Placer-lode gold relationships in the Nansen placer district, Yukon

Rob Chapman[1], Matthew Cook, Matthew Grimshaw and Scott Myles
University of Leeds, UK

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ABSTRACT

Compositional studies have been undertaken on gold particles recovered from hypogene ore, eluvial material and placer samples in and around the Klaza property. These data have been correlated with previous descriptions of *in situ* mineralization to elucidate placer-lode relationships and systematic change in gold compositions between porphyry and epithermal environments.

Gold alloy from the porphyry environment is Ag-poor with respect to Au formed in later stage veins. Silver, and to a lesser extent Cu, have been the main discriminants for inferring the source of Au within the placers, and in general, vein mineralization is a more important source-type than porphyry mineralization.

The signature of Pb-Bi-Te previously identified in the inclusion suites of Au grains from Nucleus/Revenue, Casino and Sonora Gulch has also been identified at Klaza, demonstrating that generic compositional signatures can underpin a robust exploration methodology. The relative sizes of porphyry and epithermal footprints of detrital Au together with their respective compositions are important considerations when targeting Cu-Au systems.

[1]*R.J.Chapman@leeds.ac.uk*

INTRODUCTION

The Dawson Range, south central Yukon is an emerging metallogenic province, and has been the focus of considerable study since 2009 (Allan *et al.* 2013). In part, this proliferation of exploration activity has been underpinned by the importance of widespread placer gold, which continues to support an important industry. The gold in the established placer regions can be broadly categorized into that derived from orogenic mineralization (*e.g.*, the Klondike, Sixtymile R., Tenmile R. and the White Gold District; Wrighton, 2013; Chapman *et al.*, 2014), and that derived from mineralization associated with early Late Cretaceous magmatism (Revenue/Nucleus, Casino, Sonora Gulch; Wrighton, 2013; Chapman *et al.*, 2014).

The Mount Nansen camp is situated at the south end of the Dawson Range (Fig.1); it comprises multiple mineral occurrences of porphyry and epithermal mineralization hosted within the 12 by 3 km 'Nansen Trend' within metasedimentary and meta-igneous rocks of the Yukon-Tanana terrane, (Hart and Langdon 1997; Fig. 1). The spatial relationships between porphyry mineralization and vein arrays, together with a parallel systematic change in mineralogy, are interpreted by Hart and Langdon (1997) as indicative of porphyry-epithermal transitions. Consequently, the mineralization in the Cyprus porphyry and gold-bearing precious metal veins of the Klaza deposit provide an excellent field area for study of mineralogical changes associated with an evolving magmatic hydrothermal system. The present study area comprises the northern part of the Nansen Trend and encompasses the Cyprus porphyry and the epithermal occurrences on the Klaza property, located between East Fork Nansen Creek and the Klaza River. The Klaza property is currently the focus of exploration by Rockhaven Resources.

In the Nansen Creek area, placer deposits are spatially located near the Klaza property, the very low grade

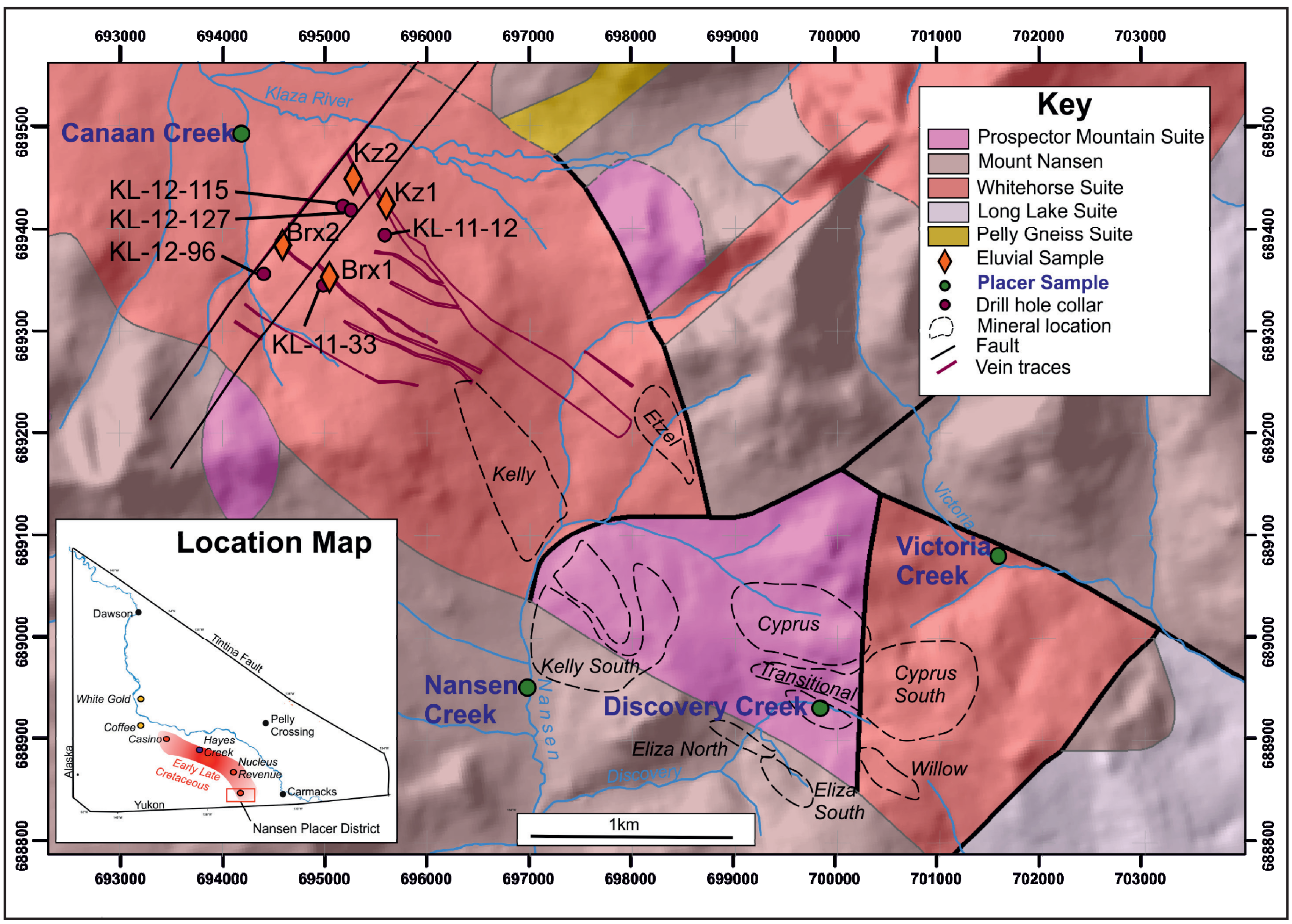

Figure 1. *Regional Geology and mineralization (after Colpron, 2006; Hart and Langdon, 1997.*

Cyprus Cu-porphyry and the Kelly occurrence. The YGS Placer Database (LeBarge, 2007) indicates that different gold fineness has been regularly reported from different creeks. Whilst bulk fineness data are only partially useful as a discriminant (due either to mixing of gold from different sources with different compositions, or derivation from a single source with a variable Au-Ag ratio), broad variation of gold composition with geographical location is suggestive of multiple sources. This study aims to establish clear compositional signatures of gold from both the hypogene and placer environments in the environs of the Klaza deposit to inform two avenues of investigation: i. evaluation of the variation in gold mineralogy within a porphyry-epithermal transition; and ii. evaluation of the relative importance of porphyry and epithermal Au as sources of local placers.

