High Sulphidation Epithermal Deposits

Presented By:
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Exploration Alliance
Global Distribution of High Sulphidation Deposits
**World Class Examples**

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

**Quimsacocha:** 102 m @ 9.2 g/t Au, 46.9 g/t Ag, 0.4 % Cu (IAMGOLD, IQD-122)

**Veladero:** 170 m @ 1.9 g/t Au (Argentina Gold, Hole 76)

**Lihir (Minfie):**
- 40 m @ 8.8 g/t Au (0-40 m),
- 80 m @ 6.4 g/t Au (40-120 m),
- 78 m @ 4.2 g/t Au (120 to 197.6 m)

**Pueblo Viejo:**
- 86 m @ 3.1 g/t Au (DPV07-74),
- 133 m @ 3.22 g/t Au (DPV07-86).

**Wafi:**
- 20 m @ 8.5 g/t Au, and
- 70 m @ 11.0 g/t Au (WR154),
Geological Setting
High Sulphidation deposits form in the upper 1 km of the Earth’s crust above subduction zones.

**Epithermal**: Shallow Heat

**High Sulphidation**: A high metal to sulphur ratio within the sulphide minerals (the sulphidation state). Characterised by minerals such as enargite and luzonite. Alteration indicative of strongly acidic conditions.
Hydrothermal deposit types are linked to large cells of circulating magmatic fluids mixed with groundwater centred on an intrusive complex.
Hydrothermal fluids exploit faults, folds and favourable host rocks, depositing minerals as they flow through those spaces.
Hot intrusions drive hydrothermal circulation. Fluids leach gold from low abundance crustal rocks – big systems source gold from large volumes of crust. Fluids migrate upwards along faults and permeable horizons. Ascending fluids may boil as they move into low pressure environment, will cool, and may change composition via mixing with near surface fluids – all of with result in deposition of carried metals.
Hydrothermal Fluids Alter Host Rocks

Alteration may be used as a vector to mineralisation but alteration haloes are larger than the ore zones. Large alteration systems may mask high grade feeder zones, alteration associated with high grade veins may have a small surface footprint, buried mineralization may have no surface expression, and many altered systems are barren.
### Alteration

**Unaltered Host Rock**

**Altered Host Rock**

<table>
<thead>
<tr>
<th>Unaltered Host Rock</th>
<th>Altered Host Rock</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Unaltered Host Rock Image" /></td>
<td><img src="image2.png" alt="Altered Host Rock Image" /></td>
</tr>
</tbody>
</table>

- These minerals have been replaced
- Texture of rock has been destroyed

Mapping these changes gives information on proximity to mineralisation.

**Alteration:** A term used to describe the chemical response of a rock to hydrothermal solutions causing mineralogical change. Alteration is used as a vector to mineralisation.
Exposure of Mineralized Systems Creates Geochemical Anomalies

Geochemical anomalies are larger than the mineralized zones

Erosion and weathering of alteration and mineralized zones results in surficial geochemical anomalies

Surficial geochemical anomalies form above and downslope of alteration zones (whether mineralized or not), in association with structures that have acted as fluid conduits, and surrounding areas of exposed mineralization.
Weathering and erosion of the Earth's surface exposes mineralized systems and will eventually remove them from the geological record. Deposits formed close to surface (such as epithermals) or those formed in rapidly uplifting terrains (such as mountain chains) have poorest preservation potential. The very oldest gold deposits are dominated by orogenic (greenstone-hosted) types which formed at significant (>3-10+ km). Almost all preserved epithermal deposits are <100 Ma.
High Sulphidation Deposits in the Hydrothermal System

High Sulphidation

Vapor Ascent

Meteoric Water

Approx. 1 km
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 Late Cretaceous to present day subduction zones.

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.
The Kikai Caldera is host to the hydrothermal system. The volcanoes post-date the caldera.

Source: Smithsonian Institute
Shallow Crustal Levels of Formation

Satsuma-Iwojima volcano, Japan (from Hendenquist, 2002)
Deposit Model
High Sulphidation deposits are spatially related to volcanic centres and diatremes. They often represent the upper parts of porphyry systems and the two types of mineralisation can often overlap or occur adjacent, for example Bor (Serbia), Lepanto (Indonesia) and Wafi-Golpu (PNG). Note the alteration of the upper parts of the volcano (shown in the photograph) caused by release of acid vapours and fluids.
The structural setting of High Sulphidation deposits in volcanic environments lends itself to mineralisation due to the hydrothermal alteration caused by underlying intrusions, and creation of space through extensional faulting in and around the caldera and back-arc basin. Furthermore, permeable volcaniclastic and sedimentary rocks are deposited in the same environment and act as fluid conduits.

