Constraints on the evolution of placer gold deposits at Gladstone Creek, Yukon (NTS 115G/7, 8)

Derek C. Cronmiller and Brent C. Ward
Earth Sciences, Simon Fraser University

Jeffrey D. Bond
Yukon Geological Survey

Daniel Layton-Matthews
Geological Sciences and Geological Engineering, Queens University

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Abstract

Gladstone Creek hosts a productive placer mine and has been glaciated at least three times. Glaciations eroded bedrock and reworked surficial materials, depositing thick sequences of sediment in Gladstone valley, which were subsequently fluvially incised during deglaciation and non-glacial intervals. Fluvial incision and reworking concentrated detrital gold in coarse gravel units that commonly overly bedrock or false-bedrock surfaces. Identifying false-bedrock units in stratigraphy may help placer miners target economical gold deposits perched above the valley bottom.

Gold grain samples were collected from four gravel units. Characterization of gold grain morphology and laser ablation ICP-MS analysis indicate multiple sources of lode mineralization. Based on regional ice flow directions and the stratigraphic and geographic locations of the gold samples, gold is likely sourced from epithermal and gold-rich porphyry deposits associated with the Ruby Range batholith, and orogenic mineralization in the Kluane schist.

* derek.cronmiller@sfu.ca

Introduction

Gladstone Creek is located in the central Ruby Range, southwestern Yukon. The Ruby Range has a long history of placer mining and mineral exploration; placer mining in Gladstone Creek began in the 1910s (Cairnes, 1915). Active and historic placer mines along this creek are well within the most recent glaciation to affect Yukon, and thus are in a much different setting than placer mines in the unglaciated Klondike. To date, no morphological or geochemical analysis of gold grains has been used to link placer gold to lode gold sources in the Gladstone area. In this paper we present the sedimentological characteristics and commonalities of economically auriferous gravels within Gladstone Creek and how glaciation has affected the development and distribution of placer deposits in Gladstone Creek. We also examine gold grain morphology and geochemistry to determine the likely sources of lode gold based on the style of mineralization in local lithological units. Understanding the mechanisms controlling the distribution of economic placer deposits will help placer miners locate economic gravels in glaciated regions. Determining the provenance of placer gold in Gladstone Creek may also inform future hard rock mineral exploration in the region. The objectives of this paper are to characterize placer gold grain chemistry and morphology to determine potential bedrock sources and how glaciation has affected the distribution and preservation of placer deposits.

Setting

The central Ruby Range is characterized by rugged peaks greater than 2100 m high, and broad undulating plateaus above 1500 m. The peaks and plateaus are drained by deep, U-shaped valleys, such as Gladstone Creek, that drain westward into the east side of Kluane Lake (Fig. 1). Cronmiller et *al.* (2018) mapped surficial materials throughout the study area. Upland surficial materials are heavily modified by periglacial processes and comprise colluvium derived from weathered bedrock and thin veneers of till below all-time glacial limits (Cronmiller et *al.*, 2018). Valley bottoms are filled with thick, stratigraphically complex Quaternary deposits comprising glacial and interglacial sediment. In Gladstone Creek these deposits are more than 115 m thick.

Glacial History

Early mapping in southwestern Yukon by Hughes et *al.* (1969) found evidence of two Cordilleran ice-sheet advances into the Ruby Range, as well as local ice

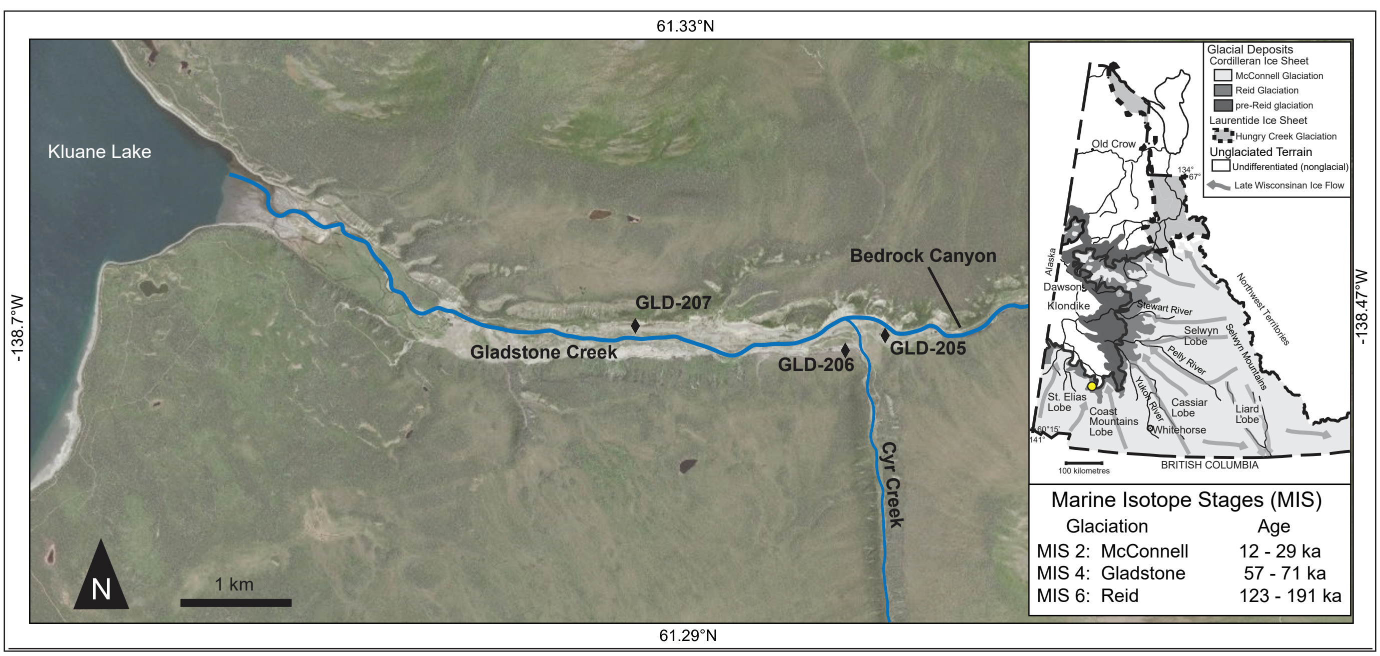

***Figure 1.** Lower Gladstone Creek and Cyr Creek. Sample sites are indicated by diamonds. Location of study area shown by yellow dot on inset map.*

cap formation on the plateau surfaces above 1500 m (Hughes, 1990). Glacial advances were initially suspected to correlate to what we now know are marine oxygen isotope stages (MIS) 2 and 6; however, recent ^{10}Be dating of erratics above Gladstone Creek suggest the local all-time limit may have occurred during MIS 4 (Fig. 1; Ward et *al.*, 2007). New field and desktop mapping (Cronmiller et *al.*, 2018) confirmed the presence of ice caps on plateau surfaces based on the orientation of moraines and meltwater channels as well as descending U-shaped valleys; all of which suggest ice growth extended beyond the high plateaus and into local trunk valleys including Gladstone Creek.