GEOLOGY AND MINERALIZATION

The regional and local geology of the study area is summarized by Hart and Langdon (1997) and depicted in Figure 1. The study area is situated in the north part of the Mount Nansen Trend; the trend is a 12 by 3 km NW-SE corridor which hosts approximately 30 mineral localities. The locations of mineralization relevant to the present study are illustrated in Figure 1 and described in Table 1 which is organized according to the classification of Hart and Langdon, (1997)

The mineralogical descriptions of the various zones presented in Table 1 indicate a progressive decrease in Cu content away from the Cyprus porphyry both to the NW and SE, into Au-Ag-Pb-Zn dominated vein systems. The Klaza property hosts multiple sub-parallel veins of which the BRX vein and Klaza zone (Fig. 1) have been explored most extensively. The veins exhibit differences in their mineralogy with the Klaza zone containing higher levels of Pb and Ag, (Tarswell and Turner, 2014). The vein outcrops are offset by an up-thrown faulted block (throw probably around 150 m) perpendicular to strike. Tarswell and Turner (2014) propose that the Klaza veins correspond to a class of 'base metal carbonate' epithermal veins described by Corbett (2002), in which metal precipitation is induced by mixing with bicarbonate-rich groundwater. Such deposits are commonly zoned, reflecting marked differences in local temperature change, aH_2S (associated with sulphide precipitation) and degree of dilution. Samples of eluvial and hypogene material from these two zones formed part of the sample suite of the current study.

Table 1. *Descriptions of mineralized localities in the study area, adapted from Hart and Langdon (1997).*

Name	Description
Central Porphyry Zone	
Cyprus1,3	Quartz monzonite porphyry, Cu-Mo zone: py, cpy, mo, Cu 0.1-0.15%. Au anomalous but erratic
Kelly1	0.275 x 2.5km NW trending potassic alteration zone identified by soil geochemistry. Trench sample yielded 0.86 g/T Au and 0.25% Cu. cpy, Cc bn and mo
Peripheral porphyry zone	
Cyprus South1	Quartz sulphide veins and stockworks in phyllic zone. Au grade of 0.31g/T recorded in core.
Kelly South1	Au recorded in pyrite shell associated with phyllic alteration
Transitional zone	
Eliza Creek extension1	Veins and stockworks associated with porphyry stocks breccia and argillic/phyllic alteration. Au grades to 17.5g/T and Ag to 27 g/T in core
Transitional	Four veins very similar to those of the Eliza Creek extension
Epithermal veins	
Klaza Zone2	py, sp, ars, ga, sb, ss. au
BRX zone1	py, sp, ars, ga, sb, ss. au
Eliza Creek South 1	Au-Ag-Zn-Pb veins. Trench samples of Au to 3.9g/T
Eliza Creek North1	Au-Ag-Zn-Pb veins. Cu content > Eliza Creek North. Au to 10.3g/T
Etzel	Au-Ag-Pb-Zn veins
Willow1	3 Au-Ag-Pb-Zn veins containing Au to 3.5g/T

Key: py=pyrite, cpy=chalcopyrite, sp=sphalerite, ars=arsenopyrite, ga=galena, sb=stibnite. 1=(Hart and Langdon, 1997), 2=Tarswell and Turner (2014), 3=YGS Minfile 1151 066.

The surficial geology of the Nansen area is described by LeBarge (1995) and comprises sediments originating in an array of pre-glacial, glacial and post glacial environments. Eight sedimentary facies are identified and each was investigated in terms of the concentration of detrital gold. Provenance of the gold in placers on Nansen and Victoria creeks and Canaan Creek was informed by clast analyses and morphological studies of the gold grains themselves. The highest concentrations of gold are observed in diamictons, interpreted to be the erosional products of pre-existing weathered ore and placers. *In situ* mineralization is observed in weathered bedrock, within the outcrop of the Cyprus porphyry such that direct liberation of gold from host to modern placer is possible at some localities. The presence of paystreaks on a false bedrock of early Pleistocene till in upper Nansen Creek till indicates that rejuvenation of the placer is ongoing (J. Bond pers. Comm.).

The Mount Nansen area has supported placer mining since the early twentieth century (LeBarge, 2007). An overview of the relative importance of various creeks is presented in Table 2, and summarizes production figures to 2005. The data show the placer resource in Nansen Creek is the most economically important. Bulk fineness data (LeBarge, 2007) indicate that most gold in the Nansen Creek system is between 800 and 850 fine, whereas gold from Victoria Creek, Canaan Creek and one of the reported Back Creek populations exhibits lower fineness values. LeBarge (2007) reports that many streams in the area were explored for their placer potential, but only a small number supported sustained activity.

PREVIOUS STUDIES OF GOLD GRAIN COMPOSITION IN THE DAWSON RANGE

Understanding the relationship between economically important placer gold deposits in Yukon and their potential lode sources has developed significantly during the last decade. Various studies have characterized gold particles derived both from lode and placers in terms of their alloy compositions and suite of mineral inclusions revealed in polished section, (*e.g.* Chapman *et al.*, 2010a,b; Chapman *et al.*, 2011; Wrighton, 2013; Chapman *et al.*, 2014). These combined data sets yield a 'microchemical signature' for a specific population of grains. Comparison of microchemical signatures of hypogene Au grains with detrital Au particles from local placer populations can establish placer-lode relationships. Wider studies are ongoing which seek to establish the characteristics of each signature which are diagnostic for different styles of gold mineralization.

A regional study of placer-lode gold relationships in the Dawson Range was undertaken between 2010 and 2012 under the auspices of the Yukon Gold Project, an academia- industry collaboration based at the Minerals Deposit Research Unit (MDRU) at UBC. Studies of placer and lode gold grains derived from the early Late Cretaceous intrusions of Revenue and Nucleus are distinct from those associated with orogenic mineralization, (Wrighton, 2013). Chapman *et al.* (2014) expanded this study to show that porphyry mineralization at Casino, Revenue/Nucleus and Sonora Gulch yield gold grains with a distinctive Bi-Pb-Te inclusion signature.

Table 2. *placer gold information (data from LeBarge 2007).*

Placer Creek	Fineness	Production (oz) to 2005	Comments
Discovery	820-850	1586	
E. Fork Nansen	No data	448	Some dendritic gold
Nansen	805-820	21,251	
Victoria	720-730	1185	
Back	760-836	3478	'Coarse' pay streak reported
Slate	800	-	Minor trib, no mining
Canaan	750	Unknown	No data in YPDB

SAMPLING

CORE SAMPLES

Core samples were selected based on the proximity of the hole collar to the localities of trench sampling (Table 3a). Selection of the intersections studied in each hole was based on the location of high Au grade. Sample preparation and analysis was undertaken at the University of Leeds.

OXIDIZED VEIN MATERIAL IN TRENCHES

The vein system at Klaza outcrops at surface and has been exposed by trenching. Decomposed vein material was collected from four localities, (*see* Table 3b and Fig. 1) and was thoroughly wetted before processing using a 'Le Trap' portable sluice. Sluice concentrates were panned to recover a 'super concentrate' containing gold grains.

COLLECTION OF PLACER SAMPLES

Samples of placer gold were collected using a combination of panning and sluicing. The details of the sample sites are provided in Table 3c and Figure 1. Characterization of Au from Nansen Creek was facilitated by study of two sample populations, the first of which is described in Table 3c. The second Nansen Creek sample comprised 56 gold grains collected by the Yukon Geological Survey close to the confluence of Nansen and East Fork Nansen creeks, although the exact locality is unknown. The inclusion assemblage of this second sample was useful to augment that observed in the sample collected slightly downstream during the current study.