Ignimbrite is a volcaniclastic rock with inherent permeability – with zones of weakness at the contact between fragments and throughout the matrix.
Acidic gases and fluids ascend from the deep magma chamber. The hydrothermal fluids will exploit any weakness such as faults or permeable lithologies. The acidity of the hydrothermal fluid is greatest within the conduits. As the fluid percolates away from the main structures it’s acidity is neutralised, creating a zoned alteration pattern. Vuggy silica is at the core of the alteration system.
Lihir – An Active Geothermal System
Vuggy silica forms in sub-vertical structures and favourable, permeable lithological units, often sub-horizontal. The acid condensate is progressively neutralised away from the source structures, creating a zoned alteration pattern. A lithocap of argillic and advanced argillic alteration forms at surface, which is commonly rich in alunite.
Late Mineralising Event Exploits Pre-Existing Voids

A later, less acidic but metal endowed fluid ascends from the deep magma chamber. The late fluid rapidly loses temperature and pressure when it reaches the vuggy silica due the abundant space, causing metals to be precipitated from the oversaturated fluids, introducing gold with pyrite. Ores are often refractory. Late steam-heated alteration forms at surface with native sulphur, and supergene minerals such as jarosite and sulfates.
The Link between High Sulphidation and Porphyry

Absence of lithocap and minerals such as native sulphur indicate a deeper level of erosion.

Lack of large advanced argillic zone should be of concern to the explorer.

Exposure of basement rocks indicates deep levels, but requires a good understanding of regional geology.

Alteration zoning points to center of hydrothermal system and potential porphyry at depth or adjacent.

At first glance the ingredients for High Sulphidation mineralisation appear to be present at surface – however the alteration zonation is small and the basement rocks are exposed. There may, however, be an opportunity to explore for associated porphyry mineralisation...
High Sulphidation and Porphyry – Mankayan District

Mankayan District, Phillipines. The Far Southeast porphyry acts as the centre of the hydrothermal system and is the source of hydrothermal fluids and magmatic gases. The Lepanto high sulphidation mineralisation is coeval with the porphyry, and the surface alteration has been shown to be a reliable tool in locating the porphyry (after Hedenquist, 2011).
Wafi-Golpu Deposit

Source: www.harmony.co.za
Exploration Challenges
High 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.
Identify Volcanic Arc and Mineral Occurrences/Mines

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Beregovo (6.9 moz Au)
Baia Mare (4++ Moz Au)
Banksia Stiaca (2.3+ Moz Au)
Kremnica (2.5++ Moz Au)
Rochovce
Recsk
Bor-Timok (9 Moz Au + Cu)
Trepca
Majdanapek (8+ Moz Au + Cu)
Ocna de Fier
Vekik Krivelji
Sofia
Recsk
Buchim
Medet
Osogovo
Radka
Krotovo
Lece
Buchim
Sofia
Rosia Montana (17 Moz Au and 80 Moz Ag)
Rosia Poieni
Brad (11 Moz Au)
Vekikj Krivelji
Chelopech (5+ Moz Au)
Elatsite
Assarel
Medet
Chelopech (5+ Moz Au)
SOFTH APUSENI MTS
SOUTH APUSENI MTS
INNER CARPATHIAN ARC
ROMÁNIA
BULGARIA
BANAT-SREDNOGORA ARC
PERIADRIATIC-RECSK ARC
HUNGARY
SLOVAKIA
UKRAINE
250 km
Epithermal
Porphyry
Identify Intrusive Centres and Volcanic Rocks

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- Epithermal
- Porphyry

- UKRAINE
- ROUMANIA
- HUNGARY
- SLOVAKIA
- SOUTH APUSENI MTS
- INNER CARPATHIAN ARC
- PERIADRIATIC-RECSK ARC
- BANAT-SREDNOGORA ARC

Locations:
- Kremnica
- Rochovce
- Beregovo
- Baia Mare
- Banksia Stiackica
- Recsk
- Rosia Poieni
- Rosia Montana
- Brad
- Volcanic Arc Sequences

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Along with the large alteration zones, many anomalies are created and it can be difficult to vector in on a mineralised system. Remnant lithocaps, zoned alteration and identification of permeable lithologies are important exploration guides.
Combining Geology, Geochemistry and Geophysics

**Geochemistry**
As, Cu, Sb, Bi, Te, Sn, Mo, S – indicative of magmatic source fluids responsible for alteration.

**Geophysics**
Low resistivity, high chargeability
Magnetite destructive alteration presents as flat response

PNG Highlands are densely forested yet host to many world class deposits.

