Exploration implications of hydrothermal alteration associated with epithermal Au-Ag deposits

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SUMMARY

This paper will present a synopsis of the results from a three year AMIRA project (P588) entitled "Epithermal Gold-silver Deposits: Geological, Geochemical and Isotopic Vectors to Target Major Deposits". Research was undertaken at the Ladolam, (Papua New Guinea), Gosowong, and Mt Muro (Indonesia), Cerro Vanguardia (Argentina) and Twin Hills and Bimurra (Australia) deposits. The sizes and styles of the deposits varied greatly from a low-grade to barren small vein-stockwork system at Bimurra and Twin Hills to high grade veins systems of different scales such as Gosowong, Mt Murro and Cerro Vanguardia to a large breccia-hosted low grade, disseminated system at Ladolam.

At each of the deposits alteration mineralogy and zonation were determined using a combination of surface mapping, drill hole logging, petrology, SWIR (PIMA), XRD and potassium feldspar staining. Electron microprobe analyses of specific minerals, whole-rock and trace element whole rock analyses and stable isotope geochemistry were utilised to characterise the geochemical signature of the hydrothermal alteration.

Results of this research have 1) substantially increase our knowledge of the mineralogical and whole-rock geochemical characteristics of hydrothermal alteration associated with low- and intermediate sulfidation epithermal deposits, 2) developed a range of vectors that point towards ore, both on district and deposit scales, which can be used when exploring in epithermal environments and 3) proposed a set of criteria for distinguishing potential ore grade systems from barren or low grade epithermal systems.

Key words: epithermal, hydrothermal alteration, mineral chemistry, lithogeochemistry, exploration vectors

INTRODUCTION

Low sulfidation epithermal deposits provide a significant contribution towards global silver and gold production (White and Hedenquist, 1990; Hedenquist et al., 2000; Simmons et al., 2005) and are an important target for precious metal explorers. Investigation of modern geothermal systems have led to many new concepts in the understanding of low sulfidation epithermal deposits which aid in the development of genetic and exploration models for this style of mineralization (Reyes, 1990).

While the characteristics of the geology and mineralization of low sulfidation epithermal deposits are generally well known and many papers (e.g. Buchanan, 1981; Heald et al., 1987; Sillitoe, 1993, 1997; White et al., 1995; White and Hedenquist, 1990, 1995; Hedenquist et al., 2000; Cooke and Simmons, 2000; Simmons et al., 2005) have described the alteration mineralogy and zonation, there has been a distinct lack of detailed information and data available on the mineral chemistry and whole-rock geochemical characteristics of the hydrothermal alteration. Alteration zones in epithermal districts are commonly larger than the related ore deposit and consequently the recognition of mineralogical and geochemical zonation within areas of alteration may provide a basis for developing vectors to the ore deposit. Some alteration zones have no known related ore deposit, and therefore the recognition of discriminators between fertile and barren alteration zones is also very important for exploration.

Information presented in this paper is based on the outcomes of a three-year (2000-2002) ARC-AMIRA collaborative investigation between researchers based at the Centre for Ore Deposit Research (CODES), University of Tasmania, Australia and the Geothermal Institute, University of Auckland, New Zealand. Deposits investigated were Ladolam, Papua New Guinea, Gosowong and Mt Muro, Indonesia, Cerro Vanguardia, Argentina and Bimurra and Twin Hills, Australia.

METHOD AND RESULTS

Deposits studied were hosted in either basaltic to intermediate-hosted (Ladolam, Mt Muro, Gosowong) or felsic-hosted (Cerro Vanguardia, Twin Hills, Bimurra) volcanic and volcaniclastic rocks with minor amounts of epiclastic sedimentary rocks. The sizes and styles of the deposits varied greatly from a low-grade to barren, small, vein-stockwork systems at Bimurra and Twin Hills to high-grade veins systems at different scales such as Gosowong, Mt Muro and Cerro Vanguardia, to a large, breccia-hosted, low grade, disseminated system at Ladolam. Table 1 summarizes the geologic, mineralization and alteration characteristics for each deposit.