In addition, many well-developed cirques are found on high, northerly aspects. Moraines descending from these cirques suggest significant local alpine glaciation coalesced with the up-valley ice from the St Elias lobe of the Cordilleran Ice Sheet (CIS; Fig. 1). Generalized St Elias lobe ice-flow directions are shown in Figure 2. Ice caps and cirques may have contributed substantially to the local extent of late Pleistocene limits and could account for the local all-time limit corresponding to MIS 4 advance. Till suspected to have been deposited by westward flowing ice from Ruby Range cirques is observed in sections as far down Gladstone Creek as GLD-205 (Fig. 1). The presence of till in the lower

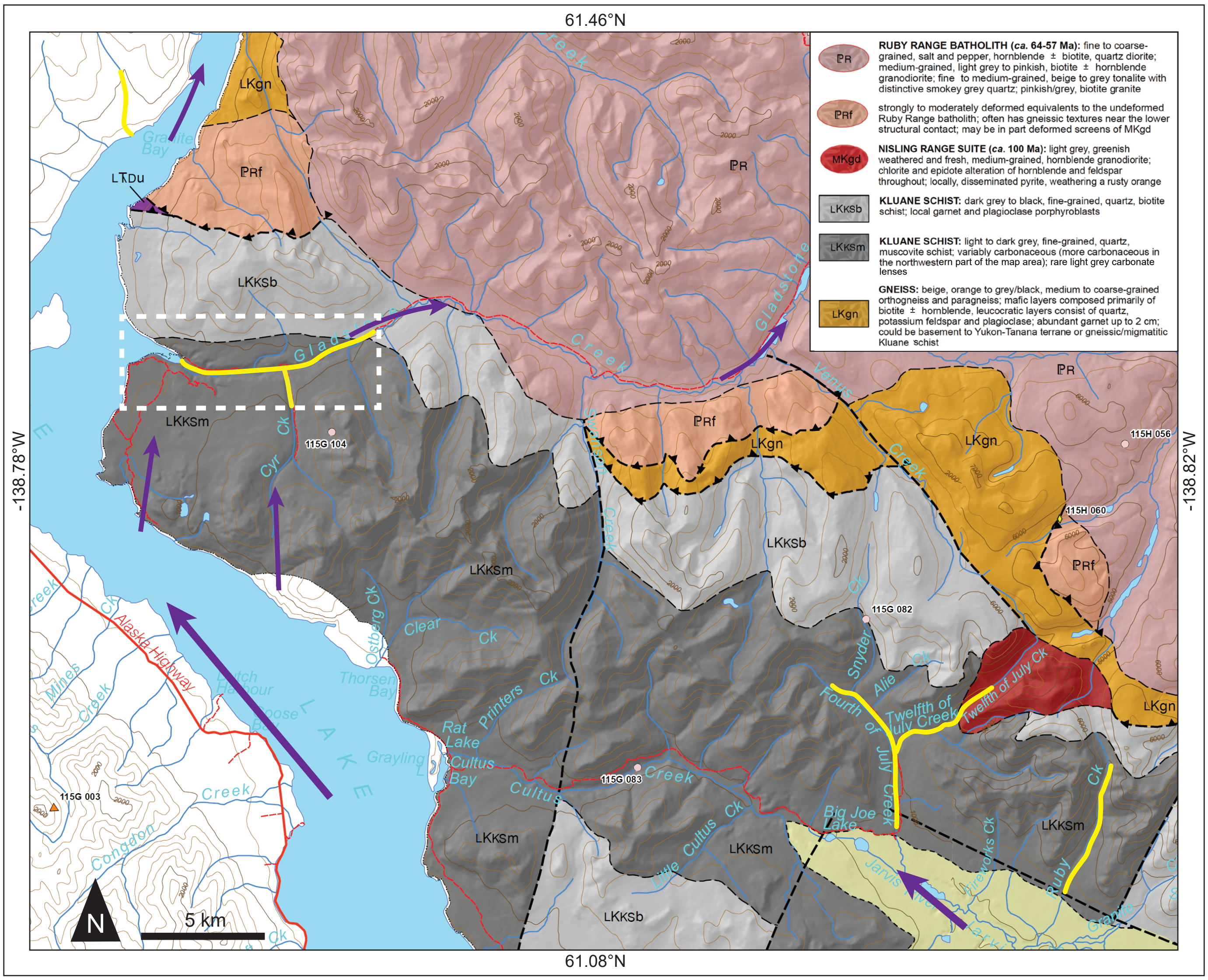

Figure 2. Bedrock geology of the west-central Ruby Range (modified from Israel et al. 2011b). The location of Figure 1 is shown by dashed white lines. Actively mined placer creeks are shown by yellow lines. Local indicators of St Elias lobe ice flow direction (Hughes et al., 1969) shown by arrows.

reaches of Gladstone Creek suggests that both east and west-flowing ice could have introduced distal-intrabasinal and extrabasinal auriferous material into Gladstone valley during glaciations.

Geology and Mineralization

Gladstone Creek is underlain by two main lithological units: The Ruby Range batholith, and Kluane schist (Fig. 2). Uncorrelated ortho and paragneiss are commonly found at the boundary of these two units that are thought to be gneissic or migmatitic equivalents of Kluane schist or the basement rock of the Yukon-Tanana terrane (Israel *et al.*, 2011a). Minor outcrops of ultramafic rock occur in association with the Kluane schist.

Ruby Range batholith

The Ruby Range batholith is a large multiphase plutonic complex comprising quartz-diorite, tonalite, granodiorite, with minor diorite, gabbro, and granite (Israel *et al.*, 2011a). The batholith contains porphyry Cu-Mo-Au mineralization (Yukon MINFILE 115G 070, 071) and epithermal Au-Ag mineralization, primarily in the upper crustal part of the batholith. The Ruby Range batholith underlies most of the upper reaches of Gladstone Creek. The main phases of the Ruby Range batholith intrusion occurred between 64 and 57 Ma.

