo Tablelands, graded to around 640 m elevation, drainage to SW (indicated with orange arrow); e) silty clay glaciolacustrine deposits (GLb) exposed below 420 m elevation along the Liard River.

Glaciofluvial deposits 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 (GFb). Landforms include kames and hummocky outwash deposits (GFh), esker ridges (GFr), terraces (GFt), spillways, meltwater channels and fan deltas (**Figures 12a-12e**). Evidence for ice collapse including slumping, kettles and irregular topography is also observed (GFh). Glaciofluvial sediments are a potential

Figure 12 Glaciofluvial deposits: a) terraced retreat-phase glaciodeltaic outwash (GFt) graded to a glacial lake surface elevation ca. 420 m, Petitot River; b) hummocky ice-contact kame-delta constructed of pebbly sand (GFh) and meltout diamictons (Th), Fort Nelson Lowland; c) organic-filled meltwater tunnel channel (Owf) incised into fine-grained till ridges (Tm) and sandy ice-contact glaciofluvial deposits (GFh); d) Fort Nelson River occupies a broad meltwater channel (yellow 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 (Tm); f) anthropogenic accumulation of granitic and metamorphic cobbles and boulders extracted from a gravel deposit in a glaciofluvial terrace (GFt) formed along the north flank of the Fort Nelson spillway.

source of granular aggregate when material is gravel-rich. Eskers and fan-deltas should be evaluated as frac sand sources if they are quartz-rich.

Till deposits comprise massive, matrix-supported diamictons deposited directly by lodgement, basal meltout, glacigenic deformation and *in situ* melting from stagnant ice. Tills are sand, silt and clay-rich with low clast contents (<20%) and contain sub-rounded granitic erratic boulders with sources on the Canadian Shield. Tills are interpreted to be deposited by the Laurentide Ice Sheet (**Figures 13a-13h**). Generally, till is compact and moderately- or well-drained. Landforms include till blankets (Tb), veneers and boulder lags (Tv), streamlined crag-and-tails, drumlins and fluted ridges (Tst), major and minor till ridges (Tm) and hummocky ground moraine with kettle depressions (Th). Polygons mapped with till as the dominant terrain unit are suitable for infrastructure placement (e.g., well pads, building sites, all-season roads).

