

The Sams Creek Peralkaline Granite Hosted Gold Deposit, Northwest Nelson, New Zealand — A New Variant on Alkaline Intrusion-Related Gold Deposits

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ABSTRACT

At Sams Creek a peralkaline granite porphyry dyke hosts gold-bearing sulfide-quartz-siderite veins. The granite dyke intrudes Ordovician-Silurian metapelite and quartzite, and has thin lamprophyre dykes along its contacts. The mineralised veins and the granite and lamprophyre dykes have been deformed during several phases of folding, the youngest of which is Early Cretaceous. The granite has been hydrothermally altered, with early magnetite-siderite±biotite alteration overprinted by sulfide and quartz-siderite veins and quartz-perthite-albite-siderite-pyrite-rutile±sericite alteration assemblages. The sulfide veins are composed of arsenopyrite + pyrite ± gold ± galena ± sphalerite ± chalcopyrite ± pyrrothite ± graphite, with minor quartz and siderite. The gold contains significant silver (up to 30.8 wt per cent) and ranges in fineness from 692 to 844. Immiscible liquid-rich fluid inclusions, in quartz protected from recrystallisation by enclosing arsenopyrite, contain carbonic liquid that homogenised at temperatures of 320 - 355°C.

The Sams Creek gold deposit is distinguished from the orogenic gold deposit type by its stockwork veining, magnetite-siderite±biotite alteration, high sulfide content, ore mineralogy and the absence of mineralisation in the metapelite country rocks. Features of the Sams Creek gold deposit do not fit neatly into existing classifications of granite-related gold-bearing deposits. The peralkaline composition of the Sams Creek granite and the absence of molybdenite and paucity of chalcopyrite, are major points of difference with gold-rich porphyry copper deposits. The presence of a low sulfidation-state ore mineral assemblage, carbonate alteration and carbonic fluid inclusions at Sams Creek are typical of many of the reduced granitic intrusion-related type of gold deposit. However, notable differences are:

1. the reduced type granites are metaluminous and calc-alkaline; and
2. Sams Creek only has high As in contrast to elevated Bi, W, As, Mo, Te, and Sb in the reduced type.

The Sams Creek deposit also shows affinities with gold deposits associated with alkaline magmatism, and it appears to be a new variant of this type as an As-Au deposit associated with a peralkaline granite and lamprophyre.

INTRODUCTION

Gold mineralisation at Sams Creek, 25 km south of Takaka in northwest Nelson, was discovered in 1974 by GW Patterson of CRA Exploration. The mineralisation was subsequently investigated by CRA Exploration (Hawke, 1982, 1984; Rosengren, 1985; Clemenston, 1987), and is currently being explored by Oceana Gold Ltd (formerly GRD Macraes Ltd) (www.oceanagold.com). The gold is associated with arsenopyrite-pyrite-quartz-siderite mineralisation in a peralkaline granite porphyry dyke, which intrudes lower Palaeozoic metasedimentary rocks. The first published record of the dyke noted that it was a recrystallised riebeckite microgranite (Shelley, 1984). Windle and Craw (1991) considered that the granite dyke had been buckled and dismembered by folding, but they concluded that the mineralising fluids were of metamorphic

origin. Tulloch (1992) described the mineralogy and chemistry of the granite as peralkaline and noted that the granite was altered by late and/or postmagmatic fluids. Osborne (1997) suggested that the mineralisation was produced by late stage magmatic hydrothermal fluids. The mineralisation is confined to the granite and the ore mineralogy, hydrothermal alteration and stable isotope compositions of the vein minerals are consistent with a magmatic-hydrothermal origin (Faure, Brathwaite and de Ronde, 2003).

Here we describe the Sams Creek deposit as a granite-hosted gold-sulfide deposit which, although it has been deformed and largely recrystallised shows many features that are similar to the reduced granite related (eg Thompson and Newberry, 2000; Lang and Baker, 2001) and alkaline intrusion related gold deposit types (eg Jensen and Barton, 2000).

REGIONAL SETTING

The Sams Creek area lies within the Eastern Sedimentary Belt of the Takaka terrane (Figure 1), a belt of Lower Palaeozoic metasedimentary rocks (Grindley, 1980; Cooper, 1989; Rattenbury, Cooper and Johnston, 1998). This terrane was deformed and metamorphosed under lower greenschist facies conditions prior to intrusion of the Late Devonian (367 Ma) Rameka Complex (Cooper, 1989). The terrane was subsequently intruded by granite and granodiorite of the Early Cretaceous Separation Point Suite (Tulloch, 1983; Muir *et al.*, 1995). Three phases of deformation have been identified in the region: a first phase of recumbent folding (F_1), a second of inclined folds (F_2) about subhorizontal north-south trending axes, and a third (F_3) of localised northeast to southeast trending folds (Grindley, 1980; Jongens, 1997). Bradshaw (2000) has shown the Early Devonian Baton Formation is affected by the F_1 and F_2 folding, and