Kluane schist

The Kluane schist occurs between the Denali fault on the west side the Shakwak trench, and the Ruby Range batholith in the east (Fig. 2). It comprises a metamorphic assemblage of metapelitic quartz-mica schist, rare ultramafic and carbonate bodies, and numerous quartz veins systems (Israel *et al.*, 2011a). Kluane schist contains muscovite-rich and biotite-rich units. The characteristics of gold in Kluane schist suggest orogenic mineralization (Israel *et al.*, 2011a). Deposition of the Kluane schist occurred between 95 Ma and 82 Ma—the onset of metamorphism.

Mining and Exploration

Gladstone Creek was first mined in the 1910s below the mouth of Cyr Creek (Cairnes, 1915). The first large-scale operation began with the Kluane Dredge Company, which extracted 5770 ounces of gold from below the confluence of Cyr Creek between 1952 and 1956 (Muller, 1967). The lower reaches of Gladstone Creek and Cyr Creek are now mined by TIC Exploration Inc. Numerous other placer mines are currently operating on the west slopes of the Ruby Range, all of which are located in Kluane schist (Fig. 2). Hard rock exploration has noted similarities between the orogenic mineralization in Kluane schist and the Juneau gold belt (Israel *et al.*, 2011a; Yukon MINFILE 115H 055, 047).

Methods

Sites were visited in summer 2017, as part of a larger program to map surficial geology and log stratigraphy of Gladstone Creek and the central Ruby Range. Thirteen sections were described on Gladstone Creek and two at Cyr Creek; three of these are described herein. Sections were divided into stratigraphic units based on sediment type and general sedimentary characteristics. Gold grain samples were collected from two sections on Gladstone Creek (GLD-205 and GLD-207) and one section at the mouth of Cyr Creek (GLD-206). The samples were obtained from gravel units identified by TIC Exploration as being economically auriferous. Gravel was screened using a 4-mesh sieve and sluiced using a portable sluice box (Fig. 3) to obtain heavy-mineral concentrate. The concentrate was panned to isolate the gold. This process was repeated until a minimum of 25 grains were collected for each sample.

Morphological and chemical analysis of the gold grains was conducted by the geochemistry lab at Queens University. High-resolution electron backscatter images were produced for each sample using a scanning electron microscope. Gold grain morphology was characterized from the backscatter images using Image Metrology's SPIP™ image recognition software. Laser ablation ICP-MS was used to determine major, minor, and trace element composition of the gold grains.

Figure 3. *Collecting auriferous gravel at site GLD-207 and sluicing the fine fraction of sieved gravels to obtain gold grain samples.*

Results

Stratigraphy

GLD-205

Section GLD-205 (Fig. 4) is a mine cut located on the left limit of Gladstone Creek, approximately 200 m downstream of a bedrock canyon (Fig. 1). A description of lithostratigraphic units is provided in Table 1. This section contains two economic gravels, Units 2 and 5. Both gravel units overlie consolidated diamicton interpreted to be tills, corresponding to MIS 4 (Unit 4) and MIS 6 (Unit 1) advances of the St Elias lobe. This interpretation is based on their dense over-consolidated nature, the presence of extrabasinal, striated clasts, and strong unidirectional clast fabrics. A radiocarbon age of 26,720 ± 170 ^{14}C yr BP (UCIAMS-197773) and Dawson tephra (*cf.* Froese *et al.*, 2002) in Unit 6 constrains the tills to pre-MIS 3. A radiocarbon age within Unit 3 of 45,600 ± 2200 ^{14}C yr BP (UCIAMS-197774) is suspected to be non-finite, due to the age being near the useful limit of the technique. Unit 2 is strongly oxidized and contains highly weathered and cryoturbated clasts. Stratigraphy and geochronology indicate Unit 4 is from a MIS 4 advance, suggesting an age of at least MIS 4 for Unit 2. Both economic gravels overlie diamicton which act as false bedrock, where gold is concentrated on an erosionally resistant surface.