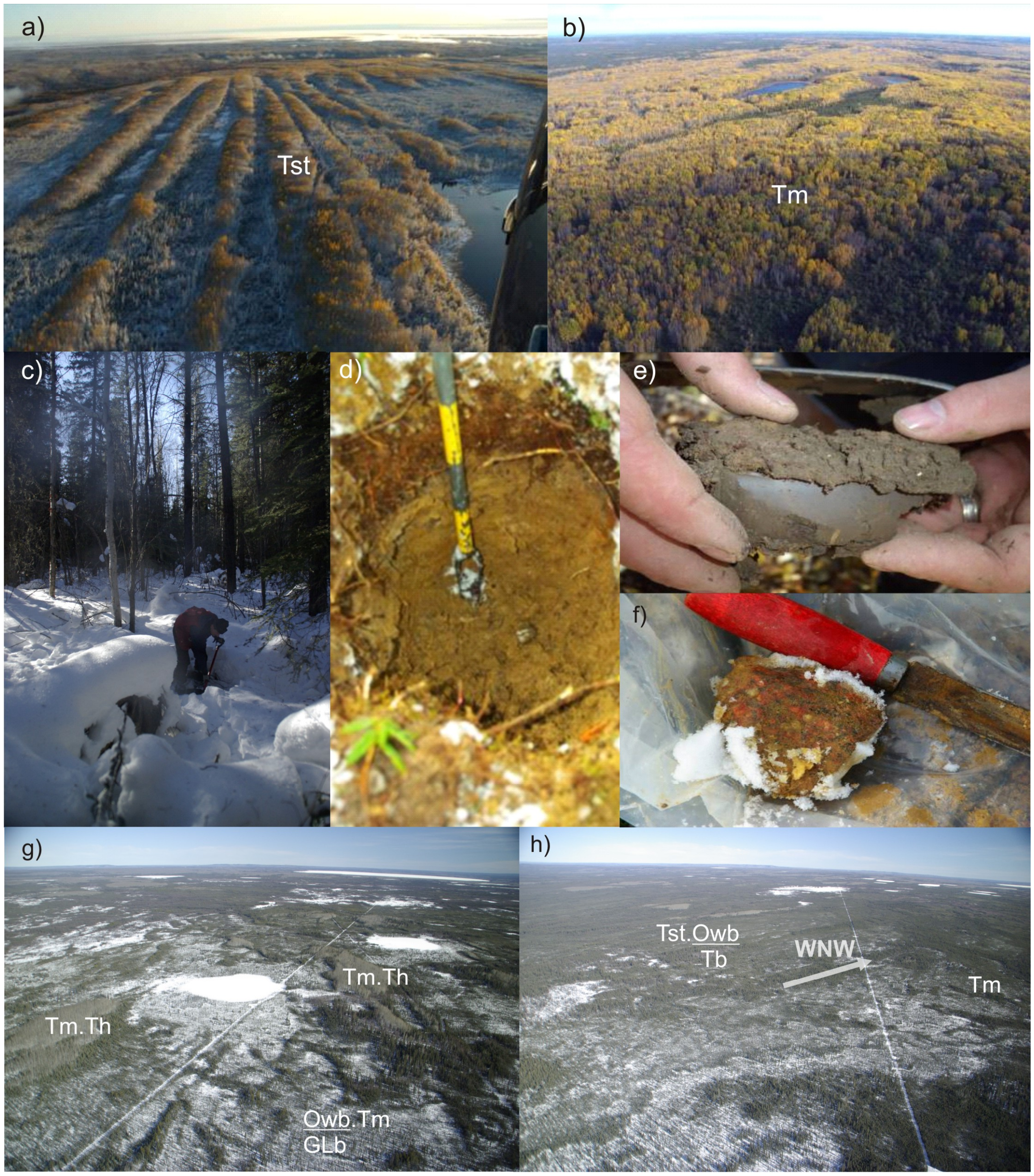

Figure 13 Till deposits: a) glacially streamlined till (Tst) indicating paleoiceflow to the southwest, Petitot River; b) ice-marginal moraine ridges (Tm), Fort Nelson Lowland; c) loess veneer draped over till ridge (Tm); d) observation pit exposing >1 m of massive, matrix-supported diamicton interpreted as Laurentide till, Tsoo Tablelands; e) Laurentide till, massive matrix-supported diamicton with a silty clay matrix and clast content < 8 %, Fort Nelson Lowland; f) granitic erratic with a Canadian Shield provenance recovered from till, Tsoo Tablelands; g) crevasse fills, minor moraine ridges (Tm) and hummocky till (Th) west of the Maxhamish Escarpment; h) glacially streamlined till plain (Tst) terminating at an end moraine complex (Tm).

Pre-Quaternary earth materials and landforms

Bedrock includes outcrops of Paleozoic to Mesozoic sedimentary rocks (R), exposed in steep cliffs along the Liard, Fort Nelson and Petitot rivers, the Maxhamish Escarpment and the Tsoo Tablelands (**Figures 14a-14b**). South of the Petitot River, limestone exposed along the Maxhamish Escarpment and clastic sedimentary rocks in the Fort Nelson Lowland are quarried as a source of crushed granular aggregate (**Figures 14c-14d**).

