

## Controls to low sulphidation epithermal Au-Ag mineralisation

Presentation to the Sydney Mineral Exploration Discussion Group

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Much of the mineralisation in low sulphidation epithermal vein deposits occurs within ore shoots which are best developed at the coincidence of several controls described below. However, it is first interesting to consider the fluids which form many veins.

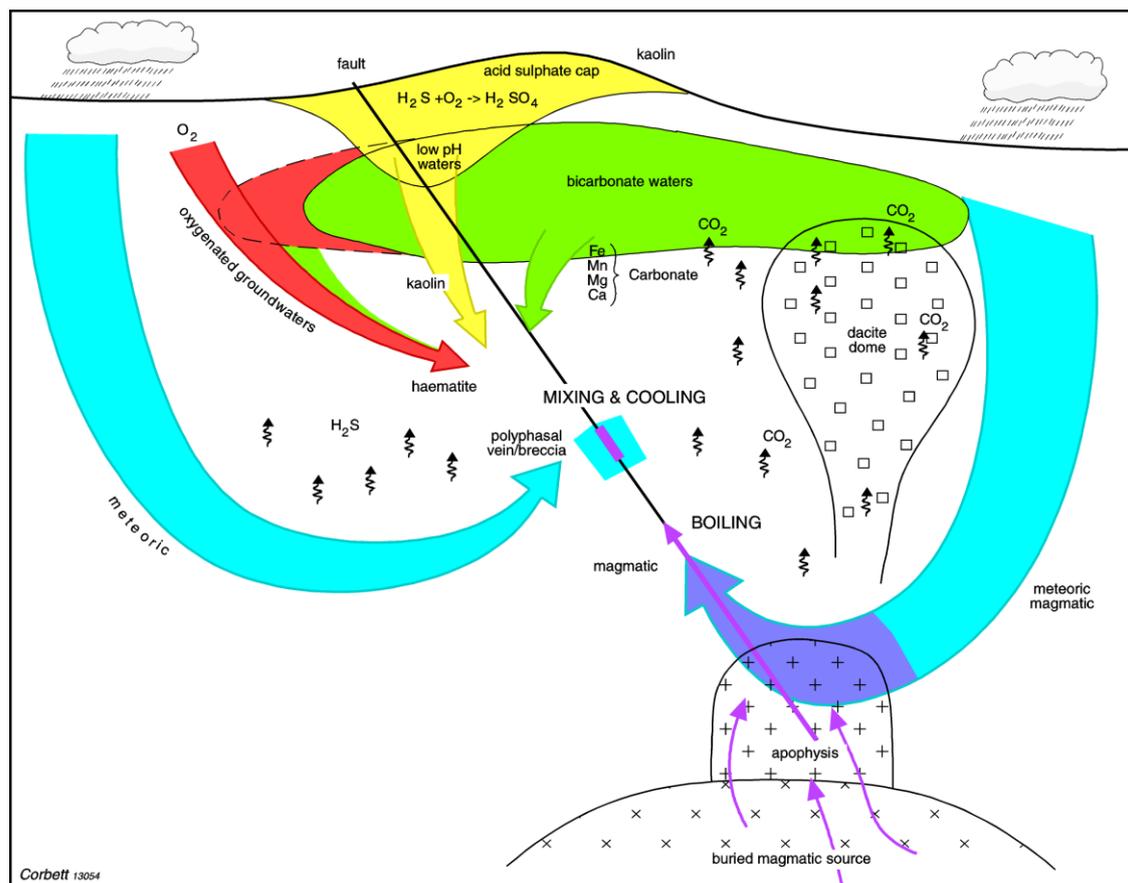


Figure 1. Model to account for varying hydrothermal fluids which contribute towards the development of banded low sulphidation epithermal Au-Ag veins containing many varied vein elements.

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.

Controls to ore shoot development in low sulphidation epithermal deposits might be considered 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.