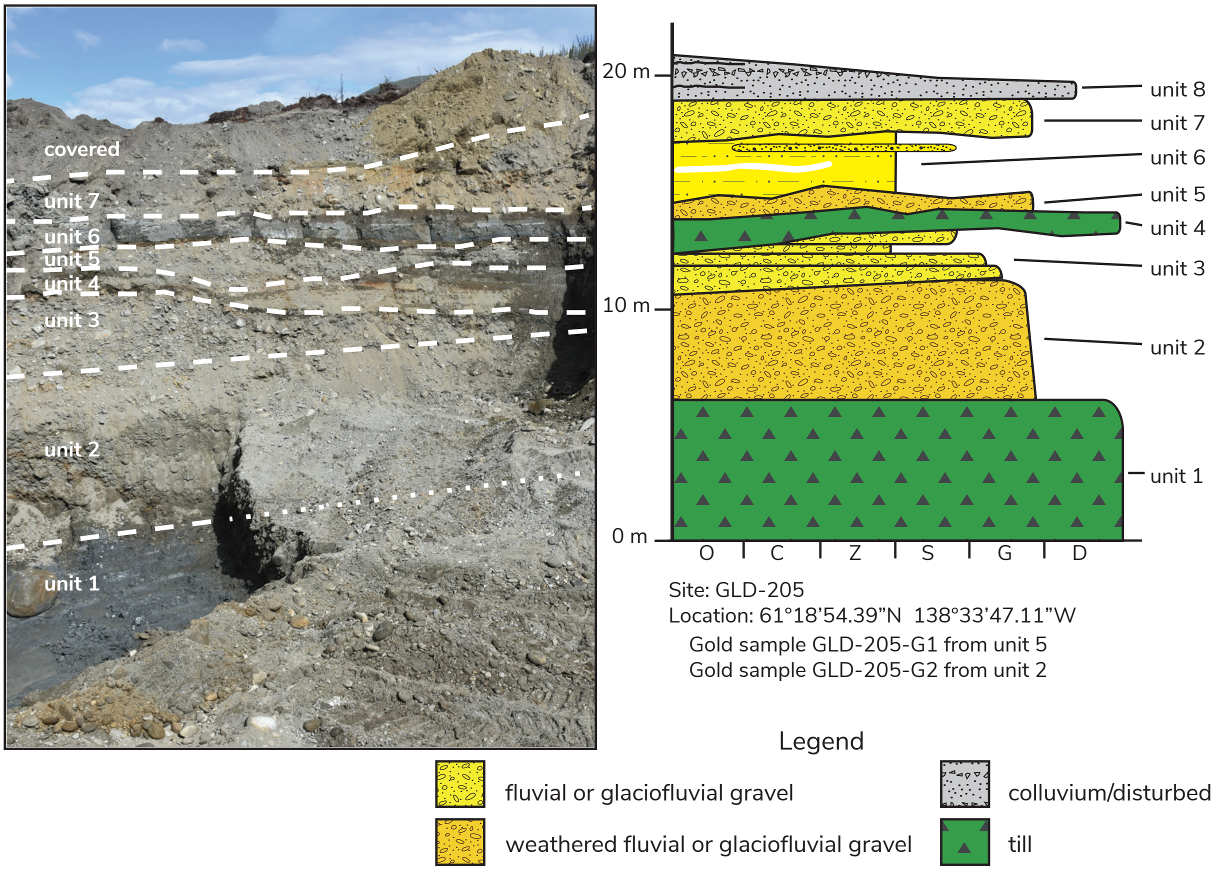

Figure 4. *Stratigraphy in mine cut on left limit of Gladstone Creek, GLD-205.*

Table 1. *GLD-205 unit descriptions.*

GLD-205 - Unit and interpretation	Description
unit 8 – Colluvium	Stratified pebbly sandy diamict with organic layers; 1 m thick; White River tephra at 7 cm depth
unit 7 – Fluvial gravel	Poorly sorted chaotic boulder gravel; 1.25 m thick, laterally variable; 10% boulders, 40% cobbles, 50% pebble; silty sand matrix
unit 6 – Fluvial silts	Fine sandy silt; 2.5 m thick; finely bedded, rare granule lenses; 10 cm thick Dawson tephra at 1.6 m above base of unit; GLD-205-M1: weevil (*Lepidophorus sp.*) macrofossils 26720 ± 170 ^{14}C yr BP (UCIAMS-197773)
unit 5 – Weathered gravel	Weathered, oxidized, auriferous, sandy boulder gravel; 15% boulder, 40% cobble, 45% pebble; silty sand matrix; 1 m thick, laterally variable in thickness and texture; economically auriferous; Gold sample GLD-205-G1
unit 4 – MIS 4 Ruby Range till	Blue grey/grey diamicton; 1.1 m thick, laterally variable; massive; 10% clasts; 90% matrix: 35% silt, 65% clay; upward increase in clast content
unit 3 – Fluvial gravel	Fining upwards silts sands and gravel; 1.9 m thick; 30% cobble, 70% pebble; rare sand lenses and silt rip-up clasts; GLD-205-M5: beetle (*Pterostichus sp.*) macro fossils 45,600 ± 2200 ^{14}C yr BP (UCIAMS-197774; assumed non-finite)
unit 2 – Weathered gravel	Weathered, oxidized, poorly sorted, chaotically-bedded, boulder gravel; 4–5 m thick; 10% boulder, 40% cobble, 50% pebble; 50% sandy silt matrix; vertically oriented clasts (cryoturbation); economically auriferous, gold sample GLD-205-G2
unit 1 – MIS 6 till, unknown source	Blue-grey diamict; >3 m thick, lower contact not exposed; 10% subangular to subrounded clasts: 90% pebble, 10% cobble; 90% matrix: 20% clay, 75% silt, 5% sand; consolidated

GLD-206

Section GLD-206 is a mine cut on the left limit of the Cyr Creek fan at the confluence with Gladstone Creek (Fig. 5). The characteristics of stratigraphic units exposed in this section are summarized in Table 2. Bedrock is exposed on both sides of the Cyr Creek valley immediately above this section that constrain lateral migration and downcutting of the channel.

GLD-207

Section GLD-207 (Fig. 6) is a mine cut on the right limit of Gladstone Creek, approximately 2.7 km downstream from the bedrock canyon. Characteristics of stratigraphic units are summarized in Table 3. Units 1 to 4 are gravels. Unit 3 contains economic concentrations of gold. This unit overlies a consolidated, poorly-sorted, matrix supported gravel (Unit 2), which was likely a paleo-floodplain surface, the age of which is not constrained. Many vertically aligned (Fig. 6 inset) and frost shattered clasts suggest Unit 2 was exposed to strong periglacial conditions. These conditions may have occurred during a glacial stage, prior to ice arrival in lower Gladstone Creek. The high silt content of Unit 2 may be from loess inputs. Like the diamicton units in GLD-205, this unit appears to act as a false-bedrock that limits downcutting due to its consolidation. Unit 5 is modern colluvium from mass wasting of the adjacent valley side.

Gold Grain Morphology

The roundness of gold grains is commonly used as a proxy for travel distance from lode source (Knight *et al.*, 1999). Well-rounded grains are considered to be more travelled than those exhibiting an angular morphology.

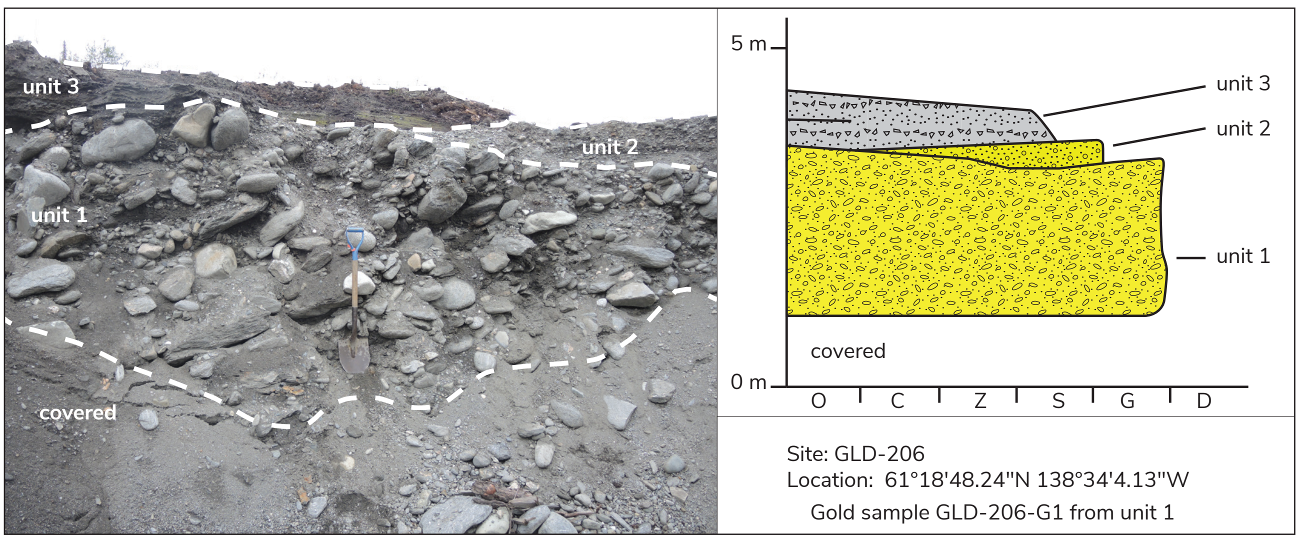

Figure 5. *Stratigraphy in mine cut on left limit of Cyr Creek, GLD-206, near confluence with Gladstone Creek. Section legend in Figure 4.*