Hydrothermal Alteration

At each of the deposits the alteration mineralogy and zonation were determined using a combination of surface mapping, drill core logging, petrology, SWIR (PIMA), XRD and potassium feldspar staining (HF and sodium colbatinitrite). There is a consistent development and zonation of alteration at each of the deposits. In all cases the development of quartz-adularia-illite is proximal to mineralisation. Moving away from the mineralisation the alteration becomes illite-smectite-rich before passing into a distal propylitic assemblage containing varying proportions of albite, chlorite, epidote and chlorite. Distinct zonation of alteration assemblages is much more pronounced in the mafic-hosted (Gosowong, Mt Muro and Lihir) as compared to the felsic-hosted systems (Cerro Vanguardia, Twin Hills and Bimurra). In the mafic-hosted systems the distal propylitic alteration is better developed compared to the felsic systems.

A key outcome of this project has been the importance of the distribution of adularia. At every case study site the identification and distribution of adularia was vastly underestimated during fieldwork. Determining the presence of adularia is also important for discriminating fertile from non-fertile structures in a district. As the presence of adularia indicates boiling of the hydrothermal fluids, and to the proximity of gold mineralisation, potassium feldspar staining should become a routine part of the exploration program.

Not all propylitic (epidote±chlotite±albite±calcite) alteration is the same. Recognition of two types of propylitic alteration, vein-related and regional, has been critical to the effective evaluation of the propylitic alteration. Care should be taken when evaluating propylitic alteration associated with epithermal systems as their mineralogy and textural characteristics are important in determining if the “green rocks” are related to a mineralising system or part or the background alteration in volcanic terrains.

Whole-rock Geochemistry

Multi-element geochemistry was undertaken on over eight hundred whole-rock samples during this project. Major and selected trace elements were analysed by XRF, with the majority of trace elements analysed by ICPMS. Various methods were employed to investigate the whole-rock geochemistry, including down hole element plots, 2D contouring of data, and the development and use of alteration indices and alteration box plots.

The alteration indices determined to be of most use when evaluating lithochemical variations surrounding low sulfidation epithermal deposits were the Alteration Index (AI) = 100(MgO + K_2O)/(MgO + K_2O + CaO + Na_2O; Ishikawa et al., 1976); chlorite-carbonate-pyrite index (CCPI) = 100(MgO + FeO)/(MgO + FeO + K_2O + Na_2O; Large et al., 2001); KVI = 100*LOI / (LOI+K_2O); KSI = 100*(K_2O+S) / (K_2O+S+MgO+Na_2O); NVI = 100*LOI / (LOI+Na_2O) and SSI = 100*S / (S+Na_2O). In almost all cases, these alteration indices have values that increase towards the deposit on district and/or deposit scale. However, the use (and abuse) of alteration indices at a specific deposit must be coupled with a thorough understanding of alteration mineralogy and processes.

Thallium

One of the new aspects of the interpretation of the whole-rock has been the relationship between K_2O and Tl. Thallium is an element that occurs in phyllosilicates (micas and clays), tectosilicates (feldspars) and sulfides (galena, pyrite and Tl-sulfides and Tl-sulfosalts) with concentrations generally are in the range of 1-10 ppm (Ikramuddin et al., 1983; Shah et al., 1994). Thallium has been noted as an element that is concentrated in altered rocks surrounding a variety of mineral deposit styles, for example VHMS (Large et al., 2001), mesothermal veins, uranium deposits, porphyry Cu-Mo deposits, and epithermal vein deposits (Shah et al., 1994). In our study, there is a distinctive positive correlation between K_2O and Tl for altered samples from both mafic-intermediate and felsic-hosted deposits, while there is little correlation between K_2O and S. Our research indicates that adularia, not sulfide or illite, contains the Tl in the altered rocks surrounding the low sulfidation epithermal deposits examined.

