Application of placer and lode gold geochemistry to gold exploration in western Yukon

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Mortensen, J.K., Chapman, R., LeBarge, W. and Jackson, L., 2005. Application of placer and lode gold geochemistry to gold exploration in western Yukon. *In:* Yukon Exploration and Geology 2004, D.S. Emond, L.L. Lewis and G.D. Bradshaw (eds.), Yukon Geological Survey, p. 205-212.

ABSTRACT

Placer gold is widely distributed throughout the western Yukon; however, lode sources for most of these deposits remain unknown. Previous studies of gold compositions in this region using scanning electron microscope (SEM) and electron microprobe (EMP) methods showed 1) that there are consistent differences in average composition (although with considerable overlap) between gold from different styles of lode gold mineralization; and 2) the composition(s) of placer gold can be matched with specific lode sources, or the most likely style of lode source can be identified. In the current study we employ SEM and EMP methods together with laser ablation ICP-MS trace element analysis and study of the micro-inclusion suite(s) to more completely characterize the major, minor and trace element composition of the gold as well as the mineralogy of the lode sources themselves. We also report new data for placer and lode gold, mainly from the Klondike District.

RÉSUMÉ

L'or placérien est largement répandu dans l'ouest du Yukon; les sources filoniennes de la plupart de ces gisements demeurent cependant inconnues. Des études antérieures de l'or de cette région à l'aide des méthodes d'analyse par microscopie électronique à balayage (MEB) et par microsonde électronique ont démontré 1) qu'il existe des différences cohérentes moyennes (malgré des recoupements considérables) entre l'or de différents styles de minéralisation filonienne et 2) que l'or placérien peut être apparié à des sources filoniennes spécifiques ou que le style le plus probable de la source filonienne peut être identifié. Dans la présente étude, on utilise les méthodes d'analyse par MEB et par microsonde électronique combinées avec l'analyse d'éléments traces par ICP-MS à ablation par laser et avec l'étude de la ou des suites de micro-inclusions, afin de caractériser de manière plus complète la composition en éléments majeurs, mineurs et traces ainsi que la minéralogie des sources filoniennes elles-mêmes. De nouvelles données sur l'or placérien et filonien du district du Klondike sont signalées dans le présent document.

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INTRODUCTION

Western Yukon hosts very widespread occurrences of placer gold, including the well-known deposits of the Klondike, Sixtymile and lower Fortymile districts. The lode (bedrock) source(s) from which most of these deposits were derived, however, remains largely unknown. This is due to several factors. Most importantly, much of the western Yukon escaped glaciation, and although this undoubtedly played a major role in the development and preservation of the placer deposits, it also resulted in very limited bedrock exposure (<1% in most areas), and consequently, a somewhat fragmentary understanding of the bedrock geology of the region. In addition, the area experienced deep surface weathering during the Paleogene and the geochemical signature of underlying mineralization in soils and silts is commonly relatively subdued on regional geochemical surveys. Exploration has identified a wide range of styles and ages of lode gold mineralization in western Yukon, but very few detailed mineral deposit studies have been carried out thus far.

The western Yukon lies in the central portion of the Tintina Gold Province (TGP; e.g., Hart et al., 2002), and some of the exploration within the TGP over the last decade has focused on this area, in part because of the presence of the placer gold deposits. Gold is widely distributed in soils and silts in the region in addition to the placer deposits themselves. Exploration has been greatly hampered, however, by the lack of detailed bedrock geology maps for the area and an inadequate understanding of what types of lode targets are present. The presence of widely distributed and commonly very rich deposits of placer gold suggests that the potential for economically important lode sources certainly exists.

One approach to assessing the significance of placer gold deposits in western Yukon, with respect to the potential for economically important lode deposits, is to examine the composition and morphology of the placer gold in various areas and attempt to determine what style(s) of lode source(s) it was derived from. Two studies of this type have previously been carried out in the western Yukon. In this study we expand on the previous work and apply new analytical approaches to a much more comprehensive suite of placer and lode gold samples from throughout the region.

