ASPECTS OF LACHLAN OROGEN MAGMATIC ARC Au-Ag-Cu

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Abstract

Exploration decisions involving the prioritisation of finite human and financial resources amongst portfolios of exploration projects are aided by an understanding of the styles and characteristics of magmatic arc porphyry Cu-Au and epithermal Au-Ag mineralisation, and the controls to metal grade, deposits size, distribution, metallurgy etc. There is an improved definition of the anatomy of intrusion-related Cu-Au deposits. Analysis of temporal and spatial patterns of mineralisation and alteration zonation within porphyry and epithermal deposits, as well as linkages between deposit types, may aid it vectoring towards economic mineralisation. Although bonanza Au-Ag grades tend to occur in the uppermost portions of low sulphidation epithermal Au-Ag deposits, the more eroded Lachlan Orogen hosts bulk low grade porphyry and wall rock porphyry Au-Cu deposits

Introduction

Porphyry Cu-Au-Mo and epithermal Au-Ag mineralisation developed within magmatic arcs account for a significant portion of the world's metal endowment. Much of the Cu and most Mo occur within porphyry deposits, while porphyry and epithermal deposits are significant sources of Au, and the latter noted as Ag resources. Here I will briefly consider selected styles of magmatic arc mineralisation, drawing upon other Pacific rim ore systems, in order to provide an introduction to the deposit case histories presented in this session of the 2007 Mines and Wines conference. Because to the limited time available, many of the concepts and terminology used are expanded upon in earlier papers by this author - www.corbettgeology.com

Magmatic arc ore systems are interpreted to host metals derived from differentiated intrusion source rocks at depth and gangue minerals deposited from hydrothermal fluids dominated by mixes of variably evolved magmatic and meteoric hydrothermal fluids. Porphyry Cu-Mo-Au deposits extend from considerable depths (as much as 6km) to within 1-2 km of the surface, the latter commonly as apophyses to more major buried magmatic source bodies. Better ore systems develop where ore fluids are concentrated in the cooler intrusion apophyses. Epithermal Au-Ag deposits formed within 1 km of the surface are distinguished as low and high sulphidation, on the basis of the ore mineralogy (Corbett and Leach, 1998 and references therein), deposited respectively from near neutral or hot acidic hydrothermal fluids. The low sulphidation deposits are further divided into varying styles as a continuum (figure 1) from porphyry Cu-Au (Ridgeway & Goonumbla, Australia), through wall rock porphyry (Cadia Hill, Australia), quartz-sulphide Au $\pm$ Cu (Lihir, Papua New Guinea; Nolan's, Australia), carbonate-base metal Au (Cowal, Australia; Porgera, Papua New Guinea; Kelian, Indonesia) and polymetallic Ag-Au (Fresnillo & Palmarejo, Mexico; Arcata, Caylloma, Corani, Peru) as the generally deeper level deposits with strongest associations with intrusions. Bonanza Au grades are more commonly associated with the two highest crustal level epithermal end members comprising: the high Au fineness epithermal quartz Au-Ag (Porgera Zone VII) style, with a stronger intrusion association, and the low Au fineness, banded chalcedony-ginguro Au-Ag veins (Vera Nancy, Australia; Waihi, New Zealand; Hishikari, Japan), which display more distal relationships to intrusion metal source rocks, and were formerly termed adularia-sericite Au deposits (figure 1). These highest crustal level epithermal deposits are not well developed in the older deeply eroded eastern Australia and so are not discussed herein.