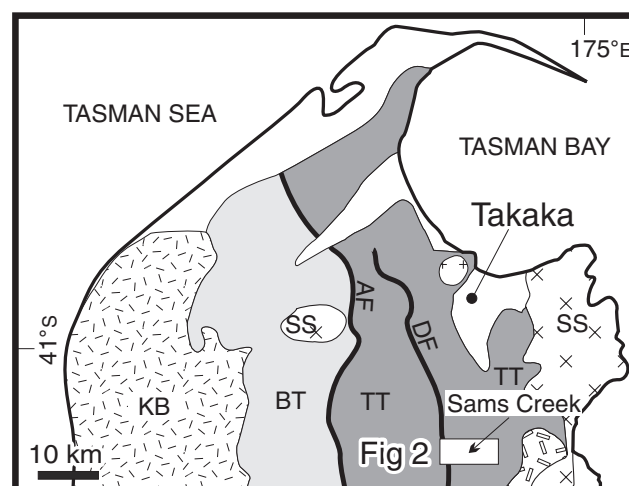


FIG 1 - Regional location map of Sams Creek area, west Nelson. Buller Terrane (BT), Takaka Terrane (TT), Karamaea Granite Batholith (KB), Separation Point Suite Granitoids (SS), Riwaka Complex (RC), Anatoki Fault (AF), Devil River Fault (DRF). Inset shows location of Figure 2.

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therefore at least the F_1 folding is Mid Devonian. Radiometric dating indicates that a northeast-trending regional schistosity in the area northwest of Takaka, which is correlated with the third phase of deformation, was associated with the emplacement of the Separation Point Batholith in the Early Cretaceous (Challis *et al.*, 1995). The region has also been affected by late Tertiary and Quaternary folding and faulting, as indicated by deformation of mid-Tertiary sedimentary rocks, which unconformably overlie the older rocks.

DEPOSIT GEOLOGY

Sams Creek is a deeply incised tributary of the Takaka River on the eastern side of the Lockett Range. The peralkaline granite porphyry, which hosts the gold-sulfide mineralisation, intrudes Ordovician-Silurian metapelite, metasandstone and quartzite of the Wangapeka Formation and Hailes Quartzite (Grindley, 1980; Rattenbury, Cooper and Johnston, 1998). The tabular morphology of the granite porphyry body, with a thickness of 30 to 40 m and extent of at least 7 km (Figure 2), together with its discordance to bedding in the metasedimentary rocks indicate that it was emplaced as a dyke.

The metasedimentary rocks have been folded and regionally metamorphosed to a lower greenschist facies assemblage of quartz-albite-muscovite-chlorite. Shelley (1984) described a recumbent fold (F_1) at Sams Creek which has been refolded by northerly-trending F_2 folds. Hickey (1986) mapped the F_2 folds as being inclined with subhorizontal axes and also identified F_3 folding about steeply plunging axes. A prominent crenulation cleavage is axial plane to the F_2 folds (Shelley, 1984; Hickey, 1986; Windle and Craw, 1991), and this cleavage also extends into hydrothermally altered lamprophyre, which occurs along the margins of the granite dyke. In the Anvil Zone (Figure 2), Windle and Craw (1991) mapped deflection of the cleavage around the margins of granite bodies that have been dismembered by deformation. This together the sinuous outcrop pattern of the granite and the presence of extensive shearing

within the dyke and along many of its contacts indicate that it has been deformed and folded.

The unaltered granite porphyry is composed of scattered phenocrysts of perthite (0.5 - 5 mm in length), arfvedsonite, aegerine and quartz (up to 4 mm) in a fine grained (~0.2 mm) hypidiomorphic granular aggregate of perthite, quartz, plagioclase, arfvedsonite and aegerine. Myrmekitic intergrowths of quartz and plagioclase are common. Ilmenite, rutile and fluorite are accessory minerals. The arfvedsonite is partly replaced by rims of riebeckite. The sodic mineralogy and geochemistry, with low Al_2O_3 and Sr, coupled with high values of Zr, Nb, Ga and Y, are characteristic of a peralkaline ($Na_2O + K_2O > Al_2O_3$) A-type granite (Tulloch, 1992). The absence of primary magnetite and a low magnetic susceptibility ($30 \text{ SI units} \times 10^{-5}$) in the least altered granite classifies it as a reduced, low oxidation-state granite (Thompson and Newberry, 2000).

Thin (0.2 - 3.0 m) dykes of ankerite-chlorite-sericite altered lamprophyre occur along the contacts of the granite porphyry dyke, and within the adjacent metapelite. The occurrence of inclusions of lamprophyre in the granite adjacent to its contacts with lamprophyre suggests that the granite was intruded into the lamprophyre (Figure 3). The least altered samples of the lamprophyre contain relict primary phenocrysts of plagioclase, titaniferous augite, brown amphibole, biotite, magnetite, ilmenite and apatite, which together with chemical analyses indicate that the lamprophyre is a camptonite (Windle and Craw, 1991). Contacts of the lamprophyre and metapelite are commonly sheared, but in some cases a sharp contact has been preserved and a crenulation cleavage extends from the metapelite into the altered lamprophyre.

A single K-Ar date of amphibole from the granite gave an age of $226 \pm 1 \text{ Ma}$ (Tulloch, 1992), but this age is probably a minimum due to resetting during the thermal and deformation events that have affected the area. Despite high Zr contents of 1180 - 1380 ppm, the granite contains insignificant amounts of zircon, and attempts to separate it for U-Pb dating have been unsuccessful.

