GEO-MAPPING FOR ENERGY AND MINERALS PROGRAM (GEM-ENERGY): PRELIMINARY SURFICIAL GEOLOGY, GEOMORPHOLOGY, RESOURCE EVALUATION AND GEOHAZARD ASSESSMENT FOR THE MAXHAMISH LAKE MAP AREA (NTS 094O), 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 Mines (BC MEM) are collaborating to produce digital surficial geology and landform maps and geodatabases of terrain, landforms and geomorphic processes in the Maxhamish Lake map area (NTS 094O), British Columbia. Our work is providing reliable geoscience information on surficial earth materials, geohazards and resource potential for granular aggregate, frac sand and groundwater to government agencies, industry, communities and the public access. In this paper we present the provisional 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 better define the regional potential for granular aggregate and frac sand resources in the map area; identify key geohazards that could impact surface infrastructure (e.g., road design, well pad locations, pipeline routing); and provide baseline information useful for future land management decisions on resource development in northeastern British Columbia. The intent of our work is to attract new investment and reduce risks for exploration and development of natural resources in northern British Columbia.

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Key Words: Geo-Mapping for Energy and Minerals program, Yukon and Liard Basin project, Maxhamish Lake, NTS 094O, 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 requires quality infrastructure development (roads and pipelines) to ensure access to the land base and reliable silica sand sources to facilitate hydrofracturing in gas wells. To help address these needs, the Geological Survey of Canada (GSC) and British Columbia Ministry of Energy and Mines (BC MEM) 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) program, Yukon Basins project (Huntley, 2010a-c; Huntley and Hickin, 2010; Huntley and Sidwell, 2010; Hickin and Huntley, 2011; Huntley et al., 2011).

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; Fisher et al., 1995; 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). The terrain model presented here conforms to the science language for the data management component of the GSC GEM geological map flow process (cf. Deblonde et al., 2011; Huntley and Sidwell, 2010). Remote predictive 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

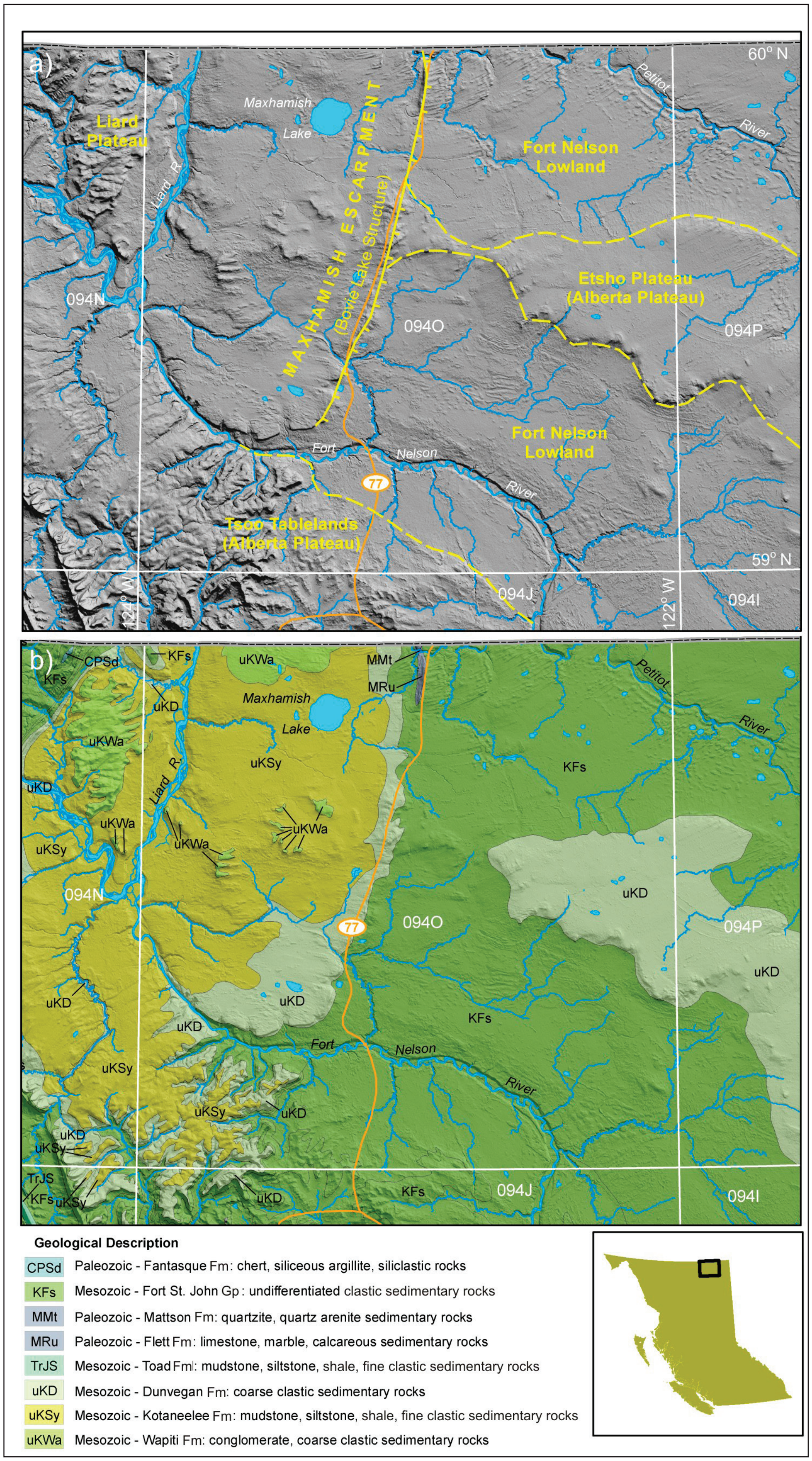

Figure 1. Limits of the Maxhamish Lake map area (NTS 094O), northeastern British Columbia: a) major physiographic regions and hydrology (after Bostock, 1970); b) bedrock geology modified from Stott and Taylor (1968); figure drafted by Mike Fournier (formerly of the BC Ministry of Energy and Mines).

