Characterization of Placer- and Lode-Gold Grains as an Exploration Tool in East-Central British Columbia (Parts of NTS 093A, B, G, H)

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Introduction

This paper describes the results of a project designed to evaluate the use of microchemistry of placer-gold grains (alloy compositions plus opaque inclusion suite) as an exploration tool in the Cariboo gold district (CGD) in east-central British Columbia. Fieldwork was completed in July 2009 and the analysis of gold grains was completed in late 2009. Some earlier results of the work have been discussed previously by Mortensen and Chapman (2010).

The geology and gold mineralization of the study area was summarized by Mortensen and Chapman (2010) and orogenic gold mineralization throughout the CGD has been described in more detail by Rhys et al. (2009) and Mortensen et al. (2011). These studies provide a geological framework within which to undertake a detailed study of placer gold in drainages within the CGD. Mortensen and Chapman (2010) provided the rationale for the placer-gold study based on a re-evaluation of gold compositional data originally presented by McTaggart and Knight (1993), enhanced by new information describing the suite of opaque minerals present in each sample set. In this paper, we present the complete analytical results and interpretation relating to the new sample suites collected during the study.

Experimental Methods

A total of 1330 placer grains from 25 placer localities have been analyzed during this phase of the study (Figure 1, Table 1). The techniques used to collect samples in the field were described by Mortensen and Chapman (2010). Analysis of gold grains was undertaken according to the methodology of Chapman et al. (2010a) and involved identifying opaque mineral inclusions using scanning electron microscopy and the determination of the alloy composition using an electron microprobe. In some cases, gold grains from a single locality were subdivided according to morphology and texture (e.g., rough, implying relatively short transport distances versus smooth and/or flaky, implying longer transport distances) prior to mounting the grains for analysis in an attempt to correlate compositional data with inferred transport distance from the source.

Presentation of Data

Characterization of the signatures of gold grain populations is based on the alloy composition and inclusion assemblages of the gold particles. The alloy compositions are represented by cumulative percentile versus increasing Ag plots in Figure 2. This approach makes it possible to directly compare populations with different numbers of grains. Suites of mineral inclusions are represented using ternary diagrams with axes selected to highlight the differences in mineralogy (e.g., Figure 3). The numbers of grains in a population containing a specific inclusion are recorded and these data are combined according to appropriate criteria, which may be mineral class or the presence of a specific mineral.

Results and Discussion

General Comments on Gold-Grain Signatures

The majority of gold grains analyzed from the CGD are simple binary Au-Ag alloys. The populations of relatively high-Ag grains from the Dragon Creek area west of Wells (Figure 4) also contained some grains with Hg above the detection limit (0.065% at The University of British Columbia [UBC]; 0.03% at the University of Leeds). No grains contained Cu above the detection limit (~0.025% at UBC); therefore, this element is not considered further in this paper. In general, the abundance of opaque inclusions within the polished grain sections was very low. The exception to this is the low-Ag gold grains from the Wells area, in which inclusions of Ni- and Co-bearing sulpharsenides, base-metal sulphides and Bi-bearing minerals were moderately abundant. The general scarcity of inclusions in populations from other areas has precluded the usual approach involving semiquantitative analyses of inclusion assemblages; however, in some cases it has been possible to combine datasets to provide additional information to characterize gold grain types.

Keywords: *placer gold, lode gold, Cariboo gold district, east-central British Columbia, alloy composition, micro-inclusions*

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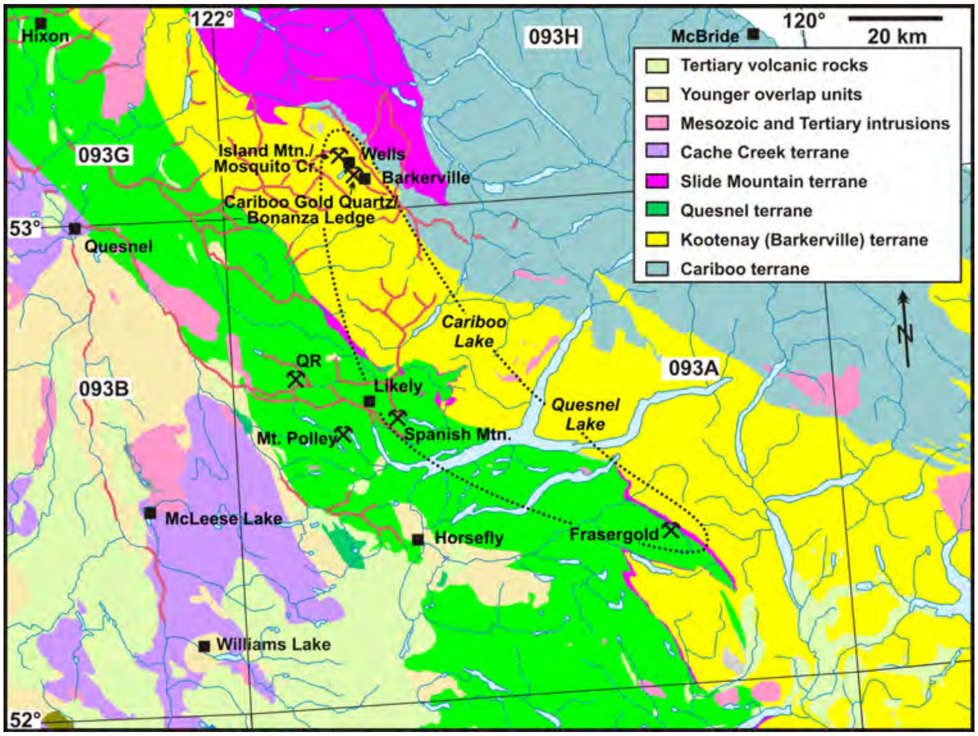

Figure 1. Regional geology of the study area in east-central British Columbia, showing locations of the Cariboo gold district (dotted black line), significant known lode-gold and copper-gold deposits (crossed rock hammer symbols) and significant placer streams (red lines).

Table 1. Placer-gold sampling localities, east-central British Columbia, July 2009.

Locality	Easting	Northing	No. grains	Notes on abundance and size of grains
Dragon Creek	583016	5885903	12	Gold very scarce in stream bed
Montgomery Creek	583950	5885450	3	Gold extremely scarce in current stream bed
Antler Creek (upper)	606398	5870152	48	Gold moderately abundant in bedrock cracks
Antler Creek (lower)	606750	5871205	91	Good site in bedrock; gold grains up to 2 mm
Beggs Gulch	606300	5875500	71	Heavily worked area, lots of outcrop, gold rare and very small; recovered from gravel at exit of road culvert
Peter Gulch	611129	5863278	27	Fine and rough gold in bedrock; gold grains very rare
Cunningham Creek at Trehouse	610500	5865900	66	Fine grains in gravel; not very abundant
Chisholm Creek (upper)	586874	5878438	96	Gold plentiful in established bar
Chisholm Creek (lower)	586791	5878197	118	Gold grains up to 3 mm under boulders
Perkins Gulch	587655	5876715	32	Gold scarce in gravel bar
Amador Creek	588853	5876180	73	Gold from a ford in the stream valley not heavily worked; gold abundant
Moustique Creek	569250	5873350	167	Bedrock cracks in the gorge plus donated samples; gold grains up to 5 mm
Burns Creek	590031	5881840	53	Grains moderately abundant in established bar
Devlin Bench	600162	5883208	8	Gold grains rare bench already stripped to remove top 0.5 m of bedrock
Williams Creek	59983	5881613	54	Gold grains up to 2 mm moderately abundant in gravel on bedrock
Lowhee Creek	596500	5883750	103	Gold grains up to 4 mm moderately abundant in gravel on bedrock
Pleasant Valley Creek	606050	5879000	1	New river course; bedrock present but only one grain
Baldhead Creek	574196	5883884	16	Flaky grains up to 3 mm in upper hydraulic pit
Hixon Creek	529328	5922040	49	Gold grains abundant and variable in colour and morphology
Keithley Creek	604183	5849514	95	Flakes up to 3 mm in bedrock traps
Little Snowshoe Creek	604600	5856500	35	Fine gold moderately common in creek bed but apparently absent from bench at the side
Morehead Creek (upper)	588292	5825369	0	Gold absent in drainage closest to Mt. Polley
Unnamed, Frasergold	666389	5797008	28	Grains up to 2 mm moderately abundant in gravel
Eureka Brook	664345	5798813	4	Grains rare inconsistent with historical reports
Mackay River	6601050	5802692	80	Flakes moderately common in gravel on bedrock near bridge