Table 3. *Samples collected for this study.*

3a. Core samples used in preparation of polished blocks

Hole _ID	Close to	Sample depth m	From (m)	To (m)	Interval (m)	Collar Easting	Collar Northing	Au ppm	Ag ppm
KL-11-33	BRX 1	121.1	120.3	121.64	1.34	382080	6889865	5.51	180
KL-12-96	BRX 2	342.8	342.46	345.36	2.9	381509	6890034	10.55	92.7
KL-11-12	KZ1	221.7	221	222.6	1.6	382724	6890305	6.81	123
KL-12-115	KZ2	219.7	219.48	221.59	2.11	382340	6890627	13.75	357
KL-12-127	KZ2	169	168.11	169.11	1	382418	6890581	5.73	204

3b. Eluvial samples collected from vein outcrop

label	Trench	E	N	g/T Au	g/T Ag	intercept (m)	Volume of -2.5 cm material sluiced (L)
BRX 1	TR 13-49	382410	6889676	8.4	548	1.31	140
BRX 2	TR 13-47	381715	6890310	87	768	1.15	400
KZ 1	TR13-66	382758	6890614	25.7	449	2.27	200
KZ 2	TR 13-70	382462	6890888	16.76	1052	3.03	200

3c. Placer samples

locality	E	N	Comments	Potential sources
Discovery Ck	386521	6885312	Sample from headwaters of creek	CyS, El.N, El.S, Tr,
Victoria Ck	388391	6886630	Side pay	Unknown
Canaan Ck	381422	6891421	From active cut	BRX, Klaza zone
Nansen Ck	383700	6885781	From active cut	K, KS, Et, Cy

Abbreviations, corresponding to mineralization described in Table 1. Cy=Cyprus porphyry, CyS=Cyprus South, El.N=Eliza North, El.S=Eliza South, Tr=transitional, WC=Willow Creek, K=Kelly, KS=Kelly South.

ANALYTICAL WORK

Polished blocks were prepared from core samples and examined using both reflected light microscopy and the scanning electron microscope (SEM). Analysis of Au grains >5 µm in diameter was undertaken by electron probe microanalysis (EMP). Gold grains from eluvial and placer samples were isolated from the sluice concentrates by picking under a binocular microscope. These gold grains were mounted according to size as described by Chapman *et al.* (2000). The extreme small size of some of the gold particles necessitated the design of a new polishing technique specifically for extremely tiny (30-50 µm) particles. This involved introducing the grains into small pools of resin placed on a glass slide. The gold grains were revealed during controlled polishing of the slides in a manner similar to that employed when preparing rock thin sections to the required thickness.

Analysis of the Au grains was carried out in two stages. Firstly, qualitative analyses were undertaken using a FEI Quanta 650 FEG-ESEM. This involved inspection of each grain section and recording alloy heterogeneity and the presence of inclusions, either of minerals or intermetallic compounds. Secondly, quantitative alloy compositions were determined by EMP using a Jeol 8230 Superprobe. The minor element suite analyzed was Ag, Cu and Hg and the detection limits for each element were 0.03%, 0.02% and 0.1% respectively. All values are expressed in wt%. Polished blocks of core samples were prepared for inspection by reflected light microscopy and SEM/EMP analysis.

RESULTS

HYPOGENE ORE

The aim of this element of the project is to identify minerals coeval with the gold and that could be subsequently correlated to the suite of inclusions recorded in placer gold samples. Native gold is identified in samples from both veins, (in cores Kl-12-96 and Kl-12-115) although many of these gold grains are less than 2 µm in diameter and consequently too small to analyze by EMP. Mostly, gold is observed as small blebs in early stage pyrite, as is Bi telluride (Fig. 2a,b). Both galena and arsenopyrite post-date the pyrite, but Au is only observed in galena (Fig. 2c). Only gold in core from hole KL-12-96 (adjacent to BRX-2) is sufficiently coarse to analyse by EMP. The Ag contents of these grains are illustrated in Figure 3a, and the co- variance of Ag with Cu is illustrated in Figure 4.

SAMPLES COLLECTED FROM VEIN OUTCROPS

The alloy compositions of Au grains from BRX 1 and BRX 2 are shown in Figure 3a. Both populations are dominated by grains in the 18-25% Ag range; however there are other small contributions from other sub-populations which exhibit lower Ag contents, one of which appears similar to the Ag range of gold grains observed in the core samples. Table 4 shows that around 90% of grains from the BRX zone contain Hg to above LOD of 0.06%, although the maximum value recorded is only 1.5%. The percentage of grains containing measurable Cu is much lower at 35% and 36% in BRX 1 and BRX 2 respectively.

The low incidence of inclusions in the samples from the BRX zone grains is probably related to the tiny size of most of these gold grains. Table 4, shows the number of gold grains that contained specific minerals. Overall the inclusion assemblage reflects the mineralogy of the hypogene ore, with minerals coeval with Au observed as inclusions (*e.g.*, galena and Bi telluride; Fig. 2d,e). Arsenopyrite is not observed as an inclusion, (neither are Au grains observed within arsenopyrite in hypogene ore) but secondary As minerals are observed coating Au grains.

Covariance of minor alloying metals is investigated using the bivariate plots shown in Figure 4. Figure 4a shows the compositional fields of grains from Discovery Creek and Figure 4b superimposes these data onto that describing gold from the BRX Zone. In the Discovery Creek sample, the relationship of Ag to Cu is generally inverse, although most grains cluster in the mid-range of Ag and Cu. The distribution of alloy compositions of gold from the BRX zone shown in Figure 4b differs because the majority of points cluster in two Ag ranges, and within these Cu varies independently. A small number of grains contain relatively high Cu values but their compositional field does not correspond to that observed for grains from Discovery Creek (Fig 4a). These two differing compositional fields have been used as a template for comparison with sample populations of placer gold from the Canaan Creek (Fig. 4d), Nansen Creek (Fig. 4c) and Victoria Creek (Fig. 4e).

