Pre-Reid surficial geology investigations in southwest McQuesten map area (115P)

***Jeffrey Bond*[1] *and Panya Lipovsky*[2]**
Yukon Geological Survey

Bond, J. and Lipovsky, P., 2010. Pre-Reid surficial geology investigations in southwest McQuesten map area (115P). *In:* Yukon Exploration and Geology 2009, K.E. MacFarlane, L.H. Weston and L.R. Blackburn (eds.), Yukon Geological Survey, p. 103-117.

ABSTRACT

Recent field investigations have improved our knowledge of the Quaternary surficial geology, stratigraphy and glacial limits in the McQuesten map area. This information has important applications to surficial geochemical and placer exploration. The Quaternary geology of this area is unique because it encompasses early to middle Pleistocene (pre-Reid) glacial surfaces that are preserved beyond the limit of the Illinoian (Reid) glacial limit. These pre-Reid surfaces have been exposed to long periods of weathering and erosion, which have diminished their original distribution and expression. Stratigraphic exposures examined in the map area provide new evidence for a large glacial lake(s) in the Lake Creek basin ('glacial lake Coldspring'); the lake developed when pre-Reid ice dammed outlets in the Willow Hills and lower Lake Creek. In addition, there is evidence that another large glacial lake ('glacial lake Rosebud') formed on the west side of the White Mountains when a pre-Reid glacier dammed Rosebud Creek. Fieldwork in the White Mountains and on Australia Mountain allowed us to delineate the pre-Reid glacial limit at approximately 1000 m (3300-3400 ft) a.s.l. This elevation is lower than the pre-Reid glacial limit previously mapped for the area by Duk-Rodkin (1999) and is consistent with mapping performed in the adjacent Stewart River map sheet by Bostock (1964), Jackson (2005a,b) and Froese and Jackson (2005).

---

[1] *jeff.bond@gov.yk.ca*

[2] *panya.lipovsky@gov.yk.ca*

INTRODUCTION

Surficial geology field investigations were undertaken in July 2009 in the southwest McQuesten map area (NTS 115P) in order to determine the distribution and character of the early to middle Pleistocene (pre-Reid) glacial surficial materials. Stratigraphy and glacial limits were also mapped to improve our understanding of the local Quaternary glacial and interglacial history. The study area encompasses a large area of pre-Reid drift surfaces (Fig. 1). These deposits are bounded by the Reid (130 ka; Ward *et al.*, 2008; Pewe *et al.*, 2009) glacial limit to the east, and unglaciated terrain to the west. Long periods of weathering and erosion have modified the distribution and expression of the drift surfaces, making air photo interpretation difficult and emphasizing the need for field work in this region. In addition, there are sparse details on ice-flow history since there has been no ground-truthing

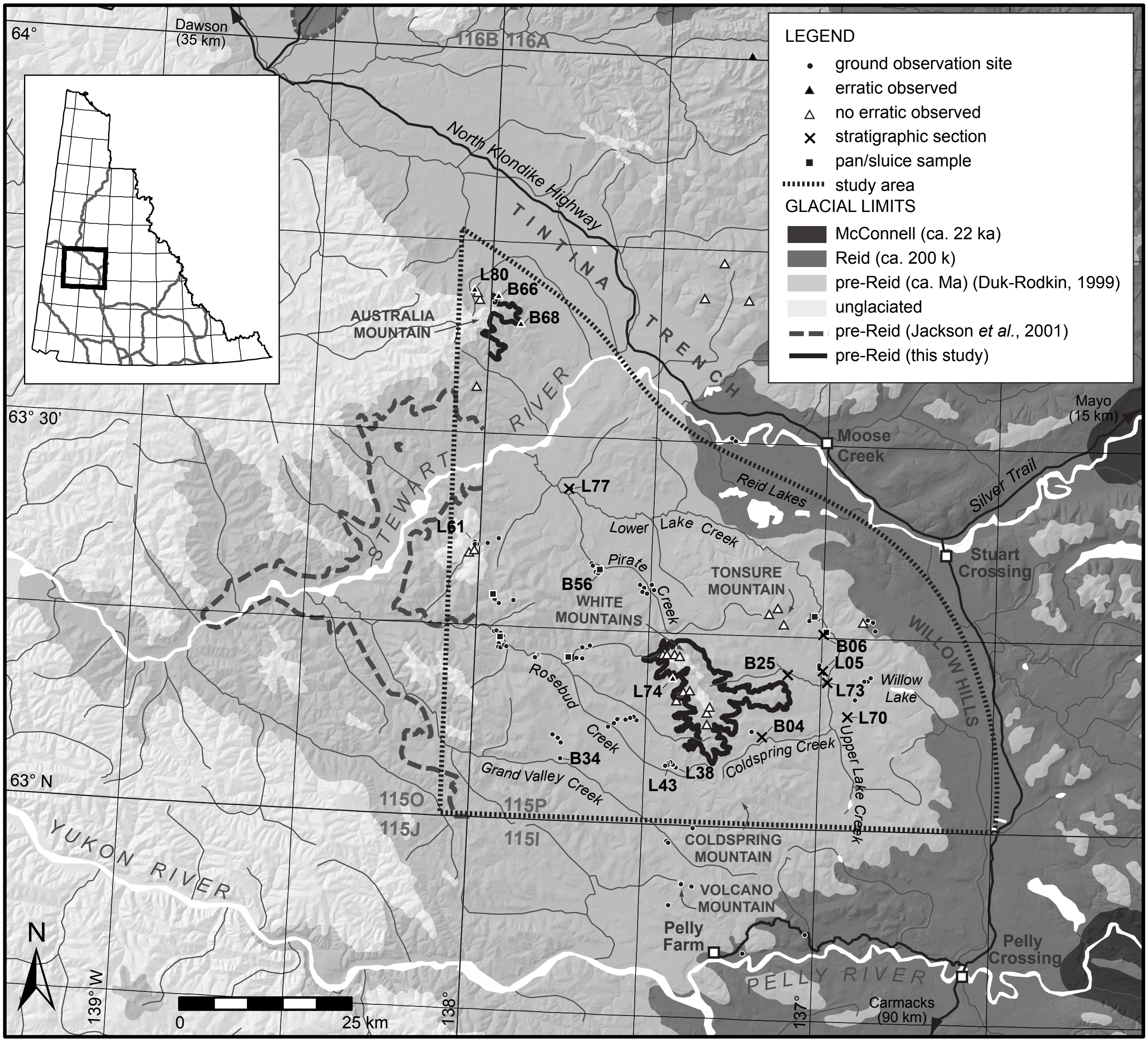

Figure 1. *Map illustrating the extent of the study area in southwest McQuesten map area (115P) in relation to glacial limits depicted by various researchers. Inset portrays location within Yukon Territory. Stratigraphic sections, pan/sluice samples, sites where erratics were either observed or not observed, and other ground observation sites are shown. Sites mentioned in text are labeled with site numbers.*

of the pre-Reid glacial limit. This paper summarizes our Quaternary geologic observations aimed at addressing these knowledge gaps.

PREVIOUS WORK

The pre-Reid drift surfaces in McQuesten map area have received considerable Quaternary research attention in the past 40 years. Bostock (1948) first recognized that there was evidence for at least two glaciations in the area and later identified four separate glaciations (Nansen, Klaza, Reid and McConnell glaciations; Bostock, 1966). In 1969, Hughes compiled glacial limits and flow patterns for central Yukon and grouped the Nansen and Klaza glaciations into the pre-Reid glaciations due to challenges differentiating the early Pleistocene limits. Hughes also produced a series of surficial geology maps for northeastern McQuesten map sheet (1983, unpublished data). Duk-Rodkin (1999) compiled the first glacial limits map of the Yukon, which included a new limit for the pre-Reid glaciations in Stewart River valley. This area has also been the focus of numerous pedological investigations aimed at differentiating glacial surfaces and identifying past climates (Rutter *et al.*, 1978; Tarnocai *et al.*, 1985; Smith *et al.*, 1986; Tarnocai and Smith, 1989; Tarnocai, 1990; Tarnocai and Schweger, 1991; Dampier *et al.*, 2009). Bond (1997) described the glacial and interglacial stratigraphy along the Stewart River in his MSc thesis and produced an unpublished 1:250 000-scale surficial geology map for the McQuesten map sheet (Bond and Duk-Rodkin, 1996). Part of the rationale for this project included field validation of the 1996 map so that it could be incorporated into the Yukon digital surficial geology compilation (Bond and Lipovsky, 2009). Surficial geology mapping in the adjacent Stewart River (115O) and Carmacks (115I) map areas was completed by Jackson (1997a,b, 2005a,b), and Froese and Jackson (2005). The most recent bedrock geology mapping for the southwest McQuesten map area was carried out by Colpron and Ryan (this volume).

