Early Pleistocene glaciation and implications for placer gold deposits in Back Creek, Mount Nansen area, Yukon

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ABSTRACT

Yukon has over a century of placer mining history, predominately in unglaciated regions. However, as these targets are exploited, focus turns to more complex landscapes where glaciation has buried, eroded and incorporated placer gold. This study examines how Early Pleistocene glaciation in the Mount Nansen area, central Yukon, has affected placer gold deposits. Detailed stratigraphic analysis and sample collection has focused on Back Creek, where placer mining has exposed a 22 m section with several gold bearing units. In the section, sediment from two glacial advances cap sporadically preserved pre-glacial gravel. The section is variably dissected by younger placer gold bearing fluvial gravel with enrichment related to intersection of inter-glacial or pre-glacial placer gold deposits. Analysis at Back Creek reveals the potential for deeply buried placer gold deposits in other glaciated regions of Yukon.

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INTRODUCTION

Beyond the influence of glaciation in Yukon, several lucrative placer deposits were exploited during the 1897 Gold Rush (LeBarge, 1995). As these prospects are exhausted exploration has shifted to more complex landscapes where glaciation may have obscured, eroded, and incorporated placer gold deposits (LeBarge, 1995). Several phases of Northern Cordilleran Ice Sheet (NCIS) glaciation, in Yukon, have modified the landscape (Duk-Rodkin, 1999; Duk-Rodkin *et al*., 2001; Jackson, 1993; 2000; Ward *et al.*, 2007), producing the palimpsest landscape present today. The earliest phases of glaciation were the most extensive in central Yukon (Fig. 1) and likely had the largest effect on placer gold deposits. To understand the effect of early glaciation on placer gold development, the Mount Nansen Placer Mining District (NTS115/I) was investigated during the summer of 2015, to determine the stratigraphy at Back Creek, derive the geologic history, and to relate this to placer gold preservation and formation. Previous work in the Mount Nansen area is discussed and the current understanding of bedrock geology, glacial history, and placer gold development is summarized. This research is a synthesis of academic interest (early Pleistocene glacial behavior) and economic importance (placer gold development) that may be used as an analogue for future studies of placer gold in glaciated terrains.

BEDROCK GEOLOGY

Large gold deposits in Yukon formed during the repeated accretion of several terranes throughout the Mesozoic era (Colpron *et al*., 2007; Knight *et al.,* 2013; Monger *et al.,* 1972; Coney *et al.,* 1980). The Yukon Tanana terrane (YTT) formed as an island-arc back-arc basin with extensive porphyry/epithermal gold deposits, and the study area is underlain by these rocks (Colpron *et al*., 2007; Selby *et al.,* 1999). The Mount Nansen area is underlain by Proterozoic-Cenozoic bedrock, and major units are further described below (Fig. 2; Hart and Langdon, 1998; Saager and Bianconi, 1971; Tempelman-Kluit, 1984). The Proterozoic-Paleozoic metamorphic Yukon Group rocks consist of the following: chlorite schist, biotite schist, feldspathic quartzite, amphibolite, quartz-biotite gneiss and biotite-hornblende gneiss (Hart and Langdon, 1998; Mortensen *et al*., 2002; Saager and Bianconi, 1971). The metamorphic rocks host several intrusions including: the early Jurassic Long Lake Suite (hornblende-biotite granodiorite-monzogranite), mid-Cretaceous Dawson Range batholith (hornblende-biotite-quartz diorite, and granodiorite), late Cretaceous Prospector Mountain suite (quartz monzonite) and the Casino Plutonic suite (leucocratic granite, quartz monzonite and alaskite; Hart and Langdon, 1998; Johnston, 1996; Mortensen *et al*., 2002; Saager and Bianconi, 1971; Selby *et al.,* 1999; Wengzynowski *et al.,* 2015). Extensive volcanic deposits formed contemporaneously with the plutonic complexes and include the Mount Nansen Volcanic Group which comprises andesite, dacite, minor rhyolite and minor Cenozoic intrusions of quartz feldspar porphyries (Saager and Bianconi, 1971; Hart and Langdon, 1998; Mortensen *et al*., 2002). Mineralization in the Mount Nansen area is hosted within Paleozoic metamorphic rocks and Mesozoic intrusive rocks (Hart and Langdon, 1998; Mortensen *et al*., 2002). Late phase hypabyssal parts of the Mount Nansen volcanic rocks (quartz feldspars porphyries, dikes and minor pyroclastic flows) are related to significant mineralization (Hart and Langdon, 1998).

Several gold bearing porphyry-epithermal complexes are concentrated within a 3 by 12 km, northwest oriented, steeply dipping corridor called the Nansen trend (Hart and Langdon, 1998). These porphyry-epithermal complexes are the likely source for the placer gold deposits in the Mount Nansen area (Hart and Langdon, 1998; Jackson, 1993; LeBarge, 1995).

GLACIAL HISTORY

The NCIS first developed in Yukon during the late Pliocene (~2.6 Ma), and several advances produced the palimpsest surficial sedimentary record present today (Fig. 1; Barendregt *et al*., 2010; Duk-Rodkin *et al*., 2001; 2004 Hidy *et al.,* 2013). The development of the NCIS glaciation is related to complex atmospheric-oceanic interactions, Milankovitch Cycles, atmospheric composition and precipitation (Burn, 1994; Guthrie, 2001; Harris, 2005; Haug *et al*., 2005; Ward *et al*., 2008). Dawson (1889) first recognized evidence for glaciation in Yukon in 1887; however, multiple glacial advances were not recognized until Bostock (1936) worked in the Mount Nansen Area. Based on this early work there are three morphostratigraphic glacial surfaces widely recognized in Yukon: the pre-Reid, Reid/Gladstone, and McConnell (Fig. 1); each represents a discrete surface associated with a maximum extent, some of which represent two (Reid/Gladstone) or multiple (pre-Reid) NCIS advances (Bostock, 1966; Demuro *et al*., 2012; Duk-Rodkin *et al*., 1999; Hughes *et al.,* 1969; Jackson *et al.,* 1999; Jackson and Clague, 1991; Westgate *et al*., 2000; and Ward *et al*., 2007).