LODE GOLD MINERALIZATION IN WESTERN YUKON

There is a very broad range of styles and ages of lode mineralization in western Yukon that are known, or inferred, to contain gold of sufficiently coarse grain size to have potentially been concentrated into placer deposits (Table 1). Based on our current knowledge of the regional geology and types of mineral deposits present in western Yukon, however, only some of these deposit types (shown in bold in Table 1) are considered to have any realistic potential of forming a deposit of economic size and grade. From an exploration point of view, it would be very valuable to be able to filter out gold geochemical anomalies (including placer gold deposits) that were derived from deposit types that are less likely to have significant economic potential.

Table 1. *Styles/ages of lode occurrences and occurrences containing gold in western Yukon. Bold type indicates deposit types that could form an economic deposit in western Yukon.*

Deposit/occurrence type	Age	Examples (occurrences and/or areas)
Epithermal vein	**Mid-Cretaceous**	**Mt. Nansen area**
Epithermal vein	**Late Cretaceous**	**Sixtymile area, Eureka Dome**
Epithermal vein	Early Paleogene	Germaine Creek (Dawson map area)
Intrusion-related vein	**Mid-Cretaceous**	**Moosehorn Range, central Dawson Range**
Intrusion-related vein	Late Cretaceous	Mosquito Gulch area (NW Stewart River map area)
Intrusion-related vein	Early Jurassic?	Tenmile Creek area (central Stewart River map area)
Gold-bearing skarn	Late Cretaceous	south side of Sixtymile River
Gold-bearing porphyry	**Early Jurassic**	**Minto, Williams Creek (Carmacks Copper)**
Intrusion-related vein	**Late Cretaceous**	**Casino**
Metamorphogenic (orogenic) vein	**Early or Middle Jurassic**	**Klondike**
“Listwanite-type” veins	Jurassic?	Atlin, Sixtymile?
Gold-enriched VMS	Permian	Lone Star, Bronson, Baldy (in Klondike Schist)

PREVIOUS GOLD COMPOSITIONAL STUDIES IN WESTERN YUKON

Two previous studies investigated the composition (and morphology) of placer and lode gold in the western Yukon. Knight et al. (1999a,b) carried out a very detailed study of gold from both placer deposits and known gold-bearing metamorphogenic vein occurrences in the Klondike District. They employed scanning electron microscope (SEM) and electron microprobe (EMP) methods to characterize the compositional ranges of gold from various lode occurrences throughout the Klondike District, as well as the compositions of unleached cores and leached rims on placer gold particles from most of the placer streams in the district. Placer gold frequently exhibits a gold-enriched rind or rim, typically 1 to 20 microns in thickness, surrounding a core. Compositional studies relating placer to lode gold typically investigate the core composition, as this has been shown to be faithful to gold grains liberated from the hypogene source (e.g., Herail et al., 1990; Loen, 1994; Lange and Gignoux, 1999). In addition to this comopositional data, the shapes of the placer grains were documented and the relationship between grain shape (especially flatness and roundness) vs. inferred transport distance was evaluated. The study by Knight et al. (1999a,b) identified several discrete source areas for compositionally distinct placer gold in the Klondike. Dumula and Mortensen (2002) carried out a regional study which examined the composition of placer gold and potential lode sources from several localities in the central and southern Stewart River map area. The main conclusions that resulted from the Knight et al. (1999a,b) and Dumula and Mortensen (2002) studies include:

- There are consistent and measurable differences in average composition (although with considerable overlap) between gold from different styles of lode gold and from specific occurrences;
- The shape of placer gold grains (flatness, roundness, etc.) changes in a consistent manner with increasing distance traveled;
- In some instances the composition(s) of placer gold can be matched with specific lode source(s), or at least the most likely style of lode source can be identified.

Two limitations of the previous studies are that only major and minor element (i.e., gold, silver, copper and mercury) concentrations could be measured using EMP methods, and there were relatively limited sample suites from a small number of areas. Importantly, Knight et al. (1999a,b) analysed a large number of grains, and thereby generated data that define the degree of internal variation within alloy composition from a particular source.

ANALYTICAL APPROACH

Our aim is to employ several different analytical methods to develop as unique a compositional signature as possible for placer and lode samples from western Yukon. We will use four main analytical approaches in this study:

- document the micro-inclusion suite within the placer (and lode) gold grains;
- determine, using electron microprobe (EMP) methods, the major and minor element composition of lode gold itself and unleached cores of placer grains;
- determine, using laser ablation ICP-MS, the trace and ultra-trace element composition of the grains; and
- examine the shape of placer gold grains using scanning electron microscope (SEM) methods to estimate how far the individual grains have traveled from their bedrock source.