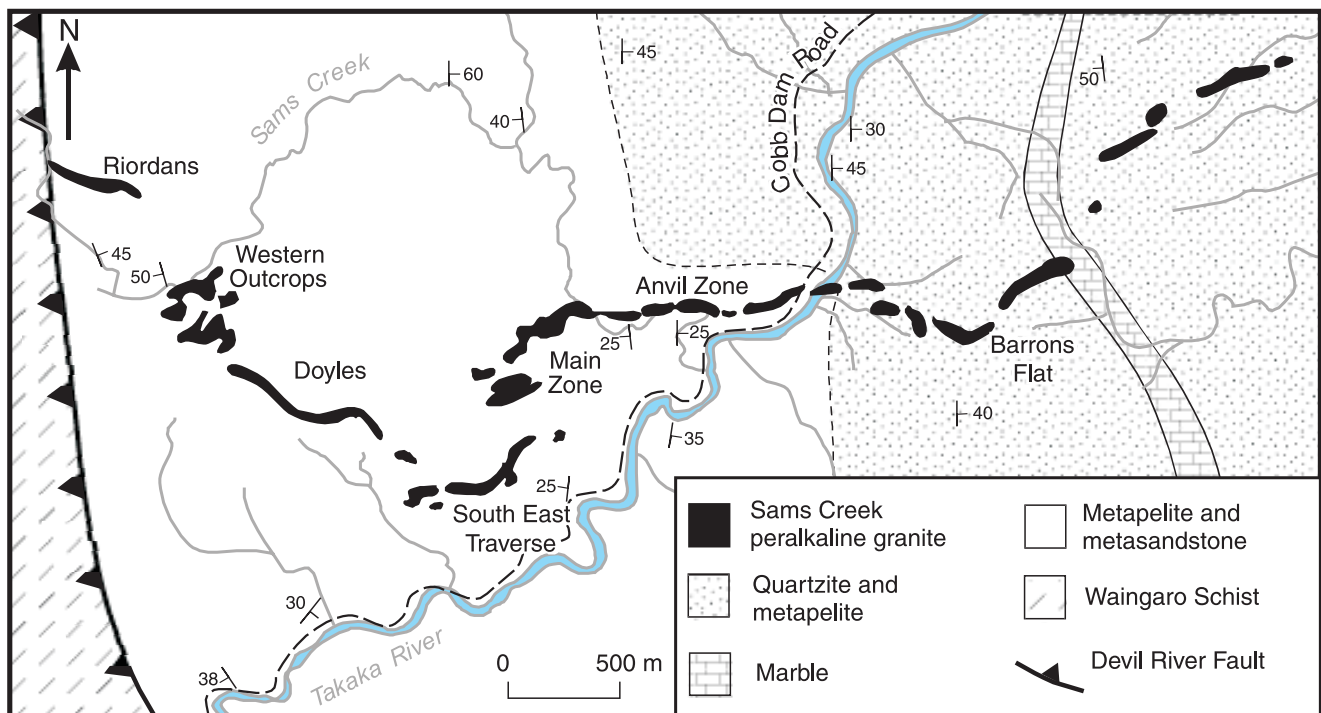


FIG 2 - Geological map of the Sams Creek area, Upper Takaka. Modified from Tulloch (1992) and based on mapping by CRA Exploration (Clementson, 1987) and Hickey (1986).

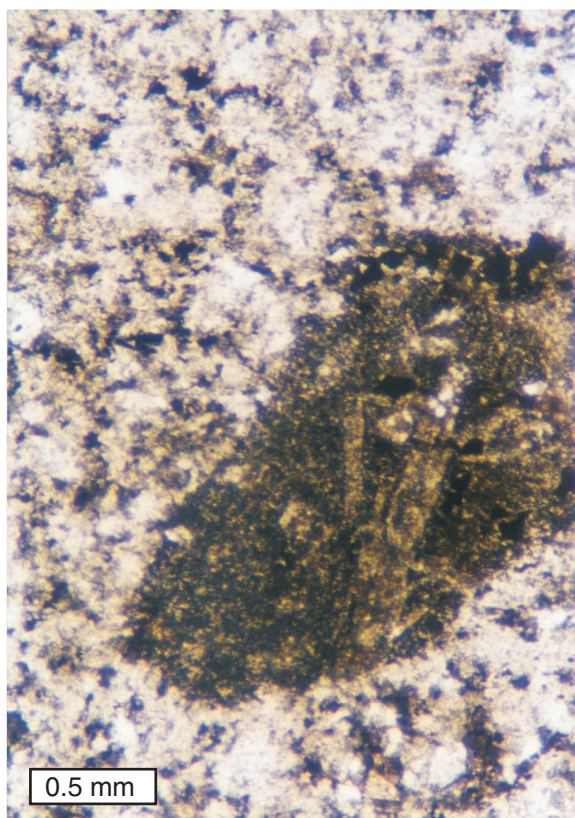


FIG 3 - Inclusion of altered lamprophyre in siderite altered microgranite. Photomicrograph in plane transmitted light.

Hydrothermal alteration and mineralisation

Three stages of alteration and associated mineralisation are recognised within the granite. Stage I is represented by a magnetite-siderite±biotite assemblage and consists mainly of magnetite and siderite grains that are clustered in and around the remnants of arfvedsonite and aegerine phenocrysts (Figure 4). In a few samples magnetite and siderite are accompanied by fine

grained biotite. In the western outcrops, this magnetite-rich assemblage is absent and a quartz-sericite-siderite alteration assemblage is present. A K-Ar date of 101 ± 2 Ma on a sericite-altered granite sample from the western outcrops may represent either the age of the hydrothermal alteration, or a closure temperature for muscovite/sericite following uplift after the Early Cretaceous thermal event that has affected the region (Tulloch, 1992).