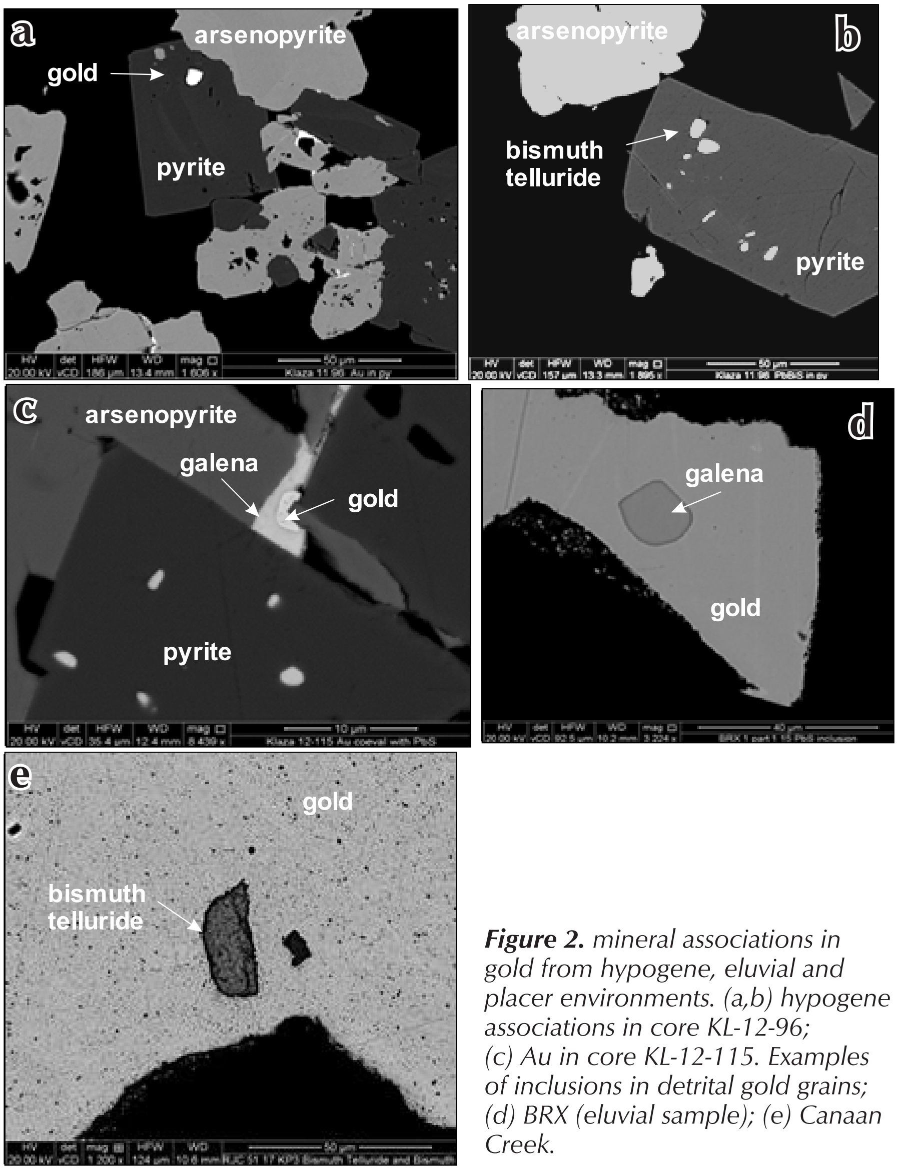

Figure 2. *mineral associations in gold from hypogene, eluvial and placer environments. (a,b) hypogene associations in core KL-12-96; (c) Au in core KL-12-115. Examples of inclusions in detrital gold grains; (d) BRX (eluvial sample); (e) Canaan Creek.*

PLACER SAMPLES

The morphology of the placer gold grains within the different sample populations are illustrated in Figure 5. Gold grains from Discovery Creek and Canaan Creek are rough, whilst the other placer samples include grains which exhibit a range of morphologies. The Ag content of the placer populations are depicted on the plots in Figure 3b. The sample from Canaan creek shows the highest overall Ag values, whilst the sample from the Discovery Creek exhibits the lowest values. These two samples have been used as ‘end members’ to evaluate other placer samples which exhibit features of both, but in different proportions. The placer sample from Victoria Creek resembles most closely that from the Canaan Creek, whereas that from Nansen Creek appears to conform to the Discovery Creek signature at low Ag values, but deviates thereafter.

The Ag curve describing Au from Discovery Creek also exhibits a shallow gradient for lower Ag values (Fig 3b). It also contains a substantial number of grains which contain higher levels of Ag, which could represent either an evolving system within the porphyry environment or additions from later vein mineralization as discussed above.

The covariance of Ag and Cu within the sample populations from Canaan Creek, Nansen Creek and Victoria Creek are shown in Figure 4c-e, where they are compared with the signatures of gold from both the BRX zone and Discovery Creek. The compositional field of gold from Canaan Creek overlaps with that of the gold from the BRX zones and shows the same general form, but it extends to a more Ag-rich area. Gold from Nansen Creek generally conforms to the compositional field of gold from Discovery Creek but there is also a clustering of more Ag-rich points similar to that observed in the sample from the Klaza River. Finally the small gold sample from Victoria Creek most closely resembles gold from the Canaan Creek, but a few grains show a high-Ag and high-Cu signature similar to the Discovery Creek sample.

The inclusion suites of the placer samples are shown in Table 4. Galena and Bi telluride are observed in every sample.

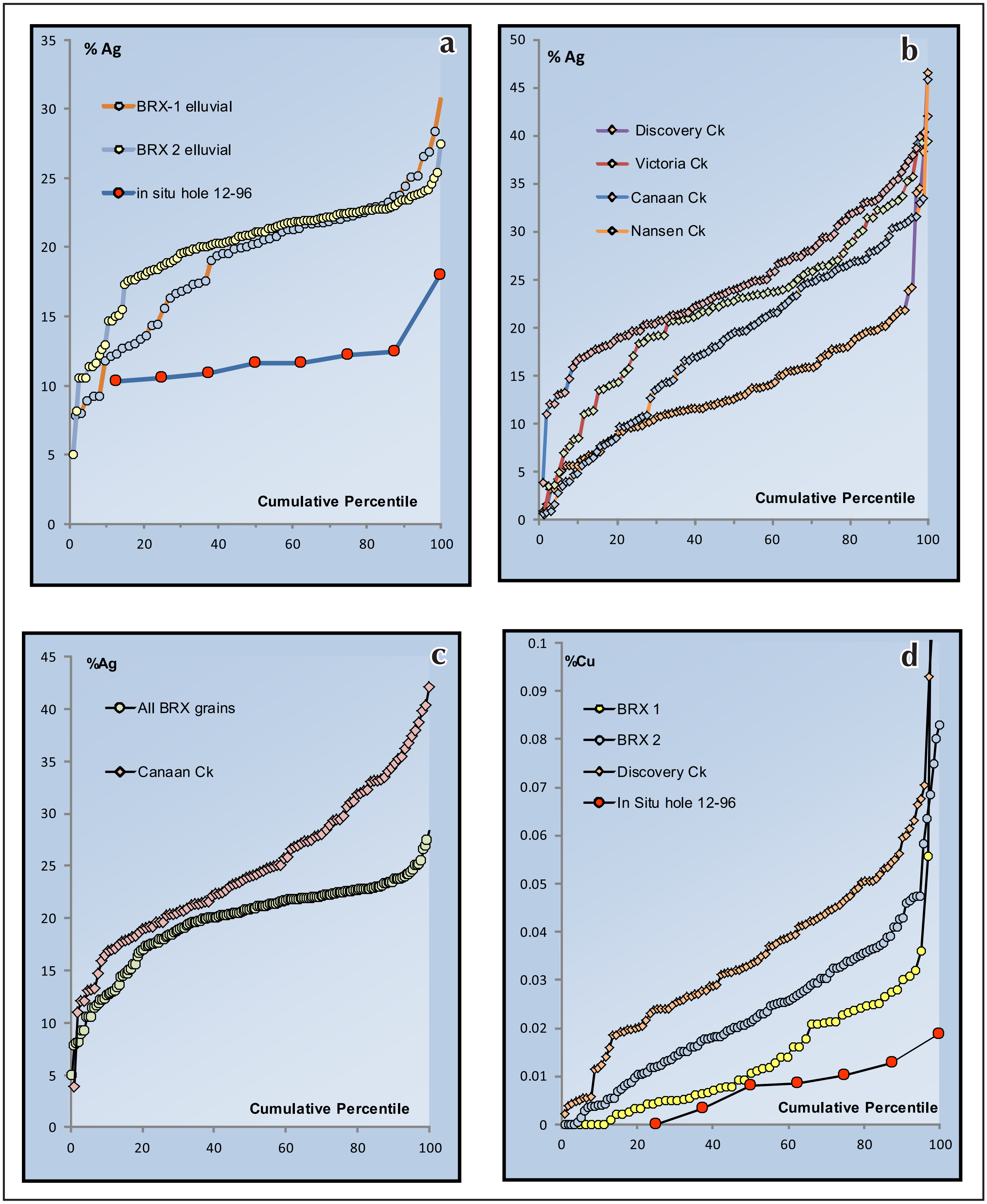

Figure 3. *Alloy compositions of gold grains from in situ eluvial and placer environments (a-c) Ag contents of alloys; (d) Cu content.*