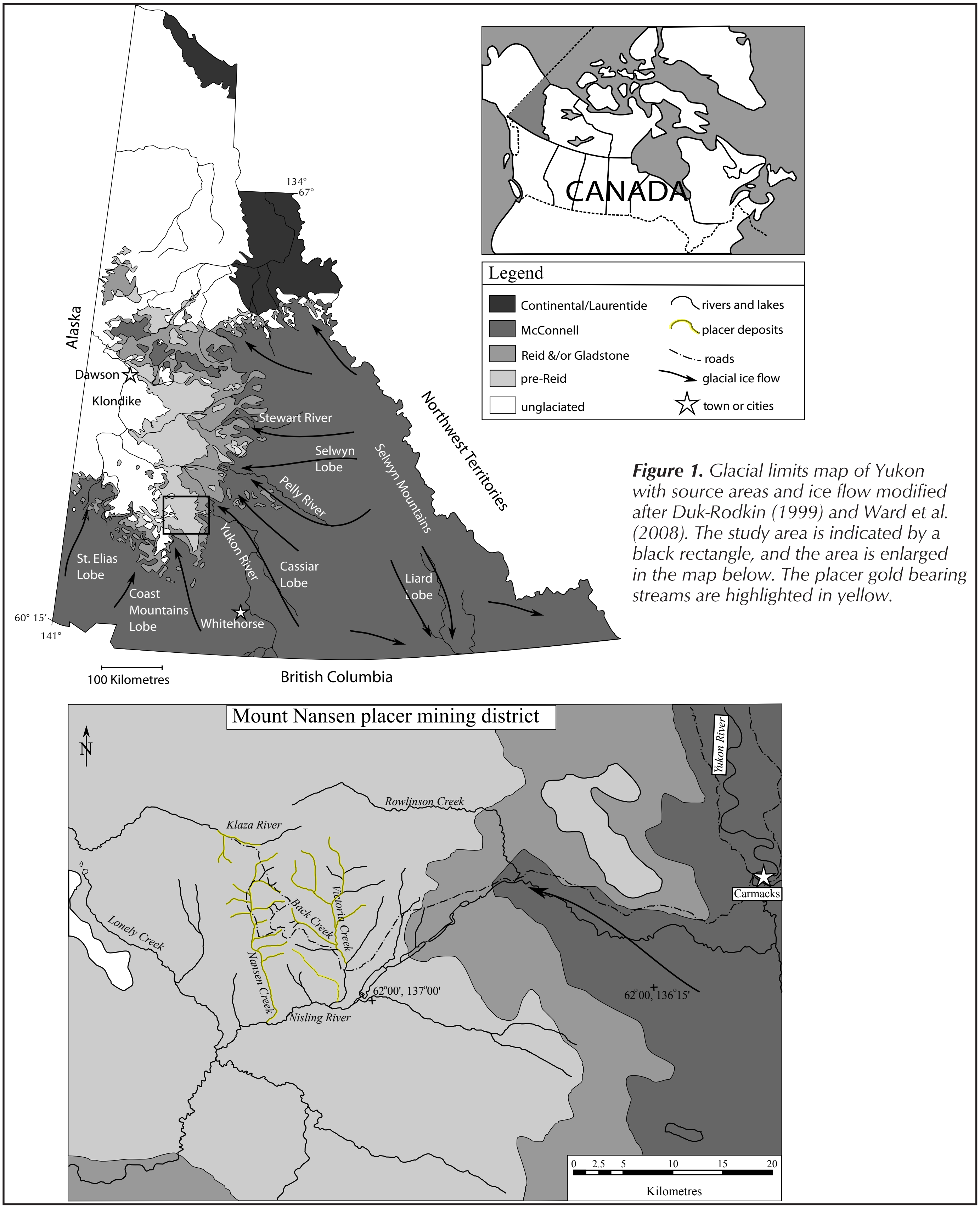

Figure 1. *Glacial limits map of Yukon with source areas and ice flow modified after Duk-Rodkin (1999) and Ward et al. (2008). The study area is indicated by a black rectangle, and the area is enlarged in the map below. The placer gold bearing streams are highlighted in yellow.*

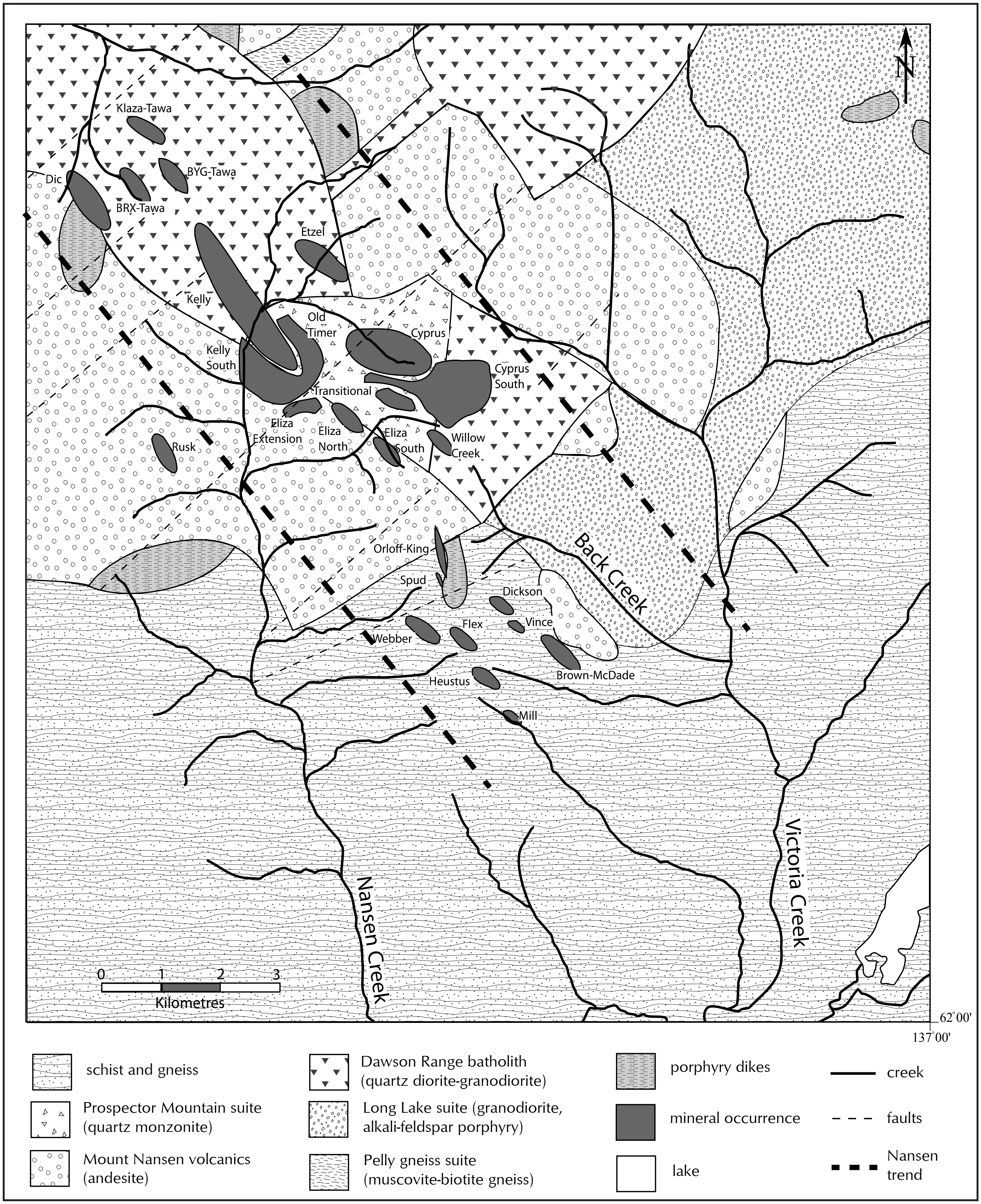

Figure 2. *Bedrock geology map of the Mount Nansen area modified after Hart and Langdon 1998.*

