Boiling Zones and Precious Metal Mineralisation in Epithermal Environments

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OVERVIEW

Epithermal Au-Ag deposits are found around the Pacific rim, and these important resources of precious metals represent small-scale features that form at shallow depths (<1 km, <300°C) in large-scale hydrothermal systems associated with volcanism. Ore bodies are localized in zones of strong paleo-permeability commonly controlled by subvertical extensional structures where very strong fluxes of boiling fluid develop episodically. The mineralogical products of boiling, comprising ore-grade mineralisation, distinct vein textures, and zoned hydrothermal alteration, have been used to interpret mineralizing conditions in prospects and deposits for several decades. Given that precious metal mineralisation is commonly blind to the surface, this type of analysis is especially useful in regard to assessing discovery potential, proximity to ore bodies, and the depth level of exposure, even in mature districts with long histories of exploration and mining. An up to date understanding of boiling processes and their mineralogical-geological effects are described below based on investigations of active epithermal environments. Descriptions of the patterns of alteration and mineralization observed in four major vein districts (Fruta del Norte, Cerro Negro, Fresnillo, Waihi-Favona) follow to show the range in size, geometry and expression of boiling zones in epithermal deposits. These illustrate how and where key indicators of boiling can be used in finding new ore bodies (Figures 1 and 2).

In modern environments, boiling zones are concentrated within the hottest parts of a hydrothermal plume at less than 2 km depth, which geometrically is represented roughly by the shape of an inverted cone. Boiling zones are hydro-pressured, and being entirely dependent on heat transfer and fluid flow, they are dynamic, expanding and contracting over very short time scales and having flow conditions that range from quiescent to explosive. The top of the boiling zone (i.e. the piezometric level) is defined by the water table, and it is represented by high-level steam-heated alteration, silica sinter, and hydrothermal eruption deposits. In geothermal wells in which boiling fluid flow appears analogous to ore-forming conditions, the base boiling level is marked by deposition of lattice calcite whereas crustiform-colloform banded silica deposits near the well head, and sandwiched in between are pipe scale deposits containing bonanza grade concentrations of gold and silver. The vertical interval of gold-silver deposition coincides with a temperature range of 180-260°C that fluctuates up and down as controlled by pressure gradient and piezometric level.

Epithermal vein districts cover large areas (2-100 km^2) wherein the geometries and spacings of veins and vein sets range widely. Major deposits can be concentrated in exceptionally small volumes of rock as illustrated by the endowment of precious metal mineralisation at Fruta del Norte, where ore is blind and it occupies a wide feeder zone that directly underlies a silica sinter cap. Importantly, there is no barren zone between the paleo-surface and the top of vein mineralisation. Blind ore bodies at Cerro Negro occupy limited lateral extents of very long vein structures that are sporadically mineralised and display widely spread boiling textures; they are concealed beneath a relatively thick sequence of polymictic breccias, which represent the paleosurface along with steam-heated alteration and travertine deposits. Across the giant Fresnillo silver vein district where outcrops of rhyolite are preserved, intense steam-heated acid alteration directly overlies the tops of major veins at >300 m depth. These three vein districts all preserve the high-level epithermal environment and they show the wide-ranging thicknesses of the barren interval of tens to hundreds of metres that separates the tops of ore bodies from the paleo-surface (Figure 1).

The 1 km long Favona vein system at Waihi also shows evidence of the paleo-surface as represented by occurrences of steam-heated alteration, silica sinter and hydrothermal eruption deposits. The underlying vein system that hosts precious metal mineralisation forms a complex upward branching structure, in which discrete ore bodies are separated by barren to poorly mineralised vein segments that contain concentrated development of lattice quartz. Within the high-grade ore shoots, however, lattice quartz is sparse, and instead vein fill is dominated by crustiform-colloform banded quartz, breccias, and laminated chert. The distribution of these features provides clues that boiling levels vary systematically along the length of the vein system, deepening beneath ore zones and shallowing in the intervening barren to weakly mineralised vein intervals. Importantly, the intersection of barren vein intervals with evidence of boiling conditions during drilling provides justification for continued along strike exploration.