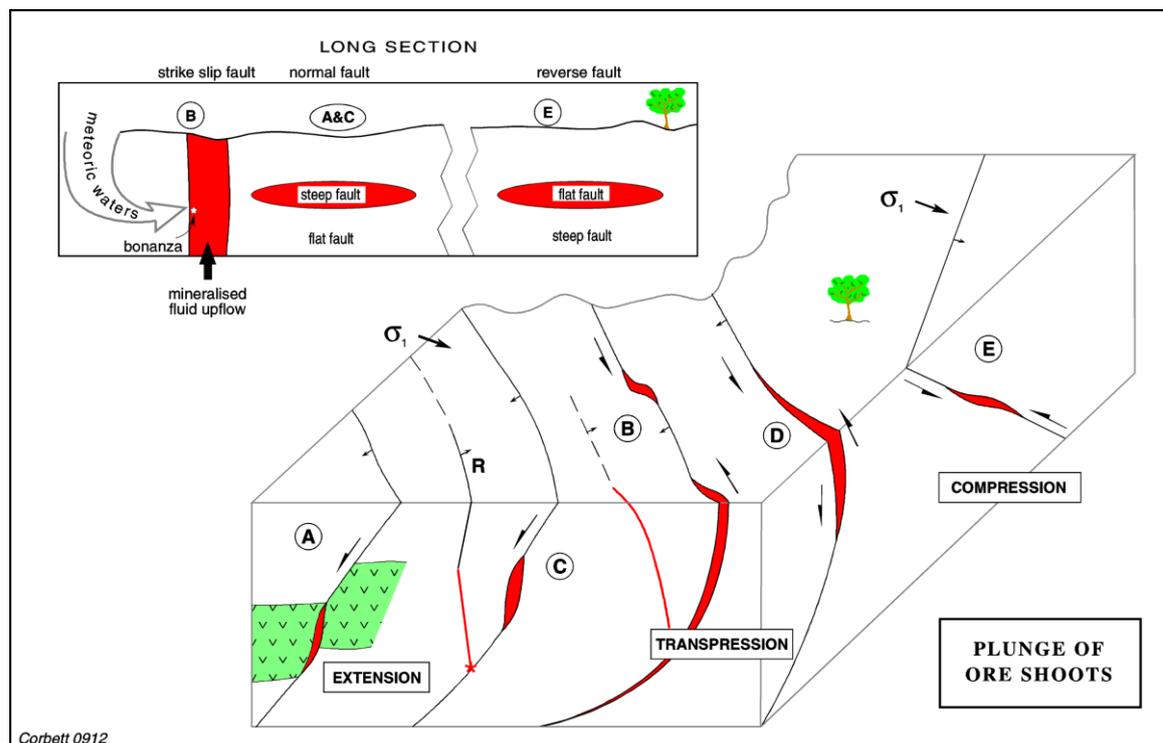


Figure 2. Illustration of the structural control to ore shoot formation in different structural environments and associated ore shoot orientations.

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). Here veins are wider and exhibit higher metal grades evident on gram x metre plots. 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. Although tension veins and dilatant sheeted veins dominate as ore hosts splays and pull-apart basins are also recognised. Vertical zonation is apparent as negative flower structures in these ore environments which extend from splay where porphyry intrusions are localised at greatest

depths, to overlying tension veins and and surficial pull-apart basins where mineralisation is localised by the normal faults (figure 3; Corbett and Leach, 1998). Normal, and in particular listric faults, in extensional settings host wider and higher grade veins as flat ore shoots in steep dipping vein portions of those structures. In compressional settings reverse faults host flat plunging ore shoots in reverse faults.