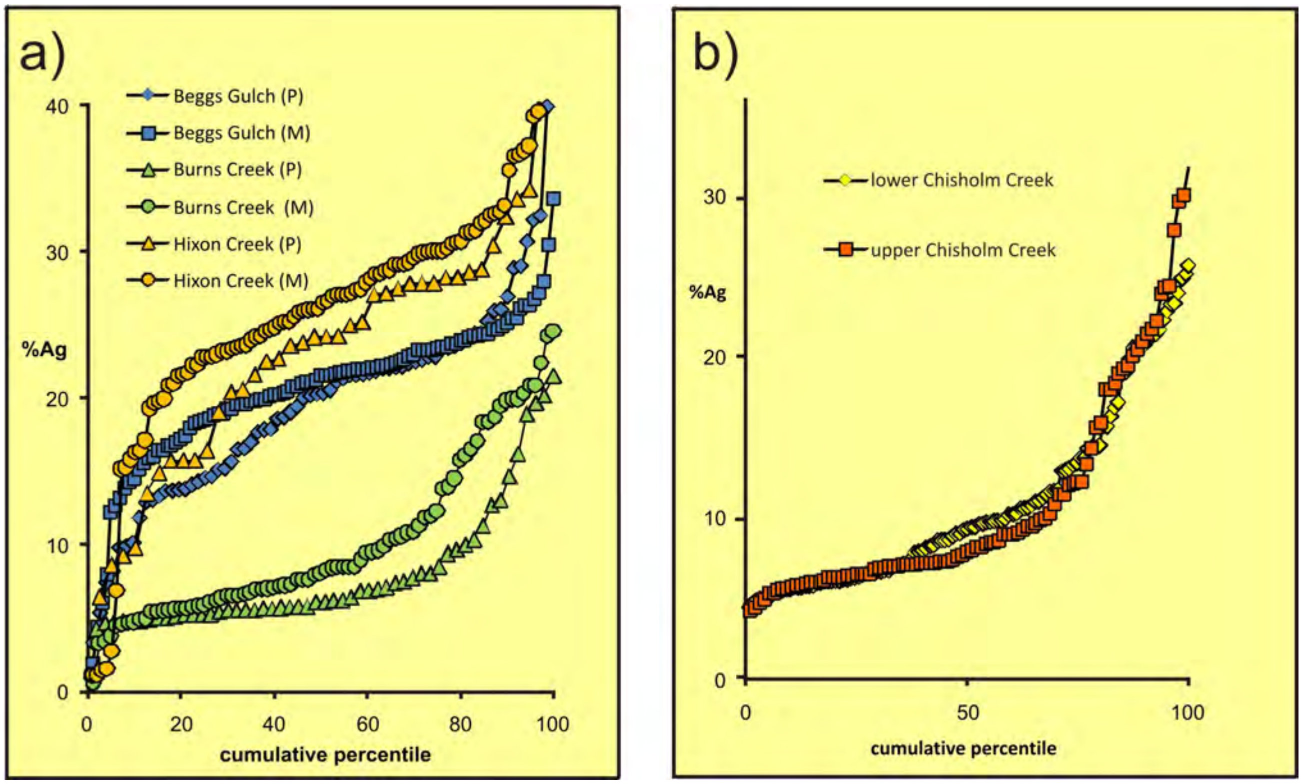

Figure 2. a) Comparison of Ag contents of sample populations as measured by McTaggart and Knight (1993) and this study, **b)** alloy signature of two samples from Chisholm Creek, east-central British Columbia (this study) taken 0.5 km apart.

The new data presented here enhances the dataset of McTaggart and Knight (1993), which was based largely on samples obtained from active placer operations in the CGD. Because of the difficulty of accessing some drainages and the scarcity of active placer operations in the study area during the 2009 fieldwork, it has only been possible to generate new data in some parts of the study area. The section below focuses on the areas where new results permit a refinement of interpretations from the previous work (Mortensen and Chapman, 2010).

Reproducibility of Data

Figure 2a compares the Ag contents of placer-gold samples taken from specific drainages during this study with that obtained by McTaggart and Knight (1993) from the same drainages. In most cases, the reproducibility of the data between the two studies is very good, indicating that analytical results obtained in UBC and University of Leeds microprobe laboratories are quite comparable. Minor discrepancies between samples are to be expected, especially in cases in which more than one compositional range is present. In such instances, it is highly likely that the proportions of each compositional subpopulation will differ somewhat from one sample to another.

Figure 2b shows the Ag contents of two placer samples collected 0.5 km apart from Chisholm Creek (Figure 4) during this study. The two alloy signatures are very similar, showing that the placer population is the same at each sampling site. In contrast, a detailed study of gold grains from several localities and sedimentary environments within Moustique Creek (Figures 4, 5) generated completely different signatures within a small geographic area. Table 2 provides the details of samples from Moustique Creek. The samples from the main creek bed were collected by the authors and

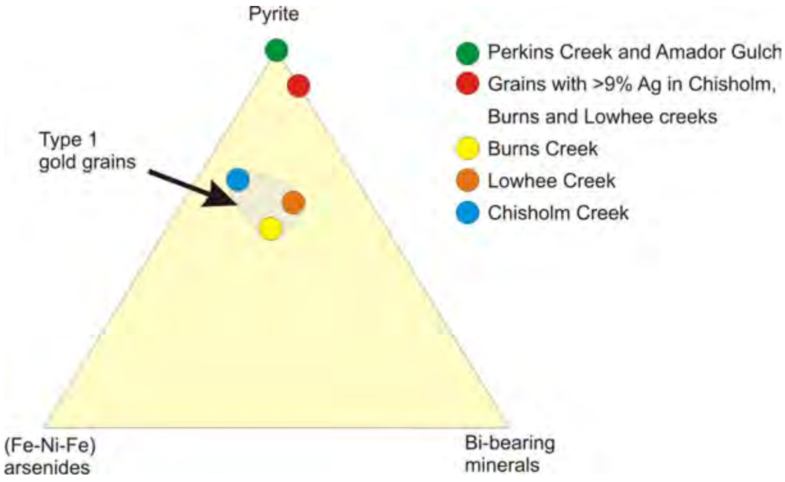

Figure 3. Ternary diagram showing the composition of inclusion assemblages in gold grains from the Wells-Barkerville area, east-central British Columbia.

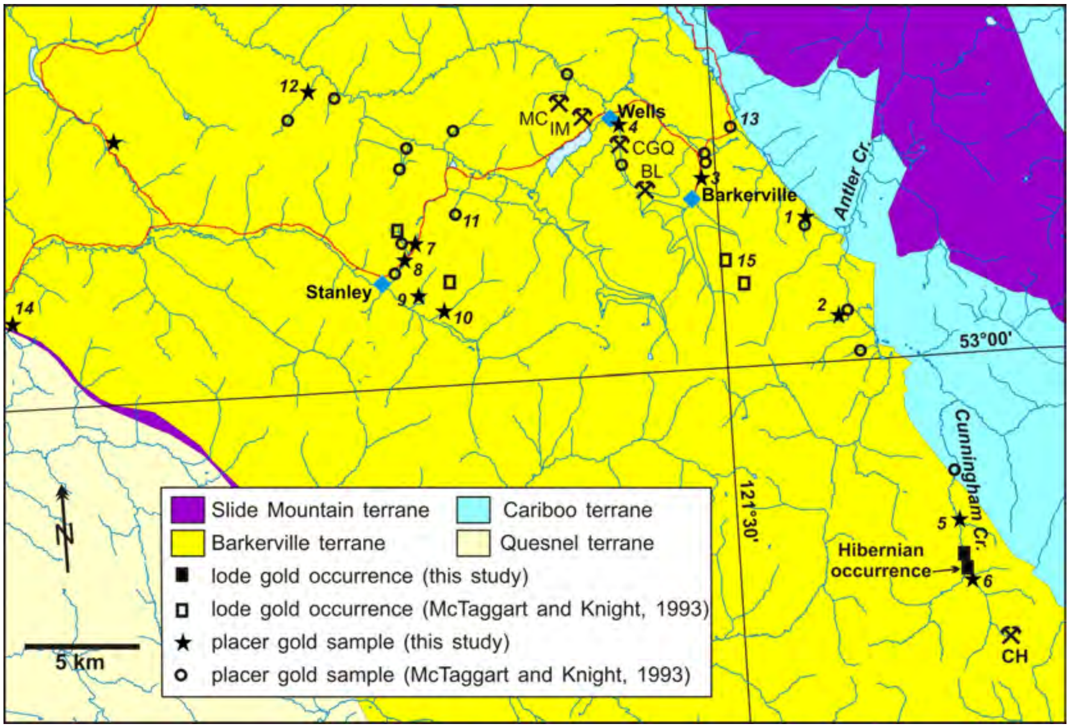

Figure 4. Simplified geology of the Wells-Barkerville and Cunningham Creek areas, east-central British Columbia, showing previous (McTaggart and Knight, 1993) and new (this study) lode- and placer-gold sampling localities. Past-producing gold mines and significant lode occurrences include Bonanza Ledge deposit (BL), Cariboo Gold Quartz mine (CGQ), Cariboo Hudson mine (CH), Island Mountain mine (IM) and Mosquito Creek mine (MC). Specific sample localities referred to in the text include 1: Beggs Gulch; 2: Antler Creek (upper and lower localities); 3: Williams Creek; 4: Lowhee Creek; 5: Cunningham Creek; 6: Peter Gulch; 7, 8: Chisholm Creek (upper and lower); 9: Perkins Gulch; 10: Amador Creek; 11: Burns Creek; 12: Dragon Creek; 13: Eight Mile Lake; 14: Moustique Creek and 15: Proserpine occurrence.