Stage II alteration/mineralisation consists of quartz-pyrite veins which are cut by the third stage of sulfide and quartz-siderite veins (Figure 4). The third stage of mineralisation is the main stage of ore mineralisation and the only gold-bearing stage. Adjacent to the Stage III veins, the granite is silicified to a pervasive quartz-perthite-albite-siderite-rutile-pyrite±sericite assemblage (Figures 5a and 5b). Remnant arfvedsonite and aegerine are replaced by siderite, and magnetite is replaced by pyrite and rutile. A fourth stage of pyrite-rich veins (1 - 2 mm thick) commonly occurs in zones of more intense deformation. These late pyrite-rich veins are aligned parallel to a schistose fabric in the host granite (Figure 5b). Country rock metapelites are locally altered to a carbonate-sericite-pyrite assemblage along dyke contacts.

Gold is associated with arsenopyrite and pyrite in an irregular stockwork of deformed sulfide-quartz-siderite veins that are confined to the granite porphyry dyke. In some drill hole intersections the Stage III sulfide-quartz-siderite veins occur over the full width of the dyke. Individual sulfide veins are relatively thin (1 mm to several centimetres, Figures 4 and 5) and consist of mainly arsenopyrite and pyrite, with minor galena, sphalerite, gold, chalcopyrite, pyrrhotite and graphite. Quartz and siderite are locally present in the sulfide veins and also occur as separate veins (Figures 4, 5a and 5b). Graphite occurs very locally in association with arsenopyrite (Figure 6a). Gold (2 - 100 μm in size) is confined to sulfide-rich veins, where it is locally common. It is associated with galena, arsenopyrite, sphalerite and chalcopyrite (Figures 6b and 7a), and is found particularly as inclusions with galena in arsenopyrite and pyrite crystals. Electron microprobe (EMPA) analyses show that the gold contains significant silver (15.6 - 30.8 wt per cent Ag) with a range in fineness of 692 - 844 (average of 781). This range in fineness is consistent with microscope observations of significant variation in colour of the gold from deep to pale yellow. Within individual samples the composition of the gold appears to be fairly uniform.

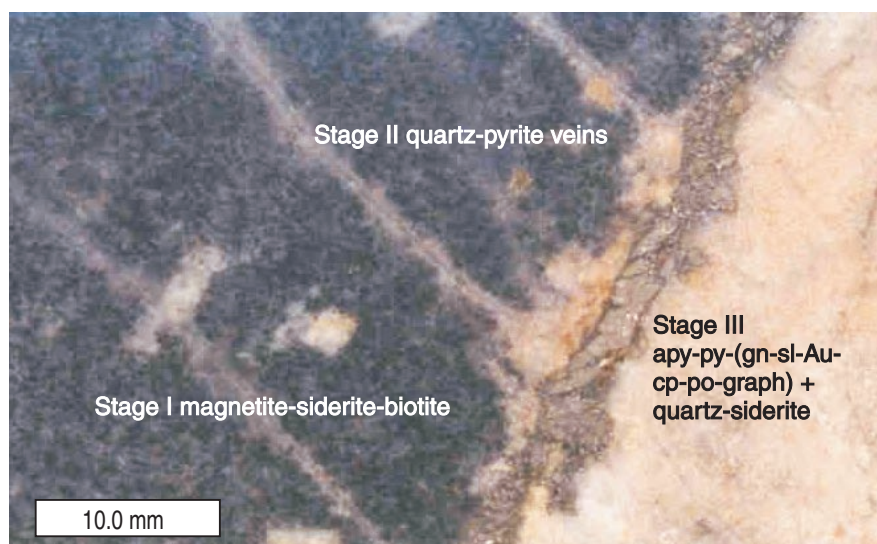


FIG 4 - Alteration and mineralisation stages within the Sams Creek granite. Stage I magnetite-siderite±biotite altered granite (mottled black) cut by 1-2 mm thick Stage II quartz-pyrite veins (white) and by a 3 - 5 mm thick Stage III arsenopyrite-pyrite-(galena-sphalerite-gold-chalcopyrite-pyrrhotite-graphite) vein (silver grey) and associated quartz-siderite (white) vein. Photo of drill core.