Glaciation in the Mount Nansen area has long been known (Cairnes, 1915), and placer mining occasionally provided insight that older glaciation had affected the area (Bostock 1966). Bostock (1966) assigned the two earliest phases of Yukon glaciation to be the Nansen (older) and the Klaza (younger) based on field observations in the 1930s. Subsequent work by Hughes *et al.* (1969), grouped the Nansen and the Klaza glacial events into the pre-Reid morphostratigraphic surface due to the challenge of separating the two advances in other areas. While several glacial periods are mapped in the Mount Nansen region only two pre-Reid glaciation events (the Nansen and Klaza) are known to have affected Back Creek (Fig. 1; Bostock, 1966; Jackson, 1993; 2000; LeBarge, 1995). The Nansen and Klaza glaciation likely advanced into the Mount Nansen area from the east and south and were part of the Cassiar and Coast Mountain ice lobes (Fig. 1; Bostock, 1966; Duk-Rodkin; 1999; Guerts and Dewes, 1993). The Nansen glaciation was extensive (affecting elevations below 1400 m), and landform evidence is restricted to meltwater channels and patchy till (Jackson, 2000; LeBarge, 1995). The antiquity of the Nansen till is reflected by the deeply weathered schist and granitic clasts contained in the till (Bostock, 1966). The timing of the Nansen glaciation is poorly constrained; however, it may be correlated to the most extensive NCIS *ca.* 2.64 Ma (Hidy *et al.*, 2013). The younger Klaza glaciation is thought to begin with local cirque glaciers developing in the Dawson Range and expanding into the valleys (Jackson, 1993; LeBarge, 1995). Further evidence of the Klaza glaciation was observed west of the study area in Lonely Creek where Bostock (1966) noted landscape modifications associated with glaciation. The Klaza glaciation may correlate to an advance in the Fort Selkirk region where basalt overlying till has been dated to greater than 1 Ma (Jackson, 2000; Jackson *et al.,* 1991; Naeser *et al.,* 1982). During subsequent mid-late Pleistocene glaciation (Reid, Gladstone and McConnell) the area was unglaciated and subjected to intense periglacial conditions (Fig. 1; Jackson, 2000; LeBarge, 1995). During the Reid and Gladstone glaciation events the Coast Mountains ice lobe dammed the Nisling River causing a glacial lake to develop. This increased the base level of the Nisling River and its tributaries Victoria and Nansen creeks (Guerts and Dewes, 1993; LeBarge, 1995). Gravel terraces associated with this episode of sedimentation are common in these tributaries to the Nisling River and are a good example of the indirect effect of more recent glaciation. This research focuses on the earliest phases of glaciation (pre-Reid) that directly affected the landscape and the associated placer gold deposits in Back Creek.

PLACER GOLD DEVELOPMENT

Placer gold deposits require mineralized bedrock and a mechanical concentration mechanism, typically colluvial and fluvial; however, it can also be glacial, eolian, or lacustrine (Els and Eriksson, 2005). In Yukon, the warmer temperatures (>4°C of current Mean Annual Temperature, MAT) and increased precipitation (>550 mm of current Mean Annual Precipitation, MAP) of the Paleogene to Neogene (66 to 2.6 Ma) produced deeply weathered bedrock mantles (>75 m) that facilitated the development of placer deposits and where lode gold became available for concentration (Ager *et al.*, 1994; Anderson and Stroshein, 1997; Dampier *et al.*, 2011; Foscolos *et al.,* 1977; Jackson, 2000; LeBarge, 1995). Beyond the reach of glaciation, placer gold deposits remained relatively undisturbed and continued accumulating throughout the Quaternary; however, in glaciated areas placer gold deposits were significantly affected by erosional and/or depositional processes (Goldfarb *et al.,* 2015; Herail *et al.,* 1989; Jackson 1993; LeBarge 1995; Levson and Blyth, 2001; Lowey, 2006).

More than 27,000 crude ounces of placer gold have been mined from several creeks in the Mount Nansen area and from various sediment types (LeBarge, 1995). A likely cause of this placer gold concentration is the abundance of mineralized bedrock in the region (Hart and Langdon, 1998; Jackson, 1993) and stable Cenozoic tectonic history that allowed residual deposits to accumulate. There are several known porphyry/epithermal deposits that may be the source of placer gold in Back Creek (Fig. 2; Hart and Langdon, 1998). Most placer mining in the Mount Nansen area extracts gold concentrated on the pervasive 'false bedrock' (till) developed on early Pleistocene pre-Reid glacial deposits (Bostock, 1966; LeBarge, 1995). These placer deposits have formed from weathering of bedrock slopes subsequent to the last regional glaciation to affect the area, and therefore, are considered relatively young. Exploitation of pre-glacial placer deposits situated on bedrock is limited due to the depth of glacial sediment cover. Recently, placer mining has exposed deeply buried deposits, which provides an important opportunity to document stratigraphic and sedimentological information regarding multiple zones of placer gold development. This study investigates one of these deeper excavations that exposes valley bottom bedrock, pre-glacial sediment, and overlying Quaternary deposits. Information presented here may provide an analogue for future placer gold exploration in neighboring drainages, such as Nansen and Victoria creeks, and in other in glaciated areas.

METHODS

During the 2015 field season several locations in the Mount Nansen Area were visited; however, this study focuses on the stratigraphy of Back Creek due to its exceptional exposure of potential pre-glacial gravel and pre-Reid glacial sediment (Figs. 3 and 4). To understand the stratigraphy at Back Creek, sediment descriptions, clast orientation measurements, and paleomagnetic samples were collected. Several units (2, 3, 4, 6 and 11) were also sampled for placer gold to characterize gold provenance.

Sedimentary analysis was completed in the field where estimates of clast character (size, shape, orientation and surface features), and matrix character (size, abundance, compaction and structures) aided in assigning separate units (Table 1 and Fig. 5). Samples from several of these units were collected for further analysis. The presence of unique features including: 'decomposed clasts', cryoturbation, iron/manganese staining and organics were noted. The term 'decomposed clasts' refers to clasts that are pervasively weathered and may be easily broken by hand; Bostock (1966) used similar terminology (rotten clasts) when describing clasts from the Mount Nansen area.

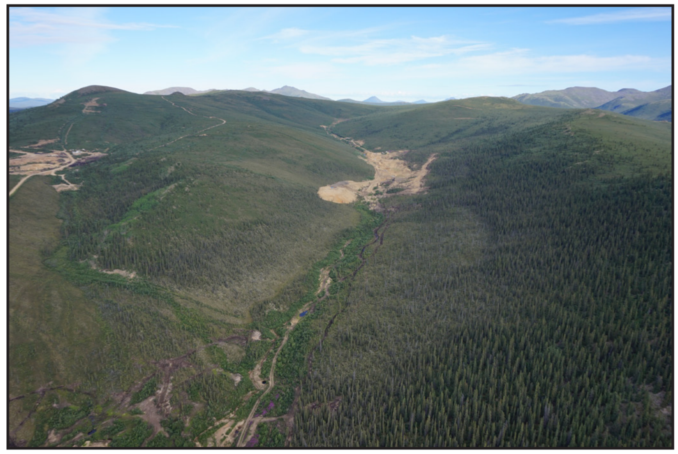

Figure 3. *A view of Back Creek looking northwest; current placer mining is in the centre of the valley.*