Table 2. *GLD-206 unit descriptions.*

GLD-206 - Unit and interpretation	Description
unit 3 – Colluvium	Weakly stratified, pebbly sandy diamict with organic layers; 0.6 m thick
unit 2 – Fluvial pebble gravel	Moderately well-sorted pebble gravel; 0.4 m thick, laterally discontinuous; 75% clasts: 10% cobble, 90% pebble; 10% coarse sand matrix
unit 1 – Fluvial boulder gravel	Poorly-sorted auriferous boulder gravel; >2.3 m thick, lower contact not exposed; 90% clasts: 40% boulder, 40% cobble, 20% pebble; 10% sand matrix; economically auriferous; gold sample GLD-206-G1

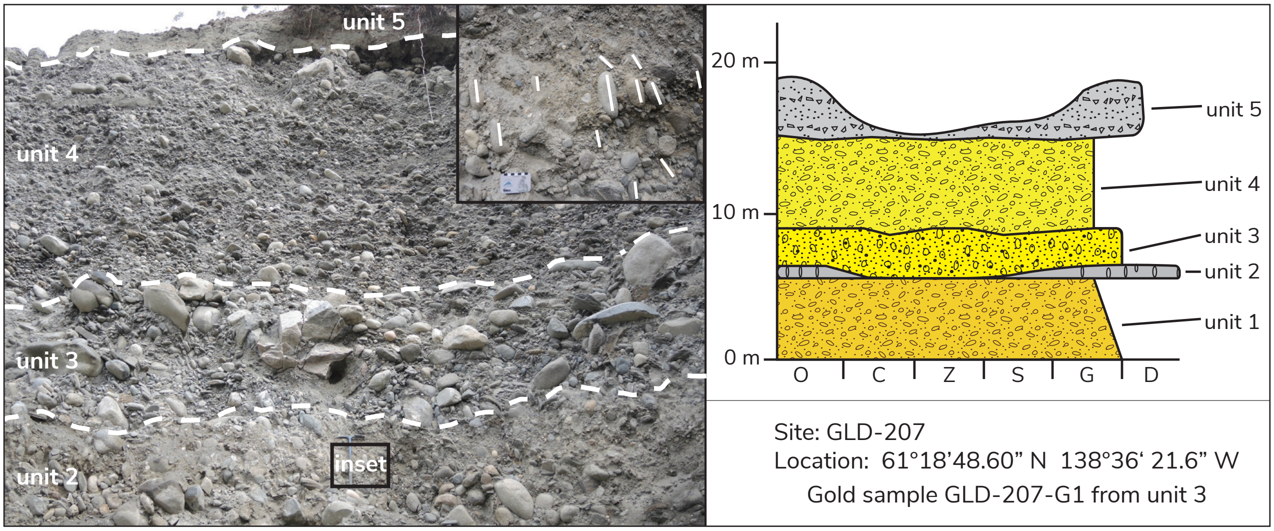

Figure 6. *Stratigraphy in mine cut on right limit of Gladstone Creek, GLD-207. Section legend in Figure 4.*

Table 3. *GLD-207 unit descriptions.*

GLD-207 - Unit and interpretation	Description
unit 5 – Colluvium	Stratified sandy silt with pebbles; 3 m thick, laterally variable; 90% sandy silt, with 5% pebbles and rare cobbles; 4 weakly-developed buried soils with organics; White River tephra 15 cm from top of unit.
unit 4 – Cobble gravel	Well-sorted cobble gravel; 4.5–5 m thick; 90% clasts: 1% boulder, 40% cobble, 59% pebble; matrix coarse to medium sand.
unit 3 – Boulder gravel	Chaotic boulder gravel; 1.9 m thick; 98% clasts; 10% boulder, 60% cobble, 30% pebble; 2% sandy silt matrix; down-valley imbrication; economically auriferous; gold sample GLD-207-G1
unit 2 – Cryoturbated cobble gravel	Cryoturbated diamictic gravel; 0.7 m thick, laterally variable; 70% clasts: common vertically oriented and frost shattered; 30% sandy silt matrix; highly consolidated
unit 1 –Cobble gravel	Oxidized, bouldery cobble gravel; >4.3 m thick, lower contact not exposed; 90% clasts, 10% sand matrix; many clasts highly weathered; crudely to well-sorted; strong down-valley imbrication;

Due to their malleability, gold grains round rapidly in the first three km of fluvial transport, and then more slowly as a stable morphology is achieved (Fig. 7).

The mean roundness of all samples from the Gladstone area is between 0.54 and 0.60; however, considerable variability in roundness is present within each sample (Fig. 8). Sample GLD-06-G1 appears to have a weak bimodal distribution, which may indicate two lode sources have contributed to the deposit. GLD-06-G1 also has the lowest average roundness, with a mode of 0.4–0.5, correlating to approximately 1 km of fluvial transport. This suggests a gold source is located within the lower reaches of Cyr Creek. Based on an empirically derived relationship between transport distance and roundness (Knight *et al.*, 1999), gold grain transport distances in GLD-205-G1 range from 2 km to more than 10 km (Fig. 7). No correlation was found between particle roundness and fineness, %Ag, or %Cu. If gold populations were sourced from discrete zones of mineralization and had simple fluvial transport histories, gold grains within a geochemical population should have a similar degree of rounding.