Some of the advantages and potential problems with each of these methods are discussed below; however, we believe that this coordinated approach to gold characterization is the most appropriate method for addressing the historically intractable problem of sourcing placer gold in the western Yukon.

MICRO-INCLUSION SUITES

This approach has not previously been employed to any significant extent in the Yukon, although it has been used to establish a specific “signature” for placer gold in other districts (e.g., Chapman et al., 2000). Micro-inclusions contained within placer gold grains should provide a sampling (albeit not necessarily a complete representation) of the ore and gangue mineralogy of the lode source from which it was derived. In some cases this should provide a unique signature for specific deposit types — e.g., inclusions of enargite might be taken to indicate that the gold was most likely derived from a high-sulphidation epithermal deposit. In other cases, an unusual mineral may be common and hence diagnostic of a specific mineralizing event. For example, argentite inclusions are present in mesothermal gold from Walhalla goldfield, Victoria, Australia. Most common mineral inclusions (e.g., pyrite, galena, sphalerite, arsenopyrite), however, are not unique to a particular deposit type. Despite this, with a large sample size, the relative proportions of mineral inclusions within gold grains that belong to the specific mineral classes (e.g., sulphides, sulpharsenides, tellurides and sulphosalts) can provide useful information for comparative studies (e.g., Leake et al., 1997; Chapman et al., 2000). Potential problems associated with this approach are that inclusions are not always initially present in the gold, and inclusions tend to become less abundant the farther a placer grain has traveled (likely due to hammering and/or alteration during transport and subsequent residence in the surficial environment).

MAJOR AND MINOR ELEMENT COMPOSITION

A considerable amount of EMP compositional data exists for gold from many different styles and ages of lode gold from around the world. This provides a template against which to compare compositions of the unleached cores of placer gold grains. Limitations of the technique are: (1) only a relatively small number of elements are commonly present in naturally occurring gold at sufficient concentrations to be measurable by EMP methods (gold, silver, copper and mercury, rarely bismuth and tellurium); (2) the compositional data for gold from different deposit types are generally not unique; and (3) a large sample size is commonly required to adequately characterize the alloy composition of gold from a single mineralizing event. This third limitation is particularly relevant when a population of placer gold grains represents more than one bedrock source.

TRACE ELEMENT COMPOSITION

Laser ablation ICP-MS (LA-ICP-MS) analyses of samples of lode and placer gold (e.g., J. Youngson, pers. comm., 2004) shows that measurable amounts of many elements (e.g., molybdenum, bismuth, tellurium, antimony, tin, etc.) are present at detectable and highly variable levels in gold from different styles of lode mineralization. This provides a much greater range of elements to use as a geochemical fingerprint for gold than is offered by EMP methods alone. To date, very little LA-ICP-MS compositional data is available for gold, therefore there are limited compositional data with which to compare the initial results from the western Yukon samples.

GRAIN SHAPE

Knight et al. (1999b) used measured shape data, especially grain flatness and roundness, for placer gold grains from the Klondike District to generate shape vs. transport distance curves (e.g., Fig. 4 in Knight et al., 1999b). Their data suggested that gold grains transported in streams flatten rapidly within the first 2 to 3 km of transport from source and then flatten at a slower but relatively constant rate with increasing transport distance. There are several considerations that must be kept in mind when constructing such a model curve. First, an estimate of the distance a particular placer grain has been transported assumes that the location of the source is accurately known. Secondly, at least some lode gold grains in the Klondike initially form relatively flat, rather than rough or equant, morphologies. Thirdly, there is undoubtedly some amount of “armouring” of gold particles during transport. The probable source of all or most of the Klondike placer deposits is considered to be gold-bearing quartz veins (Knight et al., 1999a). In this style of mineralization, gold grains commonly occur within grains or grain aggregates of pyrite or as free grains enclosed by quartz, and many such grains may have initially been encapsulated in quartz or pyrite and not liberated from their mineral host until some time after transport began. The flatness vs. transport distance curve developed by Knight et al. (1999b) is based on a very large number of grain measurements, and should be adequate to derive at least a first-order estimate of transport distance for placer gold grains, not only in the Klondike itself, but also in other parts of western Yukon that are unglaciated and shared the same general history of climate and landscape evolution.

