Epithermal Deposits
Epithermal Systems

Low and high sulphidation deposits
Submarine Epithermal Systems
The significance of Epithermal Deposits as a Gold Resource

![Pie chart showing different types of gold resources.](chart.png)
Distribution of Epithermal Deposits

High Sulphidation
Low Sulphidation
Surface expression of a low sulphidation epithermal deposit
Low Sulphidation Deposits
Ore Styles and Alteration Assemblages

Kaolinite ± alunite ± native S – opaline silica (steam-heated alteration)

Chalcedony blanket

Hot springs

Paler surface

Water table

Permeable lithology

Disseminated ore

Sericite/illite ± adularia

Chlorite-calcite ± epidote

Vein ore

Smectite/mixed-layer clay ± chlorite

Crustified quartz/chalcedony-carbonates ± adularia ± barite/fluorite

0 50–100 meters

50–100
Low Sulphidation Deposits
Fluid Inclusion Temperatures and Salinities

Temperature of final ice melting (°C)

Temperature of homogenization (°C)

Wt % NaCl equivalent

- Acupan
- Comstock
- Hishikari
- McLaughlin
- Round Mt
- Tayoltita
Low Sulphidation Deposits
Oxygen and Hydrogen Isotopic Data
Low Sulphidation Deposits
Temperature-pH Conditions

3 KAlSi$_3$O$_8$ + 2 H$^+$ = KAl$_3$Si$_3$O$_{10}$(OH)$_2$ + 6 SiO$_2$ + 2 K$^+$
The Low Sulphidation Epithermal – Geothermal Link

Champagne Pool, New Zealand

Up to 90 g/t Au

Old Faithful, Yellowstone

Wairakei Geothermal Power Plant, New Zealand
The Low Sulphidation Epithermal – Geothermal Link
Controls on the Solubility of Gold

\[
\text{Au(HS)}_2^- + \text{H}^+ + 0.5 \text{H}_2\text{O} = \text{Au} + 2\text{H}_2\text{S} + 0.25\text{O}_2
\]

\[
\text{Au(HS)}^0 + 0.5 \text{H}_2\text{O} = \text{Au} + \text{H}_2\text{S} + 0.25\text{O}_2
\]

\[
\text{AuCl}_2^- + 0.5\text{H}_2\text{O} = \text{Au} + 2\text{Cl}^- + \text{H}^+ + 0.25\text{O}_2
\]

Williams-Jones et al. 2009
A model for the formation of low sulphidation epithermal deposits

1) Magmatic vapour condenses in meteoric water
2) Gold transported as Au (HS)\textsuperscript{-2}
3) Water rises and boils, releasing H\textsubscript{2}S and destabilizing Au(HS)\textsubscript{2}-
4) Gold deposits as the native metal

\[ \text{Au(HS)}_2^- + \text{H}^+ + 0.5 \text{H}_2\text{O} = \text{Au} + 0.25\text{O}_2 + 2\text{H}_2\text{S} \]

Removed by boiling
Epithermal Systems
High sulphidation deposits
High Sulphidation Deposits
Ore Style and Alteration Assemblages
Acid-Sulphate Alteration

Vuggy silica

All components of the rock leached leaving behind vuggy silica ($\text{pH} < 1$)

Advanced argillic alteration

- Alunite ($\text{KAl}_3(\text{SO}_4)_2(\text{OH})_6$)
- Kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$)
- Quartz and Pyrite
Conditions of Acid-Sulphate Alteration

King et al., 2014
The high sulphidation Pascua epithermal deposit, Chile

Chouinard et al., 2005
Mineralization at Pascua
High Sulphidation Deposits
Oxygen and Hydrogen Isotopic Data

Acidic fluids in high sulfidation deposits

Volcanic vapors
Felsic magmas

Lepanto - alunite
La Mejicana - quartz
La Mejicana - sericite
Alunite alteration stage
Ore mineralization stage
Alteration / mineralisation
High Sulphidation Deposits
Fluid Inclusion Temperatures and Salinities

![Graph showing temperature of final ice melting against temperature of homogenization for different locations. The graph includes lines for Lepanto, Nansatsu, Rodalquilar, La Mejicana, and El Indio, with salinity values on the right axis.](image)
A Model for the Formation of High Sulphidation Deposits