the remaining samples were donated by the claim owner (D. Steele). Samples of gold grains from different gravel horizons were obtained from the upper and middle reaches of the valley, where the gravel matrix correlated with varying morphology of the gold grains. The gold grains from the creek bed were collected adjacent to the historic hydraulic mining area known as Slade's Pit, at the mouth of Moustique Creek (Table 2). The samples were mounted within sample pucks according to morphology to determine whether different signatures were associated with different grain shapes and, by inference, different sources. Figure 5b shows the Ag contents of the inclusion assemblage and various sample populations. Inclusions were extremely rare in the samples studied, but where present, they indicated a simple mineralogy of pyrite and calcite. The signatures of gold grains from the creek bed are depicted in Figure 5a. The morphological and textural differences correspond to different Ag contents of the subpopulations. All three plots exhibit a subpopulation of 5–8% Ag, although the proportion of grains with this composition varies between samples. The shape of the curve describing the 'flaky' population is much smoother than the corresponding curve for 'rough' gold grains. The population of 'dark' grains exhibited the lowest Ag contents, but most exhibited a rim of Hg amalgam (interpreted as a consequence of mining activity) surrounding a core that contained no Hg. The reason for the apparent correlation between Hg contamination and core alloy composition is unclear.

Samples of placer gold from Hixon Creek, Burns Creek and Beggs Gulch analyzed by McTaggart and Knight (1993) and this study were not collected at exactly the same locality. One explanation for the slight discrepancies between the curves for these placer samples illustrated in Figure 2a is that additions of gold from local lode sources may have increased the placer inventory between sampling sites. The variation in alloy signatures among different samples from Moustique Creek shows that in some cases, the local gold mineralization may exhibit a relatively wide range of signatures. In the absence of an influx of gold, however, the signature should be expected to remain constant, as is the case with the samples from Chisholm Creek (Figure 2b). The presence of the same Ag compositional ranges in subpopulations of gold grains from Burns and Hixon creeks and Beggs Gulch provides confidence in the analytical procedures; consequently, we conclude that minor differences between plots from different sampling points in the same drainage reflects progressive modification of the placer signature through the addition of gold from different lode

Table 2. Descriptions of samples from Moustique Creek, east-central British Columbia.

Sample	Subsample	Setting	Number of grains	% grains with inclusions	Inclusions
Creek Bed	Rough	Bedrock cracks in creek bed	32	0	
	Flaky		45	1	Pyrite (2)
	Dark		13	14	Pyrite (2)
Mid Valley (Block 20C)	'Nugget type'	Brown matrix	12	0	
	'Fine' type	Blue 'pea gravel'	32	0	
Slade's Pit		Black sand/rusty gravel	13	0	
Valley top	'Fine' type	Blue pea gravel	8	12	Pyrite, calcite
	'Nugget' type	Gravel (no clay)	12	0	
Total			**165**		

sources. The implications of this observation for regional mineralization are discussed in a later section.

Lode-Gold Signatures

Five samples of lode gold were collected during this study. The lode sample from the Spanish Mountain deposit (Imperial Pit, MINFILE 093A 043; BC Geological Survey, 2010) near Likely (Figure 6) is compared with other lode samples and a composite placer-gold sample from Spanish Creek in Figure 7a. The compositional range of the sample from the Imperial Pit (17–27% Ag) encompasses the ranges of other smaller lode samples from the Spanish Mountain area analyzed by McTaggart and Knight (1993) and correlates with the bulk of placer grains from Spanish Creek.

The Ag contents of lode samples from the Midas adit north of Yanks Peak (MINFILE 093A 035; Figure 6), the Hibernian occurrence on Cunningham Creek (MINFILE 093A 051) and the Bonanza Ledge zone in the Wells area (MINFILE 093H 019; Figure 4) are presented in Figure 7b. The lode samples from Hibernian and Bonanza Ledge appear broadly similar to signatures of populations or subpopulations previously reported (Figure 7b); however, the gold from the Midas adit (Figure 6) shows a narrow compositional range that has not been recognized elsewhere in the CGD.

McTaggart and Knight (1993) analyzed very fine grains of gold that occur as thin films and as inclusions and fracture

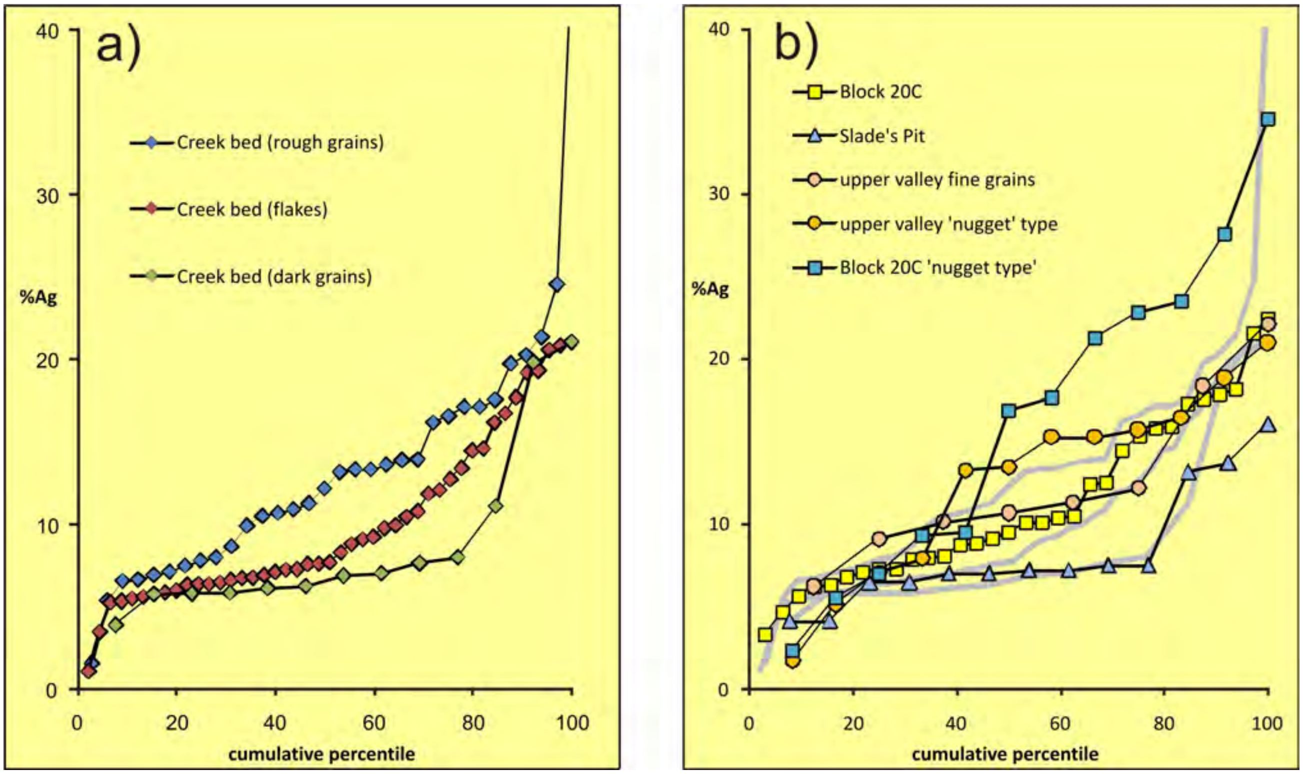

Figure 5. a) Placer-gold compositions from various sites on Moustique Creek, east-central British Columbia, including samples from the modern placer deposit and **b)** silver contents of other sample populations from the study area, with the curves from Figure 5a included for reference. There is a common break in slope at 8% Ag.