Geochemistry and alteration provide vectors to prospective targets.

Surface expression may be low grade or barren
High Sulphidation Alteration and Lithocap

A lithocap exposed in northern Iran. Note resistant cap and extensive clay development.
High Sulphidation Alteration and Lithocap

Vuggy Silica forming a ridge at the centre of the lithocap. Northern Iran
Size of Alteration Zone is Critical

Source: Hedenquist, 2002
Refractory Ores are Common

Cross Section through the Pierina Deposit

Source: Hennigh, 2012
The Southern Andes are host to some of the world's largest porphyry and high sulphidation deposits. They are largely restricted to the magmatic arc and hosted in associated intrusive and volcanic rocks. The El Indio Belt is a high sulphidation district (yellow dots) in a region otherwise dominated by porphyry and IOCG deposits (blue dots).
The El Indio deposit was discovered in 1977 and the region has since become recognised as a major gold-silver-copper district, hosting over 80 Moz gold (Sillitoe, 2008). Economic mineralisation is spatially related to calderas.

**Pascua Lama (Barrick)**
630 Mt containing 24 Moz Gold, 861 Moz Silver, 944 Mlb copper (M+I resources, 2011)

**Veladero**
476 Mt containing 12 Moz gold, 212 Moz silver (M+I resources, 2011)

**El Indio and Tambo**
Historic production of approximately 4.5 Moz gold. Closed due to refractory ores.

Modified From Chouinard et al., 2005
Barrick acquired Pascua Lama in 1994 and inherited a resource of 1.8 Moz gold. By 2004 Barrick had increased this to 17.6 Moz gold and 585 Moz silver! Mineralisation is centred on breccias and displays an obvious structural control.
Mineralisation is restricted to the advanced argillic envelope, and furthermore displays a close spatial relationship to the less extensive, vertically restricted vuggy silica alteration at the inferred mixing zone.

Deep overburden as very top of system is preserved.
Veladero Discovery History

1980s: Argentine government geologists identify large alteration zone from satellite imagery. Gold anomalies discovered through surface sampling.

1994: Argentina Gold Corp. (AGC) awarded exploration rights. Entered into JV with Barrick (original agreement with Lac Minerals)


2001: Merger between Homestake and Barrick

2005: Production commences

2015: Remaining Reserves 172 Mt @ 0.86 g/t Au (4.7 Moz)

Discovery Hole:
170 m @ 1.90 g/t Au

Follow Up:
193 m @ 1.49 g/t Au
145 m @ 1.06 g/t Au
80 m @ 1.15 g/t Au
# Veladero Discovery History

<table>
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<tr>
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<th>Event</th>
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<td>1999</td>
<td>AGC acquired by Homestake Mining. Aggressive drilling campaign.</td>
</tr>
<tr>
<td>2001</td>
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<tr>
<td>2005</td>
<td>Production commences</td>
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<tr>
<td>2015</td>
<td>Remaining Reserves 172 Mt @ 0.86 g/t Au (4.7 Moz)</td>
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- **325,284 meters drilled**
- **25 years from prospecting to production**
- **8 years from discovery hole to production**
Good Grade Continuity

Source: Barrick Technical Report
Mineralisation hosted largely in volcanic explosion breccias and tuffs which are silica altered.
Mineral Processing

Ore is heap leached and recovered by Merrill-Crowe cyanide leach.

Federico Type 2 associated with argentojarosite.

Other projects, for example Lihir, utilise pressure oxidation followed by cyanide leaching to improve recovery.