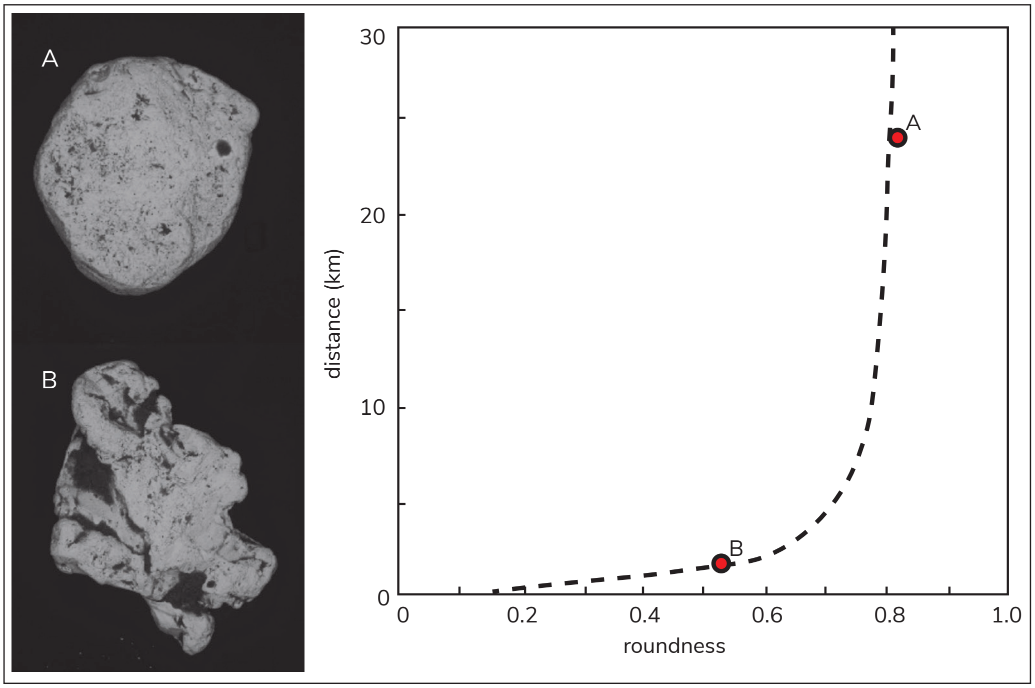

Figure 7. *Electron backscatter image of high-roundness, well-travelled (top) and low-roundness, less-travelled (bottom) gold grains from GLD-205-G1. The more rounded gold grain (0.80) has an estimated travel distance of >10 km, while the less rounded grain (0.53) has travelled approximately 2 km. The roundness-distance curve was empirically determined by analysis of gold grains in the Klondike district (Knight et al., 1999).*

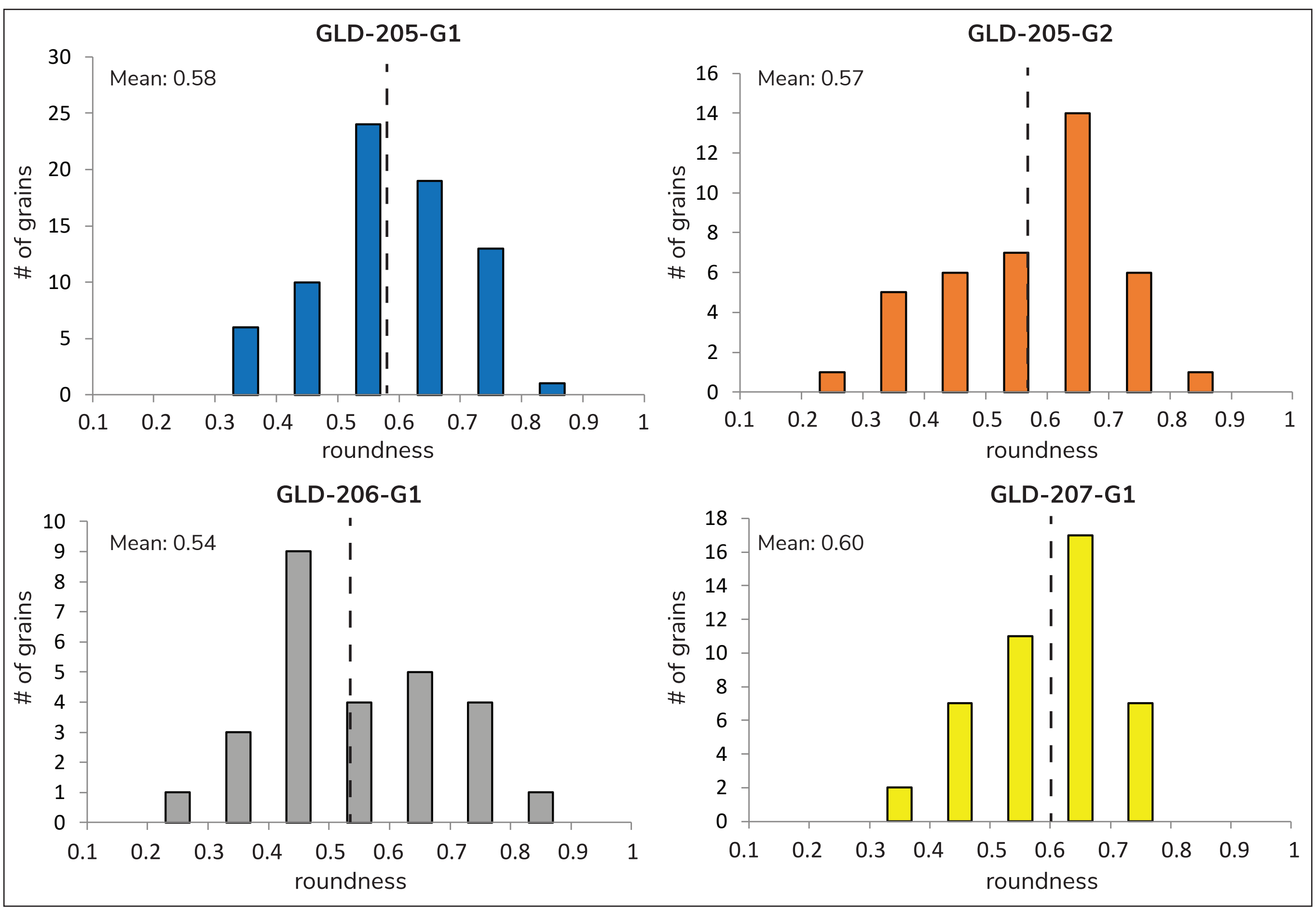

Figure 8. *Comparison of gold grain roundness at sample sites on Gladstone Creek. Dashed lines show the mean roundness of each sample.*

Mineral Chemistry

The proportion of gold, silver, and copper varies greatly within, and between samples (Fig. 9). The fineness of analyzed grains ranges from 22 to 947. Three distinct populations are identified: 950–835, 825–690, and 450–350. GLD-205-G2 contains only a single grain from the highest fineness population.