Fig. 12. Two-stage model for high-sulfidation ore formation proposed by Arribas (1995), modified to highlight likely water compositions involved in each stage of ore genesis. Stage 1 (A) is the ground preparation stage, whereby magmatic gases generate an acid sulfate high-sulfidation water that is responsible for the initial barren stage of residual silica and advanced argillic alteration. The second stage involves gold deposition from acid chloride low-sulfidation waters (B₁) or acid chloride brines (B₂).
Controls on the Solubility of Gold

\[ \text{Au(HS)}_2^- + H^+ + 0.5 \text{H}_2\text{O} = \text{Au} + 2\text{H}_2\text{S} + 0.25\text{O}_2 \]

\[ \text{Au(HS)}^\circ + 0.5 \text{H}_2\text{O} = \text{Au} + \text{H}_2\text{S} + 0.25\text{O}_2 \]

\[ \text{AuCl}_2^- + 0.5\text{H}_2\text{O} = \text{Au} + 2\text{Cl}^- + H^+ + 0.25\text{O}_2 \]

Williams-Jones et al. 2009
Lessons from Indonesia
The Sangihe Au-Ag Deposits

Py I Au 1.1 ppm  
Ag  33 ppm

Py II Au 1 ppm  
Ag  81 ppm

<table>
<thead>
<tr>
<th>Deposit</th>
<th>tonnes (t)</th>
<th>Au (g/t)</th>
<th>Ag (g/t)</th>
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<tr>
<td>Bawone Sulphide</td>
<td>5,999,000</td>
<td>1.12</td>
<td>0.97</td>
</tr>
<tr>
<td>Binebase Oxide</td>
<td>7,851,000</td>
<td>1.10</td>
<td>25.13</td>
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<tr>
<td>Sulphide</td>
<td>10,002,000</td>
<td>0.49</td>
<td>13.60</td>
</tr>
</tbody>
</table>
Metal zoning in pyrite

Copper map for Py II at Sangihe

Gold map for pyrite at Pascua

Cu (green) As (blue) maps for pyrite at Pascua
The Lycurgus Cup – dichroic glass and nanogold

A possible explanation for “invisible gold” in pyrite – electrostatic attraction of negatively charged nanogold particles to the surfaces of positively charged pyrite

Williams-Jones et al. 2009
The Sangihe Model

King et al. (2014)
Kawah Ijen - High Sulphidation Epithermal Deposit in the Making?

Dacite Dome

Alunite/pyrite

Acid lake pH 0.5

Mining sulphur
Sulphur condensation and acidity creation

\[ 4H_2O \text{(gas)} + 4SO_2 \text{(gas)} = 2S \text{ (solid)} + 2H_2SO_4 \text{ (gas)} \]

\[ H_2SO_4(aq) = 2H^+ + SO_4^{2-} \]

600 °C
pH -0.6
Sampling the gases

New dome

Alunite/pyrtite Au?

Giggenbach bottle

Gas condenser
Vapour-induced acid-sulphate Alteration
Acid-Sulphate Alteration

Pyroclastic rocks altered to alunite $(\text{KAl}_3\text{(SO}_4\text{)}_2\text{(OH)}_6$ and pyrite

Leached andesite pillow containing $> 85$ wt.% $\text{SiO}_2$ – residual silica
Acid Sulphate Alteration at Kawah Ijen

Alunite-pyrite alteration  Alunite-pyrite vein
Distribution of Alteration at Kawah Ijen

- Vuggy silica
- Alunite-pyrite
- Kaolinite
- Pyrite

Scher et al. (2013)
Gold Silver mineralisation at Kawah Ijen
Solubility of Silver in HCl-H$_2$O Vapour

Silver solubility increases with hydration

Migdisov and Williams-Jones (2013)
Water Clusters Hydrating a Metal Species in the Gas Phase

Williams-Jones and Migdisov (2014)
The effects of complexation and particularly solvation by H$_2$O clusters make heavy metals volatile.
Extracting Thermodynamic Data

The linear relationship between $\Delta G$ and reciprocal temperature enables extrapolation to high temperature

Log $K = -\Delta G/RT$

*Migdisov and Williams-Jones (2013)*
Solubility of Silver in HCl-H$_2$O Vapour

Hydration increases with increasing H$_2$O pressure or density but decreases with increasing temperature.

Solubility increases with increasing temperature but reaches a maximum because of the effect of decreasing hydration.

$\rho=0.2$ g/cm$^3$
Epithermal Au Ore Formation

Vapour-dominated hydrothermal plume rises from magma transporting Au and depositing it as temperature drops below 400°C

Hurtig and Williams-Jones (2014)
References


