

Controls to low sulphidation epithermal Au-Ag mineralisation

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Low sulphidation epithermal Au-Ag deposits are distinguished from high sulphidation deposits primarily by the different sulphide mineralogy (pyrite, sphalerite, galena, chalcopyrite) typically within quartz veins with local carbonate, and associated near neutral wall rock alteration (illite clays), deposited from dilute hydrothermal fluids (Corbett and Leach, 1998). Many low sulphidation veins are well banded and each band represents a separate episode of hydrothermal mineral deposition. Consequently recent thinking separates varying styles of rising hydrothermal fluids (figure 1) which contribute towards low sulphidation vein formation as:

- Meteoric dominated waters commonly form shallow circulating cells and deposit clean quartz, which has not come in contact with buried intrusion sources for metals and so are commonly barren.
- Magmatic-meteoric waters developed where meteoric waters circulate to sufficiently deep crustal levels to come in contact with magmatic sources for metals and so contain low grade mineralisation within disseminated sulphides.
- Magmatic dominant waters have been derived from intrusion sources for metals at depth and so contain highest precious metal values associated with sulphides.

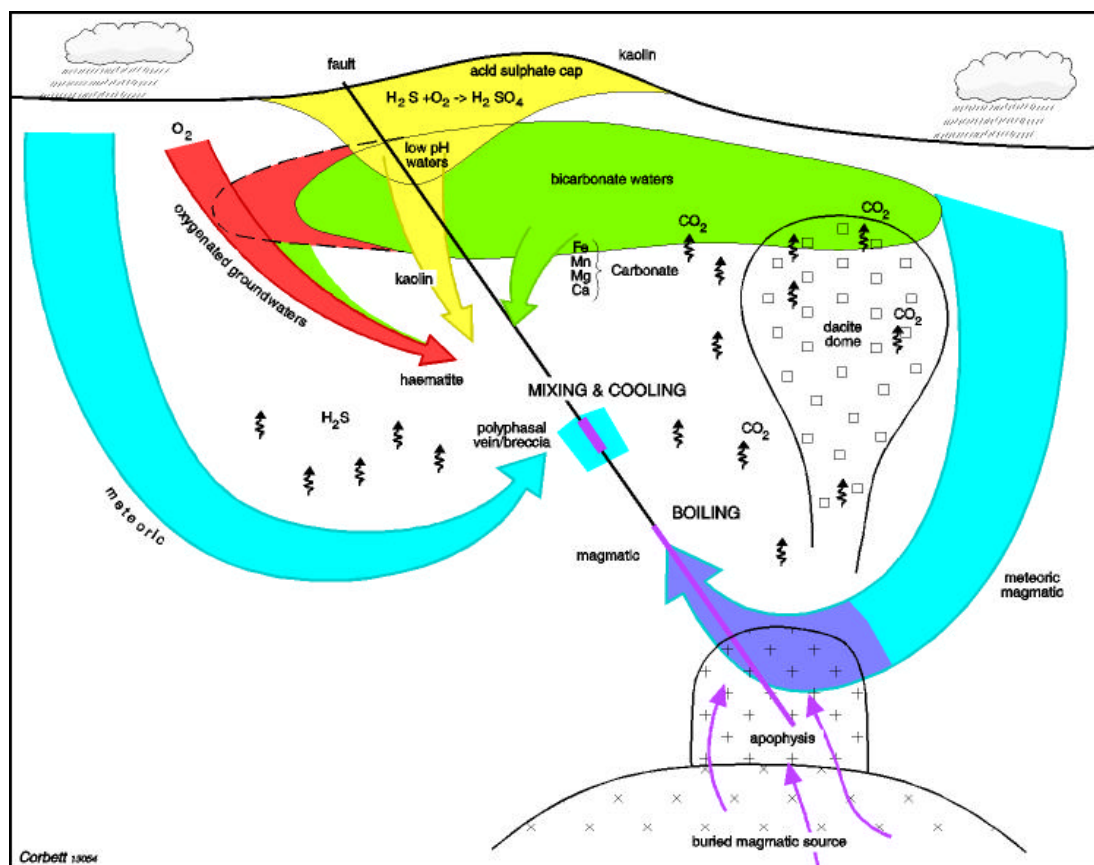


Figure 1. Model to account for varying hydrothermal fluids which contribute towards the development of banded low sulphidation epithermal Au-Ag veins containing many varied vein elements.

Quality low sulphidation epithermal Au-Ag mineralisation is best developed in settings where many of the following controls are active as:

Lithological control occurs mainly as competent or brittle host rocks which develop throughgoing fractures as vein hosts, although permeability is locally important. In interlayered volcanic sequences epithermal veins may be confined to only the competent rocks while the intervening less competent sequences host only fault structures.