Figure 4. *A view of the deep (>22 m) placer mining exposure at Back Creek. The lowest unit visible is the deeply weathered bedrock (Unit 1). In the center of the section are two till units (Units 3 and 5) separated by interglacial sediments (Unit 4). Above this is cover sediment that includes various amounts of colluviated material (Unit 9), organics (Unit 8), tephra (Unit 9), and anthropogenic sediment (Unit 12).*

Table 1. *Unit interpretations and descriptions with respective landscape evolution phases.*

Unit	Interpretation	Description	Landscape Evolution Phase
12	Anthropogenic Sediment	All of the material that has been disturbed by mining. Characteristics, contacts and lateral extent all vary based on style of formation.	Cover Development (G)
11	Modern Gravel	Moderately stratified, poorly-consolidated, clast-supported gravel with ~70% clasts and a silty sand matrix. Clasts are subrounded to rounded and clast lithology is variable but local. Lower contact is sharp and erosive, and the unit forms the base of the modern creek.	
10	White River Tephra	Pale grey-white, finely laminated, fine-medium sand sized glass shards.	
9	Colluvium	Brown, poorly stratified to massive, organic-rich, matrix-supported, diamicton with ~30% clasts, variable lithologies. Lower contact is sharp and erosive, and the unit is laterally extensive.	
8	Colluviated Organics	Organic-rich, matrix-supported, poorly-consolidated, colluviated organics, with clay to fine sand, and abundant macrofossils. Lower contact is sharp and erosive, and this unit is laterally extensive.	
7	Fluvial Sand	Tan, sub-horizontally bedded silty-sand, with minor organics. Lower contact is erosive and unit is not laterally extensive.	
6	Fluvial Gravel (pay)	Variably Fe/Mn stained, stratified, poorly-consolidated, clast-supported gravel with ~80% boulder, cobble pebble clasts. Clasts are subrounded, imbricated with variable lithologies. Lower contact is erosive and unit is laterally extensive.	Pay Gravel Development (F)
5	Klaza Till	Dark grey, massive, over-consolidated, matrix-supported, diamicton with ~20% clasts, and a clayey silt matrix. Clasts were commonly decomposed, striated and or exotic.	Klaza Glaciation (E)
4	Paleosol/ inter-glacial gravel	Sediment present includes: i) an over-consolidated, matrix-supported diamicton with a clayey silt matrix ii) yellowish red disorganized pebbly gravel with Fe/Mn staining; iii) an organic bearing normal and reversely magnetized silt/clay (Fig. 8b,c).	Inter-Glaciation (D)
3	Nansen Till	Yellowish brown, massive, over-consolidated, matrix-supported, diamicton with ~20% clasts and a clay silt matrix (Fig. 7). Clasts are commonly decomposed, striated and/or exotic. Clast fabrics indicate a shift in ice flow direction from parallel to valley to orthogonal to valley which separates the two Nansen glacial phases (Landscape Evolution Phase B and C). Lower contact is sharp erosive and unit is laterally extensive.	Maximum Nansen Glaciation (C) Early Nansen Glaciation (B)
2	Pre-Glacial Gravel	Yellowish brown, weakly stratified, matrix/clast supported, poorly-consolidated gravel, with a ~50% clasts and a variably iron stained silty sand matrix (Fig. 6). The clasts are commonly decomposed and have variable but local lithologies. Within this unit a fine-grained magnetically reversed silty clay is also present (Fig. 8a). Lower contact is gradational and lateral extent is unknown.	Cenozoic Weathering (A)
1	Long Lake Suite	Buff coloured, variably weathered (highly fractured - completely decomposed), granitoid with some sulphide mineralization.	

Clast orientations were measured to reconstruct paleoflow directions (Fig. 5). In diamictons only clasts with a greater than 2:1 length (A): width (B) were measured and utilized for trend analysis. Trend and plunge measurements were plotted using a Stereonet Program (version 9.3.3 by Dr. Allmendinger; website www.geo.cornell.edu/geology/faculty/RWA/programs.html). This technique is used to determine the direction of ice flow and the style of deposition (*cf*., Hicock *et al*., 1996). The A:B plane orientation was also measured in stratified gravel, to determine the approximate flow direction during deposition.

Paleomagnetic dating is very useful for late Pliocene-early Pleistocene glaciation (Duk-Rodkin *et al*., 1996), and several paleomagnetic samples collected from fine-grained units were analyzed by Dr. N. Roberts at the University of Lethbridge. The Earth's magnetic field can align magnetic minerals in sediment and rocks, recording polarity changes (Walker, 2005). Recognition of polarity changes can be used to assign ages to the sediment analyzed (Walker, 2005). Analysis first determined the bulk magnetic susceptibility, with a Sapphire Instruments Model SI-2B magnetic susceptibility and anisotropy meter. The natural remnant magnetism (NRM) was determined using an AGICO JR-6A spinner magnetometer and samples were incrementally demagnetized to determine their detrital remnant magnetism (DRM) acquired during deposition. Too few paleomagnetic samples were collected for a detailed determination of sediment age; however, analysis reveals the original polarity present during deposition which may indicate approximate ages.

Organic samples were collected for paleoenvironmental reconstructions and radiocarbon dating. Samples were sent to Alice Telka at Paleotec services for analysis. Organic material thought to be within the range of radiocarbon ages were dated while other samples were analyzed for macrofossil identification in an attempt to understand the environment at the time of deposition. Results from this analysis will be presented in a later publication.

Chemical characterization of gold grains is being completed from strategic placer-bearing facies in Back Creek. Sediment was sieved and panned to separate the heavy minerals and gold grains. The gold grains will be submitted for later laboratory analysis. At this time only the presence of placer gold grains in a unit are noted (Fig. 5).

RESULTS

Large exposures (>22 m) at Back Creek (Fig. 4) reveal a complex Quaternary history. During the 2015 field season twelve sections were analyzed at Back Creek, and these data were synthesized into an idealized stratigraphic column (Fig. 5) containing 12 units. The following is a brief synopsis of the stratigraphy and sedimentology present at Back Creek (Table 1 and Fig. 5).

The lowermost unit in the section is a variably weathered (minor jointing to highly decomposed) granite with sporadic sulphide mineralization (Unit 1). Based on previous mapping, Unit 1 is interpreted to be part of the Long Lake suite (Fig. 2) and is a potential source for gold mineralization in the drainage (Fig. 5 and Table 1).

Unit 2 is a matrix/clast-supported, poorly-consolidated gravel (Fig. 6). Unit 2 is less than 1 m thick with a gradational lower contact with Unit 1. This unit is locally exposed and lateral extent is unknown. The matrix is silty sand with variable iron staining and the colour is yellowish brown (10YR 5/6). There are ~50% clasts that are dominantly rounded to subrounded. The clasts are commonly decomposed and have variable, but local lithologies. The unit is crudely stratified in some exposures and a fine-grained clayey silt layer ~15 cm thick was sampled for paleomagnetic dating. Unit 2 contains placer gold, but due to the limited volume exposed it was not the main target for placer development.