Mineral Chemistry

Chlorite

A systematic zonation of chlorite chemistry is observed from the analysis of chlorites at Gosowong, Mt Muro and Cerro Vanguardia. Chlorite chemistry varies systematically with type of alteration and proximity to the deposit. Mg-rich chlorite occurs proximal to the vein in quartz-adularia-illite alteration, passing outwards Mg-Fe chlorite in illite-smectite zones to Fe-chlorite in the distal propylitic alteration zone.

Potassium feldspar

A new and novel method, laser ablation-ICPMS, for determining the mineral chemistry of hydrothermal potassium feldspar was pioneered in this project. At Cerro Vanguardia Ba, Sr, Rb, Li, Cs, Tl and Pb have elevated levels in both secondary K-feldspar and vein adularia. Both the secondary K-feldspar alteration and adularia grains at any given location have relatively constant trace element levels and are internally homogeneous. This study has identified Ba and Pb, and to a lesser extent Cs, as elements in adularia that vary systematically and can be used as vectors towards mineralisation at Cerro Vanguardia.

Pyrite

Laser ablation-ICPMS analyses of pyrite were also undertaken on pyrite from Cerro Vanguardia. Pyrite in the vein and stockwork has higher levels As, Ag, Cu and Au contents compared to pyrite in the wall rock. In comparison, pyrite in the wall rock has higher levels of Zn, Sb, Tl, Co, Pb and Bi, with lower Tl contents. Lead, Bi and Mo in pyrite have systematic increases towards a vein.

Exploration Vectors

Deposit and District Scale

A review of the data generated at each of the study sites has led to some general conclusions regarding deposit and district scale vectors for low sulfidation epithermal deposits. The most promising exploration vectors are:

- Alteration zonation. Proximal potassium feldspar adularia-quartz-illite to illite-smectite to distal chlorite-epidote-calcite-albite.

- Adularia distribution. Adularia is more abundant than generally recognised. Fertile structures have a greater abundance of adularia and a positive K_2O-Tl relationship compared to non-fertile structures. As the presence of adularia indicates both boiling of the hydrothermal fluids and, in general, proximity of gold mineralisation potassium feldspar staining should become a routine part of an exploration program.
- Mineral chemistry. Chlorite becomes Mg-rich towards a deposit. Adularia shows an increase in Ba, Pb and to a lesser extent Cs towards a deposit. Lead, Bi and Mo increase in pyrite towards a deposit.
- High or increasing illite crystallinity (>1) towards deposit.
- Geochemical variations. The consistent geochemical indicators are:
  - Basalt-andesite hosted deposits
    - Surficial: increases in as, Hg, Tl, Sb and Mo (advanced argillic alteration)
    - Halo: increases in K_2O, S, Alt. index, S/Na_2O, Tl, As, Sb; decreases in Na_2O, CaO
  - Rhyolite-dacite hosted deposits
    - Surficial: increases in as, Hg, Tl, Sb and Mo (advanced argillic alteration)
    - Deposit: increases in Au, Ag, Sb, As, Tl, Te, Li, K_2O
    - Halo: Increases in K_2O, Tl, As, Rb, Ba, Cs

Distinguishing ore grade epithermal systems from barren or low grade systems

Our best information on low-grade to barren systems comes from portions of the Cerro Vanguardia district and Bimurra, both felsic-hosted systems. No low grade or barren systems hosted in mafic to intermediate rocks were studied. The conclusions presented below are based on research from the felsic-hosted systems with inferences drawn from our understanding of the systems hosted by mafic and intermediate rocks.

