Atlin Placer Gold Nuggets Containing Mineral and Rock Matter: Implications for Lode Gold Exploration

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KEYWORDS: placer gold, intrusive-related gold, Atlin, Yellow Jacket, gold deposit, listwanite, quartz-carbonate-mariposite alteration, Surprise Lake batholith, Boulder Creek, Otter Creek, Snake Creek, Quartz Creek, Ruby Creek, Pine Creek, Feather Creek, anthropogenic gold nuggets

INTRODUCTION

Placer gold deposits are derived from lode gold bedrock sources. Thus, gold placers are a first-order exploration vector for lode gold deposits. In many placer camps lode gold sources remain elusive as past attempts to trace placer mineralization upstream to the lode source have not met with success. However, an oft-overlooked and effective means for establishing a geological context for the lode gold source is to look for diagnostic mineral matter that is intergrown with the placer gold. Non-quartz mineral or rock matter is of most use as quartz is ubiquitous. In the Atlin placer camp of northwestern British Columbia (Figure 1), this methodology was applied to the juvenile placer deposits of Feather Creek (Sack and Mihalynuk, 2004) and diagnostic mineral intergrowths of gold with thorite and cassiterite were identified. These minerals provide an unambiguous genetic linkage to the U, Th and Sn-enriched Surprise Lake batholith (Figure 2). Such a relationship is not surprising given that most of the productive placer streams in the Atlin camp have at their headwaters the Surprise Lake batholith or its thermal metamorphic halo (Figures 2, 3). However past exploration efforts in the Atlin placer camp have followed the ultramafic-associated lode gold deposit model, focusing on the widely distributed altered ultramafic rocks. Indeed, within the entire Atlin camp, the only significant lode gold production is from altered mafic-ultramafic rocks at the Yellow Jacket deposit.

As a test for the utility of searching for more subtle intrusive-related lode gold sources of gold, this project

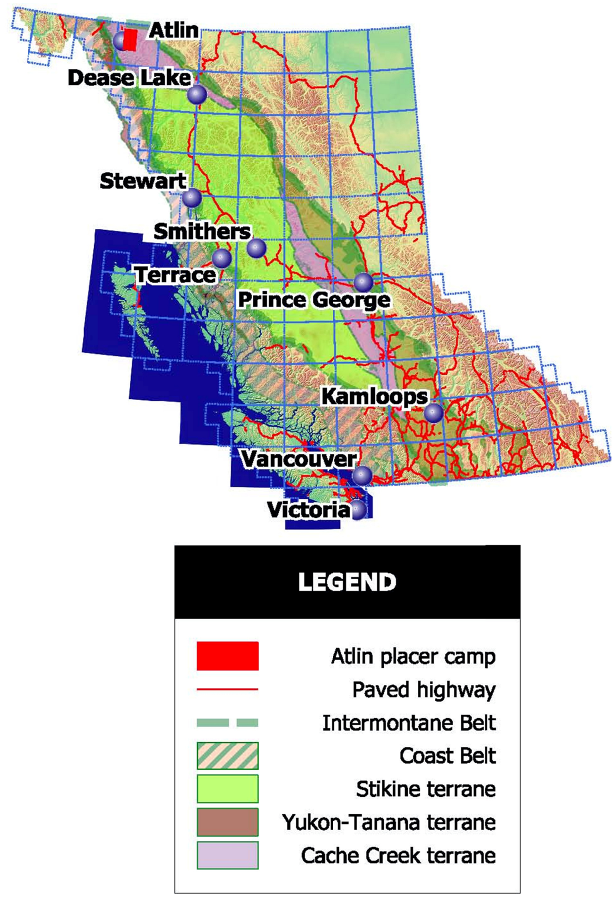

Figure 1. Location of the Atlin placer camp in northwestern British Columbia.

looked for intrusive-related mineral matter intergrown with gold in nuggets recovered from five established placer streams in the Atlin camp. So far, we have been unable to repeat the results of Sack and Mihalynuk (2004) in any other placer stream. We find no clear signal of an intrusive-related source for the placer gold, nor do we see evidence of a listwanite lode gold source. In at least one placer stream, gold is intergrown with graphitic argillite in the stream bed.