There are three distinct populations also identified in the distribution of silver content; 3–12% Ag, 38–48% Ag, and 57–60% Ag. Samples GLD-206-G1 and GLD-207-G1 have two high-silver content populations not measured in the samples from GLD-205. This may be due to high silver content in grains sourced from Cyr Creek, downstream of site GLD-205.

Copper content is below detection limits for most gold grains in samples GLD-206-G1 and GLD-207-G1. GLD-205-G1 and GLD-205-G2 have a relatively large range in copper content, between 0.02 and 0.13%, and a few outliers in GLD-205-G1 having approximately 0.25–0.3% Cu.

Chapman et *al.* (2011) used previously established gold alloy compositions from lode gold sources (Townley et *al.*, 2003) to differentiate between epithermal, gold-rich porphyry and gold-rich porphyry copper deposits. Using this method (Fig. 10), we find that epithermal mineralization is the dominant source of gold grains containing <10% Ag, and lesser amounts are derived from gold-rich porphyry mineralization. Gold grains from GLD-206 are not entirely classified in Figure 10 due to high Ag content (>10%) in more than half of the analyzed grains. Multiple grains contain more than 50% Ag. One grain in GLD-205-G2 was predominantly composed of Pb and S, suggesting galena is present from at least one of the sources.

Discussion

Source Mineralization

Most placer mines in the Ruby Range are underlain by Kluane schist, making it the most prospective source of placer gold. Figure 10 illustrates that most of the gold grains having <10% Ag appear to be derived from epithermal or gold-rich porphyry mineralization, though this requires further confirmation. The gold