METHODS

Field work was conducted from two base camps, one established south of the study area at the Pelly farm, and a second camp located on the Klondike Highway at Moose Creek Lodge (Fig. 1). Foot traverses were planned using aerial photo interpretation and completed with the assistance of a Hughes 500D helicopter and a Bell 206 Ranger. To improve the accuracy of the interpretation and planning, we acquired high resolution air photo models from Andrew Neale Digital Mapping. The models were viewed in 3D within ESRI ArcGIS using Purview third party software.

The majority of ground observations were made by examining hand-excavated soil pits, landslide exposures and cut banks. Information recorded at each site consisted of general site characteristics and specific landform and soil material descriptions. Similar information was collected at stratigraphic sections, where detailed sedimentology was also completed. The surficial geology observed at each site was classified using the British Columbia Terrain Classification system which has recently been adopted for surficial geology mapping in Yukon. Glacial limits were mapped by checking flat upland surfaces and frost boils for the presence of erratics, and by determining the upper elevation limit of meltwater channels. Erratics were identified based on lithology and degree of rounding.

SURFICIAL GEOLOGY

A large focus of the 2009 field work in the southwest McQuesten map area was on characterizing pre-Reid surficial material distribution patterns, thicknesses and textures. These findings are summarized in this section, and will be used to update Bond and Duk-Rodkin's 1996 unpublished surficial geology map.

Most surfaces are covered by a veneer of Holocene organic material, or peat, consisting of poorly to partially decomposed fibric and mesic materials, and lesser amounts of well-decomposed humic materials. These deposits are thickest (*i.e.*, generally 10-20 cm) on north-facing slopes where drainage is poor, and are very thin (<5 cm) or absent on dry, south-facing slopes. Thicker blankets of organic materials (>1 m thick) accumulate in bogs and wetlands in valley bottoms, particularly in the the broad, gently sloping valleys of upper Rosebud and Grand Valley creeks. Permafrost is often found within 1 m of the surface where organic materials exist.

A thin veneer of massive eolian silt and/or fine sand (loess) is also widespread either at the ground surface, or just beneath the organic materials. Loess is generally thin (*i.e.*, <5-20 cm thick) on uplands and moderate to steep slopes. Remobilized eolian material commonly accumulates in valley bottoms to thicknesses exceeding 1 m. The loess is typically reworked and mixed into underlying colluvial materials through cryoturbation and mass movement processes.

Modern gravel and sand deposits are found within active floodplains, stream terraces and fluvial fans. Organic-rich sandy and silty fluvial deposits are also found in backchannels and overbank environments (e.g., B06, Fig.1). Where glacial diversions have occurred, for example in Lake and Pirate creeks, the fluvial plain cuts through bedrock uplands and a significant amount of angular material has become incorporated into the alluvium.

Pre-Reid till, glaciolacustrine, and glaciofluvial complexes are predominantly preserved in valley bottoms and obscure the geochemical signature of the underlying bedrock (Fig. 2). Isolated glaciofluvial and till deposits are also preserved on higher level benches on the valley sides east of the White Mountains (Fig. 2a).

Extensive pre-Reid glaciofluvial terraces composed of poorly sorted, stratified sand and gravel are preserved in

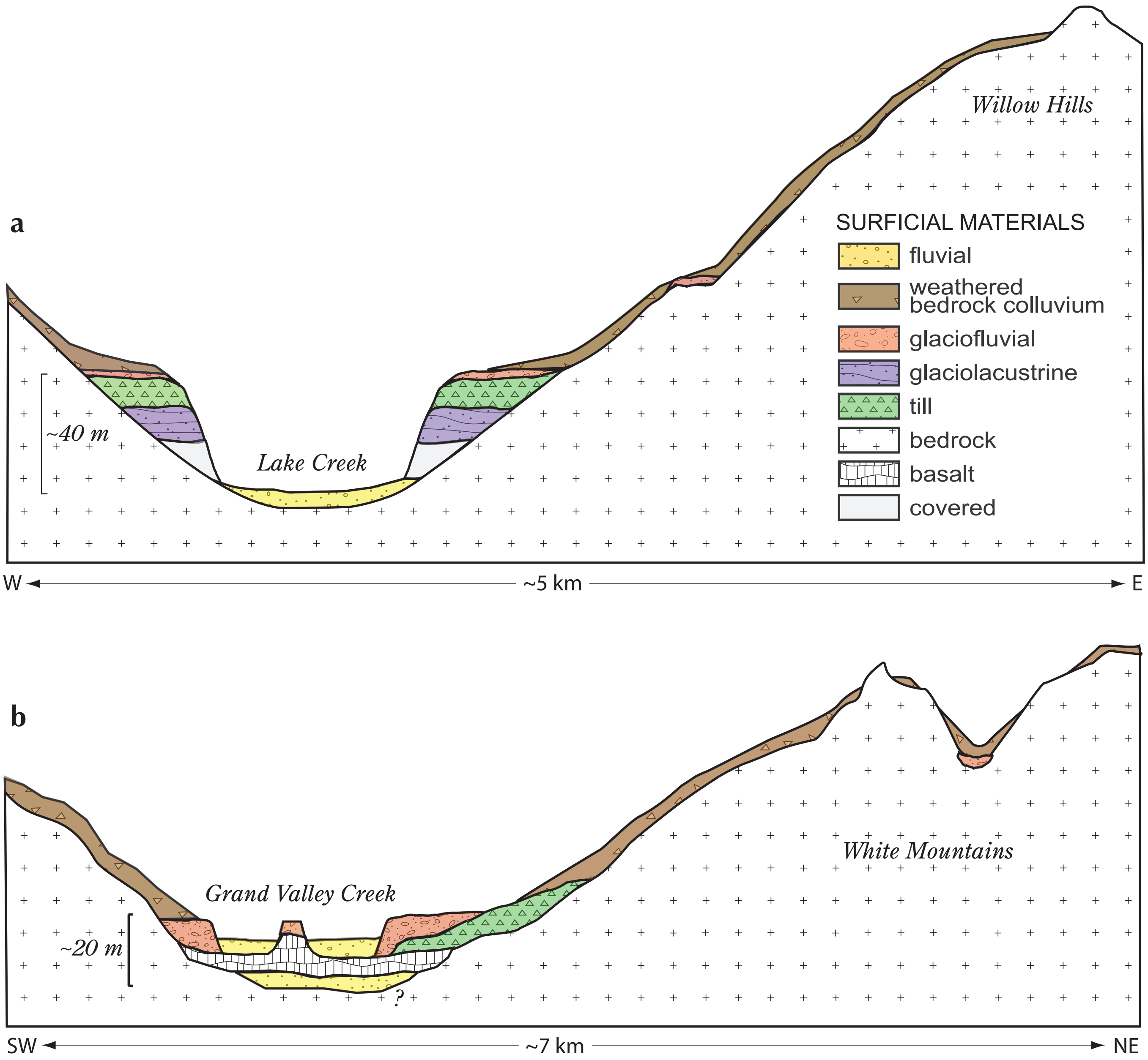

Figure 2. *Idealized cross sections illustrating the distribution of surficial materials in the study area.* ***(a)*** *East of the White Mountains, the valley bottoms are covered by thick sequences of pre-Reid drift with alluvium deposited along modern floodplains.* ***(b)*** *Glaciofluvial terraces are the dominant landform in the valley bottoms west of the White Mountains.*