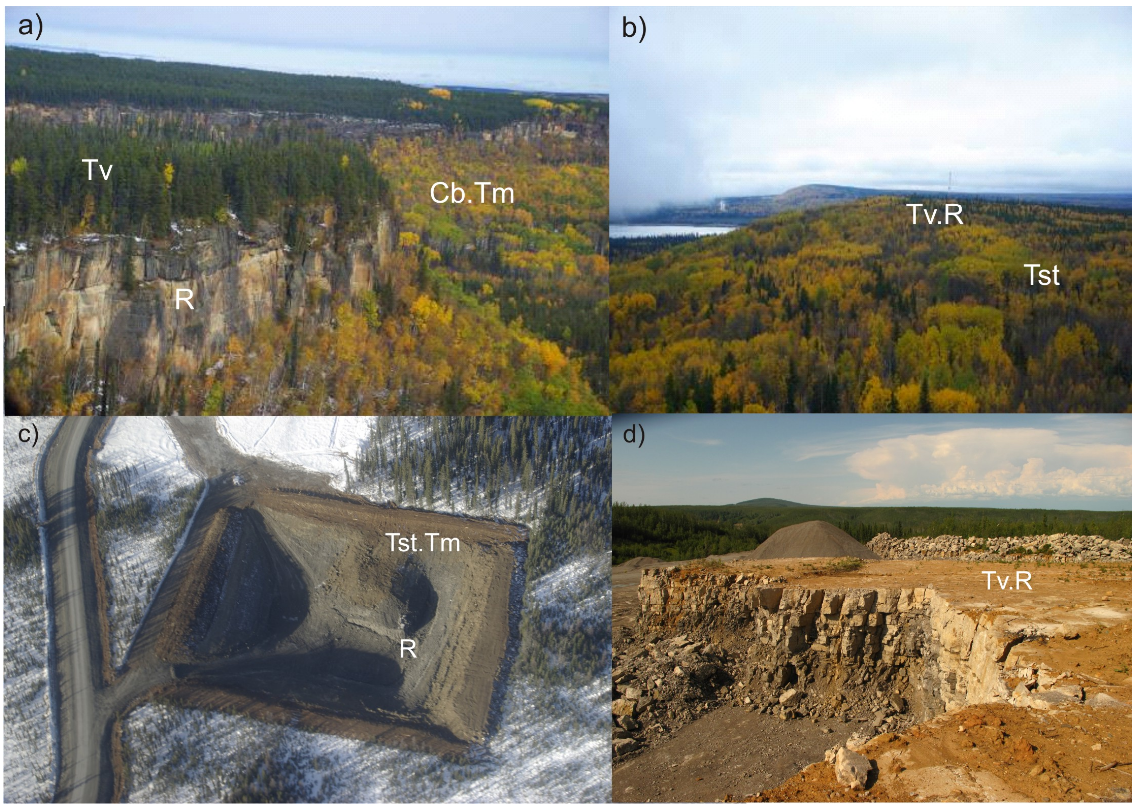

Figure 14 Bedrock: a) exposed conglomerate and sandstone (R, Dunvegan Formation) forming escarpment of the Tsoo Tablelands; b) till veneer (Tv.R) overlying glacially streamlined conglomerate, sandstone and shale (R, Dunvegan Formation); c) borrow pit exposing 3-5 m of Drumlinized Laurentide till (Tst) overlying siltstone and shale of the Cretaceous Fort St. John Group; d) crushed aggregate quarry exploiting Carboniferous Flett Formation limestone, bedrock is glacially striated indicating Laurentide iceflow towards 248^{o}, the overlying till was drumlinized by continental ice flowing towards 252^{o}.

Aggregate and frac sand resource evaluation

Important objectives of current research for the GEM-Energy Program are the regional mapping and assessment of the nature and genesis of known surficial deposits; and the recognition and description of new and/or potential granular aggregate and frac sand deposits (Hickin et al., 2010; Huntley and Hickin, 2010; Huntley and Sidwell, 2010). With the new geoscience data presented above, a further evaluation of the regional potential for granular aggregate and frac sand is now possible.

Glacial paleo-drainage features are potential exploration targets for granular aggregate, frac sand and mineral resources. Proven aggregate sources observed in the map area include: a) borrow pits in till and outwash along the highway and all-season access roads (**Figure 14c**); b) crushed limestone (Flett Formation) quarried at the northern end of the Maxhamish Escarpment (**Figure 14d**); and c) glaciofluvial terraces with access via cutlines, winter trails and access roads along the Fort Nelson and Petitot Rivers and their tributaries (**Figure 12f**). There are no known frac sand sources in the map area.

