Understanding Low Sulphidation (LS) Epithermal Deposits

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Why are LS Epithermal Deposits Important?

LS Epithermal deposits are major sources of gold and silver. Lead and zinc are common at depth and there is usually a good correlation between silver and lead grades. Copper may be present in the deepest levels of some systems.
What are Explorers Hoping For?

<table>
<thead>
<tr>
<th>Tonnage (Mt)</th>
<th>Gold (g/t)</th>
<th>Silver (g/t)</th>
<th>Lead (%)</th>
<th>Zinc (%)</th>
<th>Copper (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to &gt;200</td>
<td>1 - &gt;15</td>
<td>2 to &gt;300</td>
<td>0 - 2</td>
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Example World-Class Drill Intercepts:

**Hycroft, USA (Allied Nevada):**
- 168 meters @ 0.51 g/t gold and 17 g/t silver (Feb 4, 2008)
- 144 meters @ 0.40 g/t gold and 36.9 g/t silver (June 25, 2008)
- 212 meters @ 0.54 g/t gold and 14.2 g/t silver (Nov 1, 2007)

- Mainly open pit, oxide material.

**Kupol, Russia (Kinross):**
- 29.9 meters @ 28.4 g/t gold and 222.9 g/t silver (NI 43-101)
- 12.9 meters @ 30.5 g/t gold and 378.3 g/t silver (NI 43-101)
- 9.0 meters @ 8.7 g/t gold and 83.6 g/t silver (NI 43-101)

- From surface, over at least 200 metres vertical.

**FDN, Ecuador (Kinross):**
- 224.8 meters @ 2.1 g/t gold and 5.8 g/t silver (NI 43-101)
- 40.1 meters @ 5.3 g/t gold and 88.8 g/t silver (NI 43-101)

- Underground mining only, but high grade.

**La Guitarra (First Majestic):**
- 1.6 meters @ 1.1 g/t gold and 366.0 g/t silver (NI 43-101)
- 1.6 meters @ 1.8 g/t gold and 263 g/t silver (NI 43-101)

- Combination of underground and potential open pit on oxide material.
The high and low sulphidation epithermal deposits associated with blue coloured belts are late Mesozoic and Cenozoic in age (generally <120 Ma) and are associated with recent subduction zones including the present day Pacific Ring of Fire.

Deposits located in the middle of plates (grey coloured belts or metallogenic provinces) are associated with Paleozoic age (ca. 542 to 241 Ma) rocks which were formed in ancient subduction zones.
Cross-section through the Earth’s crust showing convergent plate boundaries where oceanic crust is subducted beneath oceanic crust (Ocean Arc setting) and continental crust (Continental Arc setting). Epithermal deposits form in these arc settings at depths of generally <500 metres to less commonly between 1 – 2 kilometres.

Due to their formation very close to the earth’s surface, in regions of active volcanic activity and mountain building which are highly susceptible to uplift and erosion, their preservation potential is very poor.
The term epithermal is derived from the Latin for shallow heat – reflecting the shallow crustal environment in which they form. Epithermal deposits are classed as High, Low or Intermediate Sulphidation based on mineral assemblage and the pH/Eh of mineralizing fluids. Epithermal deposits in general may overlie or be spatially related to deeper porphyry systems.
Low sulphidation epithermal deposits represent the uppermost (or most distal) parts of intrusion-related hydrothermal systems. They generally form within 500 metres of surface but may occasionally form between 1-2 kilometres deep. Metals are deposited at temperatures below 250°C through processes of fluid boiling, fluid mixing and vapour release. Where these systems break surface they form geysers, sinter terraces, and thermal mud pools. Modern day examples include the Yellowstone park and North Island, New Zealand.
Bulk Tonnage or Narrow High Grade Target?

Permeable horizon:
- Laterally Extensive
- Bedding Planes and Fractures act as conduits
- Disseminated Mineralisation
- Localised High Grades

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LS Epithermal Deposits – A Detailed Overview for Reference!