Unit 3 is an over-consolidated, matrix-supported diamicton (Fig. 7). The lower contact is sharp and erosive with Units 1 or 2. Unit 3 is 5 to 10 m thick and laterally extensive across the valley bottom of Back Creek. The unit is thickest towards the valley margins and thinnest towards the valley center. The matrix is clayey-silt with minor sand, and yellowish brown (10YR 5/4) at the base and brown (7.5YR 5/4) at the top (7.5YR 5/4; brown). It contains 20-25% subrounded clasts that range from pebbles to boulders and many are striated or decomposed. Diverse clast lithologies are present in this diamict, including some not found within the Back Creek basin (sedimentary). Clast orientation changes upsection from parallel to orthogonal to the valley (Fig. 5). Based on the consolidation, extent, striated clasts, erosional lower contact, diverse clasts lithologies and fabric orientation, Unit 3 is interpreted as a regionally extensive glacial diamict. Since this represents the oldest known glaciation in the Mount Nansen area it is assigned to the Nansen glaciation.

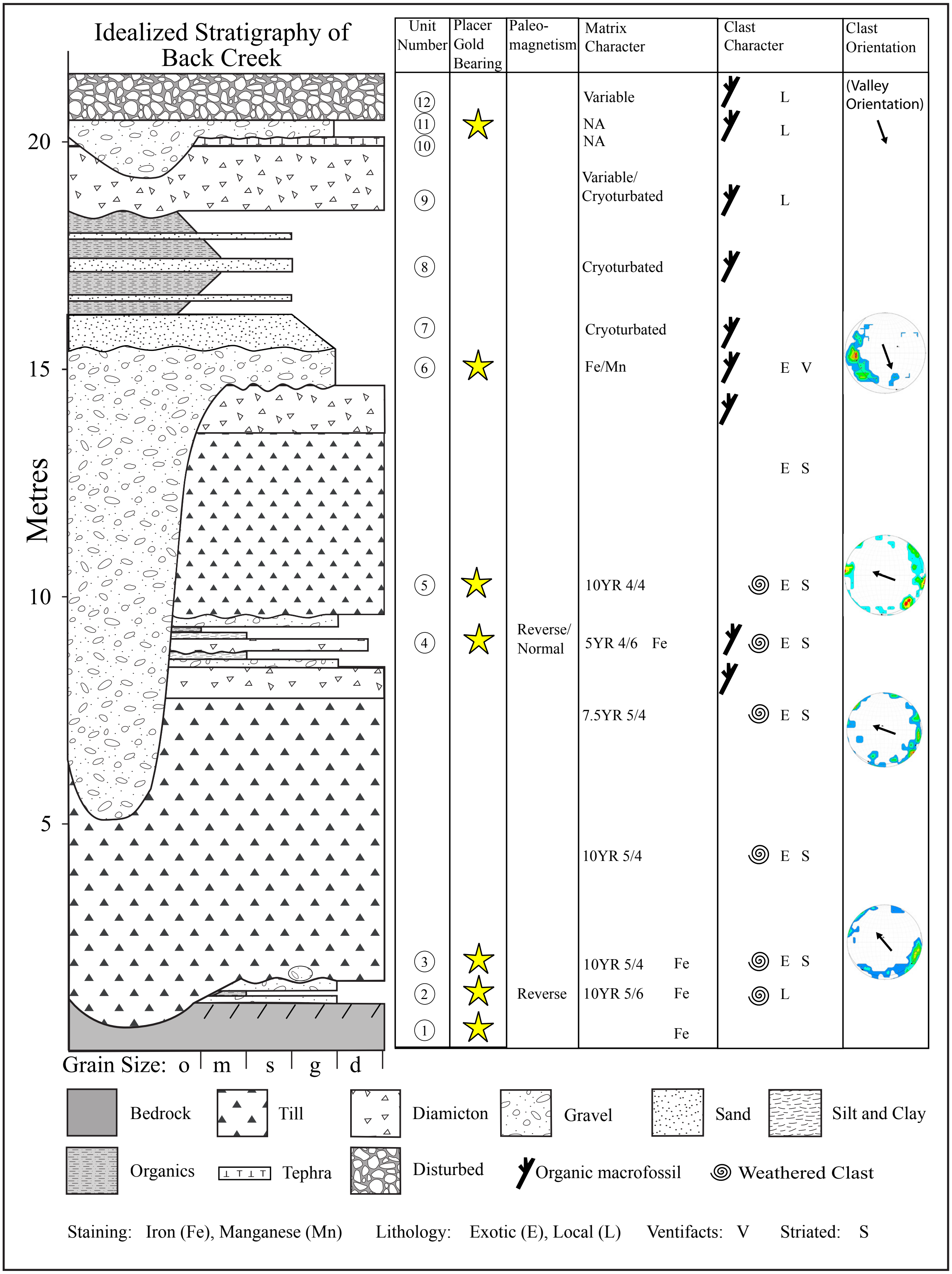

Figure 5. *Idealized stratigraphy of Back Creek. Each unit is numbered (1-12) and is further described in the results.*

Unit 4 is less than 2 m thick, laterally extensive and has a sharp, erosional lower contact. The materials and stratigraphic relationships of the sediment in Unit 4 are variable and include diamict, gravel, silt/clay and organic material (Fig. 8b,c). One sediment type is an over-consolidated, matrix-supported diamict with an erosional lower contact. The diamict has a clayey silt matrix, with 20-30% pebble-boulder sized, and subrounded to subangular clasts (Fig. 8c). Two clast-supported gravel beds are variably present in Unit 4 (Fig. 8b,c). The gravel has a silty sand matrix that is variably iron and manganese-stained. Clasts are greater than 55% pebble-cobble sized and subrounded to subangular. Furthermore, some of the clasts in the gravel are decomposed. Bedded silt/clay sediment is variably present in Unit 4 (Fig. 8b,c). Two sets of paleomagnetic samples were collected from this Unit 4 and normal (N) and reversely (R) magnetized sediment is present. Due to the small number of paleomagnetic samples collected and stratigraphic complexity it is unknown whether sediment records an N-R or an R-N-R sequence. There is an organic rich layer interstratified with silty clay. This layer was sampled for macrofossil analysis. Based on the presence of several sediment types, weathering representing potential paleosol processes and organics, Unit 4 is interpreted as inter-glacial sediment.

***Figure 6**. Pre-glacial gravel (Unit 2) exposed in lower Back Creek. Gravel is pervasively weathered and iron-stained. Clasts are variable in lithology but local in source.*

Unit 5 is an over-consolidated, matrix supported diamict. The lower contact is sharp and erosional. It is 3 to 6 m thick, and laterally extensive. The matrix is a clayey-silt with minor sand. It contains 15-20% subrounded clasts that range from pebbles to boulders, and have diverse lithologies. Striated and decomposed clasts are abundant, and several exotic lithologies are present. The clast fabric measured in this unit indicates ice flow orthogonal to the valley (Fig. 5). Based on the exotic lithologies, extent and striated clasts, Unit 5 is interpreted as a regionally extensive till. Since this represents the second oldest known glaciation in the Mount Nansen area, and it is beyond the Reid limit, it is assigned to the Klaza Glaciation.