The most favourable granular aggregate targets identified are bedrock escarpments (n = 106), eskers (n = 442), drift escarpments (n = 589), meltwater channels (n = 1451), and spillways (n = 362) graded to glacial lake surface elevations around 610 m and 420 m (**Figure 4, Figure 6**). Glaciofluvial deposits visited during the 2009 and 2010 field seasons were assessed as having low to moderate potential as granular aggregate sources (Hickin et al., 2010; Huntley and Hickin, 2010; Hickin and Huntley, 2011). 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%); sand and gravel beds (up to 5 m thick) were also observed underlying > 3 m of clay-rich till in the Petitot valley (**Figure 11a**). These sites need to be further evaluated for their frac sand and groundwater potential.

Deeply incised valleys and lower colluvial slopes on escarpments in the Tsoo Tablelands are potential sources of sandstone and conglomerate (Dunvegan Formation) for crushed aggregate (**Figure 14a**). Flat-lying terrain underlain by thick deposits of till, glaciolacustrine sediments and extensive bogs and fens covers some 87% of the map area (**Figure 4a**) and may obscure other deposits.

Possible surface frac sand targets include eolian deposits and sand-rich glaciofluvial features in the Fort Nelson River Valley (**Figure 4a, Figure 9a-9d**). However, the low frequency of occurrence and limited areal extent of bedrock (48 km^2 or 0.4%), glaciofluvial (109 km^2 or 0.8%) and eolian deposits (107 km^2 or 0.8%) suggests there is limited economic potential for surface sources of granular aggregate and frac sand in the Maxhamish Lake map area. Sedimentological and attrition experiments on glaciofluvial and eolian sand samples also indicate deposits in the region are unsuitable (Hickin and Huntley, 2011).

Geohazard assessment

With resource exploration, drilling activities, natural gas production and other land uses (e.g., forest harvesting, hunting and tourism) expected to increase and expand in the map area over the coming years, it is anticipated that there will be demand for quality infrastructure development (e.g., all-season access roads, well pads, camp sites, power-lines and pipelines) to ensure secure access to the land base. An understanding of the spatial distribution and range of geohazards is essential for regional development of energy and mineral resources.

Mass-wasting processes in the Maxhamish Lake map area include soil creep, debris flows, rock fall and landslides involving rock and surficial deposits. Colluviated glacial sediment and bedrock on the slopes of stream and river valleys, escarpments and upland plateaux covers approximately 536 km^2 (4%) of the mapped area (**Figure 4a**, **Figure 6**). Terrain identified with colluvium has either failed in the past or is expected to fail in the future, especially if disturbed by natural processes or anthropogenic activity (e.g., wildfires, construction or logging). The best management practice is to recognize locations where landslides and colluvium occur and protect infrastructure from risk of damage (e.g., pipe ruptures or damage to access roads). Continual visual inspection and instrumental monitoring of unstable and potentially unstable terrain and geohazards is recommended.

Approximately 723 km^2 (or 6%) of the mapped area is at some risk from fluvial geohazards. Existing and new infrastructure will be prone to damage by alluvial processes at stream and river crossings. Management plans must focus on measures to reduce risks for infrastructure associated with ice break-up, floods, flow diversions, channel bank erosion and deposition at stream and river crossings, and beaver activity in tributary drainage basins. Periodic visual inspection and monitoring of terrain at risk from fluvial geohazards is recommended. Mitigation measures along aggrading channel reaches must accommodate often rapid natural changes in sedimentation rates and patterns. In addition, land-use management practices must reduce the risk of hazards associated with the release of sediments during construction at stream crossings. An appropriate mitigation plan for sediment control and channel erosion in the post-construction phase is also essential to reduce risk over time.

Organic deposits are generally seen as an obstacle to year-round development in northern Canada (Smith and Lesk-Winfield, 2009). Wetland bog and fen peat deposits cover at least 4068 km^2 (or 32%) of the mapped area. Organic deposits also insulate the underlying permafrost. In 2003, undifferentiated organic deposits and peat bogs containing sporadic discontinuous permafrost blanketed till and glaciolacustrine deposits covering approximately 1603 km^2 (or 13% of the map area) on the Etsho Plateau and the Fort Nelson Lowland (Clement et al., 2004). Relict thermokarst lakes on the plateau and lowland (**Figure 7d**) indicate melting permafrost, localized land subsidence and an increase in groundwater levels over time. If organic deposits are disturbed and/or removed during development, melting of sporadic discontinuous permafrost may result in localized ground subsidence, thermokarst erosion, debris slides and thaw-flows.