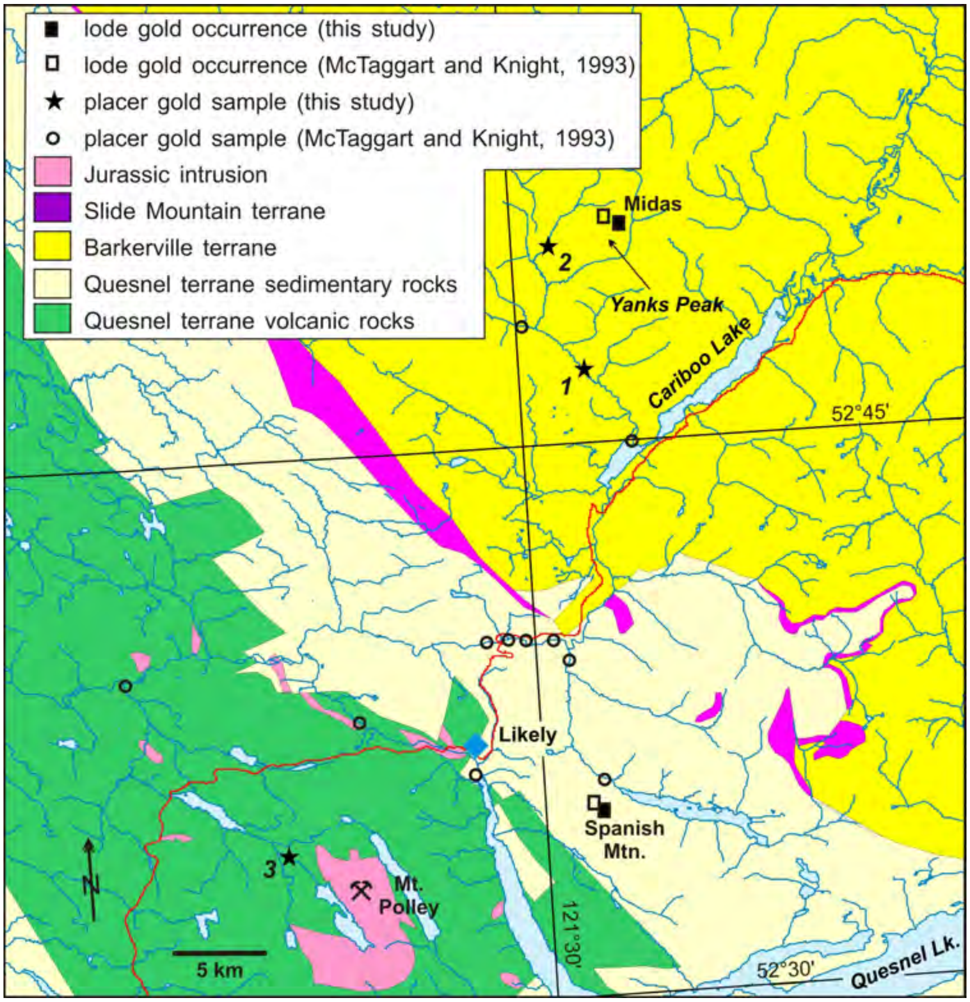

Figure 6. Geology of the Likely–Cariboo Lake area, east-central British Columbia. Specific sample localities referred to in the text are 1: Keithley Creek, 2: Little Snowshoe Creek and 3: upper Morehead Creek.

fillings within pyrite from pyritic replacement ore from the Mosquito Creek mine (MINFILE 093H 010; sample '497 Mosquito Creek' in Figure 7b), and found that these gold grains were significantly more Ag-rich than most of the vein-hosted gold in the Wells-Barkerville area. Because of the very fine grain size of this gold, McTaggart and Knight suggest that it probably would not have been concentrated in placer deposits in the area and is therefore unlikely to be recognized in placer samples.

Placer-Gold Signatures in the Wells-Barkerville Area

Mortensen and Chapman (2010) compared the signatures of lode gold to placer gold using the data from McTaggart and Knight (1993). Lode-gold signatures were commonly distinctive, with most samples comprising one or more subpopulations, each with a narrow compositional range. In some cases, however, the range of Ag contents exhibited by lode samples from the same area show a wide variation, which is consistent with the corresponding compositional variation in placer samples.

Figure 8a shows the Ag contents of samples from the Stanley area (Figure 4). Gold from Perkins Gulch and Amador Gulch shows very similar signatures that resemble but are not identical to the gold from Chisholm Creek (lower). The similarity between the overall signatures of gold from the two sampling sites on Chisholm Creek has been described earlier; however, the varied morphology of grains within the population from the upper site permitted subdivision of the gold into 'flaky' grains and 'rough' grains (Figure 8b). The population of flaky grains is clearly Ag poor with respect to the rough grains. Although a few of the rough grains exhibit a similar low-Ag composition below 12.3% Ag, there is also a high-Ag subpopulation, mostly between 17 and 25% Ag. The composition of 'rough' grains from Chisholm Creek resembles those of samples from Perkins and Amador gulches, but the low-Ag signature of flaky

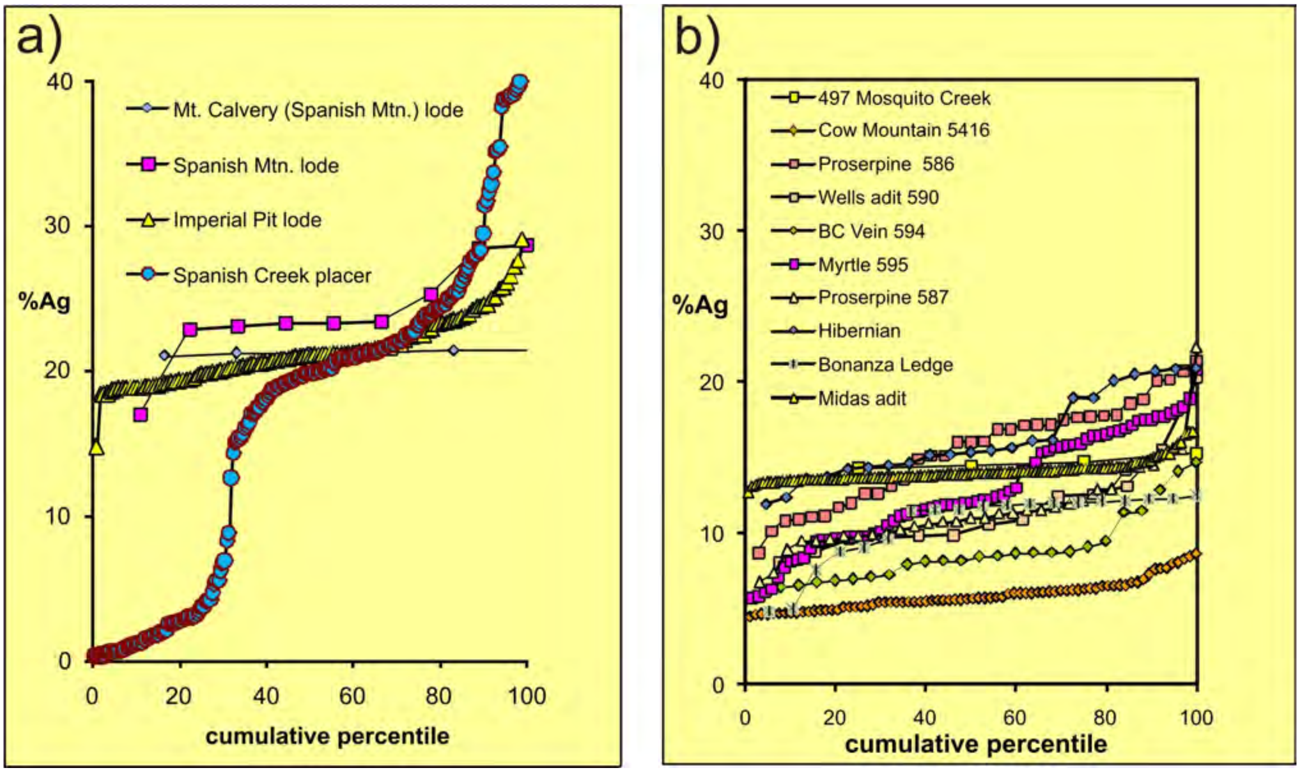

Figure 7. Alloy compositions of placer and lode gold from the Spanish Mountain area **(a)** and gold from various lode occurrences in the Wells-Barkerville area **(b)**, east-central British Columbia.