Unit 6 is a poorly-consolidated, clast-supported gravel. The bottom contact is sharp and erosive, and this unit incises the pre-existing stratigraphy to Nansen till (Unit 3). Unit 6 is approximately 20 m wide and is presumed to

***Figure 7.** Nansen Till (Unit 3), containing striated and weathered clasts. Clasts can be quite large and several exotic clast lithologies are present indicative of regional glaciation.*

Figure 8. *Paleomagnetic sample locations. (a) Paleomagnetic samples of the pre-glacial gravel (Unit 2). Pervasive iron staining is visible in this photo. (b) Paleomagnetic samples of the interglacial sediment (Unit 4) right below an organic rich horizon. (c) Several inter-glacial sediments (Unit 4) and paleomagnetic sample locations are shown.*

extend down valley for some distance. The matrix is predominately sand with minor silt, and it is variably iron and manganese stained. It contains 60 to 70% subrounded to subangular clasts that range in size from boulder to pebble. Fabric measurements in Unit 6 indicate paleo-flow direction is approximately parallel to the modern creek valley (Fig. 5). This unit is the target of current placer mining and the gold character will be analyzed and presented in a later publication.

Unit 7 is a poorly-consolidated, with sub-horizontal bedded silty sand with minor organics. It is ~1 m thick and has a sharp erosive contact. This unit is not laterally extensive. Based on the sub-horizontal bedding, organics and sharp erosive lower contact Unit 7 is interpreted to be fluvial sand.

Unit 8 is matrix-supported, poorly-consolidated clay to fine sand colluviated organics. This unit is 2 to 3 m thick and laterally extensive. The unit has interstratified sand and it contains well-preserved macrofossils. Unit 8 contains several cryoturbation features (cryoturbated sediment and ice wedges) and the unit is predominately frozen. Based on the presence of organics and the interstratification of silt/clay, and sand Unit 8 is interpreted as a valley bottom floodplain deposit.

Unit 9 is a variably thick (1-4 m), matrix/clast-supported, moderately-consolidated diamicton. Unit 9 has an erosive lower contact and is laterally extensive. This unit contains organics and it has crude stratification. Based on these features it is interpreted to be a colluvium.

Unit 10 is a variably thick (5-50 cm), pale grey, silty sand, composed of tephra. This unit has a sharp non-erosive lower contact and it is laterally extensive. Based on the sediment location and previous work in the Mount Nansen area (LeBarge, 1995), Unit 10 is interpreted as the White River Tephra (WRT).

Unit 11 is a clast-supported, poorly-consolidated gravel. The gravel has a sharp erosive lower contact, and it is variably thick (0.5-2 m). The unit has a silty sand matrix with ~70% clasts. Clasts are cobble to pebble sized, and subrounded. The unit forms the base of the modern stream and this unit contains a minor amount of placer gold; however, it is not the current target of exploration. Based on these features, Unit 11 is interpreted as the modern/recent fluvial gravel.

Unit 12 includes all material that has been disturbed during mining. This includes a variety of sediment types such as diamictons or bedded silt and sand, depending on how the material was affected. Furthermore the thickness and lateral variability of this unit is highly variable.

LANDSCAPE EVOLUTION

By synthesizing the stratigraphy of Back Creek a seven phase landscape evolution model was created (Table 1 and Fig. 10). The following interpretations relate to the model, and explain the concentration mechanisms, preservation potential, and timing of placer gold development in relation to the landscape evolution of Back Creek.

CENOZOIC WEATHERING

The first phase of development was dominated by deep weathering and fluvial concentration of placer gold (Fig. 10a). The bedrock exposed at Back Creek is highly oxidized suggesting pervasive weathering occurred over a significant time period. The pre-glacial development of placer gold is theoretically the period of greatest gold accumulation in Back Creek due to long periods of weathering and tectonic stability. The presence of highly weathered bedrock (>2 m thick) suggests that it was sub-aerially exposed for a significant amount of time. Weathering is so intense that many of the feldspar grains have become pervasively stained and decomposed in the bedrock. Pre-glacial gold concentration developed as mineralized bedrock present at the surface, weathered, and incorporated in fluvial deposits of paleo-Back Creek. The mineralized bedrock that supplied gold in Back Creek may be from several mineral occurrences (*eg.,* Willow Creek, Orloff-King and Dickson; *see* Fig. 2), and further analysis is required to determine its origin. Weathered bedrock is commonly in contact with, and incorporated into the Nansen till (Unit 3). Unit 2 (pre-glacial gravel) is only exposed in the deepest part of the valley and has a very limited lateral extent, likely related to variable paleo-bedrock topography. The valley bottom may have once had more extensive pre-glacial fluvial deposits; however, erosion during the first glaciation effectively removed most of these deposits.

NANSEN GLACIATION

The second phase of landscape evolution is during the Nansen glaciation (Fig. 10b,c). Reversely magnetized sediment sampled from overlying Unit 4 indicate the Nansen till is >780 ka, and normally magnetized sediment is interpreted to have formed during the Jaramillo (0.90-1.06 Ma) or Olduvai (1.78-2.00 Ma) subchron (Fig. 9). There are two phases during the Nansen glaciation, the advance phase (Fig 10b) and the maximum phase (Fig. 10c); these phases are based on changes in till characteristics and ice flow reconstruction from till fabric data. During the advance phase, ice flowed up-valley and likely produced a glacial lake (Fig. 10b). The ice was significantly erosive to incorporate highly weathered bedrock and pre-glacial gravel. The incorporation of oxidized bedrock produced a visible colour change from the base (10YR 5/4; yellowish brown) to the top (7.5YR 5/4; brown) of the Nansen till. As glaciation continued, ice thickened and flow became orthogonal to the valley unconstrained by underlying topography (Fig. 10c). During Nansen glacial maximum it is likely that large parts of the region were covered in ice. Both advance and maximum phases were likely significantly erosive depending on the topographic position. The glacial advance was parallel with the valley and therefore eroded the valley bottom, whereas at glacial maximum, ridge tops were likely eroded and the valley bottom remained protected.

INTER-GLACIATION

The next phase of landscape evolution occurred during a non-glacial or inter-glacial period (Fig. 10d). Unit 4 contains organic material, and a zone of weathering resembles a paleosol. These attributes suggest a period of stability following the Nansen glaciation. Two sets of paleomagnetic samples were collected from this unit and normal and reversely magnetized sediment are present. The reversely magnetized sediment suggests a minimum age of deposition >780 ka, forming when the Earth's magnetic field last had a reversed polarity. Due to the number of samples collected and the complex stratigraphic relationships between samples, the exact age of the sediment remains unresolved (Fig. 9). It is likely however, that the paleomagnetic results record the Jaramillo or Olduvai subchron (Fig 9), due to suggested age (>1 Ma) of the overlying sediment from the Klaza glaciation (Jackson, 2000). The gravel from the inter-glacial unit has pervasive staining and several weathered clasts that represent fluvial activity over a significant period of time. This inter-glacial gravel may be another target for placer exploration, although its volume is limited particularly near the valley sides where it is exposed. It is possible this gravel sub-unit is larger towards the valley center; however, it was only seen in the left limit.