Table 4. *Inclusion assemblages in placer and eluvial gold.*

Locality	Grains	Hg	Cu	Inclusion species											
				py	po	cpy	ga	sp	ars	Bi	ss	cv	hs	l	Sec
Discovery Ck	102	100	80				4		1	2					
Victoria Ck	78	95	54	1		1	1	1		3					
Canaan Ck	104	91	32	6		2	2			2		4			
Nansen Ck	157	100	40	12			5	2	3	3	1		1		
BRX-1	63	86	35	2		1	1				1				
BRX-2	114	90	56	1	1		1	1		2	1			1	2
Hayes Ck	122	12	32	6	2	3	8		2	3		1			

Mineral key as for Table 1, plus po=pyrrhotite, cv=cervelleite, (Ag_4TeS), hs=hessite, l=loelingite (FeAs), Sec=undetermined secondary (PbAs) bearing mineral on grain surface. 'Hg' and 'Cu'=% grains containing that metal to> LOD.

PLACER-LODE GOLD RELATIONSHIPS

RELATIONSHIP BETWEEN HYPOGENE ORE AND GOLD IN THE ELUVIAL ENVIRONMENT

The gold identified in polished blocks is much smaller in size than the eluvial grains recovered by sluicing. Consequently it is possible that there is a bias in the relationship between grain size and composition, although no such bias is observed in the data obtained from each block (where the samples are mounted according to size). Figures 3 and 4 show the relationships between the alloy compositions of hypogene and eluvial gold grains. The majority of the *in situ* grains (in core from around 340 m depth) show lower Ag content in comparison to most grains collected at surface. However, the lower Ag range exhibited by the gold in core is evident as a sub-population in the eluvial sample.

There is an overall similarity between the mineralogy of the hypogene ore and the inclusion suite observed within gold grains from the eluvial environment. Inspection of polished sections suggests that Au, Bi minerals and pyrite form the first phase of mineralization followed by arsenopyrite, galena and sphalerite. Table 4 and Figure 2 show that pyrite and Bi minerals form inclusions within the eluvial gold particles, whereas As is observed only as coatings of a Pb-As secondary mineral. Figure 2c shows that Au may also be coeval with galena, and galena inclusions in placer gold are also observed (Fig. 2d).

RELATIONSHIP BETWEEN ELUVIAL GOLD GRAINS AND PLACER GOLD GRAINS

The signatures of the BRX vein eluvial samples are used as a template to aid characterization of other placer samples in the study area. Figure 3c compares the Ag content of all grains collected from the BRX zone to the placer sample from the Canaan Creek. Gold grains containing >25% Ag form 97% of the population of grains from the Canaan Creek, but only 40% of the eluvial population of BRX vein Au. Figure 1 shows that the placer locality could also contain Au grains derived from veins situated between the BRX vein and the Klaza zone, although no information is available regarding their mineralogy. The Western Klaza zone is known to be relatively Ag-rich (Tarswell and Turner, 2014; Table 3) and Au grains from here could have travelled downslope to the placer sampling locality.

The suites of inclusion species observed within gold grains from the BRX zone and placer gold grains from Canaan Creek are largely compatible (Table 4), with the exception of cervelleite (Ag_4TeS). Four inclusions of cervelleite are observed the placer sample, but this mineral is not observed in either the BRX hypogene or the eluvial samples. All cervelleite inclusions are hosted by relatively Ag-rich Au alloy, and two of these exhibited Ag contents higher than any of the grains from the BRX vein. It is possible that the cervelleite-bearing grains are derived from the relatively Ag-rich Western Klaza zone or veins situated between the BRX and Klaza zones (Fig. 1).

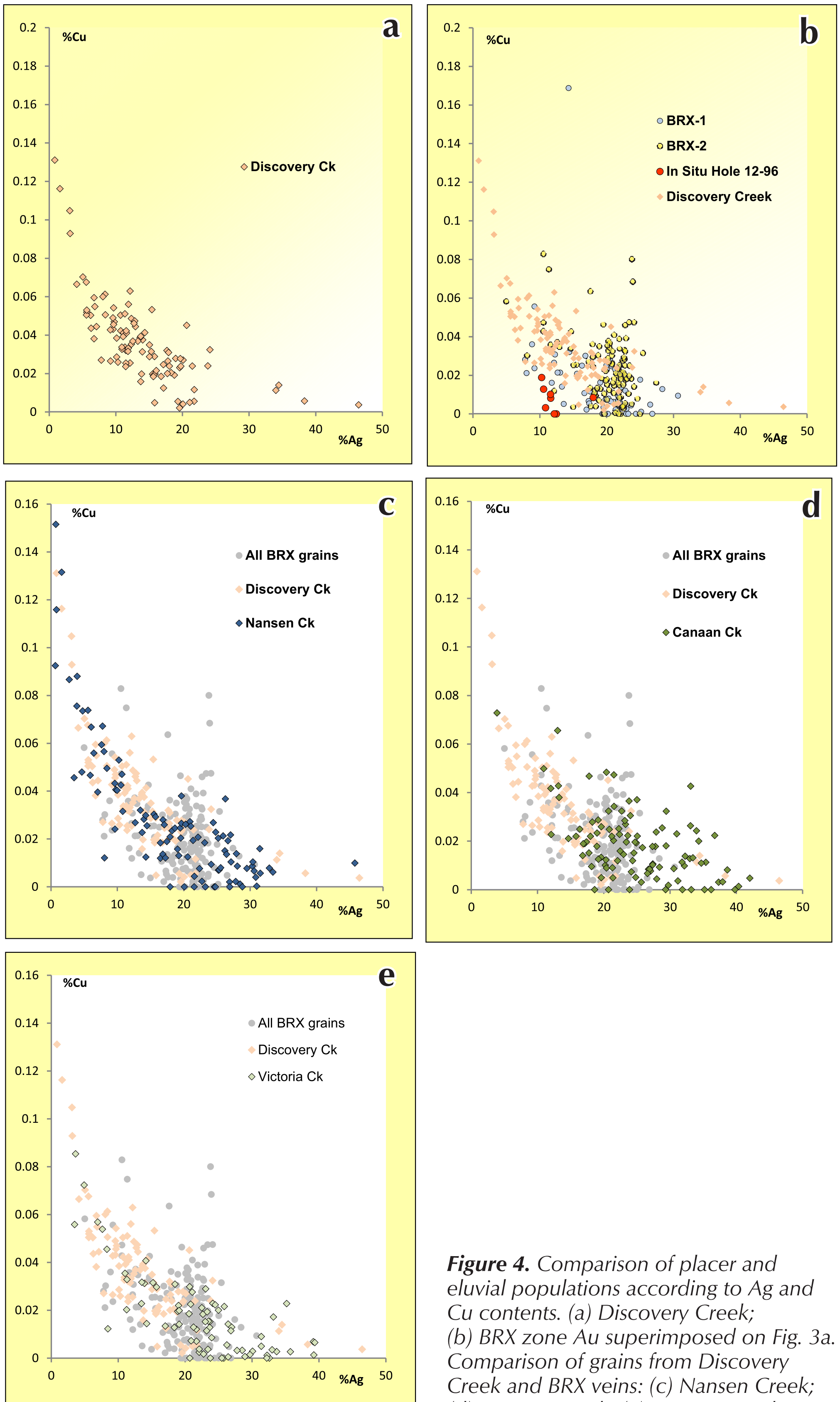

Figure 4. *Comparison of placer and eluvial populations according to Ag and Cu contents. (a) Discovery Creek; (b) BRX zone Au superimposed on Fig. 3a. Comparison of grains from Discovery Creek and BRX veins: (c) Nansen Creek; (d) Canaan Creek; (e) Victoria Creek.*