<table>
<thead>
<tr>
<th>Ore Type</th>
<th>Au Grade (g/t)</th>
<th>Recovery Formula (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federico Filo Type 1 (crushed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Au ≤ 0.3</td>
<td>38.4 * Au(g/t) + 55</td>
<td></td>
</tr>
<tr>
<td>0.3 ≤ Au &lt; 0.5</td>
<td>2.4 * Au(g/t) + 77</td>
<td></td>
</tr>
<tr>
<td>0.5 ≤ Au &lt; 1.0</td>
<td>10.0 * Au(g/t) + 65</td>
<td></td>
</tr>
<tr>
<td>1.0 ≤ Au &lt; 2.0</td>
<td>2.0 * Au(g/t) + 81</td>
<td></td>
</tr>
<tr>
<td>3.0 ≤ Au</td>
<td>87</td>
<td></td>
</tr>
<tr>
<td>Federico Filo Type 2 (crushed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Au ≤ 0.5</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>0.5 ≤ Au &lt; 1.0</td>
<td>4.0 * Au(g/t) + 38</td>
<td></td>
</tr>
<tr>
<td>1.0 ≤ Au &lt; 3.0</td>
<td>14.0 * Au(g/t) + 28</td>
<td></td>
</tr>
<tr>
<td>3.0 ≤ Au</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Amable Type 1 (crushed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Au ≤ 0.3</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>0.3 ≤ Au &lt; 0.5</td>
<td>20.0 * Au(g/t) + 52</td>
<td></td>
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<tr>
<td>0.5 ≤ Au &lt; 1.0</td>
<td>16.0 * Au(g/t) + 54</td>
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<tr>
<td>1.0 ≤ Au &lt; 2.0</td>
<td>10.0 * Au(g/t) + 60</td>
<td></td>
</tr>
<tr>
<td>2.0 ≤ Au</td>
<td>80%</td>
<td></td>
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<tr>
<td>Amable Type 2 (crushed)</td>
<td></td>
<td></td>
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<tr>
<td>Au ≤ 0.5</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>0.5 ≤ Au &lt; 1.0</td>
<td>4.0 * Au(g/t) + 38</td>
<td></td>
</tr>
<tr>
<td>1.0 ≤ Au &lt; 2.0</td>
<td>14.0 * Au(g/t) + 28</td>
<td></td>
</tr>
<tr>
<td>2.0 ≤ Au</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Federico Filo Type 1 (ROM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Federico Filo Type 2, Amable Type 1 and Type 2</td>
<td>60% of estimated crushed ore recovery</td>
<td></td>
</tr>
</tbody>
</table>
## Quimsacocha, Ecuador

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<thead>
<tr>
<th>Year</th>
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<td>1970s</td>
<td>UN exploration program identifies stream sediment anomalies.</td>
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<td>1991</td>
<td>COGEMA drilled 2944 metres</td>
</tr>
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<td>1993</td>
<td>Newmont JV with COGEMA - 7581 M drilled. Best intercept 2 metres @ 83 g/t gold, 316 g/t Ag. JV dissolved.</td>
</tr>
<tr>
<td>2011</td>
<td>INV purchase agreement with IAMGOLD.</td>
</tr>
<tr>
<td>2013</td>
<td>3684 meters drilled.</td>
</tr>
<tr>
<td>2015</td>
<td>INV announce Pre-Feasibility Study – underground long hole stoping with drift and fill mining. Sequential flotation to produce pyrite and copper cons.</td>
</tr>
</tbody>
</table>

### Facts:
- **88,861 meters drilled**
- **~45 years from prospecting to PFS**
- **11 years from discovery hole to Current PFS**
Quimsacocha, Ecuador

**1970s:** UN exploration program identifies stream sediment anomalies.

**1991:** COGEMA drilled 2944 metres

**1993:** Newmont JV with COGEMA - 7581 M drilled. Best intercept 2 metres @ 83 g/t gold, 316 g/t Ag. JV dissolved.

**1999:** IAMGOLD acquired concessions. Re-interpreted geology using PIMA analysis on drill core. Drilled 74,652 metres through to 2007.

**2008:** New Ecuadorian Constitution and amendment of mining regulations (2009).

**2011:** INV purchase agreement with IAMGOLD.

**2013:** 3684 meters drilled.

**2015:** INV announce Pre-Feasibility Study – underground long hole stoping with drift and fill mining. Sequential flotation to produce pyrite and copper cons.

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**Discovery Hole:**

102 m @ 9.2 g/t Au, 46.9 g/t Ag
0.4 % Cu
Typical High Sulphidation Morphology

from INV Technical Report
Excellent Grade Continuity

from INV Technical Report
Conceptual Model Led to Discovery

Source: Newcrest Lihir Technical Report
Thank You

Industry Proven Geologists • Most Commodities • Most Deposits Styles • All Physiographic Regimes
Exploration Alliance Consultants have Worked in over 90 Countries

‘We Have the World Covered’