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 1).

LOCATION, PHYSIOGRAPHY AND GEOLOGY

This paper focuses on the surficial geology units and landforms mapped and classified on the Maxhamish Lake map sheet (NTS 094O), an area of approximately 12,624 km^2 in northeastern British Columbia (Figures 1 and 2). The Maxhamish Lake map area encompasses the northwestern limits of the Fort Nelson Lowland, generally lying below 530 m elevation; the western Etsho Plateau, between 600 to 740 m elevation; the Maxhamish Escarpment (and Bovie Lake structure) ranging from 590 to 610 m elevation; the Tsoo Tablelands, the northernmost part of the Alberta Plateau, reaching elevations up to 820 m; and the Liard, Fort Nelson and Petitot rivers, with active flood plains at elevations below 280 m elevation (Bostock, 1970; Figure 1a).

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, shale (Mattson Formation) and limestone (Flett Formation), and Upper Cretaceous conglomerate, sandstone, carbonaceous shale and coal (Dunvegan and Wapiti formations) form escarpments, tablelands and plateaus (Figure 1b; 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

Remote predictive mapping of surficial earth materials and landforms was based on 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 NRCAN 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, ArcMap and ArcGIS) and edge-matched with published maps, reports and digital data (Bednarski, 2003a-c; Bednarski, 2005a-b; Clement et al., 2004).

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 from air photos, satellite images and digital elevation models. Earth materials were defined on the basis of landform associations, texture, sorting, colour, sedimentary structures, degree of consolidation, and stratigraphic contact relationships at approximately 300 field stations and remote observations from helicopters and trucks (Figure 3). Approximately 6% of polygons have been ground-checked, which is a survey-intensity level appropriate for regional-scale reconnaissance terrain mapping (Resource Inventory Committee, 1996).

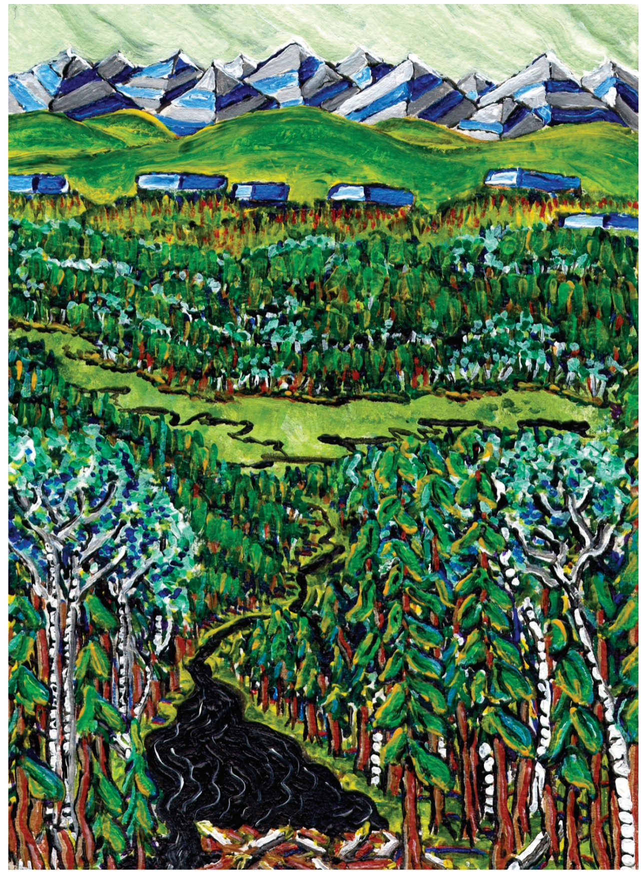

Figure 2. Maxhamish Lakescape (2003): original is 5x7 inches, acrylic on cotton, private collection; this artwork by D.H. Huntley depicts the major physiographic elements of the map area described in the text (see also Huntley, 2010a, b). In the foreground, a beaver-dammed meltwater channel incises morainal deposits with a forest cover of trembling aspen and white spruce. Mid-ground, the painting is transected by fen and peatlands. This terrain gives way to the tablelands, upland plateau and foothills to thrust-and-folded mountains.

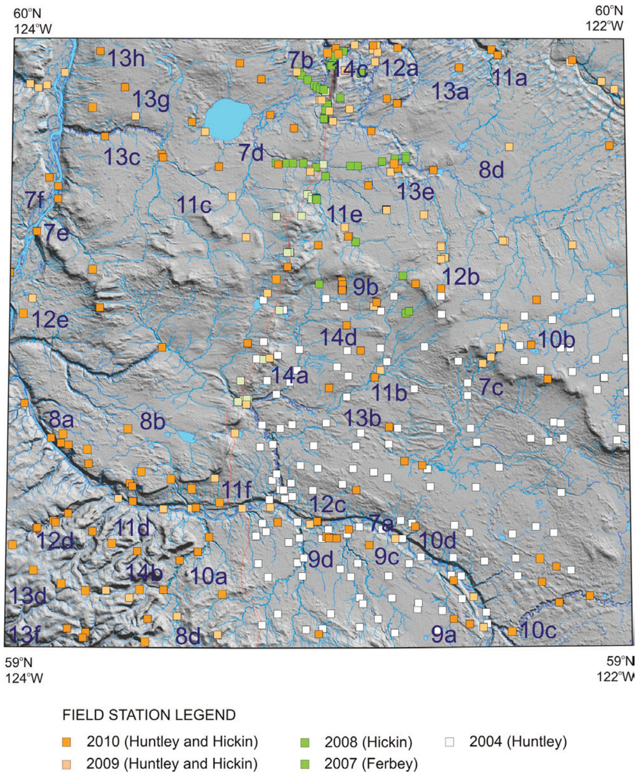

Figure 3. Location of benchmarking field observations (2003 to 2010) in the Maxhamish Lake map area; also showing locations of photographs in Figures 7 to 14.