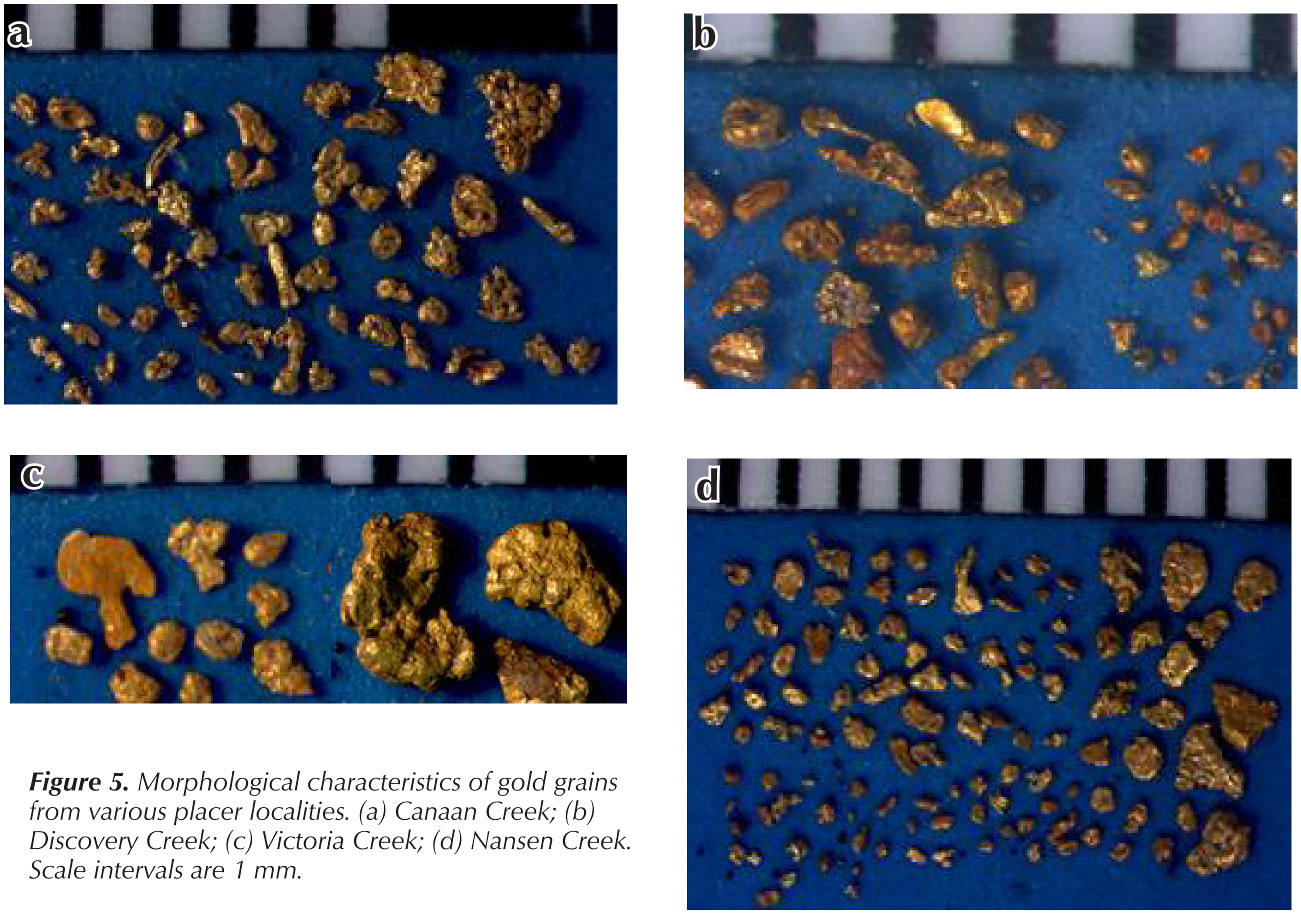

Figure 5. *Morphological characteristics of gold grains from various placer localities. (a) Canaan Creek; (b) Discovery Creek; (c) Victoria Creek; (d) Nansen Creek. Scale intervals are 1 mm.*

POTENTIAL SOURCES OF PLACERS

Consideration of the new data presented in this study has been undertaken in conjunction with bulk assay data from mining records, consideration of surficial geology (LeBarge, 1995) and the overview of regional mineralization presented in Hart and Langdon (1997) to clarify the most likely sources/source styles of mineralization for the various placers.

The Discovery Creek sample was collected from within the outcrop of the Cyprus South porphyry in the peripheral porphyry zone as defined by Hart and Langdon (1997). LeBarge (1995) reports that over 99% of the clasts in the drainage are proximal and consequently it is almost certain that all the placer Au grains were collected close to their source. Figure 5 shows that the Au grains have a rough surface texture and show little signs of fluvial transport. There are three possibilities for the source of these grains. Firstly, Au has been recorded in core samples from the phyllic alteration of the Cyprus south zone. Gold grains from this environment are probably formed from Au-bearing fluids which have stripped Au from pre-existing Cu-Au mineralization formed in the potassic zone, (Gammons and Williams-Jones, 1997). Secondly the 'Transitional' zone, in the headwaters of the Creek comprises veins and stockworks in a phyllic/argillic alteration zone (Table 1). An argillic overprint would probably not remobilize Au so the Au grains in this zone would likely resemble those in the Cyprus south mineralization. Finally there is a possibility of contribution of grains from the Eliza Creek localities although these occurrences outcrop slightly downstream of the sampling locality. From consideration of known *in situ* mineralization it could be expected that the Discovery Creek Au would consist predominantly of Au formed in an evolving porphyry environment, and indeed this sample is distinguished both by a lower Ag content (Fig. 3b) and higher Cu content (Fig. 3d).