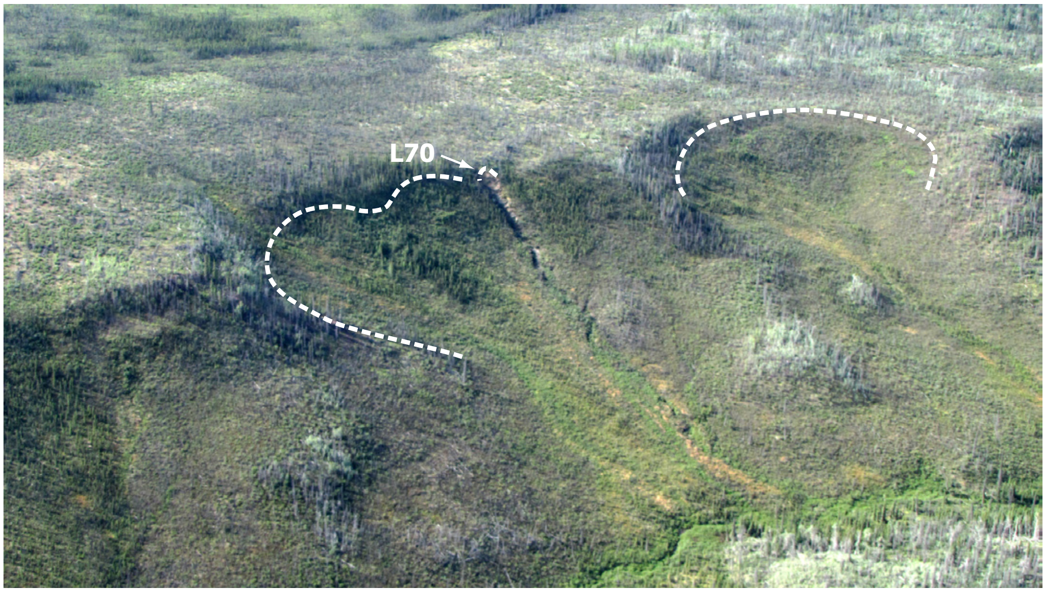

Figure 3. *Retrogressive slump scars in Willow Hills (scalloped features cutting into upper bench); view is to the south. The upper bench is approximately 70 m above the valley bottom and consists of a glaciofluvial terrace underlain by ice-rich glaciolacustrine sediments. L70 represents a stratigraphic section location.*

valley bottoms west of the White Mountains and in lower Lake Creek (Fig. 2b). On the lower slopes of broad valleys, the glaciofluvial deposits overlie and grade into pre-Reid till (Fig. 2b), while in steeper, narrower valleys, the till has been eroded from the hill sides, and the glaciofluvial deposits grade into weathered bedrock colluvium (Fig. 2b). Paleosols formed within these deposits are commonly heavily oxidized and weathered, and contain frost-shattered clasts (*e.g.*, L77, Fig. 1). Where meltwater channels cut across drainage divides, an abundance of angular clasts derived from local bedrock may be incorporated into the glaciofluvial deposits. Drift proximal to the Tintina Trench is typically quite thick as observed at lower Lake Creek (L77, Fig. 1) where pre-Reid glaciofluvial deposits and till are greater than 40 m thick.

Glaciolacustrine sediments are extensive in the Lake Creek and Rosebud Creek valleys, where thick packages of laminated fine sand, silt and clay up to 16 m thick were observed. The presence of several large retrogressive thaw slump scars originating in glaciolacustrine materials in the Willow Hills indicates that these sediments are not only widespread, but are commonly associated with massive ground ice (Fig. 3).

Pre-Reid till is poorly exposed in the map area, but where observed, it consists of a dense, poorly-sorted diamicton with weathered clasts. Matrix texture varied from sandy silt to clay, depending on proximity and relationship to glaciolacustrine units. Thicknesses up to 7 m were observed in Coldspring Creek (B04, Fig. 1) and 4 m in lower Lake Creek (L77, Fig. 1). Morainal sediments have been eroded from steep upland valley sides, leaving a mixed mantle of weathered bedrock colluvium and eolian deposits on these slopes. In broader valleys west of the White Mountains, till is commonly preserved at the base of slopes (Fig. 2b).

Periglacial activity and permafrost processes are significant mechanisms of weathering and are evident throughout the map area. Physical weathering and subsequent remobilization by periglacial slope processes such as soil creep, slopewash, landslides and solifluction have occurred since the early to middle Pleistocene. This prolonged period of landscape weathering has eroded most of the Pre-Reid glacial materials originally deposited on moderately to steep slopes and uplands, leaving these slopes mantled by weathered bedrock colluvium. On upland sites, weathered bedrock colluvium is generally a thin veneer or blanket of rubbly diamicton with angular clasts and a silty-sand matrix. On slopes, weathered bedrock colluvium is often crudely stratified (Fig. 4). Tors are present above the glacial limit and are most common along the crest of the Willow Hills, and on the White Mountains. Cryoplanation terraces were also identified above the glacial limit near the north end of the White Mountains.

The study area is situated within the extensive discontinuous permafrost zone (Heginbottom *et al.*, 1995). Near-surface permafrost distribution in the study area is primarily controlled by topography, surficial material texture, and drainage. Permafrost was not observed within 1 m of the surface on well-drained colluvial slopes, or within well-drained, coarse or sandy valley bottom materials. Permafrost was observed within 1 m of the

Figure 4. *Weathered bedrock colluvium which typically mantles valley sides and uplands. Note angular coarse fragments and stratification resulting from prolonged modification by periglacial processes and mass movement. Loess is commonly incorporated into the near-surface horizons.*

surface where thick organic materials covered, or were interbedded with, fine-grained loess, alluvium or glaciolacustrine materials in valley bottoms; shallow permafrost was also observed on north-facing slopes blanketed by silty colluvial diamicton or thick loess. Where frozen ground was observed, the depth to the frost table (in early to mid July) varied between 36 and 174 cm; therefore, active layers in the area likely vary between 0.5 and 2 m thick. At one location (L70, Fig.1), the frost table was observed at 8 m depth in glaciolacustrine materials underlying several metres of glaciofluvial gravel.

Isolated landforms indicating the presence of massive ground ice include retrogressive thaw slump scars (L70, Fig. 1) and active-layer detachment slides (L61, Fig. 1) on valley sides and thermokarst depressions (L43, Fig. 1), as well as ice wedge polygons (B34, Fig. 1) and pingos (B56 and L38, Fig. 1) in valley bottoms. A conical mound approximately 5 m high and 42 m in diameter, and composed of granitic angular rock fragments was observed at the toe of a slope in upper Rosebud Creek (L38, Fig. 1). The conical morphology and presence of a collapse crater (2.7 m deep) in the centre of the mound suggests that this feature is the remnant of an open-system rock pingo (Fig. 5).

Figure 5. *Collapsed rock pingo in upper Rosebud Creek (site L38; Fig. 1). This feature has a diameter of 42 m and developed within granitic bedrock. The largest boulder visible is 2.3 m tall.*

In Rosebud and Grand Valley creek valleys, glaciofluvial deposits locally overlie basalt flows of the Selkirk volcanic suite (Fig. 2b). Basalt flows underlying pre-Reid glaciofluvial gravel 20 km downstream from the study area in lower Rosebud Creek have been Ar-Ar dated at 2.69 Ma (Jackson, 2005b). Other bedrock exposures in the area include: Mississippian and older metavolcanic rocks of Quesnellia Terrane to the southeast; pristine Mississippian volcanic rocks and coeval granitic plutons in the Reid Lakes area; Permian and older schist, quartzite, amphibolite and orthogneiss of the Yukon-Tanana Terrane; and Triassic metavolcanic rocks of Stikinia Terrane to the southwest (Colpron and Ryan, this volume). Jurassic and Cretaceous plutonic intrusions are also found throughout the study area (Bostock, 1964; Colpron and Ryan, this volume).