<table>
<thead>
<tr>
<th>Ore</th>
<th>Gangue</th>
<th>Vein Textures</th>
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</thead>
<tbody>
<tr>
<td>Rare Gold</td>
<td>Zeolite, Calcite, Clays</td>
<td>Crystalline Carbonate</td>
</tr>
<tr>
<td>Gold in pyrite</td>
<td>Calcite, Zeolite, Agate, Stibnite, Realgar</td>
<td>Lattice Bladed + Bladed Carbonate ± agate</td>
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<tr>
<td>Silver sulfosalts</td>
<td>Quartz, Calcite, Pyrite</td>
<td>Massive Chalcedonic ± Lattice bladed</td>
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<tr>
<td>Pyrargite</td>
<td>Quartz, Adularia, Sericite, Pyrite</td>
<td>Moss + Chalcedonic &gt; Crystalline</td>
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<tr>
<td>Argentite</td>
<td>Quartz, Fluorite, Pyrite</td>
<td>Crystalline &gt; Moss + Chalcedonic ± needle adularia ± sulphide bands</td>
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<tr>
<td>Electrum</td>
<td></td>
<td>Crystalline Quartz + Adularia + Sulphide (crustiform)</td>
</tr>
<tr>
<td>Argentite</td>
<td></td>
<td>Crystalline Quartz + Carbonate</td>
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<tr>
<td>Electrum</td>
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<tr>
<td>Galena</td>
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<td>sphalerite</td>
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<td>Chalcopyrite</td>
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<td>Silica flooding and</td>
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<td>Geyser with silica</td>
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<td>Chlorite smectite</td>
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<td>200°C Kaolinite smectite</td>
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<td>Illite-Kaolinite</td>
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<td>Sericite</td>
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<tr>
<td>Silica adularia</td>
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<tr>
<td>Chlorite</td>
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<td>250°C 500 m</td>
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Modified after Buchanan 1981
Strong Vertical Zonation in Vein Textures indicate Depth of Erosion

The uppermost parts of epithermal veins have distinct textures such as carbonate blades and moulds which are generally replaced by silica (forming resistant quartz veins). White saccharoidal (sugary) quartz is also common. The presence of moulds and blades indicates that the entire epithermal system is preserved. Precious metal concentrations are generally of very low tenor in bladed and saccharoidal quartz veins - even in systems where high grade ore shoots are present at depth.
Strong Vertical Zonation in Vein Textures indicate Depth of Erosion

Stockwork veins with chalcedonic and agate-like textures are common in the uppermost parts of the system and quartz-flooding of host tuffs may be present. Breccias usually retain open space (due to low confining pressures). Sulphides include marcasite (low temperature polymorph of pyrite) and pyrite. Precious metals (if present) are of a low tenor.
Deposition of gold and silver in high grade ore shoots is associated with the process of fluid boiling. Deposition of quartz and gangue minerals from hydrothermal fluids heals fractures in host rocks. This results in over-pressured fluids which eventually causes sudden hydraulic fracturing of the host rocks. Fluids boil as pressure is released and precipitate metal and gangue minerals from solution. In mineralized systems the more times this process repeats in a given vein the higher the grade.
Base metal sulphides such as galena and sphalerite typically form below the boiling level. Dark grey sulphidic quartz with high grade gold and silver may be present with base metals in a transition zone close to the base of the boiling zone. Localized changes in pressure and temperature may cause the boiling level to migrate up and down – causing telescoping of mineral zones and vein textures.
Strong Vertical Zonation in Vein Textures indicate Depth of Erosion

Quartz vein breccia infilled by grey galena and green sphalerite. The quartz appears to be a relatively early and unmineralized phase.

Massive galena with minor clots of green sphalerite. Note late carbonate and zeolite formed as the system cooled and surface fluids percolated downwards.

The lowest mineralized levels of a LS epithermal is dominated by lead and zinc sulphides where they may form massive quartz-poor base metal-dominant veins. Due to confining pressure at these depths stockwork and breccia development is limited, unless porous lithologies permit lateral and upward flow of fluids away from the main feeder structure. Chalcopyrite may be present in some systems.
Narrow Vein at Base of System
Strong alteration zonation outwards and upwards from feeder structures provides vectors to mineralization. However, propylitic and near-surface alteration can be widespread and extend over 10’s of square kilometres making it difficult to accurately target narrow high grade ore shoots. Silica sinters or hot springs are important indicators of the uppermost levels of low sulphidation epithermal systems, but can form on distal faults that are a considerable distance from ore zones.
Geochemistry Changes Vertically Through System

There is a strong vertical zonation of geochemical signature reflecting the vertical zonation in ore and gangue minerals. Major and trace element geochemistry can be used as an indicator of level of erosion.