LODE GOLD EXPLORATION

Persistent exploration efforts in placer camps can succeed in revealing lode gold sources. One recent success story is at the margin of the historic Klondike district (Lowey, 2006), where a resurgence of lode gold

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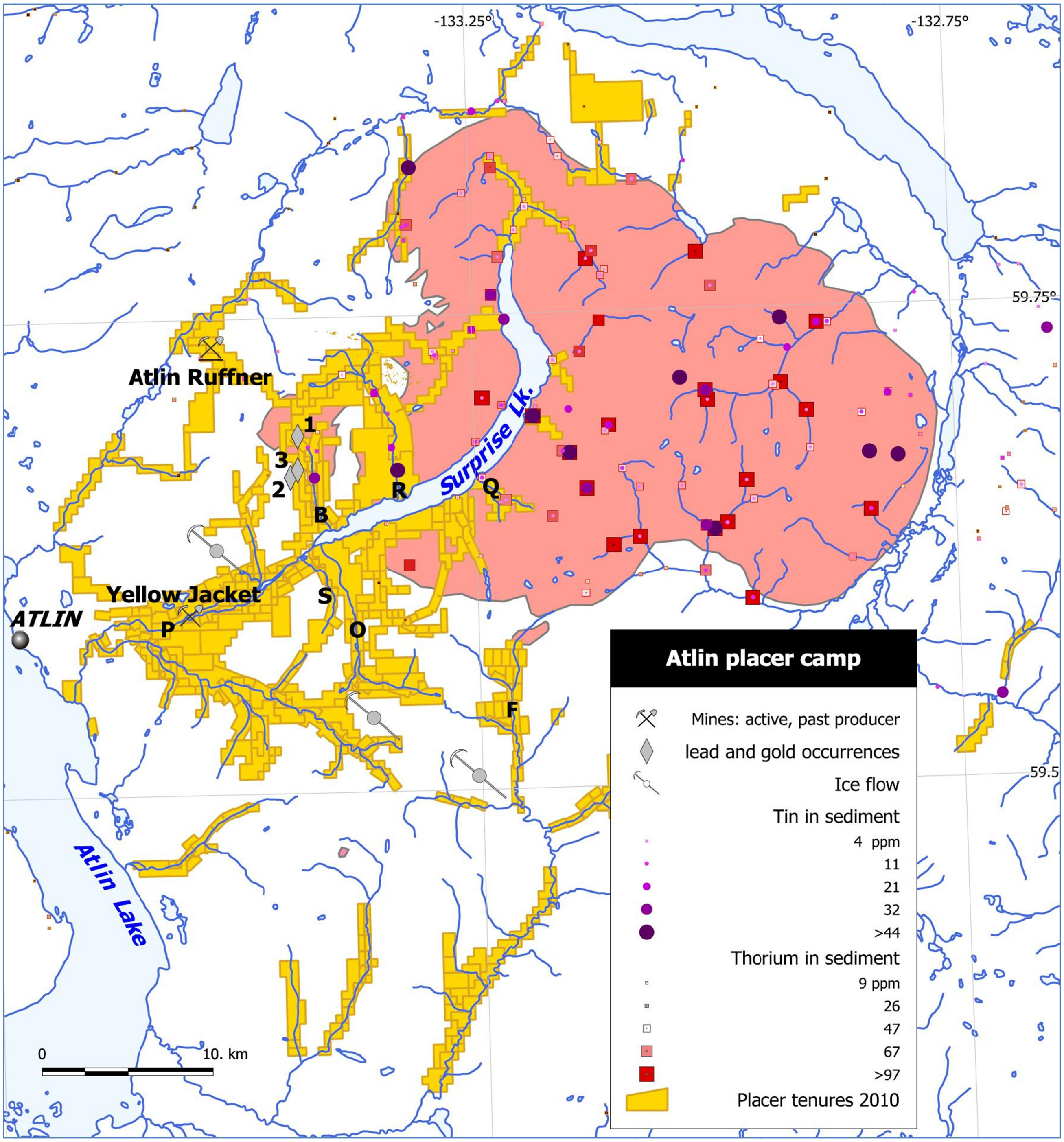

Figure 2. Map of the Atlin camp showing placer tenures (yellow) as of November, 2010. Almost all of the placer streams have the Surprise Lake batholith (pink) or its thermal metamorphic halo in their headwaters. There is a direct spatial relationship of regional stream sediment geochemical survey results for thorium (squares in shades of red) and tin (circles in shades of purple) with the areas underlain by the Surprise Lake batholith, showing that these elements are derived from the batholith. Creeks discussed in the text are denoted by the letters: B = Boulder, F = Feather, O = Otter, P = Pine, Q = Quartz, R = Ruby, S = Snake.