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 4a 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 4b are derived from mapping conventions used by the Geological Survey of Canada and by terrain analysts in British Columbia and the Yukon (Resource Inventory Committee, 1996; Howes and Kenk, 1997; Bednarski, 2003a-c; Bednarski, 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., 2011).

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 4b are presented chronostratigraphically and include alluvial sediments, organic deposits, colluvium, eolian deposits, glaciofluvial deposits,

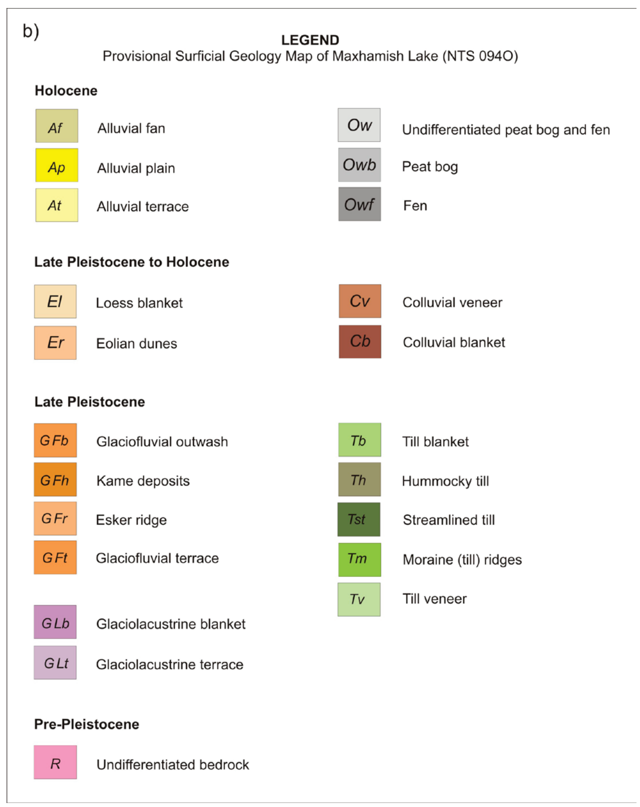

Figure 4. a) Provisional surficial geology of the Maxhamish Lake map area (NTS 94O); b) map legend.

glaciolacustrine sediments, till deposits and bedrock. The distribution of landforms is depicted on Figure 5a, with the working legend shown in Figure 5b.

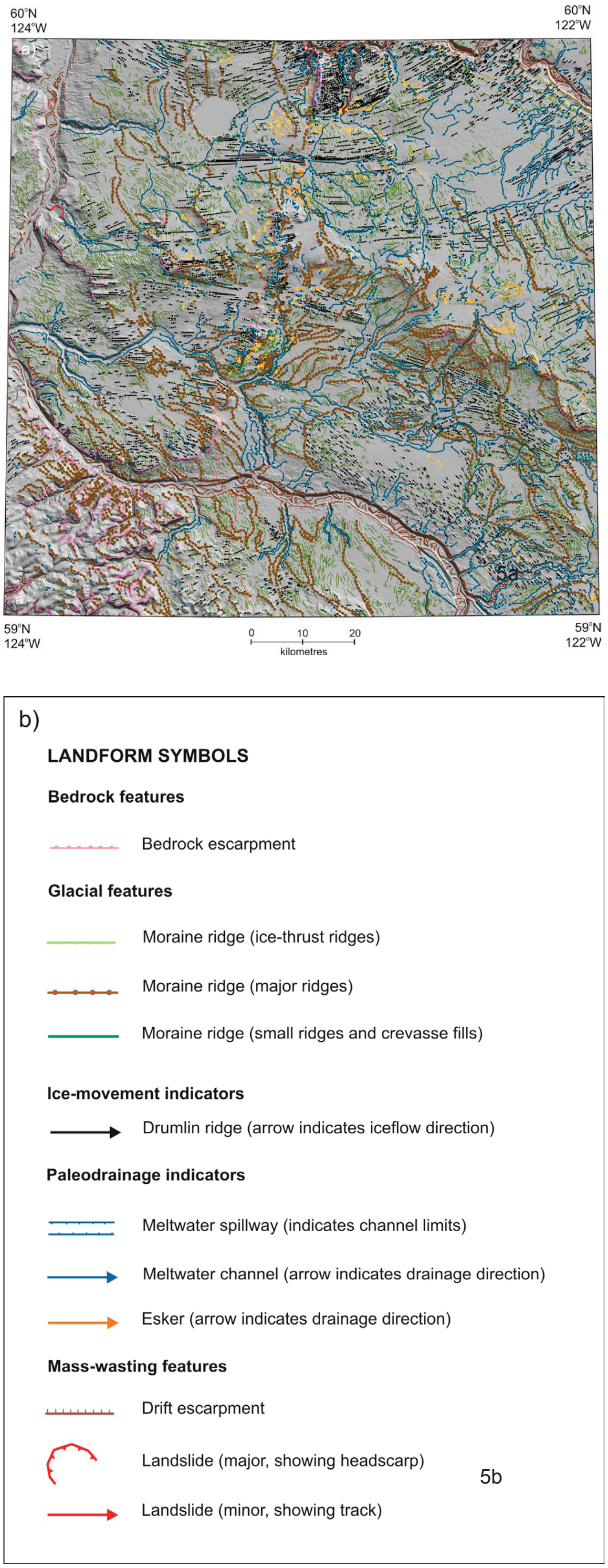

Figure 5. a) Provisional geomorphology of the Maxhamish Lake map area (NTS 94O); b) map legend.

