2. Deposit Type and Associated Commodities

By Randolph A. Koski and Dan L. Mosier

Volcanogenic Massive Sulfide Occurrence Model
Contents

Name and Synonyms........................................................................................................... 15
Brief Description .................................................................................................................. 15
Associated Deposit Types ................................................................................................. 15
Primary and Byproduct Commodities ............................................................................... 16
Example Deposits ............................................................................................................... 16
References Cited................................................................................................................. 19

Figures

2–1. Grade and tonnage of volcanogenic massive sulfide deposits..................................... 16
2–2. Map showing locations of significant volcanogenic massive sulfide deposits in the United States................................................................................................. 17

Table

2–1. Examples of deposit types with lithologic associations, inferred tectonic settings, and possible modern seafloor analogs................................................................. 18
2. Deposit Type and Associated Commodities

By Randolph A. Koski and Dan L. Mosier

Name and Synonyms

The type of deposit described in this document is referred to as volcanogenic massive sulfide (VMS). This terminology has been in use for more than 35 years (Hutchinson, 1973) and embraces the temporal and spatial association of sulfide mineralization with submarine volcanic processes. Similar terms for VMS deposits recorded in the literature include volcanogenic sulfide, volcanic massive sulfide, exhalative massive sulfide, volcanic-exhalative massive sulfide, submarine-exhalative massive sulfide, volcanic-hosted massive sulfide, volcanic-associated massive sulfide, and volcanophile massive sulfide deposits. In some earlier studies, the terms cupreous pyrite and stratabound pyrite deposits were used in reference to the pyrite-rich orebodies hosted by ophiolitic volcanic sequences in Cyprus and elsewhere (Hutchinson, 1965; Gilmour, 1971; Hutchinson and Searle, 1971). More recently, the term polymetallic massive sulfide deposit has been applied by many authors to VMS mineralization on the modern seafloor that contains significant quantities of base metals (for example, Herzig and Hannington, 1995, 2000). Other commonly used names for VMS deposit subtypes such as Cyprus type, Besshi type, Kuroko type, Noranda type, and Urals type are derived from areas of extensive mining activities.

Brief Description

Volcanogenic massive sulfide deposits are stratabound concentrations of sulfide minerals precipitated from hydrothermal fluids in extensional seafloor environments. The term volcanogenic implies a genetic link between mineralization and volcanic activity, but siliciclastic rocks dominate the stratigraphic assemblage in some settings. The principal tectonic settings for VMS deposits include mid-oceanic ridges, volcanic arcs (intraoceanic and continental margin), back-arc basins, rifted continental margins, and pull-apart basins. The composition of volcanic rocks hosting individual sulfide deposits range from felsic to mafic, but bimodal mixtures are not uncommon. The volcanic strata consist of massive and pillow lavas, sheet flows, hyaloclastites, lava breccias, pyroclastic deposits, and volcaniclastic sediment. Deposits range in age from Early Archean (3.55 Ga) to Holocene; deposits are currently forming at numerous localities in modern oceanic settings.

Deposits are characterized by abundant Fe sulfides (pyrite or pyrrhotite) and variable but subordinate amounts of chalcopyrite and sphalerite; bornite, tetrahedrite, galena, barite, and other mineral phases are concentrated in some deposits. Massive sulfide bodies typically have lensoidal or sheetlike forms. Many, but not all, deposits overlie discordant sulfide-bearing vein systems (stringer or stockwork zones) that represent fluid flow conduits below the seafloor. Pervasive alteration zones characterized by secondary quartz and phyllosilicate minerals also reflect hydrothermal circulation through footwall volcanic rocks. A zonation of metals within the massive sulfide body from Fe+Cu at the base to Zn+Fe+Pb+Ba at the top and margins characterizes many deposits. Other features spatially associated with VMS deposits are exhalative (chemical) sedimentary rocks, subvolcanic intrusions, and semi-conformable alteration zones.

Associated Deposit Types

Associations with other types of mineral deposits formed in submarine environments remain tentative. There is likely some genetic kinship among VMS deposits, Algoma-type iron formations (Gross, 1980, 1996; Cannon, 1986), and volcanogenic manganese deposits (Mosier and Page, 1988). Sedimentary-exhalative (SEDEX) deposits have broadly similar morphological features consistent with syngenetic formation in extensional submarine environments, but their interpreted paleotectonic settings (failed intracratonic rifts and rifted Atlantic-type continental margins), hydrothermal fluid characteristics (concentrated NaCl brines), absence or paucity of volcanic rocks, and association with shale and carbonate rocks distinguish them from VMS deposits (Leach and others, 2005).

The recognition of high-sulfidation mineralization and advanced argillic alteration assemblages at hydrothermal discharge zones in both modern and ancient submarine oceanic arc environments has led to the hypothesis (Sillitoe and others, 1996; Large and others, 2001) that a transitional relationship exists between VMS and epithermal (Au-Ag) types of mineral deposits. Galley and others (2007) include epithermal-style
mineralization in the hybrid bimodal-felsic subtype of their VMS classification.