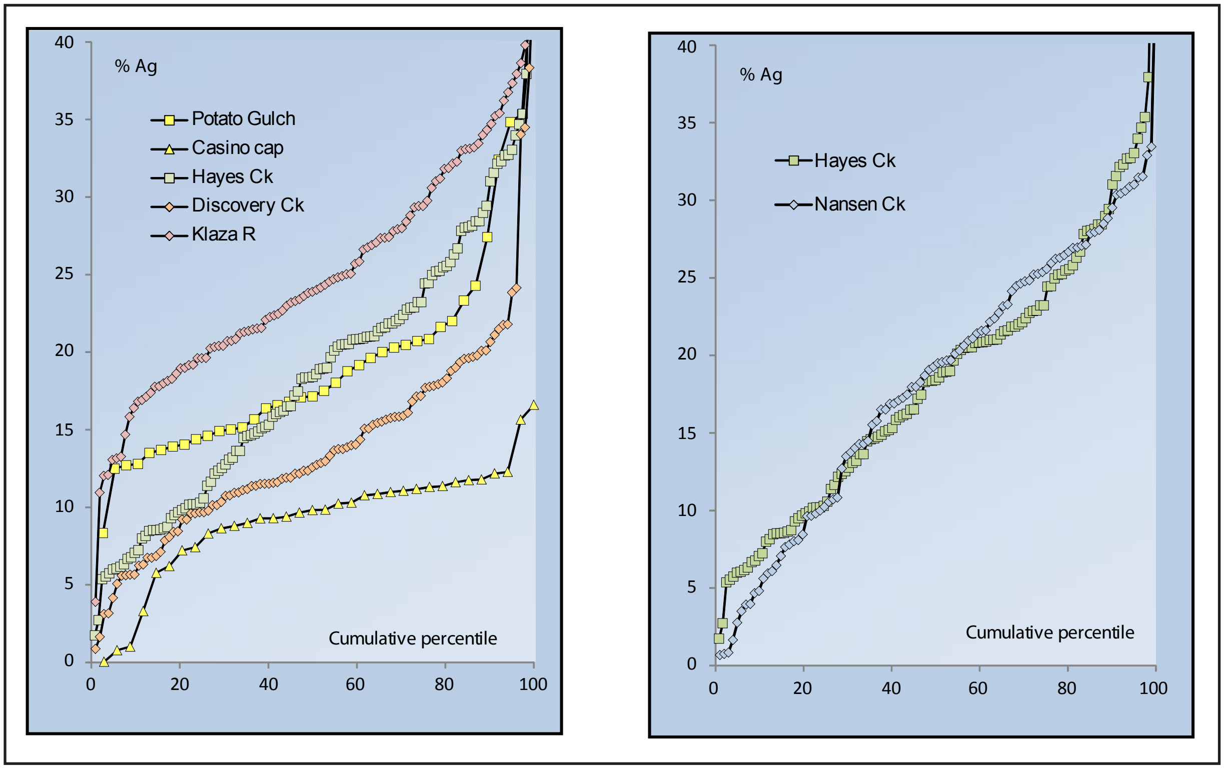

Figure 6. *Comparison of Ag contents of gold from porphyry and epithermal environments.*

Figure 3b shows that the Ag cumulative curve for Nansen Creek follows that of the gold from the Cyprus porphyry for the low-Ag component, but deviates to resemble that of the Canaan Creek sample at higher Ag values. Consideration of the Cu and Ag contents of the alloy also suggests multiple sources (Fig. 4d) as the cluster of compositions of around 30% Ag with variable Cu content is more similar to the signature of the BRX vein than the Discovery Creek gold. Figure 1 shows that Nansen Creek drains a number of potential *in situ* occurrences, principally Cyprus, Kelly and Kelly South. The Kelly and Kelly South occurrences also represent a potassic-phyllic transition, and it is entirely possible that Au from the Kelly South locality is of similar composition to that from the Cyprus south locality. There is no information available to establish whether the Au grades reported from either the Cyprus or Kelly porphyries (Table 1) relates to free Au, *i.e.*, tiny Au grains exsolved from Cu-bearing sulphides which are mostly too small to collect in placers (*e.g.*, Arif and Baker, 2004) or Au distributed within sulphide lattices.

The evidence presented in this section and the previous one, indicates that the Ag content of vein-derived Au is in general higher than that associated with porphyry mineralization. Consideration of Nansen Creek placer gold in the context of Ag content from contributing sources strongly suggests that a large proportion of the placer Au is derived from veins rather than the Kelly porphyry. Table 2 shows the large difference between the mass of placer Au recovered from Nansen and East Fork Nansen creeks. This spatial variation of Au appears incompatible with the model of the Cyprus porphyry being the major local source. It seems more probable that the bulk of Au in Nansen Creek is derived from either undiscovered or eroded veins associated with the Kelly porphyry system.

Data derived from the present study and gold fineness data (Table 2) show the Au from Victoria Creek to be relatively Ag-rich. Figure 5 shows that the grains exhibit varied morphologies, and there is a distinct population of relatively coarse, rough grains. Figure 4e shows a Ag-Cu signature very similar to that of the BRX vein sample, and it is proposed that similar, as yet undiscovered veins form the source of the Victoria Creek placer.

Although no samples of placer Au from Back Creek were available for this study, the range of fineness values reported (Table 2) suggests a contribution from both porphyry and vein Au. van Loon and Bond (2014) report that nuggets up to 2 oz have been recovered recently, and these are most likely associated with a local vein source, rather than a porphyry environment. Figure 1 shows that the Willow Creek vein and the Cyprus South occurrences could constitute distinct sources consistent with this model.

The geomorphological development of the Nansen area described by LeBarge (1995) involves glacial erosion and transport of Au from pre-existing deep weathered material and associated fluvial sediments. LeBarge (1995) reports that Au grains are present within till, particularly at the bedrock-till contact. Consequently, it could be expected that some placer samples show an influence of relatively distal Au grains, although it is clear that that individual samples retain a strong signature of the most local source. The size of Au reservoir within present glacial sediments is unknown, consequently the placer mining records represent an unknown fraction of the total regional Au inventory. In addition, the most important placer creek (Nansen Creek) has not been mined to bedrock, but to a clay layer which is approximately 24 m thick (van Loon and Bond, 2014).

VARIATION IN GOLD SIGNATURE ASSOCIATED WITH THE PORPHYRY-EPITHERMAL TRANSITION

Whilst porphyry mineralization has a localized focus, the associated epithermal expression may be considerably more widespread, and consequently the peripheral geochemical footprint of the mineralization in the surficial environment may be influenced mostly by distal epithermal veins. From an exploration perspective, establishing the link between gold signatures in porphyries and related epithermal systems provides a mechanism to establish a vector to the most economically attractive mineralization. This study has provided the opportunity to examine the relationship between the composition of native gold formed in the porphyry environment and that of gold found in the associated epithermal expression.

EMPIRICAL CONSIDERATIONS

Hart and Langdon (1997) report four zones in the porphyry epithermal transition in the Nansen area, although this sequence is best developed to the southwest of the Nansen porphyry complex, outside the current study area. Sample suites available to the current study correspond to the peripheral porphyry zone and the epithermal zone. The most striking compositional difference is the variation in Ag content between gold derived from the placer sample from Discovery Creek (low Ag-peripheral porphyry) and the vein systems on the Klaza property (high Ag; Fig. 3b), and their placer expression at the Canaan Creek. It seems probable that the higher Cu signature of the Discovery Creek placer Au is also related to a systematic compositional trend, whereas the distribution of Hg within Au alloy appears variable.

Chapman *et al.* (2014) propose a generic relationship between porphyries and associated epithermal mineralization in which some key geochemical signatures of the porphyry system are retained (*e.g.*, a Bi and Te signature in the inclusion suite) whereas the Ag content of the Au grains increases. Studies of the Casino Creek-Canadian Creek drainage and Sonora Gulch-Hayes Creek systems provided the basis for this assertion (Fig. 6a). The similarity of the Ag content of Au grains from Hayes and Nansen creeks is striking, (Fig. 6b) and indicates that the same range of alloy compositions is evident in Au grains formed in these two different mineralizing systems. This similarity is also reflected in the inclusion assemblages (Table 4) by which Hayes Creek placer may be interpreted as derived from several sources, most of which are veins.