Structures act as fluid channelways and more dilational portions of the host structures may represent sites of enhanced fluid flow and so promote the development of ore shoots which host most mineralisation in many low sulphidation vein systems (Corbett 2002a). Elsewhere fault intersections host ore shoots at sites of fluid mixing. Several structural settings provide ore shoots of varying orientations (figure 2). Steep dipping strike-slip structures provide vertical ore shoots in flexures and fault jogs. Tension veins and dilatant sheeted veins dominate in the latter setting. Normal, and in particular listric faults, in extensional settings host wider and higher grade veins as flat ore shoots in steep dipping vein portions. In compressional settings reverse faults host flat plunging ore shoots in reverse faults.

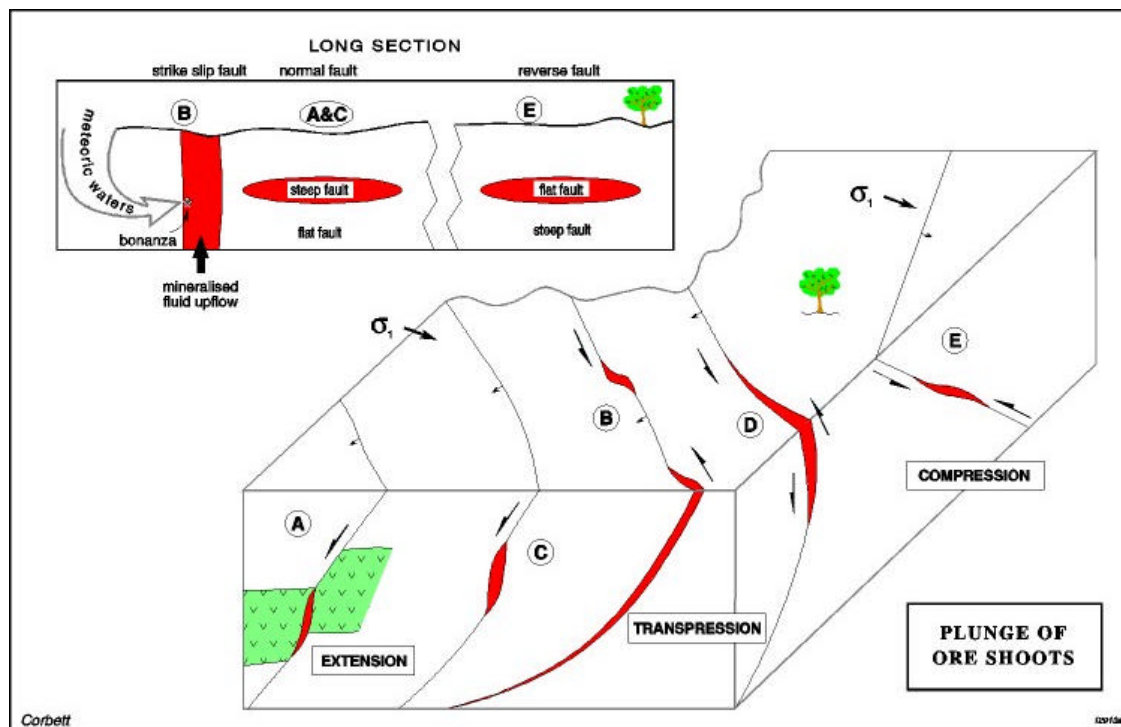


Figure 2. Illustration of the structural control to ore shoot formation in different structural environments and associated ore shoot orientations.

Styles of low sulphidation Au are distinguished (Corbett and Leach, 1998; Corbett 2002b, 2004, 2005) according to mineralogy and relation to intrusion source rocks and influence precious metal grade, Ag: Au ratio, metallurgy and Au distribution (figure 3).

Quartz-sulphide Au ± Cu mineralisation is characterised by quartz and pyrite as the main sulphide, although lower temperature marcasite, and higher temperate pyrrhotite and chalcopyrite are also recognised (Nolans, Adelong, Mineral Hill, Round Mountain, Emperor). Quenched very fine pyrite is commonly arsenean and locally displays difficult

metallurgy (Lihir), while coarser sulphides are typically associated with near surficial supergene Au enrichment.