Figure 3. A view to the north over the placer operation on Snake Creek. In the middle background are disturbed white gravels of Boulder Creek which are largely derived from the underlying Surprise Lake batholith. Light-coloured slopes on the horizon are underlain by the Surprise Lake batholith.

exploration has followed discovery of the White Gold deposit in 2008 (Burke and Lewis, 2010). About 450 km to the south, lode gold exploration on the outskirts of Atlin has been on-going for more than a century. It was not until 2008, however, that viable lode gold production was demonstrated by Prize Mining Corporation (then Muskox Minerals Corp.) with the liberation of 18.63 kg of gold (doré with unspecified fineness) from a 2880 tonne bulk sample of the Yellow Jacket deposit (Figure 2; Dandy and Price, 2010).

Yellow Jacket deposit

The Yellow Jacket deposit has a historical resource estimate of 453 500 tonnes at 10.26 g/t Au (non-NI43-101 compliant; Schroeter and Pinsent, 2000). Lode gold is hosted in a faulted and altered mafic-ultramafite rock package beneath the Pine Creek valley floor, near the location of the first claims staked within the placer camp in 1898[1]. Ash (1994) recognized the quartz-carbonate-mariposite (chrome mica)-gold association and was successful in extracting mariposite from which undisturbed radiogenic argon release spectra could be obtained[2]. These release spectra provided ages of ~165-175 Ma, consistent with cooling following tectonic emplacement of the Atlin ophiolite and accretionary complex and intrusion of the Fourth of July batholith which cuts and immediately postdates emplacement fabrics (Mihalynuk *et al.*, 2004). Thus, Ash (2001) concluded that gold deposition was genetically related to ophiolite emplacement and that “The placers are considered to be derived from quartz lodes previously contained within the ophiolitic crustal rocks" (page 25).

More recent work at the Yellow Jacket deposit has shown that the highest gold grades are associated with a dark green, fine-grained andesite (Dandy and Price, 2010). This unit is described by Dandy and Price (2010) as forming irregular pods and slivers and containing 10-15% quartz phenocrysts along with hornblende±biotite and/or plagioclase. These authors attributed the concentration of auriferous vein material to the competency contrast between the andesite and the enclosing altered ultramafite. The brittle andesite “shattered” and the spaces thus formed between the fragments were then flooded with carbonate and auriferous quartz. Dandy and Price (2010) also believe that the Yellow Jacket gold mineralization to be related to the Pine Creek fault which cuts the ophiolite emplacement fabrics of Ash (1994). Gold mineralization and the associated alteration and veining assemblages that occur along the Pine Creek fault are, therefore, related to a younger mineralizing event, of as-yet undetermined age. Late-stage mariposite, which is spatially related to gold mineralization along the Pine Creek fault zone, could display reset ages or could record the age of the mineralizing event. Further analysis of mariposite in the area needs to be undertaken to confirm the timing relationships of local gold mineralization and alteration events. It is possible that there are multiple stages of mariposite-forming alteration within ultramafic rocks in the region, related to different structural and intrusive events.

If gold mineralization at the Yellow Jacket is typical of lode gold sources for most of the placer gold in the Atlin camp, then quartz, carbonate, pyrite and mariposite should occur as intergrowths with some of the impure gold nuggets. In our investigation of nuggets from five placer creeks we have observed quartz, carbonate and evidence of weathered pyrite and other minerals/alloys, but so far, no mariposite.

COMPOSITION OF IMPURE NUGGETS

Results of our study of impure nuggets are grouped according to the composition of the impurity. Here we present observations of rock matter, carbonate, pyrite and mercury. Nuggets that are an intergrowth of gold and rock were obtained from Otter, Snake and Boulder Creeks. At this point in the study, compositional analyses have been attempted only for the rock within the Otter Creek nuggets.