Barren of Precious and Base metals at surface. Arsenic, mercury and bismuth are common pathfinder elements.

Gold-rich interval where fluids “boil”. May or may not contain silver.

Base Metal-rich interval may extend to depth +/- gold-silver credits.

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Low Sulphidation Exploration – Strategy and Challenges
Low sulphidation epithermal deposits form in Continental and Oceanic Arc settings as subducting oceanic plates melt and generate large intrusive complexes and associated hydrothermal circulation cells. Correct identification of Continental and Oceanic Arc settings is a pre-requisite for successful exploration.
Cross-section through the Earths crust showing convergent zones where oceanic crust is subducted beneath oceanic crust (Ocean Arc setting) and continental crust (Continental Arc setting). Epithermal deposits form in these arc setting at depths of generally <500 metres to less commonly between 1 – 2 kilometres. Due to their formation very close to the earths surface, in regions of active volcanicity and mountain building, their preservation potential is very poor.
Carpathian Arc-Related Epithermal and Porphyry District

Deposit size taken from a variety of sources. Most figures are historic production and Moz ++ indicates that cited numbers are likely under-estimate.)
Preserved Volcanic Sequences Host Epithermal and Porphyry Deposits

Major epithermal and porphyry deposits of the Inner Carpathian Arc. Note that epithermal deposits occur within the areas of preserved arc-related volcanic sequences in deposit clusters.
The Martha Hill Mine started production in 1878 following discovery of outcropping veins. The Mine closed in 1952 having produced 5.6 Moz Au and 38.4 Moz Ag from 11.93 Mt of ore at an average recovered grade of 14.6 g/t Au. Over 160 km of access and production drives were excavated.

The mine was reopened 1987 by Newmont. Martha is now an open pit, and together with the Favona Underground Mine, produced 108,000 oz Au and 522,129 Ag in 2010.

NOTE

- Multiple veins with strong structural control;
- Most veins not exposed at surface but alteration provides vector;
- Former high grade UG mine now mined as open pit by Newmont.
Outcropping veins at this LS epithermal mine in Mexico guided exploration and underground development. The lack of vein outcrop within the area of Miocene basalt suggested that the vein system did not extend into this region as evidenced by the location of the tailings dam. Once it was realised that the basalt was post-mineral, the prospectivity of this area was explored.
IP studies across the SE extension of the veins was conducted and chargeability anomalies were defined beneath the basalt cover. Subsequent development indicated that these veins are pyrite and base-metal rich thereby explaining the chargeability anomalies. Magnetite destructive alteration in the host granites indicates that ground magnetics would be an effective exploration tool. Similarly, elevated potassium response associated with sericite development also suggests that radiometric studies would assist with delineation of veins.
Sustained Drilling Required to Define High Grade Shoots

Although the vein system is over 2.5 km long, the ore bodies are discrete and lenticular, occurring on approximately 200 to 300 meter centres. Sub-economic and barren quartz veins occur between high grade ‘ore shoots’. Once a mineralized vein has been identified, sustained drilling is required to define the high grade shoots. This requires a robust understanding of structure which exerts a fundamental control on the distribution of the high grade zones. Note the vertical zonation from upper gold dominant to lower base-metal dominant veins.

Typical mined grades were +1.5 g/t gold and +150 g/t silver.
Caution – The Majority of Epithermal Quartz Veins are Not Mineralized

A basic premise of exploration for Low Sulphidation Epithermal deposits is that the entire system will be preserved beneath outcropping veins displaying upper level textures, mineralogy and geochemistry. However, many epithermal systems that do show these signatures at surface are not mineralized at depth – even within an existing mineralized property. Moreover, high grade mineralization typically occurs in high grade shoots that may require sustained drilling and structural understanding.
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