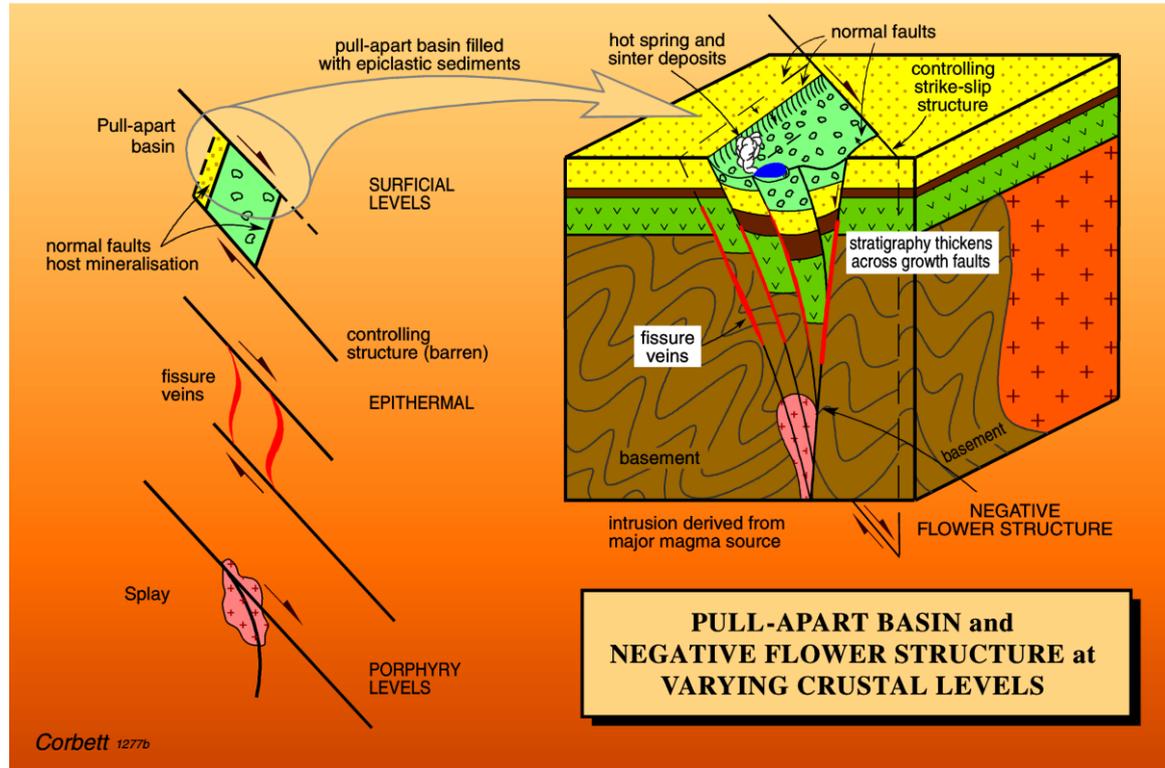


Figure 3. Negative flower structure illustrating vertical zonation in strike slip dilatant ore settings, from Corbett and Leach (1998).

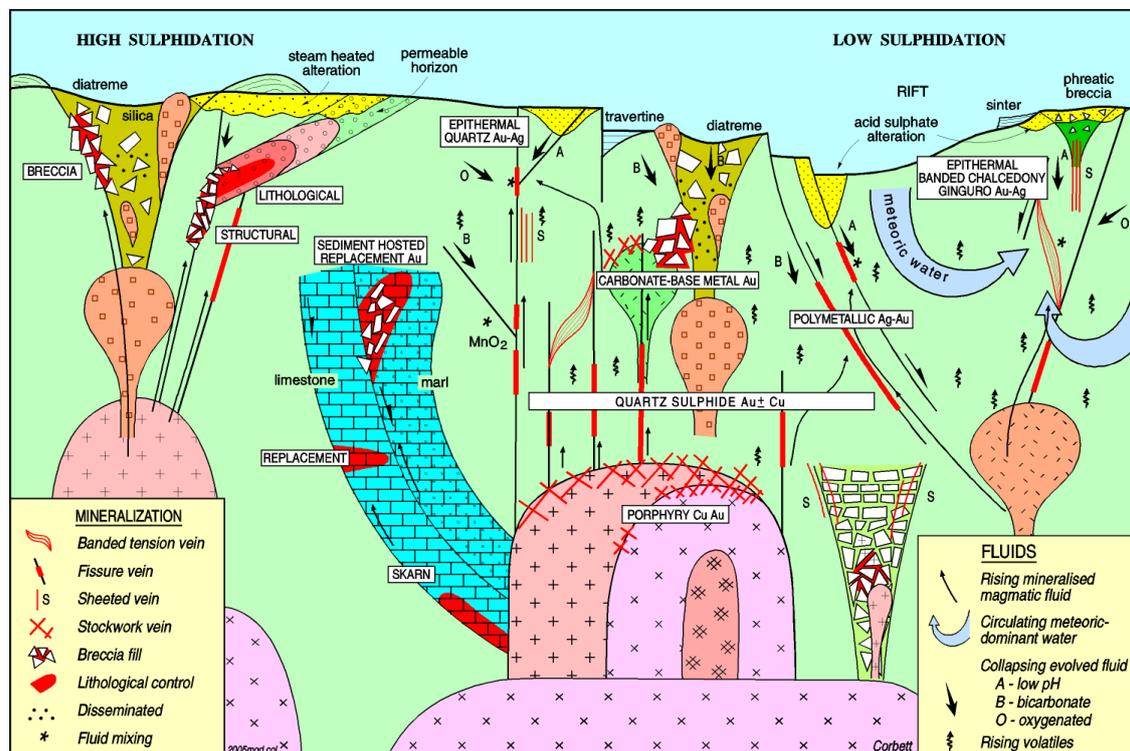


Figure 4. Conceptual model illustrating styles of magmatic arc porphyry Cu-Au and epithermal Au-Ag mineralisation.

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 4).

