Volcanogenic Massive Sulphide (VMS) Deposits
VMS Deposits in Outcrop and Core

Pyrite and sphalerite

Sphalerite

Pyrite
The Importance of VMS Deposits as a Copper, Zinc and Lead Resource

Lead-Zinc Resources

Copper Resources
Metal Distributions in VMS Deposits

World VMS
(Modified from Franklin, 1996)

10^3 tonnes per 1% area

- 1-100
- 100-1000
- 1000-10000
- >10000

SEDEX deposits → VMS deposits
# Grade and Tonnages of VMS Deposits

Table 15.3: Average grade and tonnage data for VMS deposits of selected regions. (Data from Large et al. 1987 and Lydon 1989)

<table>
<thead>
<tr>
<th>Region</th>
<th>Dominant deposit type</th>
<th>Number of deposits</th>
<th>Average grade(^a)</th>
<th>Tonnage (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abitibi Belt, Canada (Archaean)</td>
<td>Cu–Zn</td>
<td>52</td>
<td>1.47 3.43 0.07 47 31.9 0.8</td>
<td>9.2</td>
</tr>
<tr>
<td>Norwegian Caledonides (Palaeozoic)</td>
<td>Cu–Zn</td>
<td>38</td>
<td>1.41 1.53 0.05 0  na  na</td>
<td>3.5</td>
</tr>
<tr>
<td>Bathurst, New Brunswick, Canada (Palaeozoic)</td>
<td>Zn–Pb–Cu</td>
<td>29</td>
<td>0.56 5.43 2.17 28 62.0 0.5</td>
<td>8.7</td>
</tr>
<tr>
<td>Green Tuff Belt, Japan (Tertiary)</td>
<td>Zn–Pb–Cu</td>
<td>25</td>
<td>1.63 3.86 0.92 7 95.1 0.9</td>
<td>5.8</td>
</tr>
<tr>
<td>Tasman Geosyncline, Eastern Australia (Palaeozoic)</td>
<td>Cu–Au (b)</td>
<td>42</td>
<td>1.3 0.48 15.15 6.28 4 160.0 3.0</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>Zn–Pb–Cu(^b)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) \(N\) = Number of deposits for which data available to calculate average Ag and Au grades.

\(^b\) Data in this line is for some Tasmanian deposits only.
The tectonic settings of VMS deposits
The tectonic settings of VMS deposits
Kuroko Type VMS deposits
Paleogeographic Setting of Kuroko Deposits

VMS Ores

Gypsum
Canadian Noranda-Type VMS Deposits

Flows or volcaniclastic strata

Felsic flow complex

Canadian grade and tonnage
Average 5.5 Mt
Median 14.2 Mt
1.3% Cu
6.1% Zn
1.8% Pb
123 g/t Ag
2.2 g/t Au

Sericite-quartz
Chlorite-sericite
Quartz-chlorite
Chalcopyrite-pyrite veins
Detrital
Pyrite-sphalerite-galena
tetrahedrite-Ag-Au
Massive
Pyrite-sphalerite-galena
Pyrite-sphalerite-chalcopyrite
Chalcopyrite-pyrrhotite-pyrite

Barite (Au)
Carbonate/gypsum
Abitibi Greenstone Belt

VMS Deposits
Distribution of Noranda-type VMS deposits
Besshi-type Deposit - Back-Arc rift setting
Cyprus-type VMS deposits (Cu, Minor Zn)

Ophiolite
(A slice of oceanic crust)
Explorer Ridge – a VMS Deposit in the Making
Black smoker chimney and Cu-Zn Sulphides

- Chalcopyrite
- Sphalerite
- Pyrite
- Anhydrite
Chimney Development
The TAG (Mid-Atlantic Ridge) Hydrothermal Vent Field
Anatomy of a Seafloor Sulphide Mound
Mound Mineralogy
The State of the Ore Fluid, Liquid or Vapour

T °C

Diagram showing the relationship between pressure, depth, and temperature with average depth of seafloor vent sites and critical point indicated.
## Fluid Compositions