SURFICIAL EARTH MATERIALS AND LANDFORM INVENTORY

The number of units mapped (n=2700 terrain polygons) is graphically summarized in Figure 6a. Polygons most frequently contain tills as dominant terrain units (n=1085) and organic deposits (n=515). Glaciolacustrine deposits (n=272), alluvial sediments (n=290), and colluvium (n=240) are less frequent. Terrain polygons mapped with glaciofluvial sediments (n=193), bedrock (n=55) and eolian deposits (n = 50) are least common (Figure 6a).

The areal extent (km^2) of surficial units is shown in Figure 6b. The most extensive surficial units are tills (covering 5965.36 km^2 or 47.25% of the map area) and organic deposits (covering 4269.48 km^2 or 33.68 % of the map area). Glaciolacustrine deposits (881.80 km^2 or 6.98%), alluvial sediments (726.43 km^2 or 5.73%), and colluvium (552.74 km^2 or 4.38%) cover much of the remaining map area. Glaciofluvial (117.71 km^2 or 0.94%), bedrock (48.21 km^2 or 0.38%) and eolian deposits (82.05 km^2 or 0.66%) are the least areally extensive (Figure 6b).

Figure 6c shows that the dominant landforms in the map area are minor moraine ridges (n=10 185), drumlins (n=4016) and meltwater channels (n=1188). Less common are major moraine ridges (n=1211), drift escarpments (n=698), eskers (n=332), meltwater spillways (n=174), ice-thrust ridges (n=153) and bedrock escarpments (n=183).

Holocene earth materials and landforms

Alluvial deposits include boulders, gravel, sand, and silt transported and deposited by modern rivers, streams and creeks (Figures 7a to 7f). Deposits are confined to deltas and fans (Af), terraces in river valleys (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) which adversely affect stream courses or conditions, and have impacts on fish and wildlife resources.

Organic deposits include undifferentiated muskeg (Ow), peat bogs (Owb) and fens (Owf) formed by the accumulation of organic matter in poorly drained depressions or level areas (Figures 8a to 8d). 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. In 2003, discontinuous permafrost was observed sporadically at depths

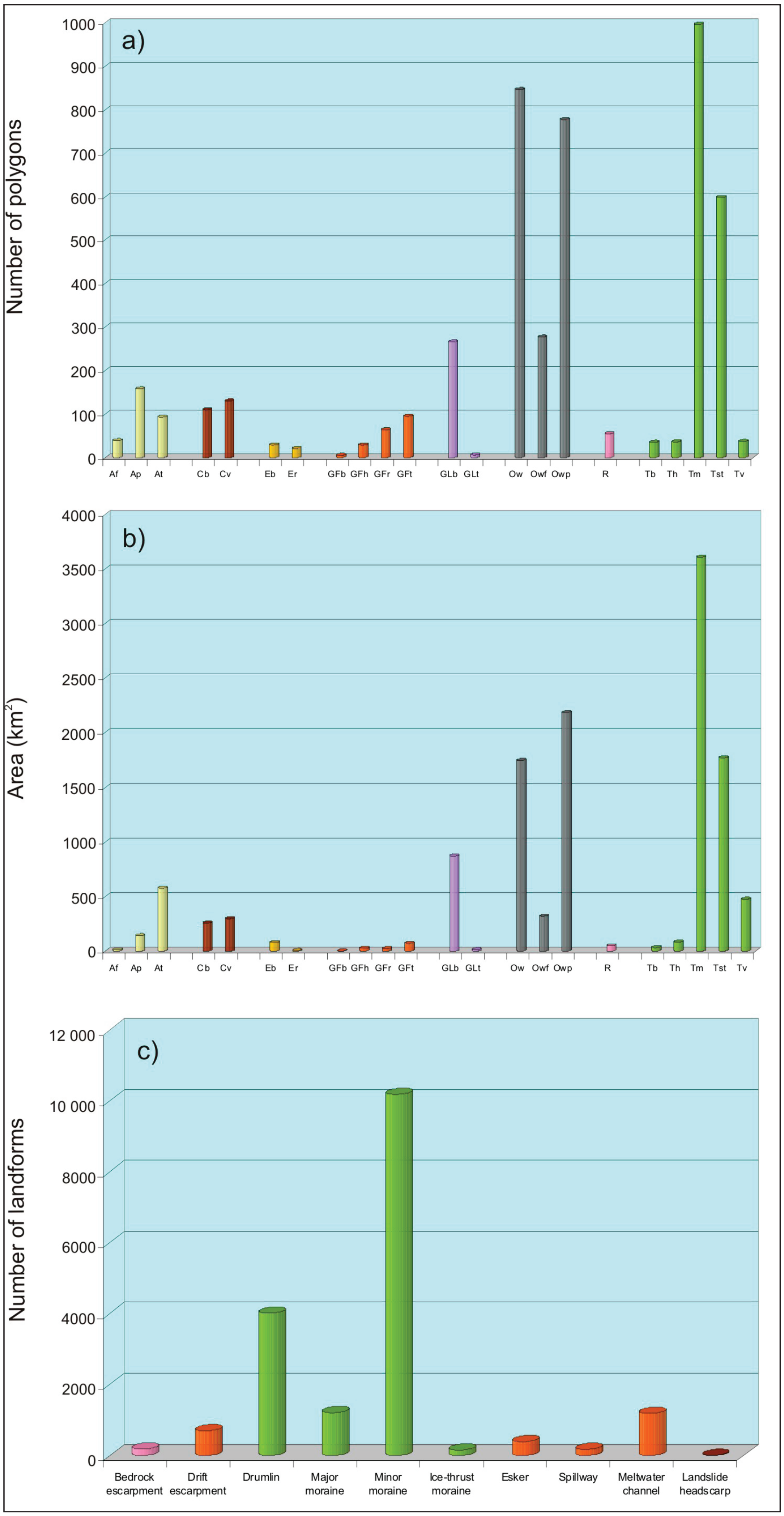

Figure 6. Summary statistics for surficial map units and landforms: a) number of polygons per map unit; b) areal extent of map units (km^2); and c) number of landforms. Note colours are generalized in relation to the map legend (see Figures 4 and 5).