Townley et al. (2003) also investigated the relationship between gold grain shape and transport distance in several localities in central Chile and developed several generic criteria indicative of transport distance.

INITIAL RESULTS

As a starting point for this study, we examined a number of samples of lode and placer gold from the Klondike District. Figure 1 shows locations of the main lode occurrences in the Klondike, and also shows the three main inferred “high fineness” and two inferred “low fineness” source areas as identified by Knight et al. (1999a). Our EMP analyses for the lode gold samples from five of the main lode occurrences are plotted as cumulative percentile plot for silver (Ag) in Figure 2a. Our results generally confirm the compositional ranges described by Knight et al. (1999a). Several features are evident from the data.

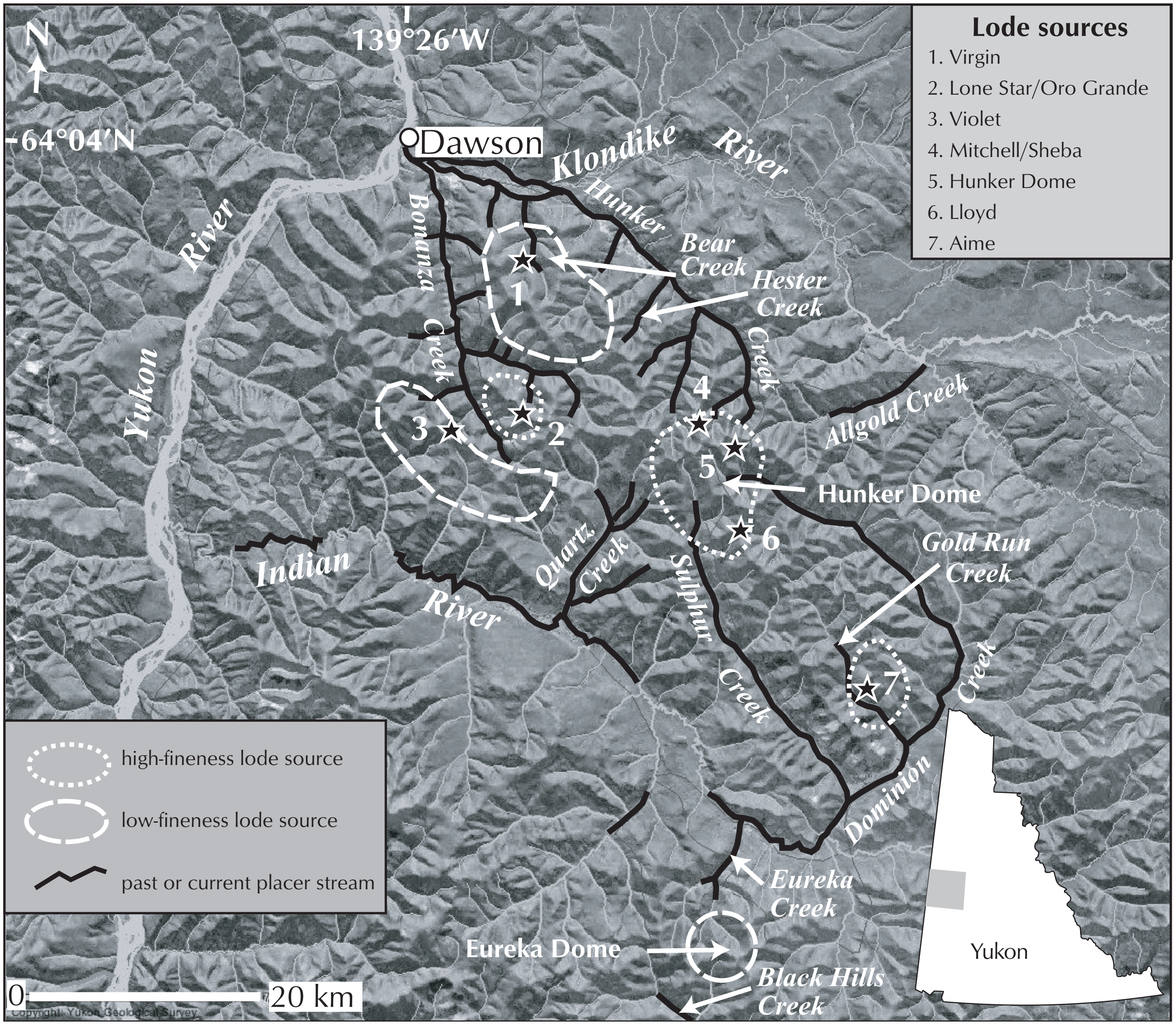

Figure 1. *Shaded relief map of the Klondike District and surrounding areas showing the main placer streams. Also shown are the main lode gold occurrences as well as inferred low fineness and high fineness gold source areas as determined by Knight et al. (1999a) and Dumula and Mortensen (2002).*