- *Quartz-sulphide Au ± Cu* mineralisation is characterised by quartz and pyrite as the main sulphide, although lower temperature marcasite, and higher temperature pyrrhotite and chalcopyrite are also recognised (Nolans, Adelong, Mineral Hill, Round Mountain, Emperor). Quenched very fine pyrite is commonly arsenian and locally displays difficult metallurgy (Lihir), while coarser sulphides are typically associated with near surficial supergene Au enrichment.
- *Carbonate-base metal Au* deposits overprint quartz-sulphide Au, display higher Au contents, increased Ag: Au 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 chalcedony-ginguro deposits and commonly display vertical metal zonation from Cu rich at depth to higher level Ag (figure 5).

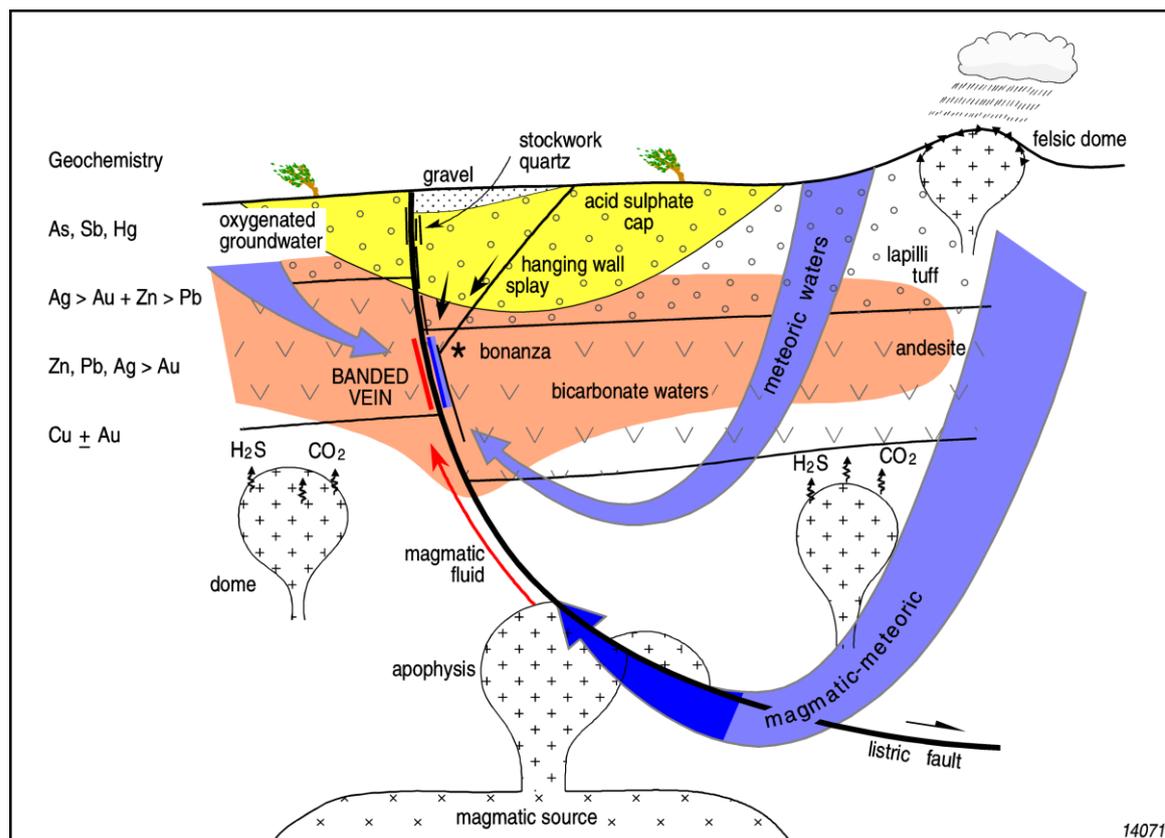


Figure 5. Conceptual model showing setting of many polymetallic Ag-Au veins in steep dipping portions of listric faults and vertical metal zonation, grading to toxic elements which may overlie economic mineralisation.

- *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) and may be Te-bearing.
- *Chalcedony-ginguro epithermal Au-Ag* deposits commonly display bonanza Au grades and occur as generally Ag-rich banded veins comprising chalcedony, adularia, quartz pseudomorphing platy calcite and ginguro black sulphidic material described by 19<sup>th</sup> century Japanese miners. While much of the gangue may be deposited from boiling meteoric dominant waters most high grade Au mineralisation occurs in the magmatically-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 and commonly account for the development of bonanza Au grades (figure 1; Leach and Corbett, 2008) 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 Au, other mechanisms might also be considered 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 (figures 1 & 4).
- Mixing of bicarbonate waters derived from the condensation of CO<sub>2</sub> 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 (figures 1 & 4).
- *Mixing of low pH waters*, developed by the condensation of H<sub>2</sub>S 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 (figures 1 & 4).

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