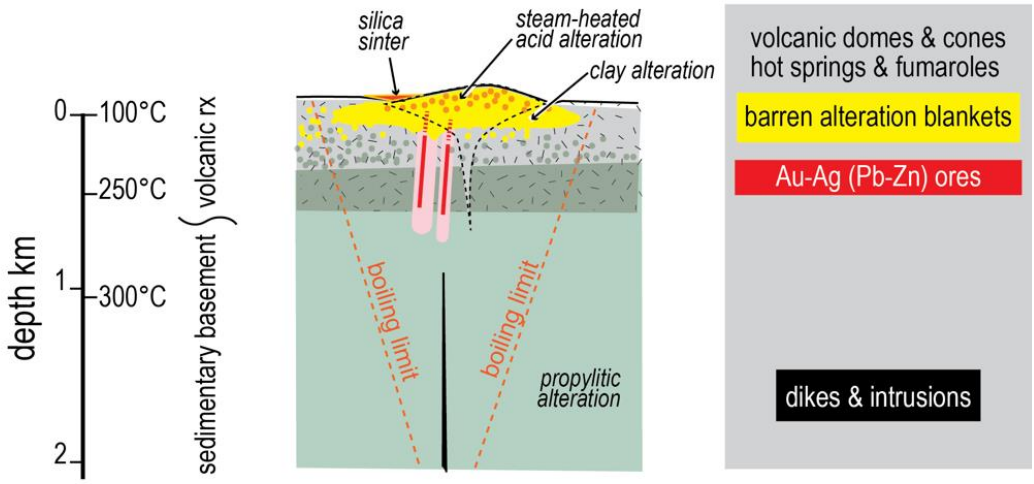

FIG 1 – Schematic diagram showing the depth level zonation of alteration and mineralisation around low-intermediate sulfidation epithermal vein deposits (sub-vertical red lines). The temperature gradient (left) is based on the hydrostatic boiling point for depth. Orange dashed lines mark the limits of boiling, which extend deep below the level of epithermal mineralization.

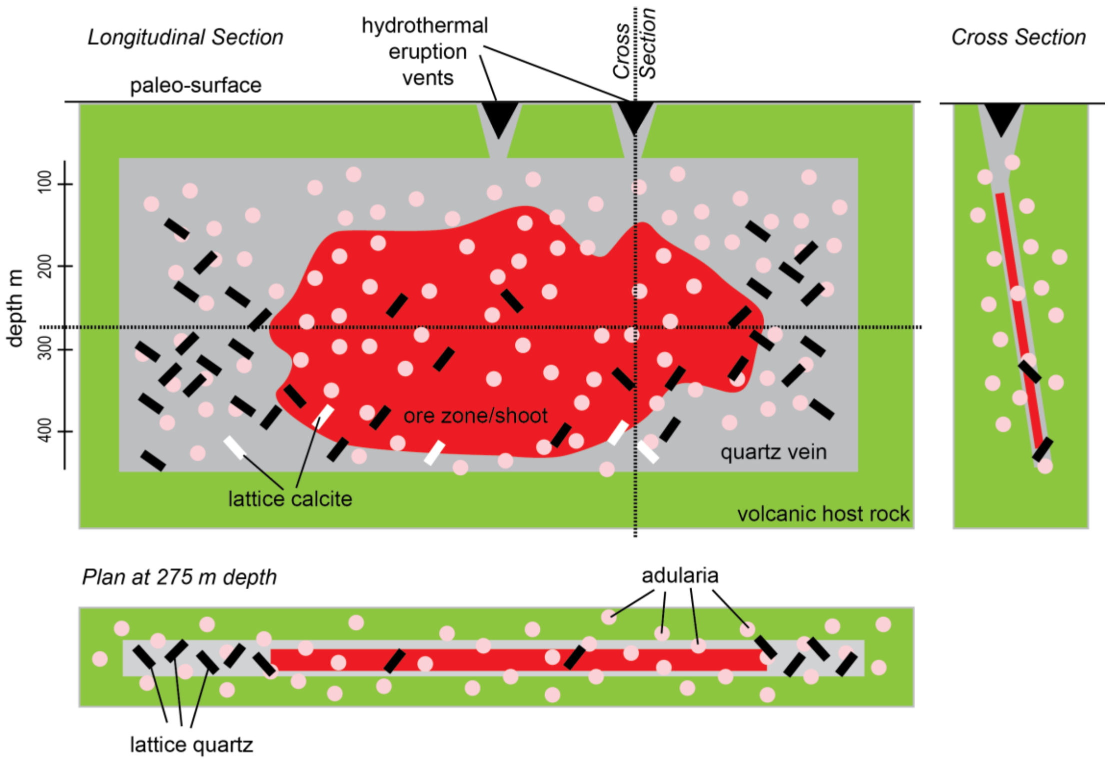

FIG 2 – Schematic views in plan and longitudinal and cross sections showing mineralogic-geologic zonation of boiling products within and around an epithermal vein based on patterns at Favona. The vein structure (grey) is hosted by volcanic rocks (green), and contains a discrete ore shoot (red), surrounded by lattice quartz (black), sparse lattice calcite (white), and widespread vein and replacement adularia (pink). For clarity, the width of the vein in plan and cross section is exaggerated, and the geometry of the vein is over-simplified.