Figure 7. Alluvial deposits: a) underfit Fort Nelson River occupying northwest-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 the 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.

of less than 1 m throughout the map area, especially where peat overlies unconsolidated glacial lake sediments. Peat in wet depressions is thawed to depths greater than 1 m.

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, tills and alluvial sediments, then transported and deposited by wind action (Figures 9a to 9d). 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.

Colluvial deposits are a product of the weathering and down-slope movement of earth materials by gravitational processes (mass wasting). Massive to stratified,

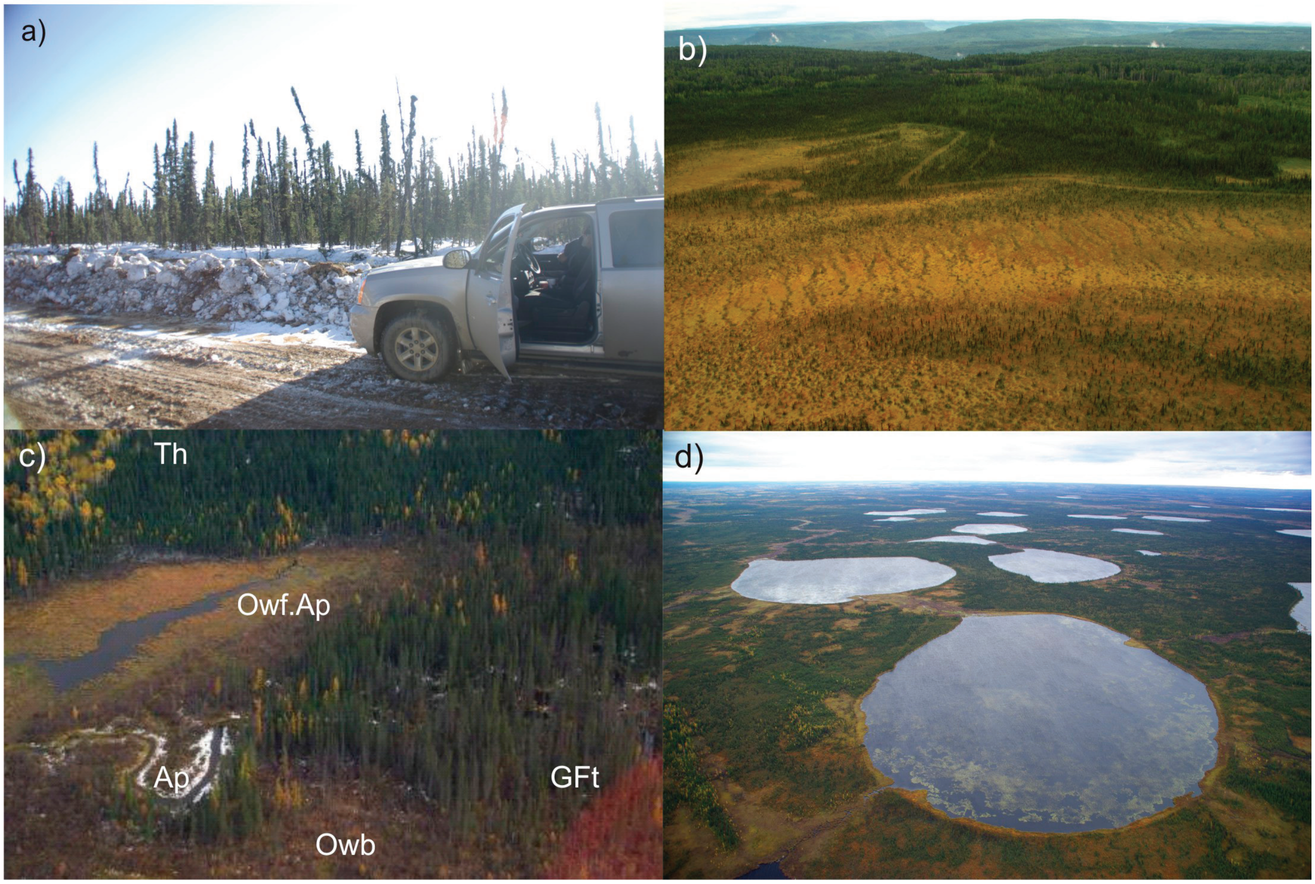

Figure 8. Organic deposits: a) hummocky bogs with sphagnum and forest peat (Owb) are formed in wet environments, usually treeless or with a cover of black spruce and ericaceous herbs; b) ribbed fen peat (Owf) are derived from sedges and shrubs in a relatively open environment with a mineral-rich water table that persists seasonally near the surface; c) fenland developed over alluvial plain (Ap) in response to beaver-damming of the meltwater channel, d) undifferentiated organic deposits (Ow) with thermokarst lakes indicate the presence of sporadically discontinuous permafrost.

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 to 10d). Earth materials on slopes above 10-15° 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°. Slope instability could present major problems for construction in some areas (e.g., the south flank of the Etsho Plateau, Fort Nelson and Petitot river valleys).

Late Pleistocene earth materials and landforms

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 11a to 11e). 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 should be evaluated as frac sand sources if they are quartz rich. Gravel deposits buried beneath till and other glacial sediments are potential groundwater aquifers.

Glaciolacustrine deposits (Figures 12a to 12e) 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 1 m, blanketing other deposits (GLb) and occasionally forming terraces (GLt). 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°are potentially unstable and prone to landslides and debris flows.

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. The till is interpreted to be deposited by the Laurentide Ice Sheet (Figures 13a to 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).