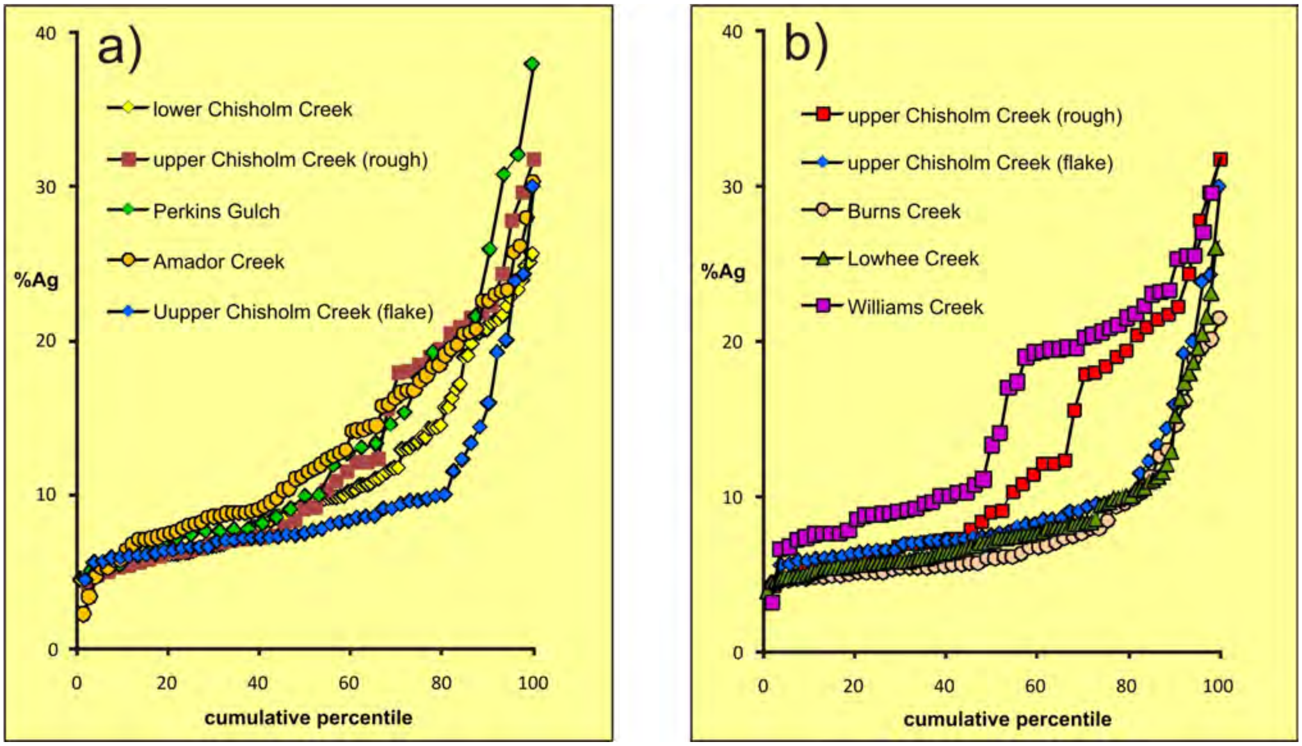

Figure 8. Alloy compositions of placer gold grains from the Stanley **(a)** and Wells-Barkerville **(b)** areas, east-central British Columbia.

gold grains from Chisholm Creek resembles that of gold grains from Burns Creek 3 km to the west (Figure 8b).

Consideration of inclusion assemblages observed within grains of different alloy compositions provides further information for the characterization of gold-grain types. Figure 3 shows the relative proportions of grains containing pyrite, Ni- and Co-bearing sulpharsenides and Bi-bearing minerals in populations of grains in the Stanley and Wells-Barkerville areas. The inclusion signature of the low-Ag population from Chisholm Creek is very similar to that of gold grains from Burns Creek in all respects; however, the inclusion suite of the high-Ag gold grains is dominated by pyrite, which is also the only inclusion species observed in gold grains from the Perkins and Amador gulches. Figure 8b shows the alloy composition of gold grains from Lowhee Creek in the Wells area are very similar to that of gold grains from Burns Creek. Analysis of the inclusion assemblage of the gold grains from Lowhee Creek (Figure 3) further emphasizes the similarity between these signatures.

A sample of gold grains from Williams Creek collected between Barkerville and Wells (Figure 4) yields a markedly different signature from that of gold grains from Lowhee Creek 2 km to the northwest. The low-Ag gold grains containing Bi-bearing and Co-Ni sulpharsenide inclusions is absent in the Williams Creek sample and the population is more Ag-rich than the gold signature from Lowhee Creek. Gold grains from Williams Creek comprise mostly two compositional populations: 8.5–11.5% Ag and 19–25.5% Ag. Inclusions are rare in this sample, but a single inclusion of arsenopyrite (containing no Ni or Co) was recorded in a grain containing 19% Ag.

Antler and Cunningham Creeks

McTaggart and Knight (1993) reported compositional data for placer gold from Cunningham Creek, as well as Beggs Gulch and California Creek, both of which are tributaries of Antler Creek (Figure 4). We sought to broaden this sample suite with placer gold from sites on Antler and Cunningham creeks and Peter Creek (a tributary of Cunningham Creek). McTaggart and Knight (1993) had established that placer gold from Beggs and California gulches exhibited unusually high Ag contents. Additional gold grains were collected from Beggs Gulch in an attempt to establish whether the different alloy composition correlated with a different inclusion suite.

Figure 9a shows the Ag contents of these placer populations. The sample from upper Antler Creek comprised both waterworn and rough grains, and the two subpopulations have been analyzed separately. Three main ranges of alloy compositions are present in these populations of placer-gold grains identified by compositional limits and common breaks in the slope of the plots. These ranges are 5–10%

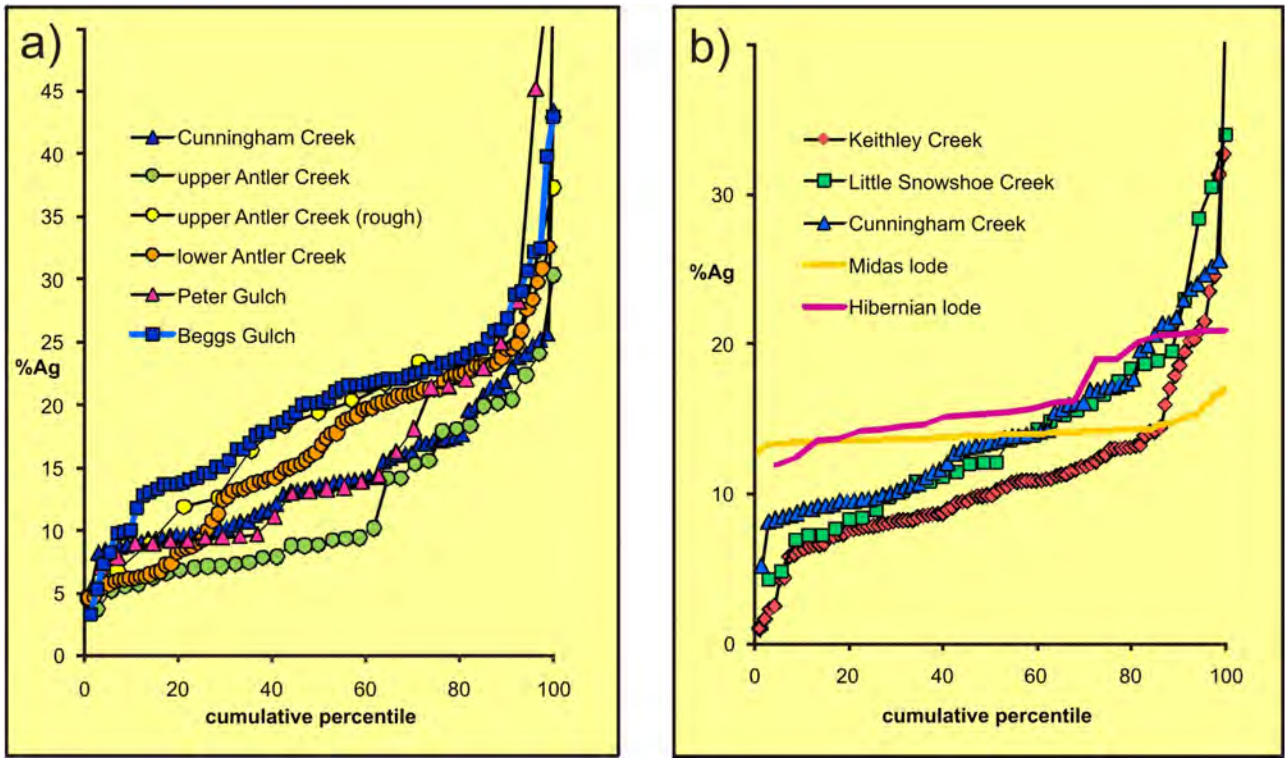

Figure 9. Gold grain compositions from the Antler and Cunningham Creek drainages **(a)** and the Keithley Creek drainage west of Cariboo Lake **(b)**, east-central British Columbia.