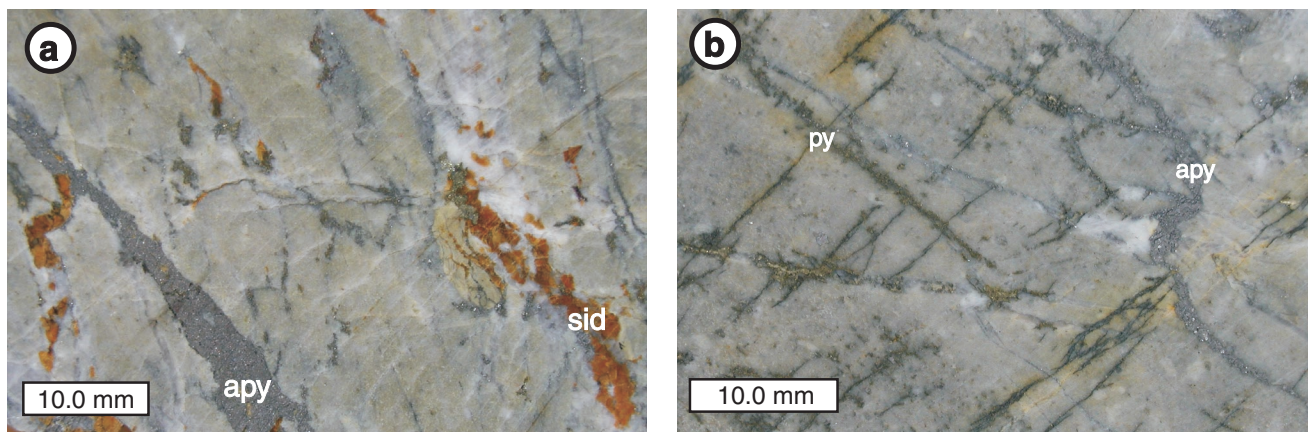


FIG 5 - Sulfide veins in silicified microgranite. (A) Arsenopyrite-rich veins (apy) and quartz-siderite veins (sid). (B) Deformed arsenopyrite-rich vein (apy) and two generations of pyrite-rich (py) veins. Note alignment of late pyrite veins along cleavage. Photos of drill core.

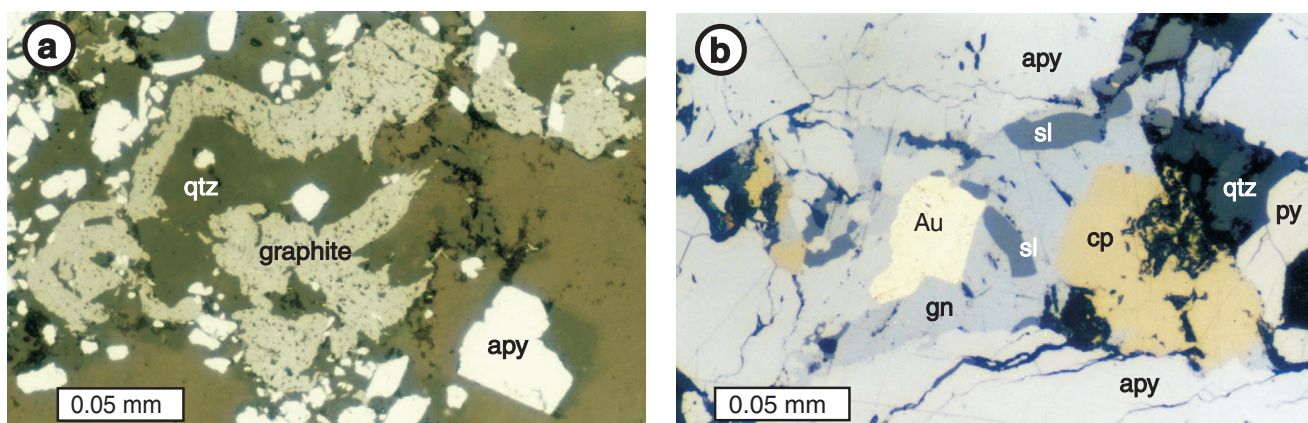


FIG 6 - Mineralisation. (A) Graphite with arsenopyrite (apy) and quartz (qtz). (B) Gold (Au) associated with galena (gn), chalcocopyrite (cp) and sphalerite (sl) with arsenopyrite (apy) and quartz (qtz). Photomicrographs in reflected light.

A number of prospects have been identified along strike of the Sams Creek dyke including Riordans, Western Outcrops, Doyles, South Eastern Traverse, Main Zone, Anvil Zone and Barrons Flat, but only one of these, the Main Zone, has been systematically drilled to date (Figure 2). The current resource estimate for Sams Creek is 10.7 Mt at 2.12 g/t Au containing 729 000 oz at a 0.7 g/t Au cut-off and limited to a depth of 140 m (Oceana Gold, formerly GRD Macraes, Quarterly Report 31 December 2003). This is based on limited drilling completed to date for the Main Zone.

Metal geochemistry

Geochemical analyses of selected elements from intersections of the granite and adjacent lamprophyre dykes in four drillholes (SC43, 44, 45 and 48) were provided by Oceana Gold Ltd. One-metre long drill core samples were analysed for gold by fire assay and As, Cu, Pb, Zn, Mo and Bi by atomic absorption spectroscopy (AAS) or by inductively coupled plasma mass spectroscopy (ICP-MS). The results (Table 1) confirm the mineralogical observations in showing moderate As (average 0.7 wt per cent) representing arsenopyrite, as well as local concentrations of zinc and lead as sphalerite and galena, with low copper as traces of chalcocopyrite, and insignificant Mo and Bi.

Inter-element correlations show a strong correlation between Au and As ($r = 0.75$) and weak correlations between Au and Ag ($r = 0.28$) and Au and Pb ($r = 0.32$). The weak geochemical correlations between Au and Ag and between Au and Pb contrast with the relatively high silver content of the gold and the common association of gold and galena. This may be a reflection of the

TABLE 1

Results of chemical analyses of granite and lamprophyre in drill core samples.