First, most of the lode gold samples from throughout the Klondike fall within the same relatively narrow range of silver contents (~13 to 20 wt.% Ag, or roughly 800 to 870 fineness). Gold from the Hunker Dome occurrence consists of two distinct populations in terms of silver content, one at ~14 to 15 wt.% Ag and one at ~17 to 20 wt.% Ag (Fig. 2a). Gold from the Virgin occurrence on Bear Creek (Fig. 1) is distinct by containing much higher silver contents (~28 to 32 wt.% Ag; Fig. 2a). Second, on a cumulative percentile plot for mercury (Hg) content of Klondike lode gold (Fig. 2b), data from most of the occurrences are similar to those shown for the Hunker Dome lode, with most analyses containing mercury levels below the detection limit of the EMP method, except for a relatively small proportion of grains with up to 0.2 wt.% Hg. This contrasts with gold from the Virgin occurrence, nearly all of which contains detectable amounts of mercury and in some cases up to several weight percent. Finally, gold compositions from the Mitchell vein occurrence are indistinguishable from the compositions of gold from samples of gold-bearing altered schist wall rocks to the vein. Gold in the wall rocks occurs within narrow (up to 40 cm in width) zones of strong bleaching, sericitization and pyritization (e.g., Mortensen et al., 1992). Gold in this altered schist mainly occurs within secondary pyrite that replaces original porphyroblasts of magnetite.

In Figure 3, silver and mercury contents of placer gold recovered from middle Bonanza Creek, lower Hunker Creek, Bear Creek and Hester Creek are plotted together with lode gold from the Hunker Dome and Virgin lode