Ag, 13–20% Ag and 20–27% Ag. The sample from Cunningham Creek exhibits all three ranges, whereas the Beggs Gulch sample comprises only the two high-Ag compositions.

Inclusions were scarce in gold grains from these sample sites. Inclusions of pyrite and Ca-Mg-Fe carbonate were the only inclusions observed in gold grains from Cunningham and Peter creeks. Gold grains from Antler Creek contained these mineral species, but chalcopyrite was also observed in one grain of very high (48%) Ag content. Two inclusions of a Ce-Al phosphate, possibly florencite $\{CeAl_3(OH)_6(PO_4)_2\}$, were also recorded in these samples. Gold grains from Beggs Gulch returned a range of inclusions, including pyrite, argentite, sphalerite and (Co-Ni-Fe) sulpharsenide. In addition, an (Fe-Pb)-S-P-O–bearing mineral, possibly corkite $\{FePb(SO_4)(PO_4)\}$, was observed. Each of these minerals, however, was recorded in one grain only; therefore, a clear inclusion signature cannot be established. Nevertheless, it appears that the mineralogy of the Ag-rich gold grains from Beggs Gulch is more complex than the simple carbonate-pyrite signature evident elsewhere in this group of samples.

Keithley and Little Snowshoe Creeks

Figure 9b shows the alloy compositions of placer-gold populations from Keithley Creek and Little Snowshoe Creek, west of Cariboo Lake (Figure 6). These signatures exhibit some differences in relative proportions of gold of different compositions, but overall the compositional range is similar. The compositional range of gold grains from Little Snowshoe Creek is also very similar to that of gold grains from Cunningham Creek. Gold from the Midas adit on the northeast side of Yanks Peak is a potential source of some of the gold in Little Snowshoe and Keithley creeks; however, gold from the Midas samples yields a very narrow compositional range (Figure 9b). It therefore cannot represent the only lode source for the placer samples.

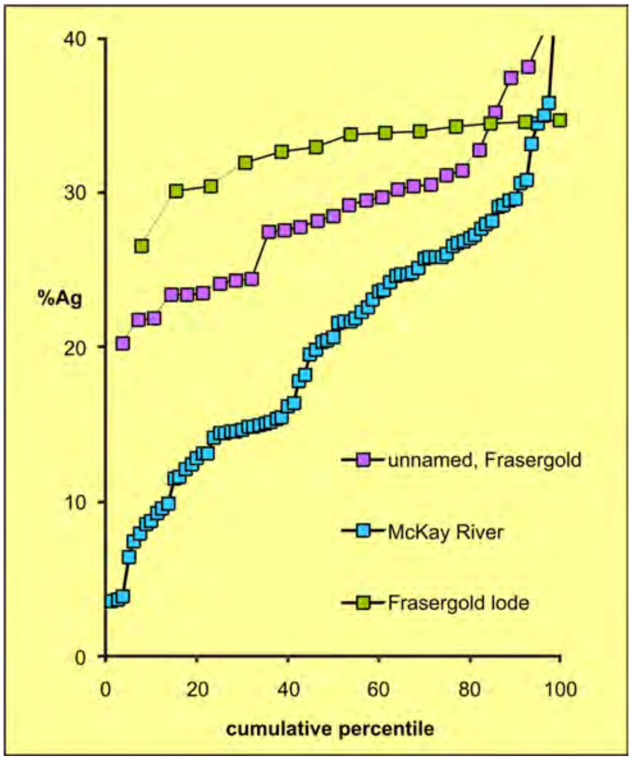

Figure 10. Placer- and lode-gold compositions in the Frasergold area, east-central British Columbia.

Inclusions are uncommon in these populations of placer grains, but the pyrite-Fe-Ca-Mg carbonate signature observed in gold grains from Cunningham Creek was again evident. In addition, inclusions of chalcopyrite, galena, sphalerite and apatite were observed in single grains.

Frasergold Area

Mortensen and Chapman (2010) reported that lode gold from the Frasergold deposit (MINFILE 093A 150; Figure 1) typically exhibits very high (30–34%) Ag contents. Figure 10 shows that most placer-gold grains recovered from a small unnamed creek approximately 1.5 km southeast of the Frasergold adit display very similar alloy compositions (27–32% Ag). There is, however, an additional smaller subset of grains within this sample that contain 20–24% Ag. Roughly half of the grains in the placer-gold sample from the McKay River, approximately 7 km downstream from the Frasergold deposit (Figure 10), correspond to this high-Ag type, but there is an additional population containing 6.5–16% Ag.

Inclusions were not observed in the placer grains from the unnamed tributary near Frasergold, and they are very scarce in the larger population collected from the McKay River. Galena was the only opaque inclusion recorded in the MacKay River gold grains, but sphene and fayalite were also observed. These inclusion species have not been previously reported in studies of this type, either in BC or elsewhere.

Hixon Creek

McTaggart and Knight (1993) reported high-Ag contents in placer gold from Hixon Creek (Figure 1). Mortensen and Chapman (2010) suggested that the atypical alloy signature could reflect derivation from either epithermal mineralization associated with local volcanic rocks, or from Frasergold-type orogenic gold mineralization. It is possible to discriminate between placer gold derived from an orogenic vein system versus gold of epithermal origin according to the suite of opaque inclusions observed (e.g., Chapman and Mortensen, 2008); however, no inclusions were observed in the sample suite of McTaggart and Knight (1993). An additional sample of placer gold was collected from Hixon Creek as part of this study and the alloy compositions (shown in Figure 2) correspond closely the data generated by McTaggart and Knight (1993). An additional 39 grains were screened for inclusions but only single inclusions of calcite, pyrite and chalcopyrite were observed. The gold grain signature from Hixon Creek is similar to that of gold grains from some other localities in the western part of the study area where an orogenic source is presumed (e.g., McKay River and some populations from Moustique Creek). No inclusions suggestive of an epithermal source have been observed but those recorded are broadly compatible with the regional signature. On the basis of these observations, it seems likely that the placer gold in Hixon Creek is also derived from orogenic mineralization.

Comparison of Placer-Gold Signatures throughout the Study Area

The low-Ag gold grains that contain Bi and Ni±Co sulpharsenides are a distinct type of gold grains with a coherent regional distribution in the Wells-Barkerville area. It has been previously observed in lode mineralization at Cow Mountain southwest of Wells (compositional data from McTaggart and Knight, 1993 and inclusion analysis from this study). The presence of this gold grain type in the flaky (travelled) subpopulation of gold from Chisholm Creek suggests a limit to the extent of the lode source for this type between Chisholm and Burns creeks (Figure 8). Lode mineralization in the Chisholm Creek catchment appears to be more similar to that which contributed to the placer deposits in Perkins Gulch and Amador Creek to the south (Figure 8), on the basis of the signature of the high-Ag component, which contains only pyrite inclusions.

Gold grains from Williams Creek show a different signature to that from Lowhee Creek (Figure 2b). Neither of the main alloy subpopulations in the Williams Creek sample matches the Lowhee Creek signature and the inclusion signature does not exhibit any of the Bi or Ni-Co minerals common in the low-Ag gold-grain type from localities immediately to the west. The high-Ag population in the Williams Creek sample, however, is very similar to the high-Ag gold grains in Beggs Gulch, both in terms of compositional range and scarcity of inclusions.

The placer samples from Antler, Cunningham and Keithley creeks and their tributaries all show common compositional ranges in component subpopulations. The compositional range of rough gold grains from Peter Creek and a larger sample from Cunningham Creek (Figure 9a) is very similar. The presence of some unusual inclusions in the high-Ag gold grains from Beggs Gulch suggest a local influence on ore fluid chemistry, but overall inclusion data does not provide any useful discriminants to distinguish between gold populations or strong indications of the origins of the ore fluids.