Controls to mineralisation

Controls to quality (higher metal grades and more substantial size) magmatic arc ore systems include:
<u>Host rocks</u> as competent rock facilitate formation of throughgoing fractures as low sulphidation vein hosts. Permeable host rocks favour fluid flow in high sulphidation deposits (Pierina, Peru; La Coipa, Chile), and some low sulphidation epithermal deposits (Round Mountain, Nevada).
<u>Structures</u> act as plumbing systems for ore fluids to rise from magmatic source rocks at depth to cooler settings of metal deposition and may focus ore fluids to provide higher metal grades commonly within ore shoots controlled by varying styles of deformation. Ore shoots develop within fault flexures and jogs, and vary from steep plunges in settings dominated by strike-slip fault movement (Vera Nancy, Waihi), and are vertically zoned within negative flower structures from near surficial pull-apart basin fracture arrays, which control the distribution of deeper level fissure veins (Cowal, Waihi), and then splays at deeper porphyry levels (Chuquicamata, Chile; Far South East, Philippines). Flat plunging ore shoots develop in flat dipping portions of reverse faults (Jaing Cha Ling, China), and steep dipping portions of normal faults (polymetallic veins of Mexico and Peru), including at the intersections of normal faults and hanging wall splays (Porgera Zone VII).
<u>Style of mineralisation</u> accounts for differences in metal ratios and ore grades varying from lower grade porphyry Cu-Mo to bonanza Au grade low sulphidation epithermal styles (discussed herein and Corbett and Leach, 1998). Metallurgical characteristics, which should be given consideration during exploration, also differ significantly. Both the hypogene enargite ores of high sulphidation systems (Peak Hill, Australia; El Indio, Chile), and Au encapsulated in fine grained quenched low sulphidation quartz-sulphide Au ores (Lihir), display costly difficult metallurgy.
<u>Mechanism of Au deposition</u> provides the greatest influence on precious metal grades varying from low Au grades where pregnant ore fluids have cooled slowly, and rising progressively in settings where ore fluids have mixed with ground waters varying from: deep circulating meteoric waters (evidenced by opal in the ore assemblage), to shallow oxygenated meteoric waters (evidenced by haematite in the ore assemblage), to bicarbonate waters (evidenced by mixed FeMnMgCa carbonates in the ore assemblage), and low pH acid sulphate waters (evidenced by kaolin in the ore assemblage).

Deposit types

<u>Porphyry Cu-Au deposits</u>, have previously been considered as large lower metal grade open pit operations (Panguna, Ok Tedi in Papua New Guinea), but newer discoveries also include higher metal grade ores associated with repeated intrusion emplacement and mineralisation in settings where major structures focus ore fluids into apophysis capping speculated buried magma sources (Ridgeway, Oyu Tolgoi, Grasberg, Goonumbla), or

with complex mineralised breccias (El Teniente, Chile). Although of low metal grades, the considerable size makes porphyry deposits attractive targets. Targeting tools vary from, the identification of the major structures, which localise intrusion apophyses to deeper level magmatic source rocks (Corbett, 1994; Corbett and Leach, 1998), and influence the trend of mineralised veins, to the analysis of zoned and overprinting alteration patterns. The increased understanding of the anatomy of porphyry Cu-Au deposits is an important exploration tool.