STRATIGRAPHY

Most of the stratigraphic sections described in the study area consist of sediments deposited during pre-Reid glaciations (Fig. 6). The oldest sediments were deposited in outwash trains and glacial lakes that formed ahead of

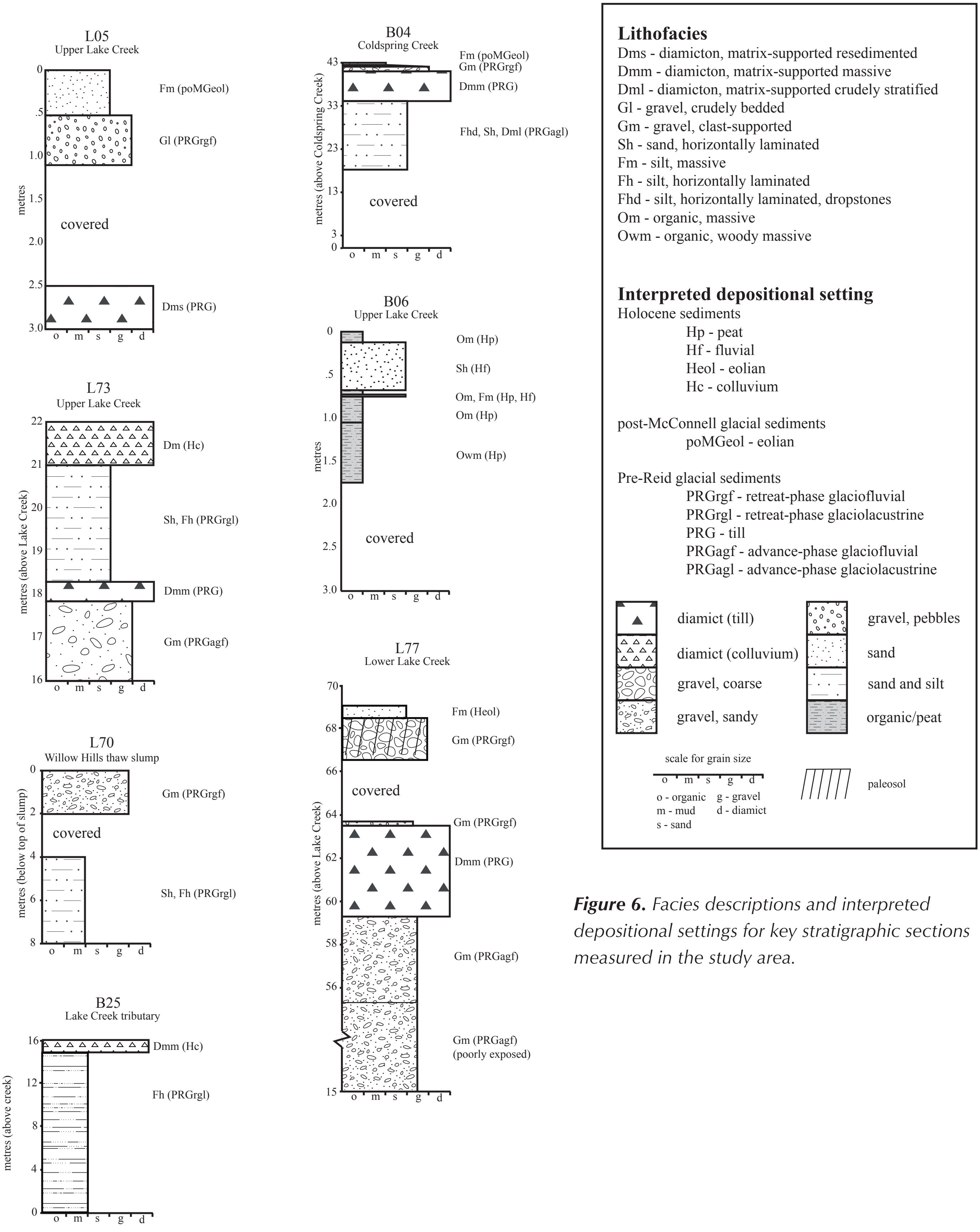

Figure 6. Facies descriptions and interpreted depositional settings for key stratigraphic sections measured in the study area.

the ice front during the advance phase of the pre-Reid glaciation(s). These sediments are overlain by pre-Reid till and retreat-phase glaciofluvial and glaciolacustrine deposits.

ADVANCE-PHASE SEDIMENTS

Advance-phase sediments were observed in the Coldspring Creek and Lake Creek valleys and represent two depositional environments: glaciofluvial (L73, L77) and glaciolacustrine (B04) (Figs. 1, 6). The advance-phase glaciofluvial gravel is typically a poorly sorted, clast-supported gravel that coarsens upward and is crudely to well bedded. Open framework gravel beds are also common, indicating they were deposited in high-energy environments associated with glacier meltwater. Glaciolacustrine sediments typically consist of horizontally laminated and bedded, well-sorted, silt, clay and fine sand (Fig. 7), and in places contain dropstones and lenses of debris-flow diamict. Loading structures are common near the upper contact with pre-Reid till. The presence of advance-phase glaciolacustrine sediments indicates that local drainages were dammed by the ice advance.

Figure 7. *Glaciolacustrine sediments exposed in lower Rosebud Creek valley.*

Figure 8. *Flow till deposited above glaciolacustrine sediments (not visible) as pre-Reid ice advanced up Coldspring Creek valley (site B04, Fig. 1). Note beds dipping up-valley and marked by dashed lines.*

PRE-REID TILL

Till is sediment deposited directly by glacier ice. Four out of the seven sections that were measured for this study contain diamictons that are interpreted to be pre-Reid till (Figs. 1, 6). The till at sections B04, L73 and L77 consists of a compact, poorly sorted diamicton with pebble to boulder-sized clasts in a silty sand matrix. Striated and polished clasts are present, reflecting the glacial origin of the sediment. In Coldspring Creek (B04), up-valley dipping lenses of stratified silt and sand within the till suggest that the diamict accumulated as a series of flow-tills deposited into a proglacial lake (Fig. 8). Tills at sites L73 and L77 were likely deposited by a combination of ablation and lodgement processes. At each of these three sites (B04, L73 and L77), the lower contact with the advance-phase sediment is sharp or erosional, reflecting warm-based ice conditions. The till described at site L05 (Figs. 1, 6) had a similar texture to the lodgement tills, but was not compacted, which may indicate post-depositional resedimentation in an ablation environment.

RETREAT-PHASE SEDIMENTS

Similar to the advance-phase, the retreat-phase of the pre-Reid glaciations was marked by glaciofluvial and glaciolacustrine sedimentation. Retreat-phase glaciolacustrine sediments are present in the Lake Creek valley (L73), the Willow Hills (L70) and in the valley of an unnamed Lake Creek tributary north of Coldspring Creek

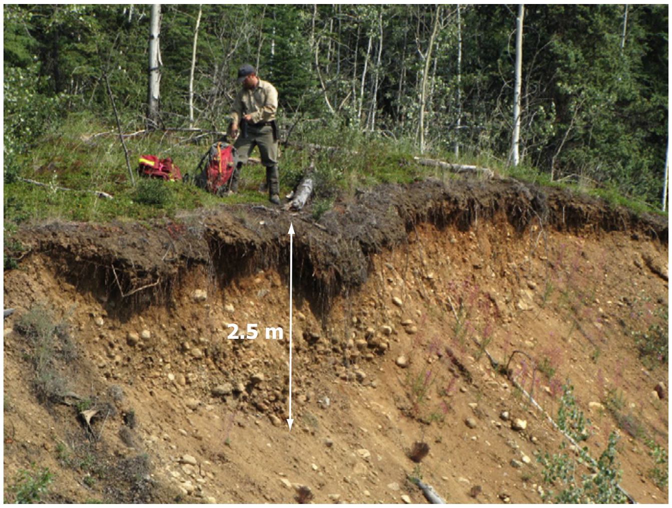

Figure 9. *'Wounded Moose' paleosol that developed in pre-Reid retreat outwash exposed at the top of the lower Lake Creek section (site L77; see also Figs. 1, 6). The paleosol shown here is 2.5 m thick and has been heavily weathered and oxidized. Abundant clasts have been shattered by prolonged frost action which has primarily taken place during the glacial periods following the pre-Reid glaciations.*

(B25; Figs. 1, 6). These sediments typically consist of laminated fine sand, silt and clay. Retreat-phase glaciofluvial sediments consist of a clast-supported, moderately to well-sorted gravel and clast sizes range from pebble to boulder.