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

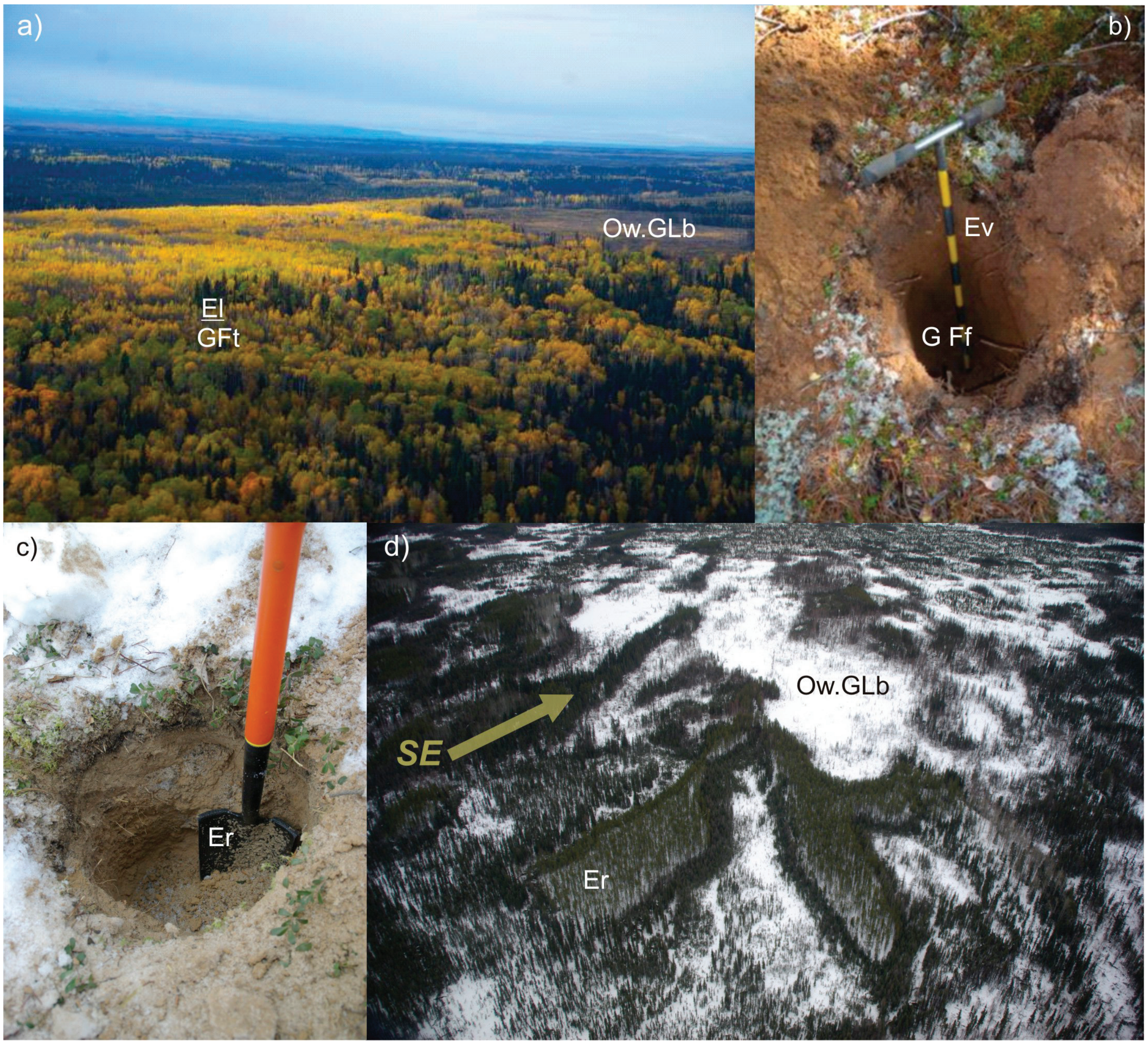

Figure 9. Eolian deposits: a) loess field (El) formed by eolian re-working of outwash (GFt) and glacial lake sediments (Ow.GLb); b) eolian veneer of silty fine sand (Ev) overlying glaciofluvial pebbly sand (GFf); c) fine to medium-grained quartz and feldspar-rich eolian sand exposed in parabolic dune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