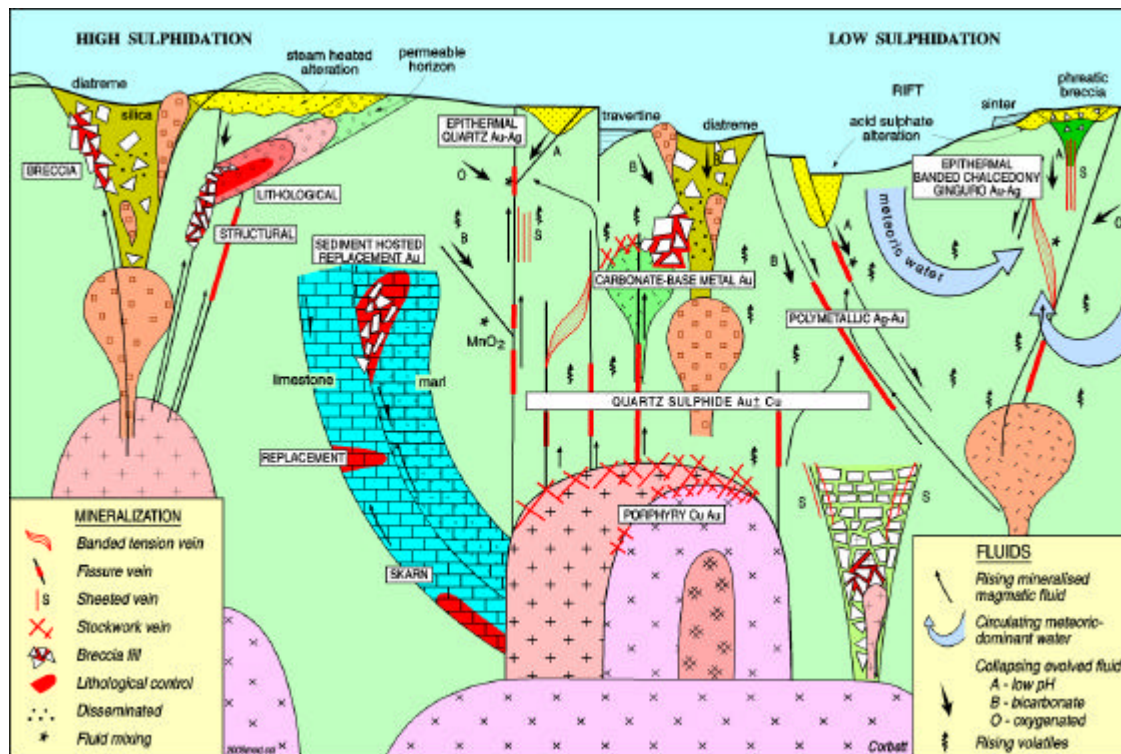


Figure 3. Conceptual model illustrating styles of magmatic arc porphyry Cu-Au and epithermal Au-Ag mineralisation.

- *Carbonate-base metal Au* deposits overprint quartz-sulphide Au, display higher Au contents, increased Ag:Cu ratios, with additional sphalerite greater than galena, and an important carbonate component, described below (Cowan, Porgera, Kelian, Acupan, Antamok). These deposits are the most prolific Au producers in the SW Pacific rim, although with locally quite irregular Au distribution, commonly as stock work and sheeted veins or breccia matrix, including in association with phreatomagmatic breccias.
- *Polymetallic Ag-Au* deposits dominate in the Americas as fissure vein Ag-rich equivalents to carbonate-base metal Au deposits (Fresnillo, Palmarejo). In dilational structural settings these pass upwards to chalcidony-ginguro deposits.
- *Epithermal quartz Au-Ag* deposits are characterised as Ag-poor often bonanza Au grades, developed greatest distances from magmatic source rocks, in association with only minor quartz, illite, chlorite and local pyrite gangue, and so can be difficult to identify. They contribute to irregular Au distribution in overprinted carbonate-base metal and quartz-sulphide Au deposits (Porgera Zone VII, Emperor).
- *Chalcidony-ginguro epithermal Au-Ag* deposits commonly display bonanza Au grades and occur as generally Ag-rich banded veins comprising chalcidony, adularia, quartz pseudomorphing platy calcite and ginguro black sulphidic material described by 19th century Japanese miners. While much of the gangue may be deposited from boiling meteoric dominant waters most high grade Au mineralisation occurs in the magamatically-derived ginguro bands deposited from rapidly cooling fluids, locally aided by mixing with ground waters.

Mechanisms of Au deposition have a profound effect upon Au grade varying from:

- *Cooling* in the case of many coarse sulphides with low grade Au contents.
- *Rapid cooling* promoted by quenched magmatic fluids evidenced by fine sulphides, or by mixing of ore fluids with deep circulating meteoric waters, commonly recognised in high precious metal polymetallic vein deposits where low temperature quartz (opal) is in contact with high temperature sulphides.
- While *boiling* fluids deposit much of the gangue (adularia, quartz pseudomorphing platy calcite and local chalcedony), in epithermal veins and some Au other mechanisms are preferred to account for elevated Au grades.
- *Mixing of oxygenated ground waters* with ore fluids at elevated crustal settings produces elevated Au grades and is evidenced by hypogene haematite in the ore assemblage.
- Mixing of bicarbonate waters derived from the condensation of CO₂ volatiles released from cooling intrusions is responsible for the development of higher Au grades as the carbonate-base metal group of low sulphidation Au deposits.
- *Mixing of low pH waters*, developed by the condensation of H₂S volatiles above the water table, and responsible for the development of near surficial acid sulphate caps, provide the highest Au grades and is evidenced by the presence of hypogene kaolin including halloysite within the ore assemblage

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