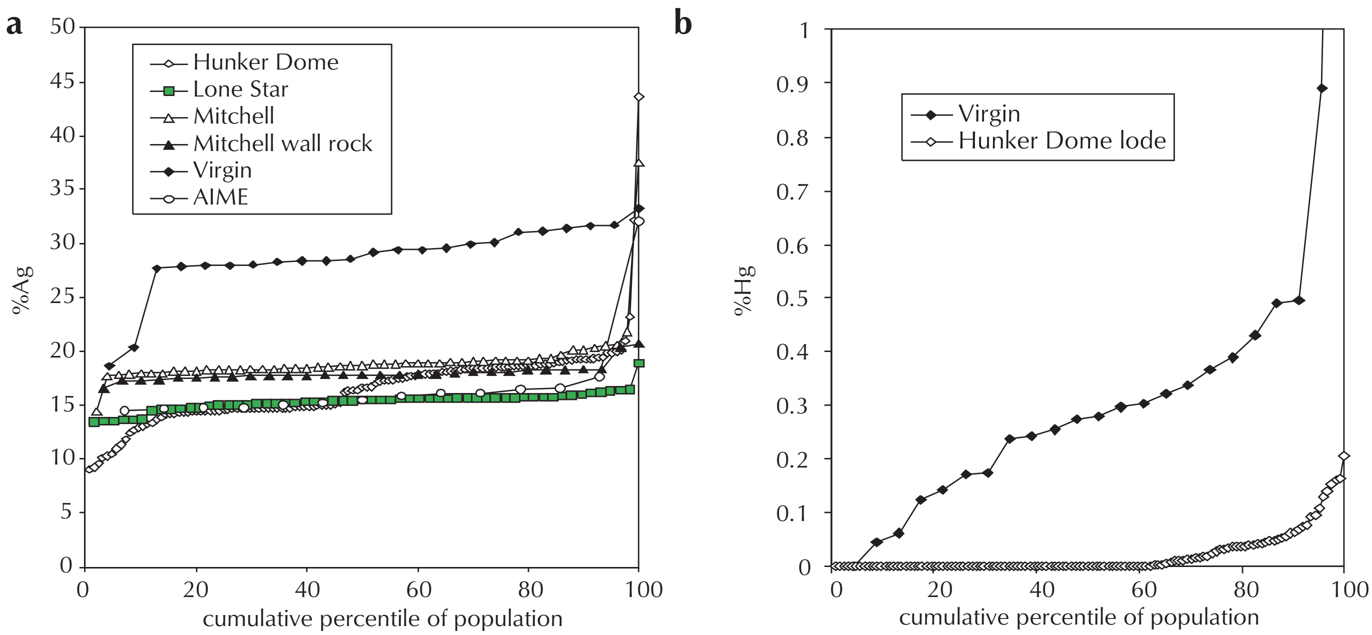

Figure 2. *Cumulative percentile plots for silver and mercury contents for gold from lode occurrences in the Klondike District.*

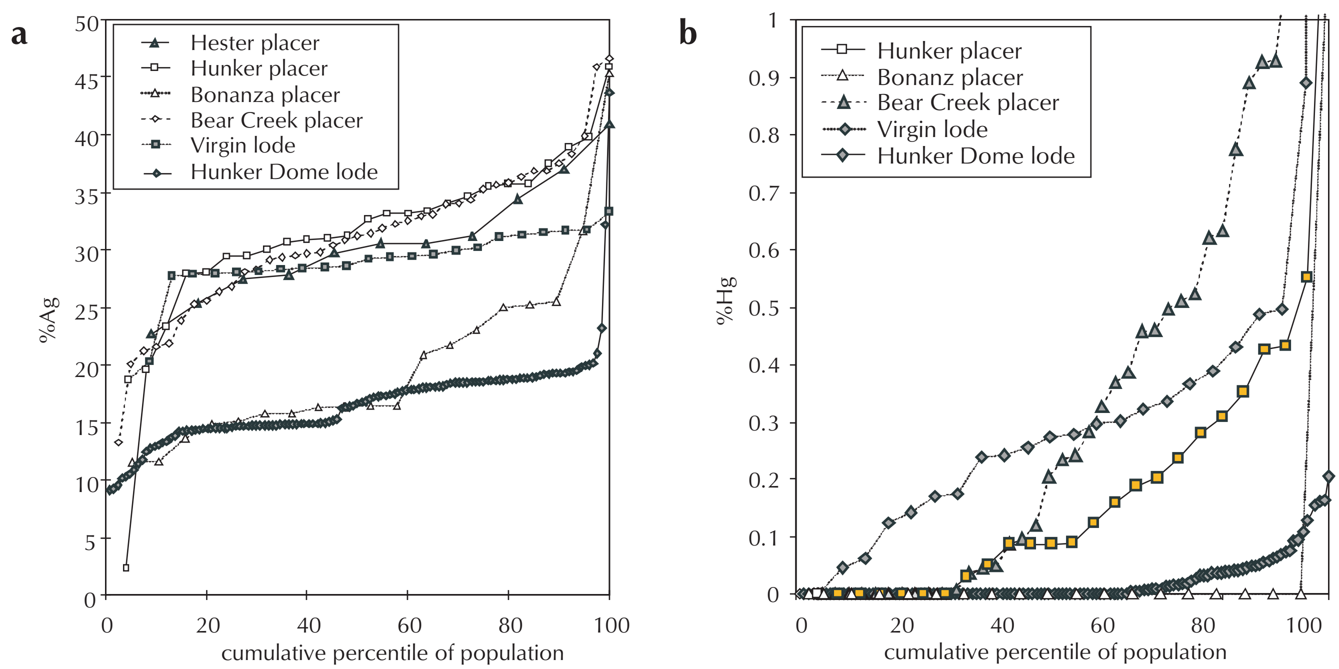

Figure 3. *Cumulative percentile plots for silver and mercury contents for gold from various placer deposits and lode occurrences in the Klondike District.*