<table>
<thead>
<tr>
<th></th>
<th>Kuroko</th>
<th>EPR</th>
<th>SJFR</th>
<th>Seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temp (°C)</strong></td>
<td>320</td>
<td>350</td>
<td>224</td>
<td>2</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>4.5</td>
<td>3.5</td>
<td>3.2</td>
<td>8.0</td>
</tr>
<tr>
<td><strong>Na</strong></td>
<td>17500</td>
<td>9800</td>
<td>18300</td>
<td>10790</td>
</tr>
<tr>
<td><strong>K</strong></td>
<td>5000</td>
<td>1000</td>
<td>2020</td>
<td>395</td>
</tr>
<tr>
<td><strong>Ca</strong></td>
<td>4400</td>
<td>860</td>
<td>3860</td>
<td>413</td>
</tr>
<tr>
<td><strong>Mg</strong></td>
<td>510</td>
<td>&lt; 1</td>
<td>&lt; 1</td>
<td>1280</td>
</tr>
<tr>
<td><strong>SiO₂</strong></td>
<td>?</td>
<td>960</td>
<td>1400</td>
<td>10</td>
</tr>
<tr>
<td><strong>Cl</strong></td>
<td>40400</td>
<td>17335</td>
<td>38640</td>
<td>19355</td>
</tr>
<tr>
<td><strong>SO₄</strong></td>
<td>?</td>
<td>&lt; 1</td>
<td>-50</td>
<td>2745</td>
</tr>
<tr>
<td><strong>H₂S</strong></td>
<td>?</td>
<td>221</td>
<td>63</td>
<td>&lt; 1</td>
</tr>
<tr>
<td><strong>∑ CO₂</strong></td>
<td>8800</td>
<td>282</td>
<td>?</td>
<td>103</td>
</tr>
<tr>
<td><strong>Fe</strong></td>
<td>6</td>
<td>100</td>
<td>1045</td>
<td>&lt; 1</td>
</tr>
<tr>
<td><strong>Mn</strong></td>
<td>?</td>
<td>34</td>
<td>197</td>
<td>&lt; 1</td>
</tr>
<tr>
<td><strong>Zn</strong></td>
<td>3</td>
<td>7</td>
<td>59</td>
<td>&lt; 1</td>
</tr>
<tr>
<td><strong>Cu</strong></td>
<td>5</td>
<td>1</td>
<td>&lt; 0.1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td><strong>Pb</strong></td>
<td>3</td>
<td>&lt; 1</td>
<td>?</td>
<td>&lt; 1</td>
</tr>
<tr>
<td><strong>Ba</strong></td>
<td>?</td>
<td>13</td>
<td>?</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>
VMS Deposits – Isotopic Data
Controls on Mineral Deposition

The diagram shows the relationship between temperature (°C) and pH, with contour lines indicating the distribution of different minerals such as Cu, Zn, and Pb. Contours are in mg/kg, and the sum of Cl (ΣCl) is 1.0 m, indicating a specific assemblage of minerals.
Model for VMS Ore Formation

- $\text{(AsO}_4)^{3-}$, $\text{(VO}_4)^{3-}$, Cu, Zn...
- FeOOH, MnO$_2$
- FeS$_2$, FeS
- 2 °C
- 360 °C
- Seawater
- Basalt
- Metalliferous Sediments
- + Fe, Cu, Mn, Cu, Zn, Pb
- Magma Chamber
- 400 °C
- 1200 °C
Model for VMS Ore Formation

(b) Generic ridge vent system

- Diffuse, low-temp flow
- Focused, high-temp flow through chimneys

Seawater

Low-T alt.

Mg $\rightarrow$ smectite/chlorite
$\leftrightarrow$ $H^+$, $\text{Ca}^{2+}$, $\text{Na}^+$

$\text{Ca}^{2+} + \text{SO}_4^{2-} \leftrightarrow$ anhydrite

$\text{MORB}$

Albitization

$S$, $\text{Cu}$, $\text{Fe}$, $\text{Mn}$, $\text{Zn}$, etc.

Phase separation/segregation

$^{3} \text{He}$, $\text{CO}_2$, $\text{CH}_4$, $\text{H}_2$

$\approx 1200^\circ C$

Heat source = magma or hot rock

$\geq 350^\circ C$ vent fluid

$\leftrightarrow$ water-rock rxn (?)
(e.g., $\Delta \text{Si}$, $\text{Cu}$, $\text{H}_2$)

"reaction zone" or "root zone"