The most promising discriminators for distinguishing high-grade from low-grade or barren systems are:

- Alteration intensity. The alteration mineralogy and zonation is essentially the same between high and low-grade or barrens systems, but the scale and intensity of alteration are much greater in the high grade systems.
- High or increasing illite crystallinity (>1) towards a deposit in high grade systems.
- Size of paleohydrothermal system. The high grade systems are larger in terms of structures, large dilatancy zones within structures, footprint of alteration and intensity of alteration.
- Fertile structures will have a greater proportion of adularia and a positive K_2O-Tl relationship compared to non-fertile structures.
- Vein textures. High grade systems have large structures with complex histories (i.e. repeated opening and fluid flow events). In general, higher grade systems have multiply generations of fluid pulses, as evidenced by complex colloform, crustiform, cockade and breccia textures.
- Presence of boiling (bladed calcite or pseudomorphs, two-phase fluid inclusions) is not a distinguishing feature. Many deposits with evidence of boiling do not have high grades.
- Geochemical variations. Research at Cerro Vanguardia has highlighted the differences between the alteration geochemistry surrounding high and low grade veins. Overall, higher grade Au-Ag veins tend to have wall rocks and veins that contain higher K_2O (>4%), Tl (>3 ppm), Rb (>150 ppm) and Ba (>300 ppm) contents than lower grade veins. The abundance of these trace elements reflects higher K_2O contents associated with intense K-feldspar alteration. Low grade to barren veins have low K_2O (<4%), Tl (<2 ppm), Rb (<150 ppm) with variable Ba contents.

CONCLUSIONS

This contribution summarises new knowledge and data on the mineralogical and geochemical characteristics of hydrothermal alteration associated with low- and intermediate sulfidation, gold-silver epithermal deposits. These data are used to develop exploration vectors for use at both deposit and district scales, plus techniques have been established to distinguish ore grade epithermal systems from barren or low grade systems.

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Deposit	Host rocks	Mineralisation	Alteration	Resources (as of 31 Dec 2002)	Source
Ladolam, Papua New Guinea	Pleistocene basalt lavas & breccias	Pleistocene disseminations & stockwork	Adularia-pyrite (proximal) Smectite-carbonate-chlorite (distal)	471 Mt @ 2.7 g/t Au (41 Moz Au)	Carmen (2003), Herrmann (2002), Cater (2002)
Gosowong, Indonesia	Miocene andesite lavas & volcaniclastic rocks	Pliocene vein & stockwork	Quartz-adularia-illite (proximal)	1.0 Mt @ 27 g/t Au, 38 g/t Ag (0.9 Moz Au)	Gemmell (2002), Olberg (2001), Olberg et al. (1999)
Mt Muro, Indonesia	Oligocene andesite lavas & volcaniclastic rocks	Miocene multiple veins & breccia	Illite-pyrite-adularia (proximal) Chlorite-carbonate (distal) Kaolinite-silica (surficial)	9.5 Mt @ 4.0 g/t Au, 102 g/t Ag (1.2 Moz Au)	Wurst (2002), Simmons & Browne (1990)
Cerro Vanguardia, Argentina	Jurassic rhyolite ignimbrites	Jurassic multiple veins & stockwork	Illite-quartz-adularia-chlorite (proximal) Illite-smectite-quartz (distal) Kaolinite (surficial)	15.9 Mt @ 8.3 g/t Au, 101 g/t Ag (4.3 Moz Au)	Sharpe (2002), Sharpe et al. (2002)
Twin Hills, Australia	Devonian rhyodacite intrusive & breccias	Devonian disseminations & stockwork	Quartz-illite-adularia-chlorite (proximal) Chlorite-adularia-quartz (intermediate) Albite-chlorite-calcite (distal)	8.3 Mt @ 2.1 g/t Au (0.6 Moz Au)	Young (2001), Sennitt (1991)
Bimurra, Australia	Devonian rhyolite lavas & volcaniclastic rocks	Devonian veins & stockwork	Quartz-illite(sericite)-adularia (proximal) Illite-smectite-pyrite (intermediate) Chlorite-smectite-calcite-pyrite (distal) Alunite-kaolinite-silica (surficial)	1.6 Mt @ 1.4 g/t Au (0.07 Moz Au)	Booth (2002), Tate (2001)

Table 1. Geologic Characteristics of Epithermal Deposits Investigated in this Study.