Drumlins, flutes and moraine ridges composed of silt- and clay rich tills (**Figure 13e**) typically rise above the surface of wetlands and comprise compact, moderately well-drained substrate suitable for the placement of well pads, building sites, road bases and other structures. Surficial geology and geomorphology maps (**Figure 4**) can be applied to best locate infrastructure, leading to less environmental impact and lower costs of installation and geotechnical mitigation over time.

South of the Petitot River valley, streamlined till, moraines and organic deposits locally overlie advance-phase glaciolacustrine silt and clay and glaciofluvial sand and gravel (**Figure 11a**; Smith and Lesk-Winfield, 2009; Huntley and Hickin, 2010; Huntley and Hickin, 2011). Variations in deposit thicknesses suggest unconsolidated glacial sediments are infilling a sub-surface basin or buried palaeochannel system. Buried sand and gravel could be potential sources of granular aggregate, groundwater and shallow natural gas hazards (cf. Smith et al., 2006; Smith and Lesk-Winfield, 2009).

Eolian deposits (loess) and parabolic dunes cover only 0.4% of the map area and support rare ecosystems (Clement et al., 2004). Dune fields mapped along the Fort Nelson River valley and localized accumulations of loess over the Tsoo Tablelands and the Etsho Plateau are environmentally sensitive areas with little potential for economic development.

Summary

Surficial geology maps (**Figure 4**) and related databases (**Figure 3**, **Figure 6**) for the Maxhamish Lake map area (NTS 94-O) provide essential baseline geoscience data relevant for a range of potential end-users including resource explorationists, geotechnical engineers, land-use managers, terrestrial ecologists, archaeologists, geoscientists and communities in the region.

In the map area, approximately corresponding to the region underlain by the parts of the gas-producing Horn River and Liard basins, key surface exploration targets for granular aggregate are glaciofluvial landforms: eskers, terraces, meltwater channels and spillways (**Figures 12a-12f**). On-site assessments indicate that most glaciofluvial deposits in the map area have low to, at best, moderate potential as granular aggregate sources (Huntley and Hickin, 2011). Eolian deposits derived from glaciofluvial and glaciolacustrine sediment may be a viable source for frac sand. Unfortunately, these deposits and landforms have a limited geographic extent and support rare ecosystems (**Figures 9a-9d**). Laboratory-based attrition experiments also indicate that dune sands are unsuitable as a frac sand source (Hickin et al., 2010; Hickin and Huntley, 2011). Polygons mapped with silt- and clay-rich till as the dominant terrain unit (streamlined till and moraine ridges) are suitable for placement of well pads, building sites, road bases and development of other infrastructure.

Geohazards in the map area include: a) mass-wasting of glacial sediment and bedrock on the slopes of stream and river valleys, escarpments and upland plateaux (affecting approximately 4% of the mapped area); b) flooding, erosion, deposition and beaver activity in valleys (impacting 6%); and c) undifferentiated organic deposits and peat bogs containing sporadic discontinuous permafrost blanketing till and glaciolacustrine deposits (13% of the mapped area) on the Liard and Etsho plateaux and the Fort Nelson Lowland (**Figure 4**).

GSC Open File reports and digital maps are available on CR-ROM or as free downloads from the GSC bookstore website:

http://gsc.nrcan.gc.ca/bookstore/

Surficial geology maps and geodatabases released as part of the GEM-Energy Yukon Basin Project will be valuable tools to help identify, classify and evaluate in more detail the potential for granular aggregate, frac sand sources, groundwater and geohazards, especially if combined with other methods of exploration. Examples of other useful geoscience data types include LiDAR, seismic shothole records, petrophysical logs, auger drilling, test-pitting, ground-penetrating radar and airborne electromagnetic surveys (e.g., Best et al., 2004; Levson et al., 2004; Smith et al., 2006, Hickin et al., 2008; Smith and Lesk-Winfield, 2009).

Collaboration between the GSC, BC MEM 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 geological history, the nature of geohazards and resource potential. Further, site-specific field studies in the Maxhamish Lake map area (NTS 94-O) 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.

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