At site L77, the retreat-phase glaciofluvial sediments have a well-developed paleosol preserved in the upper 2.5 m of the deposit (Fig. 9). This soil is similar to the Wounded Moose paleosol, observed on other pre-Reid surfaces in central Yukon. The Wounded Moose paleosol formed over a long period of time under a relatively mild and humid climate during the interglacial(s) between the pre-Reid and Reid glaciations (Tarnocai *et al.*, 1985). Typical Luvisol B horizon thicknesses in pre-Reid outwash can exceed 2 m, which is about 1.8 m thicker than the modern Brunisol B horizon in the study area. This implies that pre-Reid interglacials were considerably warmer and wetter than the present-day climate (Tarnocai *et al.,* 1985).

NONGLACIAL SEDIMENTS

A veneer (generally <1 m) of eolian sediments (loess) caps several sections in the study area (Fig. 6). The loess is typically massive silt and likely originated during McConnell deglaciation (approximately 15 ka), however, no dating has been conducted to confirm this age. Modern cliff-top eolian sand and silt accumulations were also observed where unconsolidated sediments have been exposed to wind erosion (L77, Fig. 6).

GLACIAL LIMITS

Previous mapping of the pre-Reid glacial limit in the study area was based on air photo interpretation without ground truthing. In the White Mountains, the pre-Reid limit was formerly mapped at 1370 m (4500 ft; Fig. 1; Bond and Duk-Rodkin, 1996; Duk-Rodkin, 1999). This was based on the elevation of potential meltwater channels cutting across the upland. Field-checking of these channels and other flat-lying surfaces immediately below the limit did not reveal any glacial erratics. The highest erratic found during multiple foot traverses was located at 1000 m (3300 ft a.s.l.) on the west side of the White Mountains (Fig. 1, L74). This elevation is similar to that of the highest meltwater channel identified in our re-interpretation of the upland geomorphology, at 1100 m (3650 ft) on the east side of the White Mountains. A similar pre-Reid glacial limit on Australia Mountain was also mapped at 1000 m (3300 ft), based on the highest erratics observed during multiple foot traverses (B66, B68 and L80 in Fig. 1). This elevation is lower than the limit mapped by Duk-Rodkin (1999; Fig. 1), but corresponds with the pre-Reid glacial limit mapped in the adjacent map sheet, which was based on the elevation of the highest meltwater channels (Fig. 1; Froese and Jackson, 2005).

GLACIAL HISTORY

At least 40 periods of high global ice volume can be distinguished in the benthic marine oxygen isotope record spanning the early to middle Pleistocene (Fig. 10). While these periods of high global ice volume are generally correlated with colder climatic periods, it is currently unknown how many of these cold periods produced ice sheets extensive enough to glaciate our study area.

New ages on pre-Reid glaciations were not produced as part of this study but considerable dating has already been completed by previous researchers who have worked near the confluence of the Pelly and Yukon rivers. Through a combination of Ar-Ar, paleomagnetic and fission track dating, an early Pleistocene chronological record has been produced (Westgate *et al.*, 2001; Jackson

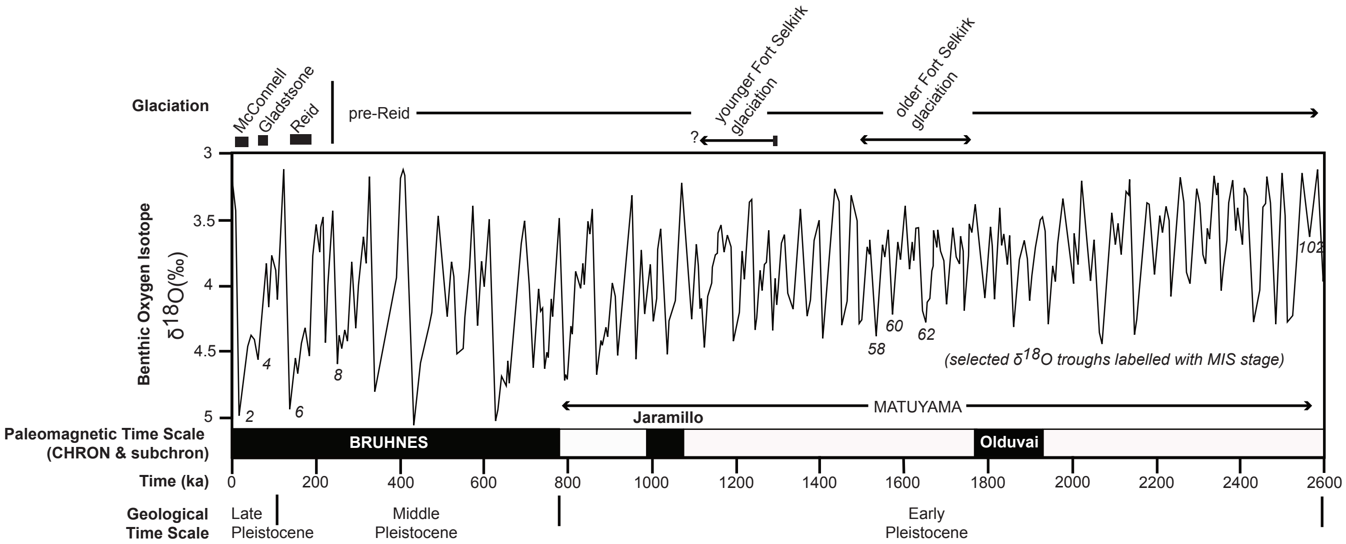

Figure 10. *Oxygen isotope (δ^{18}O) curve for the last 2.6 Ma, constructed by cross-correlating 57 globally distributed benthic marine δ^{18}O records (after Lisiecki and Raymo, 2005). The paleomagnetic time scale and local glaciations are also shown for reference (after Nelson et al., 2009). The δ^{18}O peaks indicate interglacial stages (low global ice volumes) whereas the troughs denote glacial stages (high global ice volumes). This curve highlights the multitude of global climatic fluctuations in the last 2.6 Ma.*

et al., 2003; Nelson *et al.,* 2009). The following conclusions regarding the timing of pre-Reid events can be made from these studies: the oldest pre-Reid glaciation is younger than 2.69 Ma, based on outwash gravel overlying basalt of known age in lower Rosebud Creek (Jackson *et al*., 2003); the older Fort Selkirk glaciation occurred between 1.77 Ma and 1.5 Ma (Nelson *et al.*, 2009); and the younger Fort Selkirk glaciation occurred after 1.33 Ma (Fig. 10). Surface sediments from the younger Fort Selkirk glaciation are preserved above basalt near Pelly Farm (Jackson *et al*., 2003). While the limit of the individual pre-Reid glaciations is not known, it is certain they were more extensive than the Reid glaciation and therefore would have glaciated the southwest McQuesten map area. Future Quaternary chronological studies within the map area should focus on the paleomagnetic record preserved within the pre-Reid glaciolacustrine sediments that have been discussed in this study.