CONSIDERATIONS OF FLUID CHEMISTRY

Correlations between the fluid chemistry of a hydrothermal system and the resulting Au alloy compositions has been discussed in general by Morrison et al. (1991), and Gammons and Williams-Jones (1995). The alloy compositions reported above may be considered in terms of the nature of the prevailing and evolving hydrothermal systems. Gold and Ag are transported as their chloride complexes ($AuCl_2^-$, $AgCl_2^-$), in the environment of potassic alteration (Gammons and Williams-Jones, 1997; Williams-Jones and Heinrich, 2005). The most common manifestation of Au in this zone is as tiny exsolved blebs on grain boundaries of bornite and chalcopyrite (Kesler *et al.*, 2002), which are too small to report to the placer inventory. Subsequent remobilization of Cu and Au in propylitic and phyllic environments occurs under a different hydrothermal regime following the collapse of the original hydrothermal system (Gammons and Williams-Jones, 1997) in which Au is transported as the hydrosulphide complex. Depending on specific conditions, Au may be re-precipitated within the porphyry (together with chalcopyrite) or removed into the epithermal environment. In both cases the controls on alloy composition are the same, *i.e.* $([Au]/[Ag])_{aq}$, temperature, pH, $aHS^{-}_{(aq)}$ and $aCl^{-}_{(aq)}$ (Gammons and Williams-Jones, 1995). Decreasing temperature results in a decrease in the Ag content of the alloy, as does decreasing $(Au/Ag)_{aq}$ resulting from the preferential precipitation of Au over Ag. It follows that small temperature variation in the porphyry setting could be expected to generate a relatively small range in Au alloy compositions, and this is observed in the grains from the hypogene environments at Casino, reported by Chapman *et al.* (2014), and in the sample from Discovery Creek reported here. Transition to the epithermal environment would be associated with more variable and generally lower temperature, and rapidly evolving $(Au/Ag)_{aq}$ following precipitation. In addition, there may be influences on fluid composition associated with fluid mixing. The net effect is to generate more Ag-rich Au alloy, and whilst locally the Au alloy signature may be constrained, it could be expected that there would be larger variation over the whole mineralizing system. This hypothesis is consistent with the observed compositional variation in the BRX and western Klaza zones as inferred by the eluvial samples and consideration of Canaan Creek placer sample. In general these observations are compatible with the 'Base-Metal-carbonate' model of Corbett (2002) but equally do not provide diagnostic evidence for that model.

Figure 4 shows two different types of relationship between the Ag and Cu contents of Au alloys. The porphyry mineralization (Discovery Creek) shows a predominant inverse relationship between Ag and Cu. The vein samples and their placer expressions yield Au in which Ag and Cu vary independently. At present, the underlying reasons for this difference in behaviour is not understood, but it has proved a useful discriminant in interpreting the origins of detrital gold in different placer populations. Similarly, the underlying reasons for the sporadic presence of Hg in some grains remain unclear.

The data presented in Table 4 show that the Bi-Pb signature is strong and pervasive. Interpretation of the significance of the abundance of other mineral inclusions is to some extent constrained by the relatively small sample sizes.

IMPLICATIONS FOR EXPLORATION

A study of the microchemical signatures of gold grains derived from the porphyry mineralization at Revenue/Nucleus, Casino and Sonora Gulch reported by Chapman *et al.* (2014) identified a common Pb-Bi-Te signature in the inclusion assemblage. This association is also observed in the present study which has further enhanced the potential for applying microchemical characterization of detrital gold grains in an exploration context. In addition, gold grains from these porphyry environments exhibit concentrations of Cu in the Au alloy consistently higher than gold grains derived from orogenic mineralization. Populations of placer grains from associated epithermal mineralization show wider variations in the concentration of Ag and perhaps substantial variation between the signatures of placer samples collected within a small area if there are multiple vein sources.

The Nansen trend is regionally atypical in the abundance of Au-bearing veins associated with the porphyry systems. Furthermore, the Cu-Au porphyry mineralization is weaker than that observed in broadly equivalent mineralized environments elsewhere. Gammons and Williams-Jones (1995) suggest that collapse of a magmatic hydrothermal system may result in overprinting of the potassic alteration zone by retrograde pyrite-rich phyllic alteration with the associated remobilization of gold in a hydrosulphide-rich fluid. Hart and Langdon (1997) report pervasive strong phyllic alteration and pyrite in a halo surrounding the potassic core of the Cyprus porphyry, and a similar feature is reported in Kelley South. Remobilization of Au provides a source for strongly developed epithermal mineralization which would inherit some of the geochemical signatures of the source mineralization, (*e.g.*, Bi, Pb and Te). It is also highly probable that the particle size of Au within late stage and epithermal veins is larger than that found in the earliest porphyry mineralization. Consequently the size and mineralogy of Au grains within placers may not correspond to the Au particles within the primary ore that are ultimately one of the targets of exploration. Understanding the genetic relationships between evolving porphyry systems and their epithermal expressions in terms of Au mineralogy is therefore key to interpretation of the characteristics of placer grains collected during reconnaissance.

CONCLUSIONS

The mineralogy of the inclusion suite revealed within polished sections of detrital gold grains from weathered outcrop in the BRX zone and the Canaan Creek placer are comparable with that of the Au-bearing stages of the hypogene ore observed in core samples, indicating that gold grains pass from the hypogene to the surface environments unmodified.

In this study, Ag content has proved a useful discriminant between porphyry and vein-derived Au. In general it has been possible to map Ag content onto end members of the porphyry-epithermal transition, and this has facilitated interpretation of the origins of placer Au in the Nansen district. The signature of gold grains collected from the BRX vein outcrop is replicated in the Canaan Creek placer, but a (very) high Ag component of the Canaan Creek placer is probably derived from other vein systems such as Western Klaza Zone. The placer Au in Nansen Creek is primarily of vein origin, although there is likely a strong contribution of Au from the Kelly rather than Cyprus porphyry. The wide range of Ag content observed in the Nansen Creek placer Au corresponds to fluctuations in fineness reported in production records and is interpreted as indicative of influx from several sources. The placer Au in Victoria Creek is predominantly vein derived although the sources remain undiscovered. Overall the study has shown that Au derived from veins is the most important contributor to placer development in the Nansen Creek area. In general the composition of Au in the various placers is consistent with the nature of the potential sources and generic relationships between porphyry and surrounding epithermal mineralization.

The values and variability of Ag and Cu contents of Au derived from porphyry and vein mineralization observed during this study may be correlated with the environment of Au precipitation. Gold veins formed during phyllic alteration from fluids which stripped Au from pre-existing mineralization in the potassic zone yielded Au of high Cu content and low Ag content and range, reflecting the relatively stable environment of mineralization. In contrast the precipitation of Au in the epithermal environment may be in response to abrupt changes in a variety of parameters and this is mirrored in the alloy signature, although the grains exhibit a similar inclusion suite as their porphyry derived counterparts.

This study augments previous work which described a generic Bi-Pb-Te signature of gold from calc-alkaline Cu-Au porphyries in Yukon, and that signature has also been identified in both porphyry and epithermal Au from the Nansen area. The importance of understanding the relationship between a porphyry system and its epithermal expression has been highlighted. The compositional ranges of populations of detrital Au particles collected during reconnaissance stream sediment sampling are more likely to be derived from relatively widespread epithermal mineralization than the relatively geographically constrained porphyry. The epithermal Au may be Cu-poor even though the primary mineralization is a Cu-Au porphyry.

The study has highlighted the need to consider stream order when interpreting Au-grain signatures. Both the Canaan Creek and the Discovery Creek placer samples were collected from first order streams, with geographically well constrained sources. The delicate nature of many Au particles reflects this proximity to source, and these samples were the most useful in developing a placer-lode model for the study area. The morphology of Au grains from Nansen Creek indicate fluvial transport, which raises the potential for multiple sources cited in various tributaries. In cases such as this it is more difficult to develop robust placer-source relationships, unless a large (typically >200) number of Au grains are available which may be considered in terms of both morphology and composition.

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