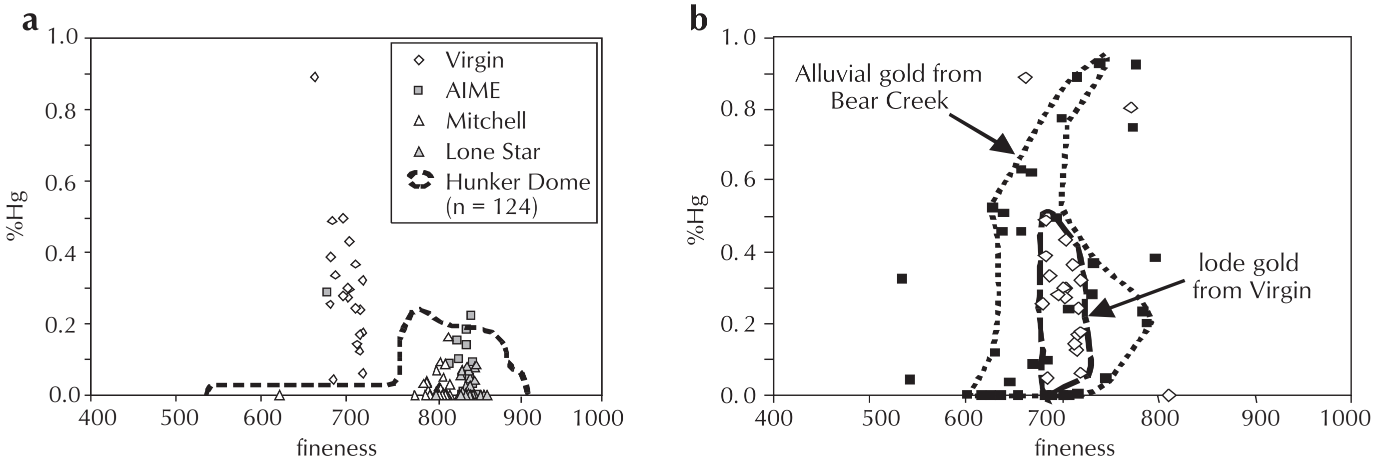

Figure 4. (a) *Plot of mercury content vs. fineness for gold from various Klondike lode occurrences;* ***(b)*** *detailed comparison between placer gold from Bear Creek and lode gold from the Virgin lode occurrence.*

occurrences. Figure 3a shows that placer gold from Bear, Hester and lower Hunker creeks displays similar high wt.% Ag (low fineness) to that from the Virgin lode, and is quite distinct from low wt.% Ag (high fineness) gold from the Hunker Dome lode. Some of the placer gold from the middle part of Bonanza Creek has compositions that are similar to those of high fineness gold from the Hunker Dome occurrence, whereas some of the gold has distinct compositions with more intermediate silver contents. All but one of the placer gold grains analysed from Bonanza Creek do not contain detectable mercury and therefore most resemble the Hunker Dome lode gold (Fig. 3b). Placer gold grains from Bear and lower Hunker creeks contain variable but generally substantial mercury and therefore most closely resemble gold from the Virgin lode.

The lode gold data for the Klondike District is recast in a plot of wt.% Hg vs. fineness (Fig. 4a). This plot highlights the overall similarity in composition of most of the lode gold in the Klondike and the very distinct composition of gold from the Virgin lode. Gold from the Violet lode occurrence (Fig. 1) yields similar low fineness and high mercury compositions (Knight et al., 1999a). A detailed comparison of the compositions of placer gold from Bear Creek and lode gold from the Virgin occurrence (Fig. 4b) shows clearly that the Bear Creek gold was derived from the Virgin lode and/or lodes of similar geochemical character.

WORK IN PROGRESS

We are currently preparing an extensive suite of placer gold samples from deposits from throughout western Yukon for detailed study. These samples are first examined using binocular microscope and SEM methods to characterize the overall shape characteristics. The grains are then mounted in epoxy 'pucks', ground down to expose the centres of each grain and brought to a high polish. The grains are mounted in an orientation that allows the aspect ratio of each grain (a measure of flattening) to be directly measured on the SEM. The nature and thickness of leached rims is then examined on the SEM using back-scattered electron images, and mineral micro-inclusions are identified and analysed. The major and minor element composition of the cores and in some cases the rims of the grains are determined using EMP methods. Finally, the trace element composition of the gold grains is determined using laser ablation ICP-MS methods. All shape, micro-inclusion and compositional data is then compiled on a sample-by-sample basis. Approximately 50 to 100 individual grains are analysed from each placer sample in order to confidently identify all the main compositional populations.

ACKNOWLEDGMENTS

We thank the Yukon Geological Survey for providing seed funding for the project, as well as numerous placer miners from western Yukon for contributing samples for study. Thanks also to many of the lode and placer mining exploration personnel working in the region for guidance and discussions in the field.

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