A reconstruction of pre-Reid ice flow can be derived from the stratigraphy and geomorphology we documented in the southwest McQuesten map area. The main conduits for the Cordilleran ice sheet entering the study area were the Pelly and Stewart river valleys. The leading edge of the ice sheet would have resembled a system of westwardly advancing valley glaciers (Fig. 11a). These valley glaciers converged on the eastern side of the Willow Hills and continued to advance around the Willow Hills and through the Willow Lake valley. At this time, the regional eastward drainage off the White Mountains would have been blocked by the ice front, which caused the upper Lake Creek basin to flood, creating glacial lake Coldspring (Fig. 11a). This glacial lake would have developed during each pre-Reid glaciation that advanced into the Willow Hills. Stratigraphic studies also indicate that the lake formed during both ice advance and retreat. At its maximum extent, glacial lake Coldspring was approximately 35 km long and 250 m deep. The main outlet was located south of the White Mountains at an elevation of 900 m (2950 ft) and drained westward into Grand Valley Creek (Fig. 11a). As the ice continued to advance up the eastern flank of the White Mountains, glacial lake Coldspring evolved into a series of separate proglacial lakes occupying the east-west oriented valleys in the Lake Creek drainage. Multiple outlet channels were established at this time as these separate glacial lakes overtopped their divides, or spilled northward into neighbouring valleys. The resulting channels were cut into bedrock and are relatively resistant to weathering and erosion; they therefore provide strong geomorphic

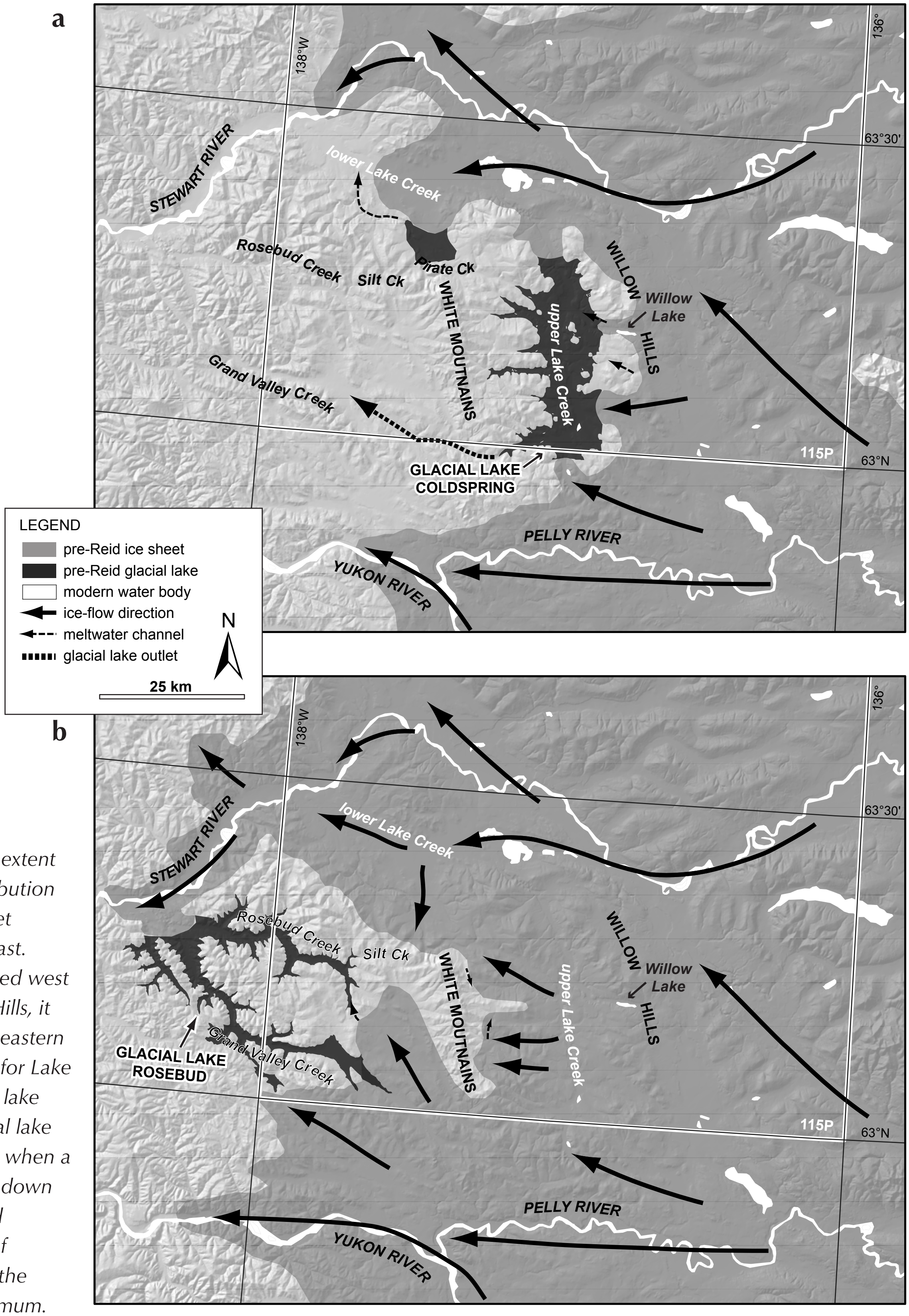

Figure 11. *Schematic reconstruction of ice extent and glacial lake distribution as a pre-Reid ice sheet advanced from the east.* ***(a)*** *As the ice advanced west through the Willow Hills, it blocked all potential eastern and northern outlets for Lake Creek forming glacial lake Coldspring.* ***(b)*** *Glacial lake Rosebud was formed when a lobe of ice extended down the Stewart River and blocked the mouth of Rosebud Creek near the pre-Reid glacial maximum.*

evidence for the glacial limit in the area. The up-valley flowing ice on the east side of the White Mountains reached an elevation of 1100 m.

As the ice continued to advance westward, it was bifurcated by the White Mountains (Fig. 11b). Ice flow to the south of the White Mountains advanced down Grand Valley and Rosebud creeks, whereas ice flow to the north of the White Mountains advanced westward down lower Lake Creek and into the Stewart River valley. North-flowing tributaries to Lake Creek, such as Pirate Creek and its unnamed tributaries, were dammed by the southern margin of the glacier occupying lower Lake Creek valley (Fig. 11a). Glaciolacustrine sediment is exposed in one location in a tributary to Pirate Creek and is likely a common material preserved at depth in this area. As the glacier continued to advance down lower Lake Creek, ice and meltwater spilled southwestward across low divides into Rosebud Creek (Fig. 11b). Remnant glaciofluvial terraces documented in Silt Creek support this history.

Meltwater draining pre-Reid ice in lower Lake Creek valley deposited thick glaciofluvial sediments. Terraces preserved on the margin of the valley contain a complete sequence of pre-Reid advance-phase outwash, till and retreat-phase outwash. This section has been unofficially termed the pre-Reid type section within central Yukon (L77; Figs. 1, 6).

Ice advancing down the Stewart River valley eventually blocked the mouth of Rosebud Creek (Fig. 11b). This caused glacial lake Rosebud to flood Rosebud and Grand Valley creeks. Glaciolacustrine sediment related to this lake was observed in Rosebud Creek valley. A significant supply of the meltwater entered the lake from the ice sheet occupying the upper parts of the basin (Fig. 11b).

Paleosols preserved on the drift surfaces of upper Grand Valley Creek are some of the most oxidized in the study area. Typical weathering features include *in situ* clay formation, clay skins and strong brown Munsell colours (7.5YR 4/6). This degree of soil weathering and rubification was not observed to the east of the White Mountains, for example in the Willow Lake channel, where paleosols were also documented on outwash terraces. A likely explanation for this difference is that the surfaces on the west side of the White Mountains are older than those observed on the east side.