A rather enigmatic type of Co-, As-, and Cu-rich massive sulfide mineralization in serpentinized ultramafic rocks of some ophiolite complexes (for example, Troodos and Bou Azzer) has been attributed to magmatic (syn- or post-ophiolite emplacement) and serpentinization processes (Panayiotou, 1980; Page, 1986; Leblanc and Fischer, 1990; Ahmed and others, 2009). Recent discoveries at slow-rate spreading axes of the Mid-Atlantic Ridge reveal that high-temperature hydrothermal fluids are precipitating Cu-Zn-Co-rich massive sulfide deposits on substrates composed of serpentinized peridotite (for example, Rainbow vent field; Marques and others, 2007). Based on these modern analogs, it is suggested that Co-Cu-As mineralization in ultramafic rocks of ophiolites may in fact belong to the spectrum of VMS deposits.

**Example Deposits**

Worldwide, there are nearly 1,100 recognized VMS deposits including more than 100 in the United States and 350 in Canada (Galley and others, 2007; Mosier and others, 2009). Locations of significant VMS deposits in the United States are plotted on a geologic base map from the National Atlas of the United States in figure 2–2. Selected representatives of this deposit type, grouped according to their lithologic associations, are presented in table 2–1 along with inferred tectonic settings (modified from Franklin and others, 2005) and possible modern analogs.

![Figure 2-1. Grade and tonnage of volcanogenic massive sulfide deposits. Data are shown for 1,021 deposits worldwide. U.S. deposits are shown as red dots. Data from Mosier and others (2009) (Cu, copper; Zn, zinc; Pb, lead).](image-url)
Figure 2–2. Locations of significant volcanogenic massive sulfide deposits in the United States.
<table>
<thead>
<tr>
<th>Examples of ancient deposits</th>
<th>Lithologic associations</th>
<th>Inferred tectonic settings</th>
<th>Possible modern analogs</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rio Tinto (Spain); Brunswick 12 (Canada); Stekenjokk (Sweden); Delta (USA); Bonnifield (USA)</td>
<td>Siliciclastic-felsic</td>
<td>Mature epicontinental margin arc and back arc</td>
<td></td>
<td>Ancient deposits: Tornos (2006); Goodfellow and others (2003); Grenne and others (1999); Dashevsky and others (2003); Dusel-Bacon and others (2004)</td>
</tr>
<tr>
<td>Hanaoka (Japan); Eskay Creek (Canada); Rosebery (Australia); Tambo Grande (Peru); Arctic (USA); Jerome (USA)</td>
<td>Bimodal-felsic</td>
<td>Rifted continental margin arc and back arc</td>
<td>Okinawa Trough; Woodlark Basin; Manus Basin</td>
<td>Ancient deposits: Ohmoto and Skinner (1983); Barret and Sherlock (1996); Large and others (2001); Steinmüller and others, 2000); Schmidt (1986); Gustin (1990)</td>
</tr>
<tr>
<td>Horne (Canada); Komsomolskoye (Russia); Bald Mountain (USA); Crandon (USA)</td>
<td>Bimodal-mafic</td>
<td>Rifted immature intraoceanic arc</td>
<td>Kermadec Arc; Izu-Bonin Arc; Mariana Arc</td>
<td>Modern analogs: Binns and others (1993); Halbach and others (1993); Binns and Scott (1993)</td>
</tr>
<tr>
<td>Windy Craggy (Canada); Besshi (Japan); Ducktown (USA); Gossan Lead (USA); Beaton (USA)</td>
<td>Siliciclastic-mafic</td>
<td>Rifted continental margin; sedimented oceanic ridge or back arc; intracontinental rift</td>
<td>Guaymas Basin; Escanaba Trough; Middle Valley; Red Sea</td>
<td>Modern analogs: Wright and others (1998); Glasby and others (2000); Hannington and others (2005)</td>
</tr>
<tr>
<td>Skouriotissa (Cyprus); Lasail (Oman); Lokken (Norway); Betts Cove (Canada); Bou Azzer (Morocco); Turner-Albright (USA)</td>
<td>Mafic-ultramafic</td>
<td>Intraoceanic back-arc or fore-arc basin; oceanic ridge</td>
<td>Lau Basin; North Fiji Basin; Trans-Atlantic Geothermal (TAG) field; Rainbow vent field</td>
<td>Ancient deposits: Constantiou and Govett (1973); Alabaster and Grenne and others (1999); Stephens and others (1984); Upadhyay and Strong (1973); Leblanc and Fischer (1990); Zierenberg and others (1988)</td>
</tr>
</tbody>
</table>

Modern analogs: Fouquet and others (1993); Kim and others (2006); Rona and others (1993); Marques and others (2007)
References Cited


Gustin, M.S., 1990, Stratigraphy and alteration of the host rocks, United Verde massive sulfide deposit, Jerome, Arizona: Economic Geology, v. 85, no. 1, p. 29–49.