[1] *Placer workings that were about 50 years old were reported by the early placer miners ca. 1898. These old workings were probably of Russian origin, and indicate that low-grade placers were known in the Atlin camp by ca. 1850, prior to discovery of the rich placer deposits on Pine Creek (Bilsland, W.W. (1952): Atlin, 1898-1910: The story of a gold boom; British Columbia Historical Quarterly, Volume 16, Numbers 3 and 4; Reprinted in 1971 by the Atlin Centennial Committee, 63 pages with pictorial supplement) University of Victoria, Victoria, BC.*

[2] *Subsequent attempts (by MGM) to acquire undisturbed spectra from mariposite collected from altered ultramafic rocks elsewhere in the Atlin region have not been successful.*

Analytical Methods

All elemental analyses reported here are semi-quantitative. They have been obtained using the University of Victoria Advanced Microscopy Facility Hitachi S-4800 scanning electron microscope (SEM) fitted with a Bruker Quantax energy-dispersive x-ray spectroscopy (EDX) system. Operating conditions were optimized for EDX analysis of both points and fields on the grains. Working distance was set to approximately 15mm with a beam voltage of 20kV. Samples were mounted to aluminum or carbon stubs with either carbon tape or carbon paste. One sample from upper Otter Creek required a carbon coating as it was not sufficiently conductive.

Otter Creek nuggets

Rock matter intergrown with gold in nuggets recovered from the upper portions of Otter and Snake creeks appears to be of local derivation. In both cases the hostrock is fine-grained sediment that has been recrystallized. Like most placer workings, the Zogas operation on upper Otter Creek recovers gold from both pay gravels and regolith (Figure 4). Processing of regolith is primarily for detrital gold that has worked its way down into cracks within the fractured and weathered bedrock. Rock scraped from the placer pit in 2010 was black, graphitic and phyllitic argillite, commonly with quartz veins less than 1 cm thick. We know of two recently recovered nuggets with pieces of the graphitic argillite attached. The smaller of these, donated to us for analysis, is shown in Figure 5. Scanning Electron Microscope and Energy Dispersive Spectral analysis revealed nothing unexpected. The mineral matter is mainly quartz, with some Mg-Fe-bearing mineral, probably chlorite, and graphite(?); however, because it was necessary to coat the nugget with conductive carbon, carbon analyses are meaningless.

Snake Creek nuggets

Near the top end of Snake Creek, a small dredging operation has recovered nuggets of gold intergrown with rock (Figure 6). The rock matter appears to be recrystallized fine grained siliceous sediment. Unfortunately we were unable to obtain a sample for analysis. Outcrops of thermally altered cherty argillite and argillaceous chert located within the drainage basin at an elevation above the dredging operation represent the bedrock from which the gold was likely derived.

Boulder Creek nugget

A nugget of gold intergrown with very dark green to black rock was obtained from Boulder Creek. No elemental analysis of the rock has yet been performed. It appears monomineralic, has a hardness of ~3 (Figure 7), and is probably chlorite or serpentine.

Figure 4. Aerial overview of the Zogas' operation on upper Otter Creek. The deep part of the pit at right is excavated down to bedrock.

Figure 5. Gold intergrown with graphitic phyllite like that of the local creek bedrock (about 1.5 cm across).

Figure 6. Nugget from Snake Creek is gold intergrown with rock which is like thermally-altered argillaceous chert comprising the bedrock upstream. Scale divisions are millimetres.

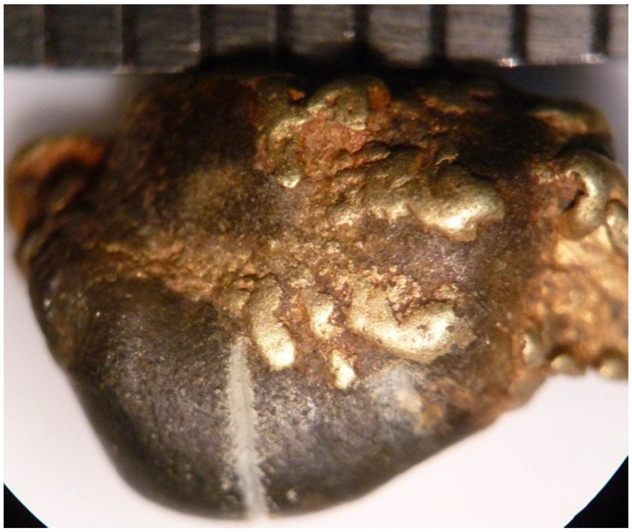

Figure 7. Photomicrograph of intergrown gold and rock nugget from Boulder Creek. The homogeneous rock matter was easily scratched to produce the furrow. Scale markings are millimetres.

