2. Deposit Type and Associated Commodities

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Volcanogenic Massive Sulfide Occurrence Model

Scientific Investigations Report 2010–5070–C

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012

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Suggested citation:
Koski, R.A., and Mosier, D.L., 2012, Deposit type and associated commodities in volcanogenic massive sulfide occurrence model: U.S. Geological Survey Scientific Investigations Report 2010–5070 –C, chap. 2, 8 p

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2. Deposit Type and Associated Commodities

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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-sediment-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.

Primary and Byproduct Commodities

Volcanogenic massive sulfide deposits are a major global source of copper, lead, zinc, gold, and silver. Figure 2–1 illustrates the broad ranges in combined base-metal concentrations (Cu+Zn+Pb) and tonnages for more than 1,000 VMS deposits worldwide. Although generally present as trace constituents, a number of other elements are of interest as economically recoverable byproducts or environmental contaminants: arsenic, beryllium, bismuth, cadmium, cobalt, chromium, gallium, germanium, mercury, indium, manganese, molybdenum, nickel, selenium, tin, tellurium, and platinum group metals.

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.

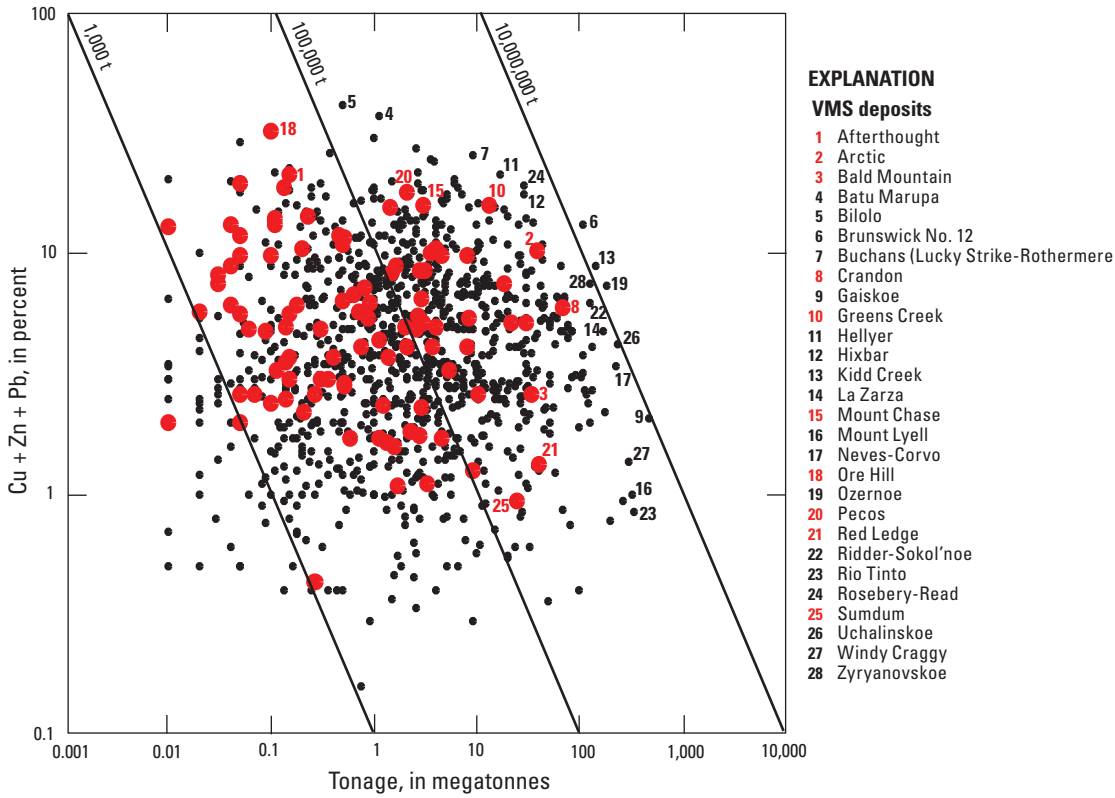

Figure 2–1. Grade and tonnage of volcanogenic massive sulfide deposits. Data are shown for 1,021 deposits worldwide. U.S. deposits are shown as red dots. Data from Mosier and others (2009) (Cu, copper; Zn, zinc;.Pb, lead).