KLAZA GLACIATION

The Klaza glaciation (Fig. 10e) produced till with similar sedimentological characteristics to the Nansen till; however, clast orientations have a larger range in value that may be related to post-glacial disturbance or to the primary depositional environment. This unit is laterally extensive on the side of the valley, but placer excavation in the center of the valley effectively removed most of this unit. The preserved paleosol (Unit 4) below the Klaza till suggests that ice was largely non-erosive, which is encouraging for preserving inter-glacial placer gold deposits. The Klaza till is likely the 'false bedrock' that is pervasive throughout the Mount Nansen area and is known to have placer gold concentrated on it or in it.

PAY GRAVEL DEVELOPMENT

The next phase of landscape evolution (Fig. 10f) is the formation of post-glacial fluvial gravel. Fluvial incision following the Klaza glaciation eroded into the Nansen till, and potentially into the pre-glacial gravel. Currently, this gravel is the main placer gold target at Back Creek. Placer gold has four potential sources in the area i) bedrock; ii) till enriched with placer gold; iii) inter-glacial fluvial gravel; or iv) pre-glacial gravel. Additional studies into gold character may highlight the amount of reworked gold that is contributing to the placer deposit.

COVER DEVELOPMENT

The final phase of landscape evolution is the formation of cover (Fig. 10g). Hillslope colluviation, periglacial weathering and eolian processes were all dominant after glaciation. These processes produced thick cover (>5 m)

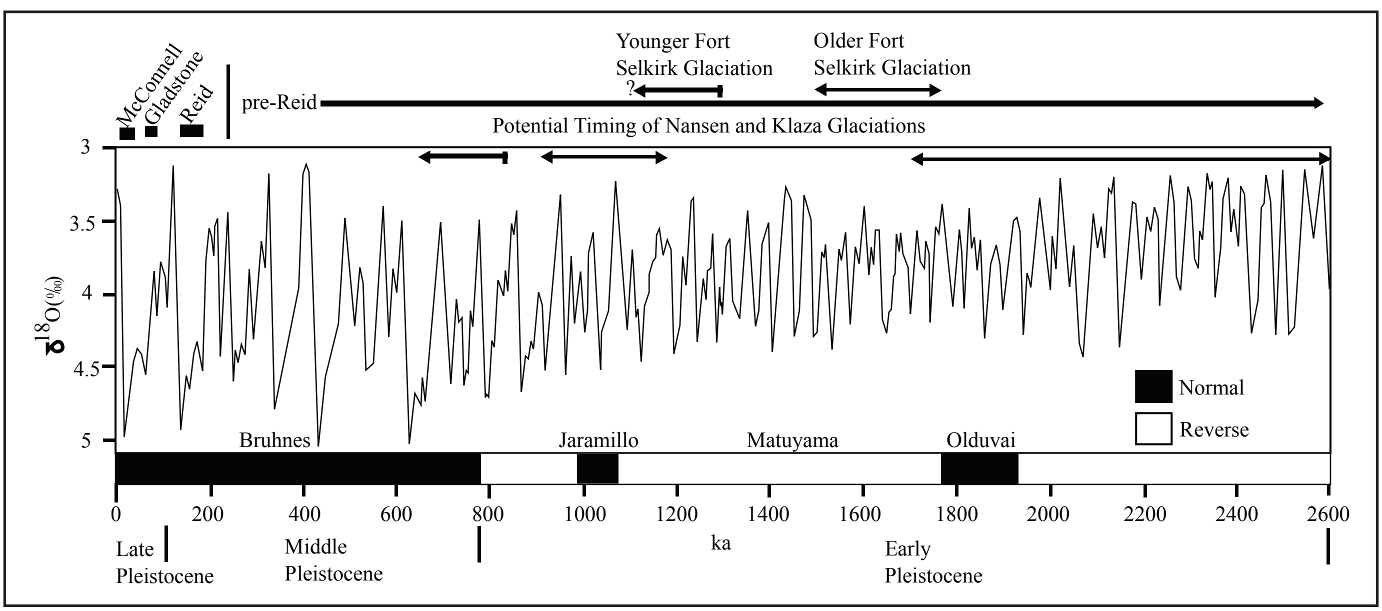

Figure 9. *Paleomagnetic timescale and the oxygen isotope ($\delta^{18}O$) curve modified from Lisieki and Raymo, 2005. The ($\delta^{18}O$) curve fluctuations indicate climate changes, where troughs denote glacial stages and the peaks are non-glacial. The timing of local glaciation is summarized for reference (after Nelson et al., 2009; Bond and Lipovsky, 2010), and the potential timing of the glaciation of Nansen and Klaza are highlighted*

with a variety of characteristics. The cover sediment is generally depositional in nature and therefore has not removed the underlying units. The presence of marker horizons such as the White River tephra (Unit 10) deposited ~1200 years ago (*cf.*, Clague *et al.,* 1995), indicate sediment has remained undisturbed since deposition. Most cover sediment contains little placer gold (Unit 11) and is not a placer mining target.

PLACER POTENTIAL

Two distinct tills are present at Back Creek and based on their extent, striated clasts, diverse clasts lithologies, and an intercalated paleosol, they are interpreted to represent Nansen and Klaza glaciation. This assignment is consistent with earlier glacial stratigraphy work in the region (Bostock, 1966; LeBarge, 1995). Nansen and Klaza glaciation has significantly impacted placer gold deposits in Back Creek. To understand the evolution of placer gold deposits at Back Creek, concentration mechanisms, preservation potential and a timing of placer gold deposits were synthesized into a model (Fig. 10) which highlighted three main placer gold targets (pre-glacial, inter-glacial, and post-glacial fluvial sediment). The influences of the Nansen and Klaza glaciation on these deposits are examined below.

PRE-GLACIAL DEPOSITS

Pre-glacial placer deposits should contain the highest gold concentrations because these deposits formed over a sustained period during the Paleogene and Neogene when climate was warmer, resulting in significant weathering of mineralized bedrock and fluvial concentration of gold (Ager *et al*., 1994; Anderson and Stroshein, 1997; Dampier *et al*., 2011; Foscolos *et al.,* 1977; Jackson, 2000; LeBarge, 1995). Channel avulsion may have resulted in laterally extensive pre-glacial placer deposits across Back Creek valley. Significant erosion likely occurred during the Nansen glaciation because Nansen till is in direct contact with bedrock near the valley side and incorporates weathered bedrock. Therefore, extensive removal of pre-glacial placer deposits likely occurred during this glaciation. Variable bedrock topography would decrease the efficiency of glacial erosion and this may preserve placer gold deposits. In Back Creek, gold-bearing pre-glacial placer deposits are most likely preserved in valleys oriented at a high angle to ice flow and where local bedrock topographic features like paleo-canyons or bedrock highs provide protection from glacial erosion. For exploration, preserved pre-glacial placer gold deposits could be anticipated by identifying areas of undulatory bedrock (canyons or ledges) using geophysics. Highlighting these areas might increase the chance of successfully drilling into a pre-glacial gravel. The discontinuous nature of these pre-glacial placer deposits in valleys aligned with regional ice flow makes them a challenging exploration target.