Metals (ppm)	Au	Ag	As	Zn	Pb	Cu	Mo	Bi
Average	1.8	1.1	6972	324	148	16	5.6	0.4
Number	260	249	249	249	249	249	249	249
Maximum	9.2	34.5	43 500	4350	2050	320	26	7

different sampling scales of metre lengths for the geochemical analyses and few millimetres for the polished thin sections.

Deformation textures

The granite and the Stage III sulfide and quartz-siderite veins have been deformed and recrystallised. Quartz crystals in the Stage II veins commonly show a schistose fabric, with the quartz crystals elongated parallel to the vein walls. Vein pyrite and arsenopyrite, being competent sulfide minerals are extensively fractured and brecciated. Fractures within arsenopyrite are locally filled by galena and gold (Figure 7a). Galena is a ductile sulfide mineral, which under deformation readily migrates to low pressure sites. Vein quartz shows local development of cataclastic and mortar textures with broken quartz fragments in a matrix of fine grained recrystallised quartz. Quartz pressure shadows are formed around larger arsenopyrite crystals (Figure 7b), indicating that the arsenopyrite crystals are pre- or syn-tectonic. Quartz in phenocrysts and veins shows undulose extinction, deformation bands and deformation lamellae.

Fluid inclusions

Vein quartz is extensively recrystallised and contains tiny, single-phase fluid inclusions (<2 μm in size) as a monophasic haze. Early fluid inclusions are rare and are only preserved in vein quartz that is associated with massive arsenopyrite veins in the Main Zone (Figure 8a). The rigidity of the arsenopyrite appears to have protected the quartz and its contained inclusions from recrystallisation. The early inclusions occur as small (<10 μm) two- and three-phase immiscible liquid-rich carbonic inclusions (Figure 8a) and two-phase liquid-rich inclusions. At room temperature, the immiscible liquid-rich carbonic inclusions contain two liquid phases (carbonic-rich and H_2O -rich), with or without a vapour phase as a CO_2 vapour bubble.

A previous study by Windle and Craw (1991) described CO_2 -rich inclusions from the western part of the dyke (Western Outcrops and Riordans), which coexisted with liquid-rich inclusions and therefore represented trapping of immiscible carbonic- and liquid-rich fluids at temperatures of 260 - 340°C. The carbonic phase and clathrate melting temperatures of these CO_2 -rich inclusions indicated that the carbonic phase was mainly CO_2 .

In this study, the carbonic inclusions homogenised by disappearance of the H_2O -rich phase at temperatures of 320 to 355°C, which are probably less than the actual trapping temperatures (cf Shepherd, Rankin and Alderton, 1985). During freezing runs the carbonic phase melted ($T_m\text{CO}_2$) at temperatures of -62.0 to -66.0°C and a clathrate phase melted ($T_m\text{C}$) at 11.6 to 12.5°C. These data suggest that the fluid contains other gases

such as CH_4 and N_2 in addition to CO_2 , particularly because $T_m\text{CO}_2$ is well below the -56.6°C triple point of pure CO_2 (eg Diamond, 2003). The presence of CH_4 in the fluid is consistent with the occurrence of graphite in the mineralisation.

The liquid-rich carbonic inclusions have T_h values of 258 to 310°C and contain clathrates, as shown by $T_m\text{C}$ values in the range of 9.2 to 11.6°C. Liquid CO_2 was not observed in these inclusions and a $T_m\text{CO}_2$ value of -57.6°C indicates near pure CO_2 in the carbonic phase. T_{mi} values of -1.7 to -6.2°C convert to apparent salinities of 1.7 to 6.2 wt per cent NaCl equiv.

Remnants of early fluid inclusions occur within deformed vein quartz as decrepitated fluid inclusions and as healed empty inclusions (Figure 8b). These remnant fluid inclusion morphologies are similar to those described from a metamorphosed ore deposit by Giles and Marshall (1994). The healed inclusions were interpreted by these authors as leaked inclusions which re-equilibrated to a lower bulk density under conditions of high internal overpressure.

COMPARISON OF THE SAMS CREEK GOLD DEPOSIT WITH OROGENIC AND INTRUSION RELATED GOLD DEPOSITS

Commonalities with orogenic lode gold deposits, are the low sulfidation state of the ore mineral assemblage (arsenopyrite and pyrite), carbonate alteration and carbonic fluid inclusions at Sams Creek (Table 2). However, significant differences are that the Sams Creek deposit has a high sulfide content, contains significant galena, sphalerite and chalcocopyrite and no scheelite or