Gold with mercury

Gold nuggets with conspicuous light silver patches were recovered from Quartz and Boulder creeks, and are common in placer gold recovered from Pine Creek. This patchy silver colouration is known as “mercury staining” (Figures 8a, b, c). SEM-EDX analyses of the silver patches confirmed that they are mixtures of mercury and gold. While the silver patches are distinct, they have diffuse margins. At high magnification, the surface of the gold appears fissured (Figure 8b) as a result of amalgam removed following attack by mercury.

Figure 8a. Nuggets from Quartz Creek with silver patches. Width of top nugget is about 1.5 mm.

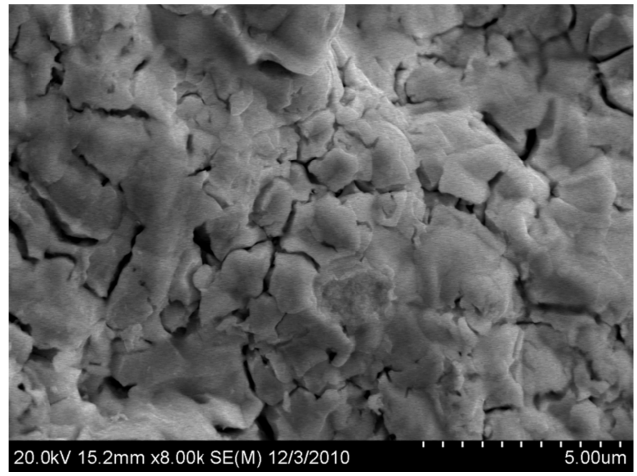

Figure 8b. SEM photomicrograph of sponge-like fissures created by mercury attack of a Boulder Creek nugget.

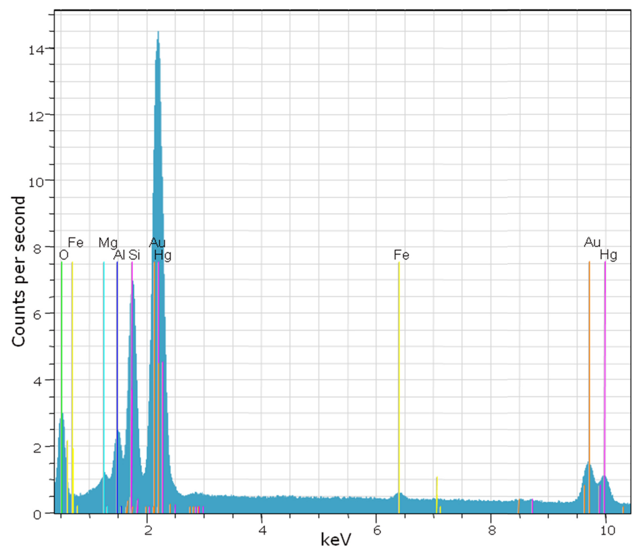

Figure 8c. EDX analysis of a broader field of view includes quartz and Fe-Mg mineral, probably chlorite.

Mercury was commonly used in most old placer camps to aid in recovery of fine gold from heavy separates, and staining from introduced sources of mercury is well known in Pine Creek, especially near the old Discovery showing. Modern knowledge of the cumulative toxicity of mercury in humans and the environment has resulted in severe curtailment of its use in all but the least regulated of nations. Naturally occurring native mercury is also common in most placer camps and we argue below that the mercury etching seen on nuggets from Boulder Creek could be a natural phenomenon rather than anthropogenic.

PSEUDO-BIOGENIC GOLD

One gold nugget from Boulder Creek was analyzed at high magnification to reveal a network of ovoid and filiform morphologies which resemble bacteria (Figure 9). Although evidence for gold mobility in biofilms has

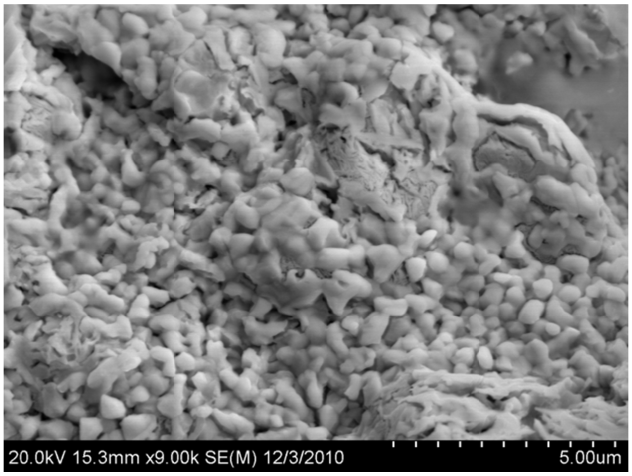

Figure 9. Pseudo-biogenic features on the surface of a gold nugget from Boulder Creek. EDX analysis shows the field of view to be Au with minor Ag.