INTER-GLACIAL DEPOSITS

Inter-glacial gold deposits are another target for placer gold exploration. In these deposits gold must be sourced from either mineralized bedrock or from the Nansen till. LeBarge (1995), found that till may contain large quantities of gold grains, so the Nansen till could be a significant source of placer gold. In addition the Nansen till provides a false-bedrock for placer gold deposits to accumulate on. The Klaza glaciation did not result in significant erosion of these inter-glacial placer gold deposits. The deposits may be extensive and represent a favorable exploration target due to their shallow depth relative to pre-glacial deposits. Drilling and geophysical surveys could be employed to identify these inter-glacial targets within the Mount Nansen area.

POST-GLACIAL DEPOSITS

Post-glacial placer gold deposits have historically been the primary exploration targets in the Mount Nansen area, and they are most continuous deposits present in Back Creek. Gold in the post-glacial deposits may be sourced from (i) bedrock; (ii) till enriched with placer gold; (iii) inter-glacial fluvial gravel; or (iv) pre-glacial gravel. The gold abundance in post-glacial deposits may reflect various sources. Significant increase in gold abundance likely reflects intersection of underlying placer gold deposits, and should warrant detailed study to determine if intersected deposit is an extensive target. Sand, organics, colluvium, tephra, gravel, and anthropogenic deposits cover the post-glacial placer gold deposits. The thickness of this overlying material dictates the economic viability of mining post-glacial placer deposits.

DISCUSSION

This research shows that the early Pleistocene Nansen and Klaza glaciation had a significant impact on placer gold concentration in Back Creek. Three placer gold targets exist in the Back Creek area including the pre, inter and post-glacial deposits. Although historical exploration

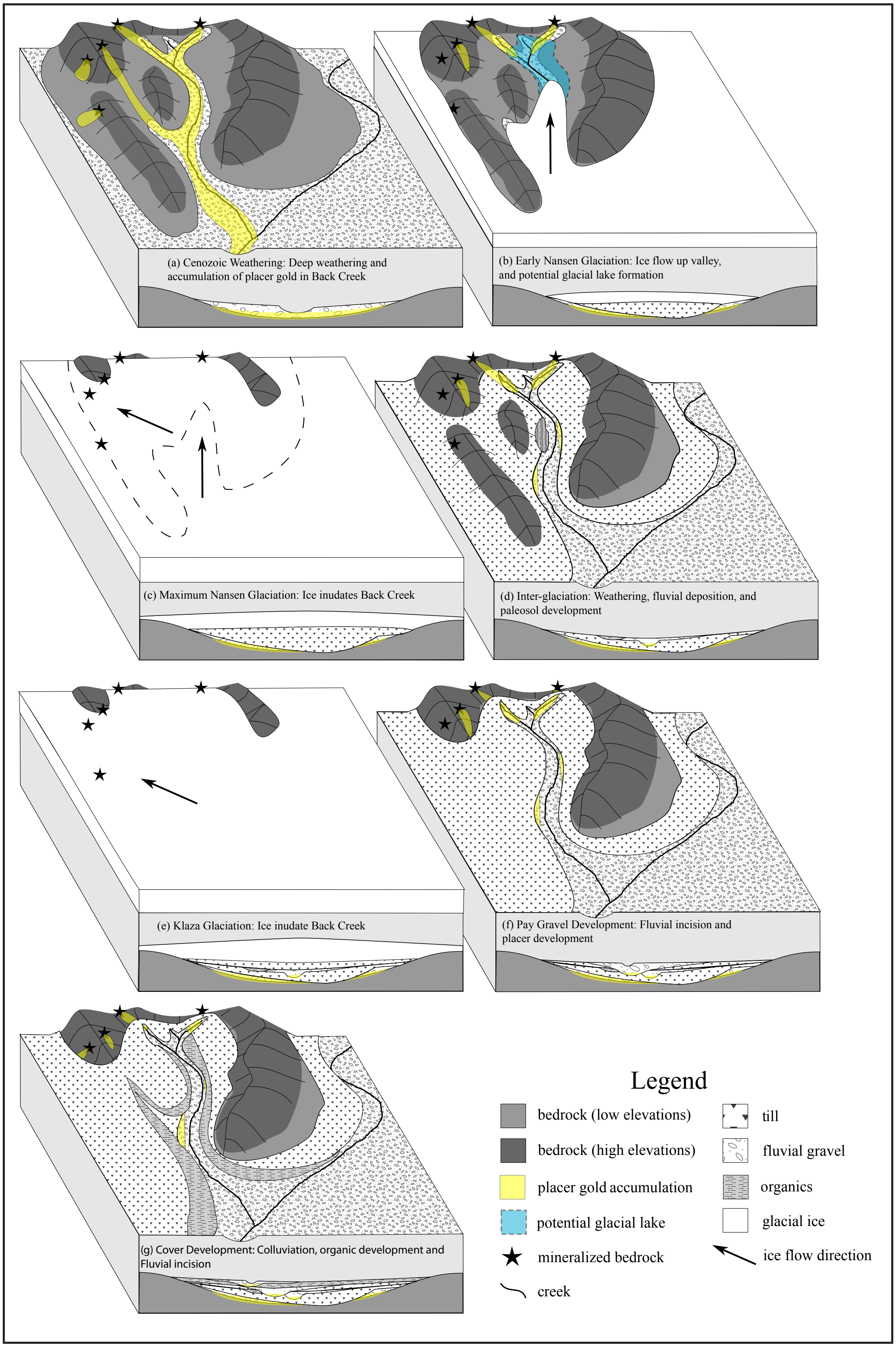

Figure 10. *The landscape evolution of Back Creek is described in these 7 block diagrams. This model illustrates both the spatial and stratigraphic distribution of placer gold from pre-glacial to modern time.*

has focused on the post-glacial deposits, it is likely that lucrative pre-glacial and inter-glacial deposits exist at depth where glacial erosion was minimal. The landscape evolution model presented here is for Back Creek (Fig. 10); however, could be applied to other placer gold exploration targets in the Mount Nansen district and in early Pleistocene glaciated fringe of Yukon (Fig. 1).

CONCLUSION

Early Pleistocene glaciation had a significant effect on placer gold deposits in Back Creek. Two phases of glaciation are present and were separated by a period of weathering and pedogenesis. These two glacial events likely represent the Nansen and Klaza and are interpreted to have occurred before the Jaramillo or Olduvai subchron based on paleomagnetic results. The Nansen glaciation destroyed much of the earliest placer gold deposits leaving little evidence of pre-glacial gravels, only where bedrock topography permitted preservation. The Nansen glaciation was pervasive in the landscape and till fabrics recorded ice thickening and changing directions. Between periods of glaciation, a long period of pedogenesis occurred and inter-glacial placer gold deposits formed. The Klaza glaciation did not result in significant erosion of these inter-glacial placer gold deposits, and they may represent an important target for placer exploration. Post-glacial fluvial gravels are the main target for placer gold mining in Back Creek and variable gold abundance is likely related to incision of previous concentrations of placer gold. The thickness of sediment covering the post, inter or pre-glacial placer gold deposits has a significant impact on the economics of the deposit and should be considered during exploration. In conclusion, analysis at Back Creek reveals the potential for deeply buried placer gold deposits in other glaciated regions of Yukon.

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