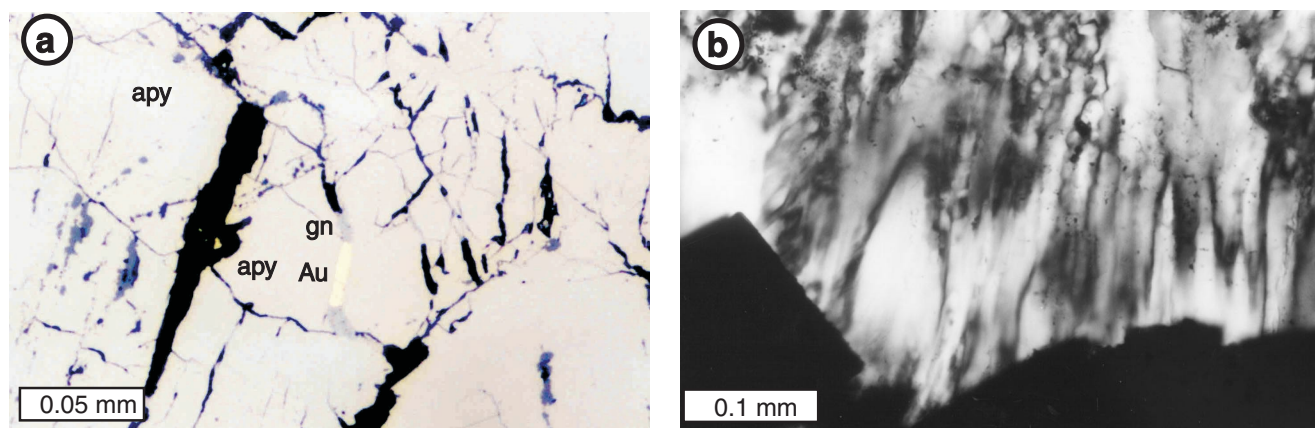


FIG 7 - Deformation and recrystallisation textures. (A) Fractured arsenopyrite (apy) with one fracture infilled by galena (gn) and gold (Au). (B) Recrystallised quartz as pressure shadow around arsenopyrite (black). Photomicrographs in reflected light.

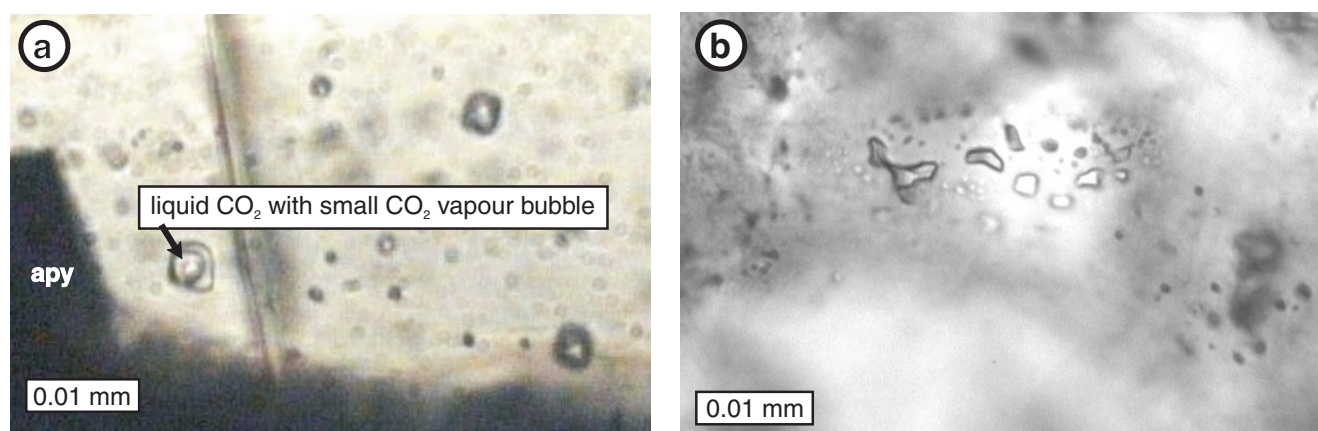


FIG 8 - Fluid inclusions in vein quartz. (A) Immiscible carbonic liquid-rich inclusions in quartz enclosed by arsenopyrite (apy). Note three phase inclusion containing H_2O -rich liquid and liquid CO_2 -rich bubble vapour bubble enclosing small CO_2 -rich vapour bubble. (B) Secondary healed empty inclusions. Photomicrographs in plane transmitted light.

TABLE 2
Comparison of Sams Creek gold deposit with other types of gold deposits.

	Sams Creek Au deposit	Porphyry Cu-Au-Mo deposits	Reduced granite Au deposits	Alkaline intrusion related Au deposits	Orogenic Au deposits
Granite: type composition oxidation-state	A Peralkaline Oxidised-reduced	I Calc-alkaline Oxidised	I Sub-alkaline Reduced	A and I Alkaline-peralk Oxidised	No direct spatial relationship
Lamprophyres	Yes	No	Local	Variable	Variable
Tectonic setting	Anorogenic	Subduction-related plutonic arcs	Continental inboard plutonic arcs	Continental inboard plutonic arcs	Orogenic slate belts
Vein style	Stockwork	Stockwork and breccia	Stockwork and breccia (shallow) Planar (deep)	Stockwork	Planar fault-hosted
Metals+Fe+Au	As, Zn, Pb, Ag	Cu, Mo, Pb, Zn, Ag	Bi, Mo, W, Sb, (Sn)	Cu, Mo, Te	As, W, Sb
Sulfide content	High 10 - 30 %	High	Low <5 %	High	Low <3 %
Ore minerals+gold	apy, py, gn, sl, cp, po	py, cp, bn, mo	po, py, apy, mo, sch	cp, bn, py, mo, mt, hm	py, apy, sch, stbn
Sulfidation-state	Low	High	Low	Moderate	Low
Alteration: early Alteration: late	mt-sd-(bt) qtz-sd-py-rt-(ser)	kspar-bt-mt qtz-ser	ab-kspar ser-cb	kspar-bt-mt-anh cb-(ser)	ser-cb-qtz-chl
Fluid inclusions	V-rich carbonic	V-rich and high salinity	CO ₂ -rich and high salinity	Mod-high salinity and CO ₂ -rich	Liquid-rich carbonic
References	This study	Sillitoe (2000)	Thompson and Newberry (2000)	Jensen and Barton (2000)	Groves <i>et al</i> (1998)