recently been demonstrated for gold nuggets in Australia (Reith *et al.*, 2010), the textures that we observed are probably artefacts. Identical textures were discovered by John Watterson of the US Geological Survey during an SEM study of acid-cleaned gold nuggets from Lillian Creek in Alaska. These textures were found to be widespread in Alaskan placer deposits prompting the suggestion that bacteria was widely implicated in Alaskan gold nugget formation (Watterson, 1992). Watterson later retracted this hypothesis after he was able to reproduce the pseudo-biogenic structures with a combination of amalgam attack and nitric acid leaching (Watterson, 1994). Treatment of nuggets with nitric acid is a common practice in many placer camps and is specifically used to remove mercury staining.

We suspect that the Boulder Creek nuggets have NOT been subjected to nitric acid etching because such treatment leaves the gold bright and shiny; whereas the Boulder Creek nuggets are dull and partly Fe-oxide stained. These nuggets may have been subjected to low pH fluids formed naturally through the aqueous oxidation of pyrite which generates sulphuric acid. Cubic pits within some of the gold nuggets imaged suggest that pyrite, once intimately intergrown, has been removed by oxidation or mechanical action. Nevertheless, it is difficult to rule out the possibility that acid cleaned nuggets were subsequently stained. Such staining can occur in a few days if nuggets are left in waterlogged sluice concentrates together with rusting magnetite and pyrite.

MINERAL INCLUSIONS IN GOLD

Mineral inclusions within gold nuggets of the Atlin placer camp have been identified on the basis of crystal morphology and composition as determined by semi-quantitative EDX analyses. Identified minerals include: chlorite, Mg-calcite or dolomite, cerussite ($PbCO_3$), a range of Fe-oxides/hydroxides and quartz. Except for cerussite, these minerals are ubiquitous within the veins and country rocks of the Atlin camp. Cerussite is a common alteration product of galena and its occurrence in gold nuggets may indicate that gold streaks occur within sulphide veins. Auriferous polymetallic veins at the old Atlin Ruffner mine, located 5 km northwest of Boulder Creek headwaters (Figure 2), are associated with carbonate-altered lamprophyre dikes which cut the Fourth of July batholith and are, in turn, cut by the Surprise Lake batholith. Ore produced from 1916 to 1981 from the Ruffner had an average grade of 5% combined lead and zinc, 600 grams silver and 0.42 grams gold (MINFILE, 2006). Quaternary ice-flow direction is to the northwest (Levson and Blyth, 1993) and opposite to that required to carry ice-scoured materials from the Atlin Ruffner deposit to the Boulder Creek drainage. However, skarn mineralization at the South and Silver Diamond prospects (MINFILE, 2006), located at the margin of the Surprise Lake batholith in the Boulder Creek drainage (Figure 2, locations 1 and 2), is reported to contain galena. Gold is not reported as a commodity in these prospects, but the intervening Sunbeam occurrence (Figure 2, location 3) purportedly returned high gold assays (MINFILE, 2006).

Anthropogenic nuggets

For more than 100 years placer miners have been living and working along the placer streams of the Atlin camp. During much of this time waste materials were discarded into the bush or burned. Trash burning remains the most common form of garbage disposal. In the mid-1900s plastics would have been introduced to burning barrels and in the last few decades, electronic circuitry might have been added.

Some of the samples that we analyzed are likely "burning barrel nuggets". One nugget from Boulder Creek is primarily composed of lead, probably originally part of a lead acid battery. Another Boulder Creek nugget is a mixture of plastic and gold, perhaps the product of a smelting mishap, an accidental cabin fire, or a melted electronics component. A nugget from Snake Creek is relatively pure gold with a "splattered droplet" of lead-tin-zinc alloy (Figure 10) of the type used in the electronics industry prior to widespread replacement of lead-based solders with tin-silver-copper±antimony alloys. It is likely the product of a melted circuit board.