The similarity of the signature of gold grains from Little Snowshoe Creek with that from Cunningham Creek suggests a related source for placer gold on either side of the watershed of Yanks Peak (Figure 9b). The small variation between signatures of gold grains from Keithley Creek and Little Snowshoe Creek suggests an influx of gold within the Keithley Creek catchment.

The high-Ag gold grains reported in lode samples from Frasergold by Mortensen and Chapman (2010) is the main component of the placer gold in a nearby creek, but only half of the grains from a locality farther downstream on the McKay River are of this composition. The origins of the low-Ag population in the McKay River sample remain unclear.

The scarcity of inclusions in grains from Hixon Creek suggests a similarity with many other populations of gold grains of orogenic origin throughout the CGD. Furthermore, the few inclusion species observed provide no evidence for a magmatic influence on the mineralizing fluids.

Characterization and Distribution of Gold Types

Studies of placer and lode gold in regions where multiple signatures are present usually benefit from classification of gold-grain types according to microchemical signature. Populations of placer gold containing multiple gold-grain types may be subsequently defined in terms of their relative

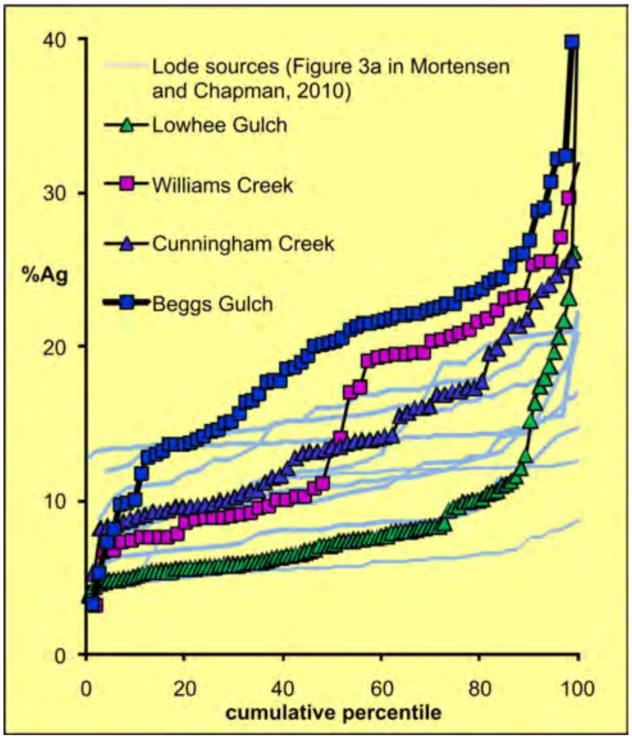

Figure 11. Placer-lode comparisons in the Wells-Barkerville area, east-central British Columbia.

proportions. This approach has been applied here, although the nature of the various signatures precludes identification of many clearly definable gold-grain types. Figure 11 shows the plots of some lode-gold populations from the Wells-Barkerville area representative of the whole dataset, with some of the most distinctive silver compositional plots for placer gold superimposed.

The most distinctive signature is that of the low-Ag gold grains associated with the (Co-Ni-Fe) arsenide-Bi–bearing mineral assemblage (type 1 gold grains). This gold-grain type is dominant in the central part of the Wells-Barkerville area and to the west in Burns Creek. The signature is identical to that recorded in gold grains from lode samples of Cow Mountain, immediately to the southwest of Wells. Gold from replacement-style ore at the Mosquito Creek mine in Wells analyzed by McTaggart and Knight (1993) had higher Ag contents (14% Ag) than most of the type 1 gold grains; however, inclusions of Pb-Bi sulphide were identified during the examination of Mosquito Creek gold in this study.

Most gold grains we have examined in the CGD other than type 1 are simple Au-Ag alloys showing occasional inclusions of carbonate, base-metal sulphides and rare sulpharsenides. The inclusion signatures in samples from different localities are not sufficiently well defined to permit identification of distinct gold grain types. Similarly, the continuum of alloy compositions precludes characterization on the basis of alloy chemistry alone. This gold-grain signature (which may exhibit Ag contents between 1 and 30% Ag) has consequently been classified as type 2. We interpret this signature as indicative of gold deposition from broadly equivalent hydrothermal systems where the varying Ag content in the gold grains is a consequence of local mineralizing conditions (see discussion below).

Despite the noise in signatures at a local level, it is possible to recognize some regional trends in placer-gold composition within the study area. The distribution of type 1 gold grains is geographically coherent and the distribution area is surrounded by localities that yield type 2 gold grains. However, a variation on the high-Ag gold grains occurs in the vicinity of Dragon Creek, where placer-gold grains contain up to 7% Hg (McTaggart and Knight, 1993). This gold-grain type has been designated type 3.

The samples with the highest Ag contents are found at the eastern, southern and western extremities of the study area. In general, the Ag contents of gold populations rises with distance from Wells, although both high-Ag and low-Ag subpopulations may coexist at these localities. This observation raises the possibility of zonation of alloy compositions on a regional scale. Samples are scarce north of Wells but the presence of a relatively high proportion of high-Ag gold grains from Summit Creek near Eight Mile Lake (Figure 1; McTaggart and Knight, 1993) lends some support to the hypothesis of a large, broadly zoned system. The occurrence of a zone of Hg-rich gold grains also rich in Ag at the periphery of a larger zone of Ag-rich gold grains has been previously recorded in the Klondike District in western Yukon (Chapman et al., 2010a, b). These authors interpreted the presence of Hg as indicative of lower-temperature hydrothermal activity emplaced at higher structural levels. Only the gold sample from Dragon Creek in the western part of the Wells-Barkerville area (Figure 4) contains a significant amount of Hg, which could be consistent with formation at the cooler outer fringe of a zoned hydrothermal system.

Placer-Lode Gold Relationships and Implications for Exploration

Comparison of Placer-Lode Compositions

In the Wells area, the distinctive signature of type 1 gold grains is evident in populations of placer gold from nearby drainages. Elsewhere, close relationships are more difficult to establish because of the variability of the alloy compositions between adjacent localities and commonly within lode-gold populations from individual localities. Nevertheless, in areas where compositions of lode and placer gold are available, there is substantial overlap (e.g., Spanish Mountain, Frasergold). The wider range of compositions in the placer-gold samples may either be a consequence of gold grains derived from other as yet undiscovered sources, or the consequence of vertical variation in Au alloy composition in a deposit or cluster of deposits with highly heterogeneous signatures.

The alloy signatures of gold grains are indicative of the chemical environment of Au precipitation (Gammons and Williams-Jones, 1995). Consequently, variation in the alloy compositions of single populations provides information concerning the stability of the environment of Au precipitation. Inspection of the Ag plots for lode gold (Figure 7) shows that while some samples are dominated by a narrow range of compositions (e.g., Midas and Cow Mountain lodes), others comprise a series of well-defined steps (e.g., BC Vein, Myrtle and Hibernian). Other lodes, such as Proserpine AU586 (MINFILE 093H 021), show a continuum of compositions over a range of Ag contents. Gammons and Williams-Jones (1995) identified the parameters that control the Au/Ag ratio in Au alloys, and Chapman et al. (2010a, b) discussed the influences on the variation in gold-grain composition in the Klondike placer-gold district. These authors explained the variation in gold composition within single veins as a consequence of temporal variation in both temperature and in particular the aqueous ratio of Au/Ag. Because gold is preferentially precipitated from these solutions, the alloy composition becomes progressively richer in Ag with time. This effect is amplified if precipitation occurs within a closed system; i.e., in the absence of influx of mineralizing fluid. Thus, horizontal plots can indicate a strong mineralizing system where the precipitation of Au does not substantially alter the Au/Ag_{aq}. Conversely, continuous steep curves suggest rapid alteration of the precipitation conditions, perhaps associated with a closed (smaller) system. Steps in the curve, where confidently identified in large (>50 grain) sample sets, are interpreted as indicative of a break in the history of precipitation, implying successive pulses of mineralizing fluids.

Previous studies have demonstrated the benefit of taking samples of placer gold from the headwaters of drainage systems (e.g., Chapman et al. 2010a, b). The resulting sample populations commonly yield a clearer signature of gold derived from proximal mineralization. In this study, however, the signatures recorded from such sampling sites were commonly complicated. There are two possible reasons for this. First, the placer composition may faithfully represent the real variability in the local source mineralization. Comparison of the Ag contents of gold grains from the BC Vein (MINFILE 093H 019) and the Myrtle occurrence (MINFILE 093H 025) near Wells (Figure 7b) illustrates the degree of variation of signatures possible in a small geographic area. Placer signatures, however, may show variation, either as a consequence of mixing subpopulations, each with a narrow Ag range (e.g., Williams Creek; Figure 8b), or because the signature of a single lode source exhibits a continuum of alloy compositions (e.g., Proserpine and Myrtle; Figure 7b). Secondly, the complex geomorphological history of the study area may affect crosscontamination of signatures between current drainages. Levson and Giles (1993) presented a detailed sedimentological study of the main placer localities throughout central BC. These authors showed that paleochannels cut across the drainage pattern of the current topography. This is the first major study of placer-lode gold relationships in which there is a possibility of cross-drainage 'contamination' of the placer signature. In the light of this potential complication, the practice of mounting gold grains from the same site according to morphology provides valuable information.