Abbreviations: ab = albite, anh = anhydrite, apy = arsenopyrite, bt = biotite, bn = bornite, cb = carbonate, chl = chlorite, cp = chalcopyrite, ep = epidote, gn = galena, kspar = potassium feldspar, mo = molybdenite, mt = magnetite, peralk = peralkaline, po = pyrrhotite, py = pyrite, qtz = quartz, sch = scheelite, ser = sericite, sd = siderite, sl = sphalerite, stbn = stibnite.

stibnite, and has early magnetite-siderite±biotite alteration. Additional differences from orogenic gold deposits are the stockwork-type veining and absence of mineralisation in the metapelite country rocks at Sams Creek. Windle and Craw (1991) proposed that the Sams Creek deposit was of the 'slate belt' (orogenic gold type) and contended that the mineralisation was confined to the granite because of its distinctive Fe³⁺-rich composition. However, this view is at odds with their description of deformation textures in the quartz and sulfide veins, which indicates that the mineralisation pre-dated the deformation and metamorphism. It is conceivable that the mineralisation could be syntectonic, but the lack of any through-going structural control on the veins and the gross relationship of the mineralisation and the alteration to the granite host rock are inconsistent with a syntectonic origin (cf Marshall and Gilligan, 1993). Also, its A-type chemistry, suggests that the Sams Creek granite was emplaced in an anorogenic tectonic setting.

As listed in Table 2, features of the Sams Creek gold deposit show similarities and differences with the various types of gold-rich porphyry and granite-related deposit types. The high sulfide content, stockwork style sulfide-quartz veining and the presence of an early magnetite-biotite hydrothermal alteration are features of many gold-rich porphyry Cu deposits (eg Sillitoe, 2000). However, the tectonic setting, high-SiO₂ and peralkaline composition of the Sams Creek granite, the absence of molybdenite and paucity of chalcopyrite, the low sulfidation state of the ore mineral assemblage and the carbonic fluid inclusions are major points of difference.

A low sulfidation-state ore mineral assemblage (with arsenopyrite, pyrite and pyrrhotite), carbonate alteration and carbonic fluid inclusions are typical of the reduced-granitic intrusions type (eg Thompson and Newberry, 2000; Lang and Baker, 2001). However, there are some notable differences between the reduced-granitic intrusions type and the Sams Creek gold deposit. The Sams Creek granite is A-type and peralkaline, whereas granites of the reduced type are generally I-type and metaluminous and sub-alkaline or rarely alkaline granite. The Sams Creek gold deposit has a high sulfide content and only has high As in contrast to a low sulfide content and elevated Bi, W, As, Mo, Te ± Sb in the reduced type.

An association of gold-rich deposits with alkaline magmatism has also been recognised (eg Jensen and Barton, 2000). The Sams Creek gold deposit shows affinities with this type, although there are some differences (Table 2). The alkaline intrusion-related type covers a range of compositions from alkaline to peralkaline and are typically oxidised. Early magnetite-biotite alteration and late carbonate alteration are typical, as at Sams Creek. Some examples of this deposit type have an association with alkaline lamprophyres (eg Rock *et al.*, 1989), such as the Porgera gold deposit in Papua New Guinea. However, alkaline granites with high SiO₂, comparable with the Sams Creek granite, are commonly associated with Mo±Au mineralisation and have moderate to high, rather than low, sulfidation states in the ore mineral assemblage.

Gold deposits associated with granitoids are a diverse group and the Sams Creek gold deposit, while showing some features of the various groups, appears to be a new variant of the alkaline intrusion-related type, as an As-Au deposit associated with a peralkaline granite and lamprophyre.

CONCLUSIONS

Stockwork vein mineralisation at the Sams Creek gold deposit, consisting of quartz, siderite, and arsenopyrite + pyrite ± Au ± galena ± sphalerite ± chalcopyrite ± pyrrhotite ± graphite, is restricted to a peralkaline granite porphyry dyke that intruded metasedimentary rocks. The granite dyke and the sulfide and quartz-siderite veins within it have been deformed and recrystallised during two phases of folding, the youngest of which is of Early Cretaceous age from the regional geological history. Therefore the emplacement of the granite and associated mineralisation is at least pre-Early Cretaceous.

The presence of stockwork veining, magnetite-siderite±biotite alteration, a high sulfide content with significant galena, sphalerite and chalcopyrite, and the absence of mineralisation in the metapelite country rocks distinguish the Sams Creek deposit from the orogenic gold deposit type. In relation to granite type, sulfide content and alteration, the Sams Creek gold deposit resembles alkaline intrusion-related gold deposits, whereas in its

low sulfidation-state ore mineralogy with arsenopyrite, it is more akin to reduced-granite gold deposits. The association of a peralkaline granite with alkaline lamprophyre is a key feature and suggests that the occurrence of these rock types provides a target for exploration of analogues of the Sams Creek deposit in other terranes. The fact that the Sams Creek was only discovered in the 1980s is an enigma, because the gold-bearing sulfide-quartz veins at Sams Creek crop out in a region that was intensively prospected for gold in the late 1800s.

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