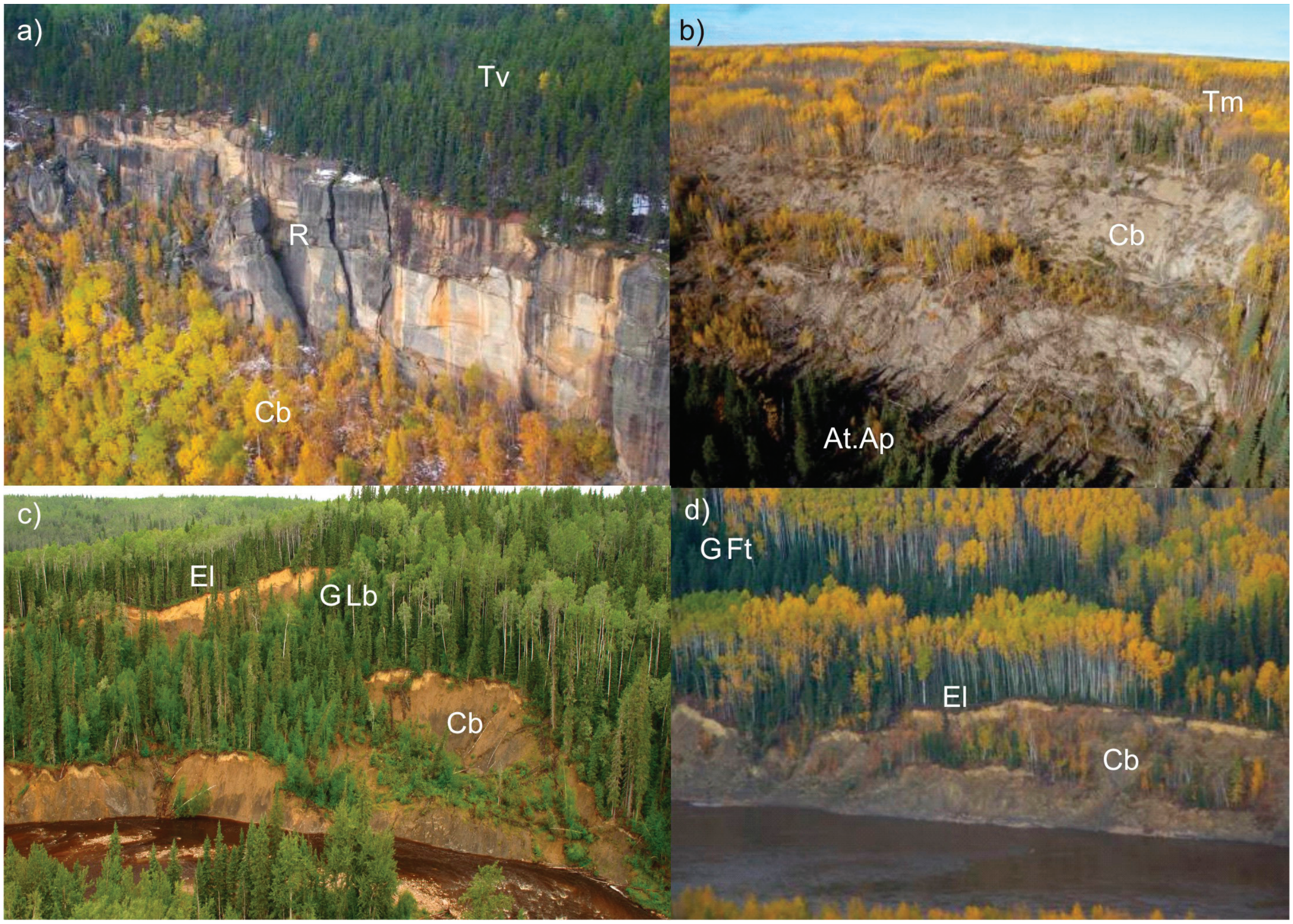

Figure 10. Colluvial deposits: a) Tsoo Tablelands, conglomerate and sandstone escarpment (Dunvegan Formation, indicated by R) prone to toppling, rock slides and failure along debuttressing fractures subparallel to the escarpment face (Cb); b) Etsho Plateau, complex retrogressive, rotational-translational bedrock-debris slide (Cb) incorporating shale, sandstone and siltstone (Fort St. John Group) and Quaternary glacial deposits, landslide triggered by postglacial 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).

Escarpment and the Tsoo Tablelands (Figures 14a to 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 to 14d).

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 (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 paleodrainage 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 11f). There are no known frac sand sources in the map area.

The most favourable granular aggregate targets identified are bedrock escarpments (n=183), eskers (n=392), drift terraces (n=698), meltwater channels (n=1188), and spillways (n=174) graded to glacial lake surface elevations at approximately 610 m and 420 m (Figures 5 and 6). Glaciofluvial deposits visited during the 2009 and 2010 field seasons were assessed as having low to moderate potential as granular aggregate sources (Huntley and Hickin, 2010).

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 7f); sand and gravel beds (up to 5 m thick) were also observed underlying > 3 m of clay-rich till in the Petitot River valley (Figure 12a). These sites need to be further evaluated for their frac sand 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 88% 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 11. Glaciofluvial deposits: a) terraced retreat-phase glaciodeltaic outwash (GFt) graded to a glacial lake surface elevation of approximately 420 m, in the Petitot River valley; 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.

Figure 12. 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) approximately 610 m elevation, associated with proglacial lakes confined to flanks of the Etsho Plateau and the Maxhamish Escarpment; c) glaciolacustrine plain with end moraines (GLb.Tm), incised by the 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 draining Tsoo Tablelands to the southeast, graded to approximately 640 m elevation; e) silty clay glaciolacustrine deposits (GLb) exposed below 420 m elevation along the Liard River.

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) trembling aspen and white spruce and jack pine stand on loess veneer (El) draped over the 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) in the vicinity of Maxhamish Lake.