The new glacial limit we are proposing for the southwest McQuesten map area also has regional implications for the ice limits further west in the Stewart River map area. Duk-Rodkin (1999) interpreted the all-time pre-Reid limit reaching the mouth of the Stewart River, whereas Bostock (1966) and Jackson *et al.* (2001) mapped a less extensive all-time limit, which only extended 15 km downstream from the mouth of Rosebud Creek (Fig. 1). The results from this study suggest less-extensive pre-Reid ice flowed into the lower Stewart River valley than what Duk-Rodkin (1999) mapped. Our findings therefore support the previous limits mapped by Bostock (1966) and Jackson *et al.* (2001).

IMPLICATIONS FOR MINERAL AND PLACER EXPLORATION

As outlined in the previous section, field-based glacial-limit mapping confirms that the pre-Reid glacial limit in the southwest McQuesten map area is lower in elevation than previously interpreted by Duk-Rodkin (1999) and Bond and Duk-Rodkin (1996); unglaciated uplands are therefore more extensive than previously interpreted. In addition, upland glaciated slopes have been so heavily weathered and eroded since the early to middle Pleistocene that virtually no glacial deposits remain; these surfaces can essentially be considered unglaciated for surficial geochemical sampling purposes.

Soil geochemistry sampling, and geological interpretation in upland unglaciated regions is generally less complicated than in glaciated regions and valley bottoms because surficial materials are primarily derived from weathered bedrock of local provenance. The main complicating factor in these settings is that any loess present at the surface or mixed into underlying soil horizons will dilute the geochemical signature (Bond and Sanborn, 2006). Loess up to 20 cm thick is present on most upland surfaces in the study area, and is commonly reworked into underlying soil horizons through cryoturbation and mass movement processes, particularly on north-facing slopes (Smith *et al.*, 2009).

In flat and gently-sloping low-lying areas below the glacial limit, abundant eolian, fluvial, glaciofluvial, glaciolacustrine and morainal materials mask the underlying bedrock. In these cases, surficial material genesis and local ice-flow patterns must be carefully considered when planning sampling programs and interpreting both soil and stream geochemistry anomalies. For example, the widespread glaciolacustrine and glaciofluvial materials present in valley bottoms in the map area would generally be unsuitable for soil geochemistry sampling. Till is a more desirable material to sample, but glacial transport and dispersion must be accounted for. For example, basal till deposited along the eastern flanks of the White Mountains was deposited by ice flowing up-valley, whereas the opposite applies to till deposited on the western flanks.

A rudimentary heavy mineral sampling program was carried out as part of the 2009 field program. Eight samples were collected by portable sluicing and/or panning in tributaries to upper Rosebud Creek, Pirate Creek and upper Lake Creek near locations of former placer exploration activity (Fig. 1; Lipovsky *et al.*, 2001; Caulfield and Ikona, 1986). No significant gold colours were identified in any of the pan concentrates.

Additional placer prospecting is recommended in two locations: in lower Rosebud Creek where basalt bedrock outcrops in the valley bottom and is overlain by fluvial or glaciofluvial gravel; and in the vicinity of a bedrock terrace found on the south side of the Stewart River, west of the fine-gold deposits found in Steamboat Bar (Fig. 12). Both the accessible bedrock surfaces and the relatively thin alluvium at these sites will increase the potential to find placer gold concentrations.

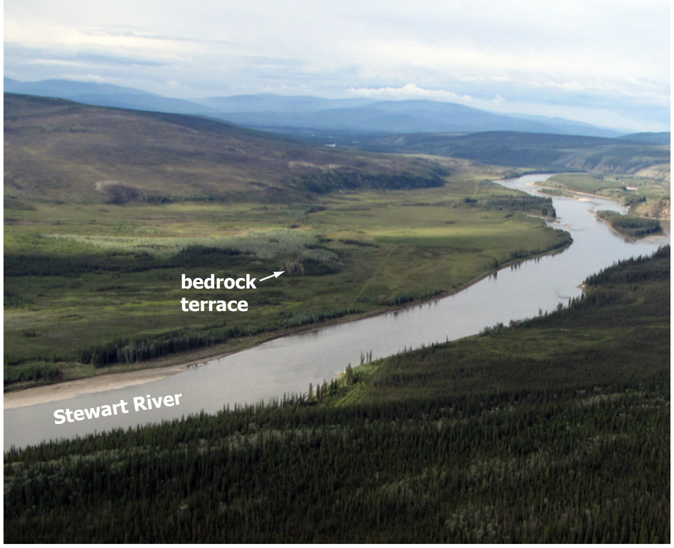

Figure 12. *A low bedrock terrace (see arrow) in the Stewart River floodplain, west of Steamboat Bar. Depth to bedrock in adjacent areas of the floodplain may be relatively shallow, which may increase the grade of fine-gold deposits. View is to the southwest.*

CONCLUSIONS

Pre-Reid drift surfaces in southwest McQuesten map area are preserved in valley bottoms and on low-angle slopes. The stratigraphy of these sediments indicates that up-valley flowing pre-Reid ice sheets dammed upper Lake Creek which drained the eastern flanks of the White Mountains. The upper Lake Creek basin was then inundated by glacial lake Coldspring, which likely formed numerous times during the early to middle Pleistocene. As ice continued to advance west of the White Mountains, moraine and glaciofluvial sediments were deposited in the valleys of Rosebud and Grand Valley creeks. Glaciolacustrine sediments were also deposited in the Rosebud Creek valley when pre-Reid ice sheets dammed the mouth of Rosebud Creek and created glacial lake Rosebud.

Determining the limit of pre-Reid glaciations on upland surfaces is challenging as prolonged periglacial weathering and colluviation have modified or eroded the glacial deposits. The upper elevation of erratics in the White Mountains and on Australia Mountain was determined to be 1000 m (3300 ft). This elevation correlates with previous mapping by Bostock (1966) and Jackson *et al.* (2001), and is lower than the limit mapped by Bond and Duk-Rodkin (1996) and Duk-Rodkin (1999).

Prospectors using surficial geochemical techniques in southwest McQuesten map area must consider the distribution of surficial materials on the landscape before planning their exploration programs. Upland surfaces and moderate to steep slopes located within the pre-Reid glacial limit have similar surficial material characteristics compared to unglaciated terrain. This also applies to first order drainages with steep gradients. Glacial dispersion and potential dilution must be accounted for in samples taken in valley bottoms and second or third order drainages. Placer prospecting in the study area should target bedrock terraces in Rosebud Creek and on the south side of the Stewart River near Steamboat Bar.

ACKNOWLEDGEMENTS

This project was a success due to the hard work of a number of people. It all started with the construction of a first-rate camp which was organized and managed by Jim Ryan and Maurice Colpron; we sincerely thank them for allowing us the luxury of just showing up and getting straight to work. We also had great field assistance from Riley Gibson, Samantha Darling and Derek Turner, and their motivation and enthusiasm made all the difference. The skill of our helicopter pilot Yoshio (Prism Helicopters) was outstanding and sold us on using the 500D. A debt of gratitude is owed to all the camp support staff including: the ever-inquisitive and creative Gord (Aurora Geosciences) who kept camp running smoothly; Eileen, who prepared incredible meals and was always positive and pleasant; and the staff at Moose Creek Lodge for their hospitality during our final week of fieldwork. Much appreciated comments and improvements to this paper were provided by Derek Turner and Leyla Weston.

REFERENCES

Bond, J.D., 1997. Late Cenozoic History of McQuesten (115P), Yukon Territory. Unpublished MSc thesis, University of Alberta, Edmonton, Alberta, 161 p.

Bond, J.D. and Duk-Rodkin, A., 1996. Surficial geology, McQuesten, Yukon Territory. *In:* Late Cenozoic History of McQuesten (115P), Yukon Territory, Unpublished MSc thesis by J.D. Bond, University of Alberta, Edmonton, Alberta, 1:250 000 scale map.

Bond, J.D. and Lipovsky, P.S. (compilers), 2009. Yukon digital surficial geology – preliminary data release. Yukon Geological Survey, Open File 2009-42.