One major objective of the project was to establish whether placer-gold signatures could be employed to target Cu-Au porphyry mineralization of the Mount Polley type currently unidentified in the low-lying and poorly exposed areas in the west of the study areas. Central to this aim was the identification of the signature of the gold associated with this style of mineralization. Sampling in upper Morehead Creek, the nearest practical location to the Mount Polley mine (MINFILE 093A 008; Figure 1), failed to recover any gold grains despite considerable effort. Subsequently, discussions with geologists from the Mount Polley mine revealed that the particle size of the gold was too fine to permit accumulation in placer deposits. Consequently, we conclude that the placer samples from Morehead Creek reported by McTaggart and Knight (1993) are likely derived from orogenic-style gold mineralization, and that the particle size of the gold associated with some Cu-Au porphyry outcrops presents a barrier to their discovery using panned grains of gold.

Correlation of Compositional Data with Production Records

Holland (1950) provided production figures for most placer streams in the Cariboo Mining District until 1945, indicating a total of 14 200 000 g (500 000 oz.). While incomplete, these figures provide an indication of the relative economic importance of the placer deposits. Placer deposits comprising the low-Ag type 1 gold grains can be identified both by their locality (with respect to the zone of type 1 gold grains identified in this study) and the fineness data presented by Holland (1950). Lightning Creek was by far the largest single producer in the region (total production approximately 3 700 000 g [130 000 oz.]; Holland, 1950) and the drainage overlaps the zone of type 1 gold grains. Consequently, it is certain that the gold inventory of Lightning Creek includes type 1 gold grains, although the proportion cannot be inferred from fineness data alone. The compositional data of McTaggart and Knight (1993) show that approximately 35% of the placer grains from Lightning Creek contains less than 9% Ag and are likely to be type 1 gold grains. Summation of the production figures for placer deposits where it is possible to estimate the amount of type 1 gold grains yields a figure of 4 800 000 g (170 000 oz.), which is approximately one third of the total production of the region. Type 1 gold grains are present only in a small part of the whole placer area, which suggests a centre of mineralization at this point.

This analysis highlights the two mechanisms by which placer deposits can form. Small creeks close to the source may be rich in gold by virtue of lack of transport of the gold particles, whereas those in the trunk drainages usually form as a consequence of favourable sedimentary conditions. The small gold-rich placer streams near Wells and Barkerville form an excellent example of the first type (e.g., Lowhee Gulch: 2 100 000 g [74 000 oz.], Mosquito Creek: 510 000 g [18 000 oz.] and Stouts Gulch: 430 000 g [15 000 oz.]), whereas Lightning Creek (3 700 000 g [130 000 oz.]), Slough Creek (850 000 g [30 000 oz.]) and the Cottonwood River (280 000 g [10 000 oz.]) provide examples of the second model of placer formation. Most notably, Williams Creek (2 400 000 g [84 000 oz.]) exhibits two distinctive ranges of Ag (see Figure 8b), which is also reflected in the range of published fineness values (Holland, 1950). Many of the placer streams to the north, east and south of Barkerville were also relatively rich (e.g., Grouse Creek: 400 000 g [14 000 oz.] and Antler Creek: 960 000 g

[34 000 oz.]). In general, the richest placer deposits are relatively close to the towns of Wells and Barkerville or are present in rivers that drain this area.

The type 2 gold grains found in Williams and Antler creeks comprise identifiable subpopulations. Type 2 gold grains could represent a different episode of mineralization to type 1 gold grains, but the two types appear to have a clear geographic demarcation, which is more suggestive of zonation than multiple episodes of fluid influx. It is interesting to note that the most important placer deposits of type 2 gold grains contain the high-Ag subpopulation (20–25%). This signature has not been identified in any lode source but is a major component of gold grains in both Williams and Antler creeks.

The regional distribution of gold grain compositions in the Wells-Barkerville area differs from that previously recorded in a similar study in the Klondike District in western Yukon (Chapman et al., 2010 a, b). In the Klondike, discrete hydrothermal systems were proposed on the basis of the correlation between high Au abundance and low Ag contents. This correlation was ascribed to the progressive impoverishment of the mineralizing fluids in Au, and the minor Ag-rich signature was interpreted to be indicative of a waning hydrothermal system. This model is only partially applicable to the CGD. It may be that type 1 gold grains represent the centre of activity of a regional-scale hydrothermal system, which preferentially deposited Au and other metals such as Bi, Co and Ni. In some economically important placer localities, however, Ag-rich gold grains form an important part of the gold inventory (e.g., Williams and Antler creeks). Consequently, the genetic relationship between type 1 and type 2 gold grains in this area remains unclear. The spatial relationships of the occurrence of the two types are suggestive of zonation, but the high abundance of Ag-rich gold grains (of narrow compositional range) at several localities suggests the presence of a separate strong hydrothermal system. Alternatively, the high-Ag gold grains could represent a separate mineralizing episode either pre- or postdating a zoned system such as those observed in the Klondike.

Lode-gold occurrences in the Cunningham and Antler creek drainages generally contain significantly higher Ag contents than those in the Wells area (Mortensen et al., 2011), which is consistent with the higher Ag contents observed in the placer gold in these drainages. The ^{40}Ar/^{39}Ar ages for hydrothermal mica from gold-bearing veins in the vicinity of Wells fall in the same age range as those from the Cunningham and Antler creeks areas (ca. 148–135 Ma; Mortensen et al., 2011); thus, type 1 and type 2 gold mineralization appears to have formed at the same time, consistent with the presence of a single laterally zoned system centred approximately on Wells.

The presence of placer-gold signatures in both the Spanish Mountain and Frasergold areas that differ significantly from the signatures of known lode occurrences in the vicinity suggests that other lode occurrences, possibly of somewhat different in style, may be present in these areas.

Discussion

This study has shown that there is systematic regional variation in gold composition around the Wells-Barkerville area in the CGD. The most important gold-grain signatures have been identified from correlation of compositional studies of lode and placer gold with placer production records. The major proportion of placer gold (and nearly all of the lode gold) discovered in the Cariboo was from the area close to Wells and Barkerville, and comprised type 1 gold grains, a low-Ag gold with a distinctive Bi-Co-Ni-As signature, and type 2 gold grains, binary alloys with a simple mineralogy commonly featuring a component alloy of relatively high (20–25%) Ag. At a local level, there is typically substantial variation in the composition of gold grains, which suggests some variability in the physicochemical conditions in the mineralizing system. While the signatures of some lode and placer populations are entirely typical of orogenic gold regions elsewhere, this degree of variation has not been previously observed in an important placer area. The genetic relationship between gold grains types 1 and 2 remains unresolved but we believe that the observed abundances of the various compositional types and subpopulations are best explained by the augmentation of a zoned goldfield by a separate mineralization event that contributed a second generation of gold grains of higher Ag contents. Nevertheless, we acknowledge that this explanation is highly speculative in the absence of evidence gained from the examination of lode sources.

Comparison of gold signatures throughout the study area shows that type 2 gold grains are present in all areas except in the zone of type 1 gold grains. Although the Ag contents of populations tends to increase away from Wells, the more distant localities commonly exhibit a mixture of both high-Ag and low-Ag populations. Variation in the alloy composition alone is insufficient to differentiate between a single event with temporal variation in mineralizing conditions or multiple episodes of fluid influx. In many cases, it is possible that an economically viable placer resource may have formed from several relatively minor vein systems; however, the interpretation of the nature of placer-gold signatures can indicate whether the contributing sources are derived from a large stable hydrothermal system or smaller mineralizing events. Consequently, it would appear that the best targets for exploration are in the vicinity of the known rich placer deposits. In particular, the absence of gold grains containing 20–25% Ag, which is a major component of rich placer deposits near Wells but unknown in lode mineralization, shows that potentially important mineralization remains to be discovered in this area. By a similar analysis, the low-Ag gold grain population in the placer gold of the MacKay River indicates the presence of other undiscovered lode sources within this drainage.

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