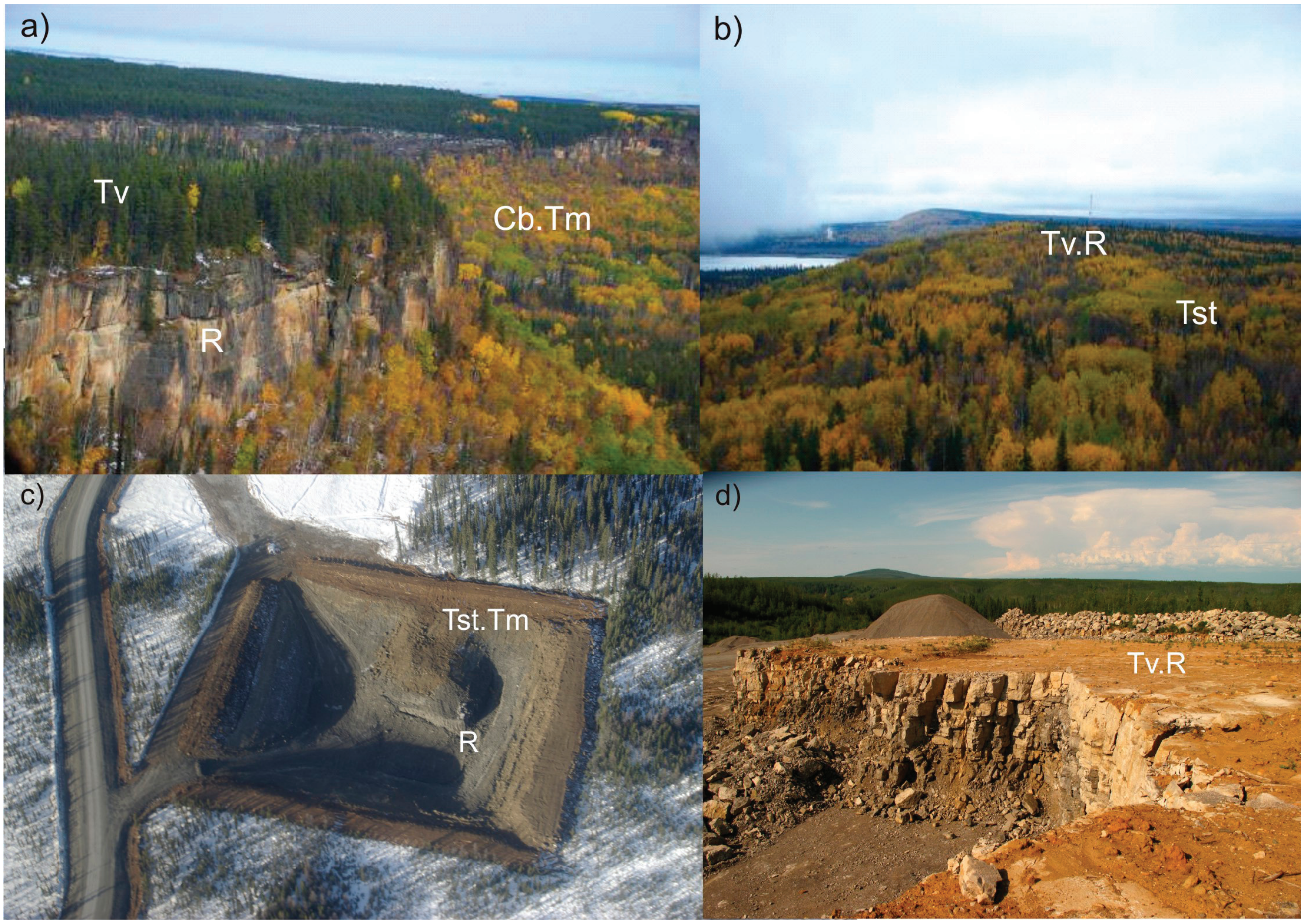

Figure 14. Bedrock: a) exposed conglomerate and sandstone (R, Dunvegan Formation) forming an escarpment of the Tsoo Tablelands; b) till veneer (Tv.R) overlying glacially streamlined conglomerate, sandstone and shale (R, Dunvegan Formation); c) borrow pit exposing 3-5 m of drumlinized Laurentide till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

(Figures 4a and 9a-d). However, the low frequency of occurrence and limited areal extent of bedrock (48.21 km^2 or 0.38% of the map area), glaciofluvial (117.71 km^2 or 0.94%) and eolian deposits (82.04 km^2 or 0.65%) suggests that there is limited economic potential for surface sources of granular aggregate and frac sand in the Maxhamish Lake map area. Sedimentological analyses and attrition experiments indicate that sand deposits in their natural state have limited potential as regional sources of frac sand (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, campsites, 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 552.74 km^2 (or 4.38%) of the map area (Figures 4a and 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 to avoid infrastructure development where geohazards are present. In the case of existing infrastructure located within zones of potential geohazards they should be protected 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 726.43 km^2 (or 5.73%) of the map 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. Wetland bog and fen peat deposits cover approximately 4249.48 km^2 (or 33.68%) of the map area. Organic deposits also insulate underlying permafrost. In 2003, undifferentiated organic deposits and peat bogs containing sporadic discontinuous permafrost blanketed till and glaciolacustrine deposits covering approximately 1603.45 km^2 (or 12.68% 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 8d) 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. In addition, large areas of fen can be inundated following drainage damming by beaver activities.

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 infrastructure development. Surficial geology and geomorphology maps (Figures 4 and 5) can be applied to best locate infrastructure, leading to less environmental impact and lower costs of installation and geotechnical modification 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 (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 and parabolic dunes cover only 0.65% 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 (Figures 4 and 5) and related databases (Figures 3 and 6a to 6c) for the Maxhamish Lake map area (NTS 094O) 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 11a to 11f). On-site and laboratory-based assessments indicate that most glaciofluvial deposits in the map area have low to, at best, moderate potential as granular aggregate sources (Hickin and Huntley, 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: approximately 0.66% of the map area and support rare ecosystems (Figures 9a to 9d). Polygons mapped with silt- and clay-rich till as the dominant terrain unit (streamlined till and moraine ridges) are suitable for well pads, building sites, road bases and other infrastructure development.

Geohazards in the map area include mass-wasting of glacial sediment and bedrock on the slopes of stream and river valleys, escarpments and upland plateaus (affecting approximately 4.38% of the map area); flooding, erosion, deposition and beaver activity in valleys (impacting 5.73%); and undifferentiated organic deposits and peat bogs containing sporadic discontinuous permafrost blanketing till and glaciolacustrine deposits (12.68% of the mapped area) on the Liard and Etsho plateaus and the Fort Nelson Lowland (Figure 4a).

Project outputs include GSC Open File Reports and digital maps (available on CD-ROM) which can be used in mineral and energy resource evaluations, environmental assessments and for drift geochemical exploration. Reports and maps are available as free downloads from the GSC bookstore website (http://gsc.nrcan.gc.ca/bookstore/). Surficial geology maps (e.g., Figures 4 and 5), released as part of the GEM-Energy Yukon and Liard 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 shot-hole 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, the BC Ministry of Energy and Mines, 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, site-specific field studies in the Maxhamish Lake map area (NTS 094O) 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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