SUMMARY

Analysis of intergrown rock and gold nuggets in Otter and Snake creeks show that in each case the rock matter can be explained by a local bedrock source. In Otter Creek at least, a local source is consistent with angular, gold rich colluvium within the pay gravels (Levson, 1992). A rock-gold nugget from Boulder Creek could be the product of altered lamprophyre dike, but this hypothesis needs to be tested with further analyses. If so, it might have been sourced from mineralization similar to that of the nearby Atlin Ruffner mine where auriferous

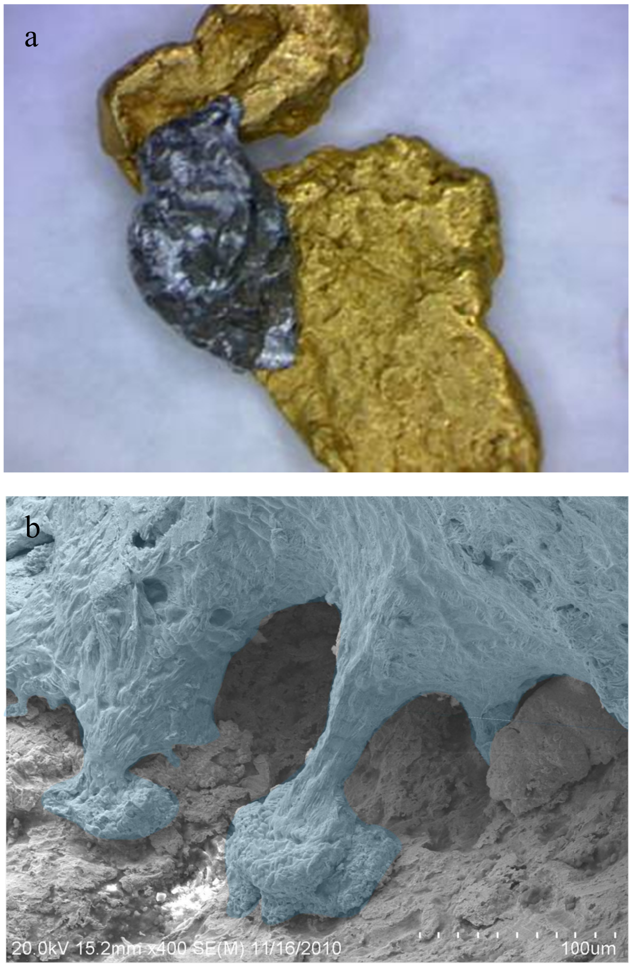

Figure 10. (a) Soft blue-grey metal attached to gold nugget (~0.5 cm long in photo) is shown to be a lead-tin-zinc alloy by analysis with SEM-EDX. It displays a morphology (b) interpreted as arising from a formerly molten drop (coloured blue) adhering to a gold substrate. It is probably the product of a melted circuit board.

lead-zinc ore was associated with lamprophyre dikes and may also be the source of cerussite intergrown with another Boulder Creek nugget.

In no nuggets did we find intergrown listwanitic alteration assemblage characterized by mariposite, as is found at the Yellow Jacket deposit (*e.g.* Dandy and Price, 2010), nor did we find cassiterite and thorite intergrown with gold as has been reported by Sack and Mihalynuk (2004). Multiple bedrock sources for the Atlin placer gold seems most likely, and the Surprise Lake batholith is still the most likely candidate for the ultimate source of gold. However, proving or disproving its role will require further study, including isotopic age determinations from both stages of mariposite growth at the Yellow Jacket, age of mineralization at the Atlin Ruffner, and age of thermal metamorphism of fine-grained sediment with gold-quartz veins in the Otter and Snake creek drainages. Future work also needs to focus on the composition of placer nugget impurities in the outlying creeks within the Atlin placer camp. Workers who study attached mineral matter need to be aware of the possibilities of anthropogenic contamination of gold nuggets.

An unequivocal underlying cause for the concentration of gold in the Atlin camp remains to be discerned.

ACKNOWLEDGMENTS

John Zogas generously provided samples of gold-rich placer clean-ups and impure nuggets from Otter Creek. Norm Graham liberally loaned nuggets from Quartz and Boulder creeks. Larry McKay shared his knowledge of placers in Snake Creek. SEM-EDX results presented here arise from the B.Sc. thesis work of T.K. Ambrose. SEM-EDX work at the Advanced Microscope Facility benefitted from the sage advice of Dr. Elaine Humphrey and Adam Schuetze. This research has been made possible by a NSERC Discovery grant to S.T. Johnston.

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