Bond, J.D. and Sanborn, P.T., 2006. Morphology and geochemistry of soils formed on colluviated weathered bedrock: Case studies from unglaciated upland slopes in west-central Yukon. Yukon Geological Survey, Open File 2006-19, 70 p.

Bostock, H.S., 1948. Physiography of the Canadian Cordillera, with special reference to the area north of the fifty-fifth parallel. Geological Survey of Canada, Memoir 247, 106 p.

Bostock, H.S., 1964. Geology, McQuesten, Yukon Territory. Geological Survey of Canada, Map 1143A, 1:253 440 scale.

Bostock, H.S., 1966. Notes on glaciation in central Yukon Territory. Geological Survey of Canada, Paper 65-36, 18 p.

Caulfield, D.A. and Ikona, C.K., 1986. 1985 summary report on the Pirate mineral claims, McQuesten Gold Project, Stewart Crossing, Yukon Territory. Assessment report prepared by Pamicon Developments Ltd. for Miramar Energy Corporation, 34 p.

Colpron, M. and Ryan, J.J., 2010 (this volume). Bedrock geology of southwest McQuesten (NTS 115P) and part of northern Carmacks (115I) map area. *In:* Yukon Exploration and Geology 2009, K.E. MacFarlane, L.H. Weston and L.R. Blackburn (eds.), Yukon Geological Survey, p. 159-184.

Dampier, L., Sanborn, P., Bond, J., Clague, J.J. and Smith, S., 2009. Soil genesis in relation to glacial history in central Yukon. *In:* Yukon Exploration and Geology 2008, L.H. Weston, L.R. Blackburn and L.L. Lewis (eds.), Yukon Geological Survey, p. 113-123.

Duk-Rodkin, A., 1999. Glacial limits map of Yukon Territory. Geological Survey of Canada, Open File 3694, Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Geoscience Map 1999-2, 1:1 000 000 scale.

Froese, D.G. and Jackson, L.E., Jr., 2005. Surficial geology, Australia Mountain (105O/09), Yukon Territory. Geological Survey of Canada, Open File 4586, 1:50 000 scale.

Gordey, S.P., Williams, S.P., Cocking, R. and Ryan, J.J. (compilers), 2006. Digital geology, Stewart River area, Yukon (v. 1, DVD-ROM), Geological Survey of Canada, Open File 5122 (DVD-ROM).

Heginbottom, J.A., Dubreuil, M.A. and Harker, P.T., 1995. National Atlas of Canada (5th edition), Permafrost, Plate 2.1, (MCR 4177), 1:7 500 000 scale.

Hughes, O.L., 1969. Glacial map of Yukon Territory, South of 65 Degrees North Latitude. Geological Survey of Canada, Preliminary Map 6-1968, 1:1 000 000 scale.

Jackson, L.E., Jr., 1997a. Surficial geology, Victoria Rock, Yukon Territory. Geological Survey of Canada, Map 1877A, 1:100 000 scale.

Jackson, L.E., Jr., 1997b. Surficial geology, Granite Canyon, Yukon Territory. Geological Survey of Canada, Map 1878A, 1:100 000 scale.

Jackson, L.E., Jr., 2005a. Surficial geology, Ladue Creek (150O/01), Yukon Territory. Geological Survey of Canada, Open File 4573, 1:50 000 scale.

Jackson, L.E., Jr., 2005b. Surficial geology, Rosebud Creek (105O/08), Yukon Territory. Geological Survey of Canada, Open File 4585, scale 1:50 000.

Jackson, L.E., Jr., Barendregt, R.W., Baker, J. and Irving, E., 1996. Early Pleistocene volcanism and glaciation in central Yukon: a new chronology from field studies and paleomagnetism. Canadian Journal of Earth Science, vol. 33, no. 6, p. 904-916.

Jackson, L.E., Jr., Shimamura, K. and Huscroft, C.A., 2001. Late Cenozoic geology, Ancient Pacific Margin NATMAP Project, Report 3: A re-evaluation of glacial limits in the Stewart River basin of Stewart River map area, Yukon Territory. Geological Survey of Canada, Current Research 2001-A3, 8 p.

Jackson, L.E., Jr., Huscroft, C.A., Barendregt, R.W., Froese, D.G. and Villeneuve, M., 2003. A 2.5 Ma chronology of regional glaciation in west-central Yukon, Canada, based on radiometric and paleomagnetic dating of volcanic rocks. Geological Society of America Abstracts with Programs, 57-1, p. 175.

Jackson, L.E., Jr., Froese, D.G., Huscroft, C.A., Nelson, F.E., Westgate, J.A., Telka, A.M., Shimamura, K. and Rotheisler, P.N., 2009. Surficial geology and late Cenozoic history of the Stewart River and northern Stevenson Ridge map areas, west-central Yukon Territory. Geological Survey of Canada, Open File 6059, 414 p.

Lisiecki, L.E. and Raymo, M.E., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic δ^{18}O records. Paleoceanography, vol. 20, PA 1003, doi: 10.1029/2004PA001071.

Lipovsky, P., LeBarge, W., Bond, J. and Lowey, G., 2001. Yukon placer activity map (1:1 000 000 scale). Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Open File 2001-34.

Nelson, F.E., Barendregt, R.W. and Villeneuve, M., 2009. Stratigraphy of the Fort Selkirk Volcanogenic Complex in central Yukon and its paleoclimatic significance: Ar/Ar and paleomagnetic data. Canadian Journal of Earth Science, vol. 46, p. 381-401.

Pewe, T.L., Westgate, J.A., Preece, S.J., Brown, P.M. and Leavitt, S.W., 2009. Late Pliocene Dawson cut forest bed and new tephrochronological findings in the Gold Hill Loess, east central Alaska. GSA Bulletin, vol. 121, p. 294-320.

Rutter, N.W., Foscolos, A.E. and Hughes, O.L., 1978. Climatic trends during the Quaternary in central Yukon based upon pedological and geomorphological evidence. *In:* Quaternary Soils, W.C. Mahaney (ed.), GeoAbstracts, Norwich, England, p. 309-359.

Smith, C.A.S., Tarnocai, C. and Hughes, O.L., 1986. Pedological Investigations of Pleistocene Glacial Drift Surfaces in the central Yukon. Géographie physique et Quaternaire, vol. 40, p. 29-37.

Smith, C.A.S., Sanborn, P.T., Bond, J.D. and Frank, G., 2009. Genesis of Turbic Cryosols on north-facing slopes in a dissected, unglaciated landscape, west-central Yukon Territory. Canadian Journal of Soil Science, vol. 89, p. 611-622.

Tarnocai, C., 1990. Paleosols of the Interglacial Climates of Canada. Géographie physique et Quaternaire, vol. 44, no. 3, p. 363-374.

Tarnocai, C., Smith, S. and Hughes, O.L., 1985. Soil development on Quaternary deposits of various ages in the central Yukon Territory. Current Research, Part A, Geological Survey of Canada, Paper 85-1A, p. 229-238.

Tarnocai, C. and Smith, C.A.S., 1989. Micromorphology and development of some central Yukon paleosols, Canada. Geoderma, vol. 45, p. 145-162.

Tarnocai, C. and Schweger, C.E., 1991. Late Tertiary and early Pleistocene paleosols in northwestern Canada. Arctic, vol. 44, p. 1-11.

Ward, B.C., Bond, J.D., Froese, D. and Jensen, B., 2008. Old Crow tephra (140 ±10 ka) constrains penultimate Reid glaciation in central Yukon Territory. Quaternary Science Reviews, vol. 27, no. 19-20, p. 1909-1915.

Westgate, J.A., Preece, S.J., Froese, D.G., Walter, R.C., Sandhu, A.S. and Schweger, C.E., 2001. Dating early and middle (Reid) Pleistocene glaciations in central Yukon by tephrachronology. Quaternary Research, vol. 56, no. 3, p. 335-348.