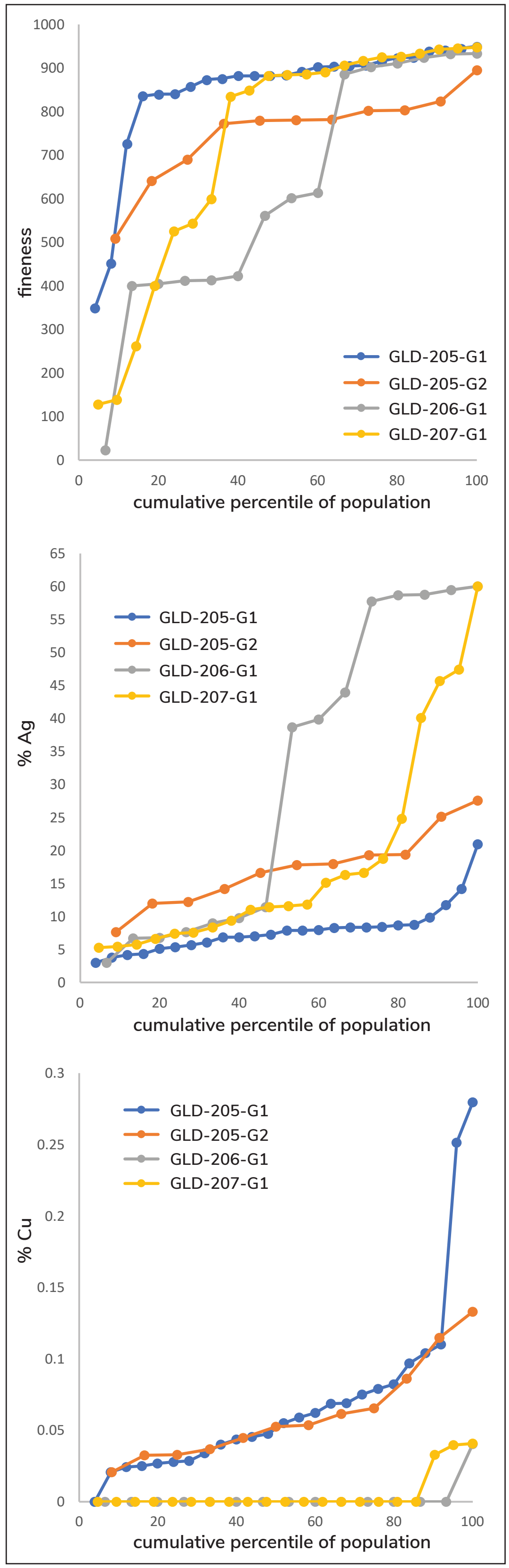

Figure 9. *Composition of major elements in sampled gold grains.*

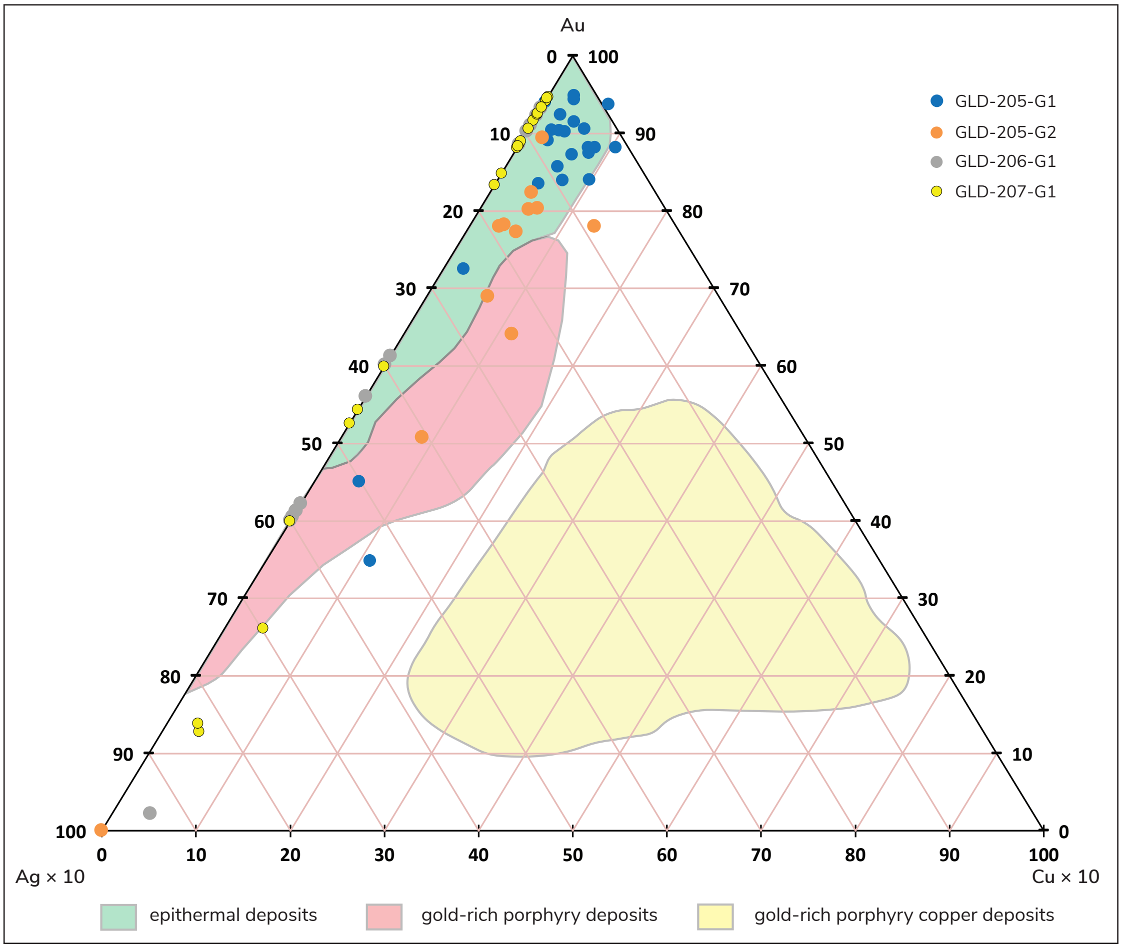

Figure 10. *Au, Ag, and Cu plotted against composition ranges of epithermal, gold-rich porphyry, gold-rich copper porphyry deposits from Townley et al. (2003). Epithermal mineralization appears to be the dominant contributor to placer gold within Gladstone Creek, with minor contributions from gold-rich porphyry; however, many gold grains do not fit on this diagram due to >10% Ag content.*

grains having >10% Ag do not appear on this diagram and make up more than 50% of sampled gold grains, are likely orogenic gold from the Kluane schist. Stream sediment geochemistry in tributaries on the south side of lower Gladstone Creek have gold anomalies as high as 1315.5 ppb, with Swanson Creek having the highest values (Berdahl, 2013). These tributaries are therefore likely contributors to placer gold in Gladstone Creek.

Identifying gold particles derived from orogenic mineralization is commonly not possible based on Au, Ag, and Cu alone. Chapman et *al.* (2018) suggest that analysis of mineral inclusions may allow for differentiation, based on the presence of Bi-Pb-Te-S in the inclusions. Analysis of the geochemical signatures of inclusions is a logical next-step for further work to confirm the suspected contribution of orogenic gold from Kluane schist.

Gold from porphyry and related epithermal systems is typically above 800 fineness (Sillitoe, 2000). Native gold particles coarse enough to be sorted into placer deposits are rare in the main porphyry, therefore, placer gold is typically sourced from later-stage epithermal mineralization (Chapman et *al.*, 2018). This epithermal mineralization may be related to Cu-Mo-Au porphyries (Yukon MINFILE 115G 070, 071) in the drainages north of Gladstone Creek. One active placer mine on Bliss Creek, 10 km north of Gladstone Creek, overlies Ruby Range batholith (Bond and van Loon, 2018), supporting the possibility of the batholith hosting other gold deposits.

Placer in a Glaciated Landscape

The stratigraphy exposed on Gladstone Creek records at least three glacial advances, represented by till units and associated glaciofluvial and glaciolacustrine deposits, and intervening non-glacial stages. The three tills in section likely correlate to MIS 2, 4 and 6. Radiocarbon ages and tephra constrain the MIS 2 and 4 tills. The lowest till, GLD-205 Unit 1, has no lower age constraint. This till is suspected to be MIS 6; pre-Reid glaciation in southwestern Yukon was much less extensive than MIS 6 and has only been observed in sections on the west side of the Shakwak trench, much closer to source areas (Turner *et al.*, 2016). If this interpretation of the stratigraphy is correct, the GLD-205-G2 placer deposit would have accumulated during the MIS 5 interglacial. GLD-205 Unit 4 is a till not bracketed by glaciolacustrine sediment, diagnostic of up-valley ice from the St Elias lobe, suggesting down-valley ice from the Ruby Range preceded arrival of the CIS. GLD-205-G1 accumulated during MIS 3, an interstadial period, and GLD-206-G1 accumulated during the Holocene (MIS 1). GLD-207-G1 is suspected to have accumulated on an erosion- resistive glacial-stage floodplain surface.

The placer deposits examined in this study all appear to have accumulated during interglacial periods, or during later phases of deglaciation when valleys are ice-free, providing lower base levels and allowing incision through glacial sediments. It is likely that pre-glacial deposits exist in paleochannels somewhere under the thick stratigraphy of Gladstone Creek, but have not yet been uncovered. Bedrock crops out at one location on lower Gladstone Creek, approximately 400 m above GLD-205. It is likely that most of the pre-glacial placer accumulation would have occurred on this bedrock surface.

Placers sampled at GLD-205 and GLD-207 accumulated on clay-rich glacial sediment (GLD-205 Unit 1 and Unit 4) and paleosurfaces (GLD-207 Unit 2). Clay-rich glaciolacustrine units found elsewhere in Gladstone Creek may also limit downcutting (*cf.* Levson and Blyth, 1994) and should be explored for placer accumulation.

Gold grain populations defined by fineness (Fig. 9) are morphologically heterogeneous (Fig. 8). This could be due to widespread mineralization in the vein systems in the Kluane schist resulting in wide-ranging transport distances. In Gladstone Creek, some of the gold would have been transported by ice and subsequently subject to fluvial transport, thus transport distance curves may not apply as morphological modification may occur at different rates during glacial transport. This is a possible explanation for the indistinct rounding signatures of the samples, despite large differences in chemical composition. Based on transport distances suggested by gold grain roundness, gold sourced from mineralization in the Ruby Range batholith must have been transported in part by down-valley ice.

Conclusions

Economic placer deposits accumulate where bedrock, or resistant false-bedrock materials such as till or other relatively impervious surfaces, limit downcutting. Regional studies of glacial history and ice flow directions suggest the possibility of distal-intrabasinal and extrabasinal gold sources; however, in Gladstone Creek the most likely sources of mineralization are local Kluane schist and the Ruby Range batholith. Geochemical analysis suggests three populations of gold are present in Gladstone Creek. A high fineness population may be derived from epithermal mineralization, the other appears to be derived from gold-rich porphyry mineralization, both of which are likely hosted by the Ruby Range batholith. More than half of the gold grains sampled are not well constrained by Au-Ag-Cu analysis and are suspected of being derived from orogenic mineralization within Kluane schist. Further analyses, including gold grain microchemistry and inclusion mineralogy, are required to confirm these results.

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