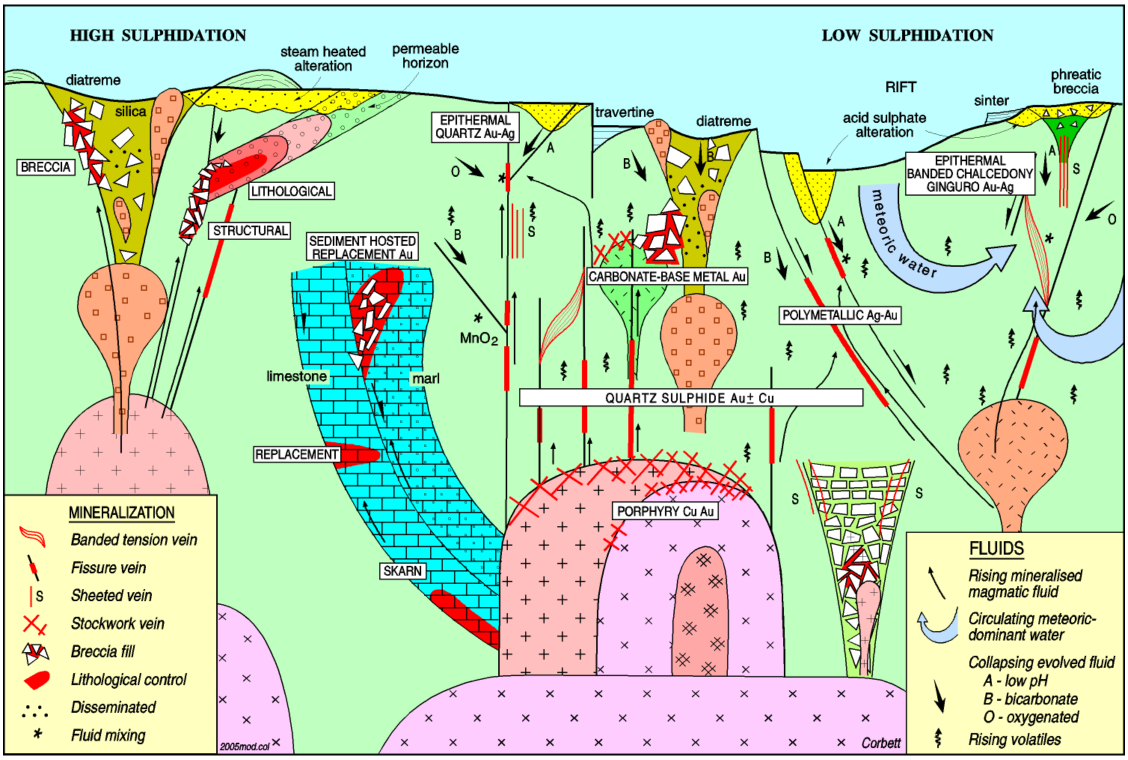

Figure 1. Model for zonation in styles of magmatic arc Au-Ag-Cu-Mo mineralisation.

Wall rock porphyry Au deposits comprise porphyry-style mineralisation as sheeted veins deposited outside the 'productive' intrusion within competent wall rocks, commonly intimately associated with lower metal grade porphyry intrusions and breccias (Cadia Hill; Gaby, Ecuador, Maricunga Belt, Chile). Dilational structural environments are an important component to allow concentration of metals during evolution from deep crustal level low metal grade intrusion source rocks, to higher level cooler settings of mineral deposition. Although of low metal grades, the large size, high Au:Cu ratios and generally favourable metallurgy render these deposits attractive exploration targets.

Quartz-sulphide Au + Cu mineralisation occurs in transitional crustal settings between wall rock porphyry and low sulphidation epithermal deposits as deep crustal level low sulphidation 'epithermal' locally including D veins described in the porphyry Cu literature (Gustafson and Hunt, 1975). Quartz-sulphide ores occur as an early stage in many carbonate-base metal deposits described below (Porgera, Kelian), and vary from high grade underground lodes (Adelong & Mineral Hill, Australia) to bulk low grade disseminated and stockwork vein deposits (Nolan's, Australia; Round Mountain, Nevada; San Cristobal, Chile). Coarser grained ores commonly display favourable metallurgy and so very low Au grades are treated in heap leach operations (0.9 g/t Au at Round Mountain). However, rapidly quenched ore fluids result in difficult metallurgy, fine grained ores where Au may be encapsulated within in pyrite, and more commonly arsenean pyrite. Caution is urged as quartz-sulphide Au mineralisation is susceptible to near surficial supergene Au enrichment and so sub economic veins often distract explorationists but fail to develop into meaningful targets.

Carbonate-base metal Au deposits occur in higher crustal level more distal settings to intrusion source rocks than porphyry Cu-Au deposits, where magmatic ore fluids have mixed with bicarbonate ground waters as a most efficient mechanism of Au deposition (Leach and Corbett, 1994; Corbett and Leach, 1998). Consequently these deposits have been some of the most prolific Au producers in the SW Pacific rim (Porgera, Kelian; Antamok & Acupan, Philippines). Dilational structures such as pull-apart basin fracture arrays are important to facilitate the evolution of ore fluids into elevated crustal settings (Cowal) of mineral deposition. In eastern Australia, where generally older ore systems are deeply eroded, the telescoping of carbonate-base metal Au mineralisation upon quartz-sulphide Au $\pm$ Cu deposits provides elevated Au grades (Kidston). In younger tertiary rocks many carbonate-base metal Au ores are associated with phreatomagmatic breccias within diatreme flow dome complexes.

Polymetallic Ag deposits of Central and South America provided significant wealth to the Spanish empire and Catholic church for several hundreds of years, but were passed over by major mining companies during the later 20th century. These deposits have more recently represented exciting exploration targets for junior companies (Palmarejo & Fresnillo in Mexico; Arcata, Caylloma, Corani in Peru; San Cristobal in Bolivia; El Penon in Chile; San Jose [Hevos Verde], Martha in Argentine Patagonia), and as such commonly represent ‘company makers’. While mined primarily for Ag, many include Au credits, as well as significant Pb-Zn and locally Cu, particularly at deeper levels. Recent discoveries in Australia including Twin Hills by Macmin and Mungana by Kagara are typical of this deposit type. Two end metallurgical end members represent Ag within tennantite-tetrahedrite (commonly freibergite), or the metallurgically more favourable argentite-acanthite ores. Polymetallic deposits, similar to the related carbonate-base metal Au style (Corbett and Leach, 1998), are strongly temporally and spatially zoned with a bonanza Ag grade portion locally developed where the uppermost portion is preserved, such as within blind deposits below clay caps. In strongly dilational structural settings with appropriate hydrothermal fluid input, these deposits may evolve at higher crustal levels into the chalcedony-ginguro Au-Ag low sulphidation epithermal deposits.

High sulphidation epithermal Au deposits represent only a very small part of the metal budget in Australia (Peak Hill, Gidginbung), but are major Au-Ag resources in South America (Yanacocha & Pierina, Peru; El Indio, La Coipa & Pascua, Chile; Lama & Veladero, Argentina). These deposits vary from precious metal rich at elevated crustal settings to Cu-rich at depth, while SW Pacific rim high sulphidation deposits are Ag-poor while those in South America are Ag-rich. A two stage magmatic-derived hydrothermal fluid comprises an early hot acid volatile-dominant portion which promotes the development of characteristic zoned wall rock alteration, while the later liquid-dominant portion deposits overprinting sulphides such as auriferous pyrite-enargite, varying to low temperature luzonite, and covellite at deeper levels, with quartz-alunite-barite-sulphide gangue (Corbett and Leach, 1998). Permeability controls to mineralisation include variable combinations of structure (dilational feeder structures), lithology (permeable tuffs) and breccias (often phreatomagmatic breccias in flow dome complexes). Although these deposits display generally low metal grades with poor recoveries, and significant environmental liabilities (Hg, As and acid mine drainage), localised temporal and spatial evolution to lower sulphidation mineralisation contributes towards the development of higher Au grades and better metallurgy either overprinting or marginal to high sulphidation systems (El Indio, Wafi, Papua New Guinea; Goldfield, Nevada). At Mt Carlton, (Australia) the presence of low sulphidation minerals (polybasite) and local elevated Ag are consistent with such an evolution.

Conclusion

Mineral exploration management often includes allocation of finite resources (human and financial) to portfolios of exploration projects which must be prioritised according to apparent merit of each project on the data to hand. The use of empirical geological models developed by the comparison of many exploration properties facilitates exploration management decisions as to which projects may be more prospective. Studies of other Pacific rim magmatic arc deposits, which might be well exposed in deeply dissected terrains (Peru) or by extensive drill testing, have aided in an understanding of the anatomy, including patterns of temporal and spatial alteration and mineralisation zonation, in porphyry Cu-Au-Mo and intrusion-related epithermal Au-Ag deposits, as well as linkages between deposit styles. This understanding of the three dimensional geometry of magmatic arc deposits allows better targeting of mineralised portions of particular prospects, including ore shoots, especially in blind high crustal level deposits noted for bonanza ore shoots (polymetallic Ag veins), and facilitates the evaluation of poorly mineralised projects. In particular the analysis of the controls to low and high sulphidation deposits aids in an understanding of whether anomalies, or poorly mineralised prospects, are likely vector towards economic mineralisation, as well as provision of some exploration science to facilitate exploration decisions.

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