Figure 2–2. Locations of significant volcanogenic massive sulfide deposits in the United States.

Table 2–1. Examples of deposit types with lithologic associations, inferred tectonic settings, and possible modern seafloor analogs.

Examples of ancient deposits	Lithologic associations	Inferred tectonic settings	Possible modern analogs	References
Rio Tinto (Spain); Brunswick 12 (Canada); Stekenjokk (Sweden); Delta (USA); Bonnifield (USA)	Siliciclastic-felsic	Mature epicontinental margin arc and back arc		Ancient deposits: Tornos (2006); Goodfellow and others (2003); Grenne and others (1999); Dashevsky and others (2003); Dusel-Bacon and others (2004)
Hanaoka (Japan); Eskay Creek (Canada); Rosebery (Australia); Tambo Grande (Peru); Arctic (USA); Jerome (USA)	Bimodal-felsic	Rifted continental margin arc and back arc	Okinawa Trough; Woodlark Basin; Manus Basin	Ancient deposits: Ohmoto and Skinner (1983); Barrett and Sherlock (1996); Large and others (2001); Steinmüller and others, 2000); Schmidt (1986); Gustin (1990) Modern analogs: Binns and others (1993); Halbach and others (1993); Binns and Scott (1993)
Horne (Canada); Komsomolskoye (Russia); Bald Mountain (USA); Crandon (USA)	Bimodal-mafic	Rifted immature intraoceanic arc	Kermadec Arc; Izu-Bonin Arc; Mariana Arc	Ancient deposits: Gibson and others (2000); Prokin and Buslaev (1999); Schulz and Ayuso (2003); Lambe and Rowe (1987) Modern analogs: Wright and others (1998); Glasby and others (2000); Hannington and others (2005)
Windy Craggy (Canada); Besshi (Japan); Ducktown (USA); Gossan Lead (USA); Beatson (USA)	Siliciclastic-mafic	Rifted continental margin; sedimented oceanic ridge or back arc; intracontinental rift	Guaymas Basin; Escanaba Trough; Middle Valley; Red Sea	Ancient deposits: Peter and Scott (1999); Banno and Sakai (1989); Stephens and others (1984); Gair and Slack (1984); Crowe and others (1992); Modern analogs: Koski and others (1985); Zierenberg and others (1993); Goodfellow and Franklin (1993); Shanks and Bischoff (1980)
Skouriotissa (Cyprus); Lasail (Oman); Lokken (Norway); Betts Cove (Canada); Bou Azzer (Morocco); Turner-Albright (USA)	Mafic-ultramafic	Intraoceanic back-arc or fore-arc basin; oceanic ridge	Lau Basin; North Fiji Basin; Trans-Atlantic Geothermal (TAG) field; Rainbow vent field	Ancient deposits: Constantinou 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) Modern analogs: Fouquet and others (1993); Kim and others (2006); Rona and others (1993); Marques and others (2007)

References Cited

Ahmed, A.H., Arai, S., and Ikenne, M., 2009, Mineralogy and paragenesis of the Co-Ni arsenide ores of Bou Azzer, Anti-Atlas, Morocco: Economic Geology, v. 104, p. 249–266.

Alabaster, T., and Pearce, J.A., 1985, The interrelationship between magmatic and ore-forming hydrothermal processes in the Oman ophiolite: Economic Geology, v. 80, p. 1–16.

Banno, S., and Sakai, C., 1989, Geology and metamorphic evolution of the Sanbagawa metamorphic belt, Japan, in Daly, J.S., Cliff, R.A., and Yardley, B.W.D., eds., Evolution of metamorphic belts: Geological Society of London Special Publication 43, p. 519–532.

Barrett, T.J., and Sherlock, R.L., 1996, Geology, lithogeochemistry and volcanic setting of the Eskay Creek Au-Ag-Cu-Zn deposit, northwestern British Columbia: Exploration and Mining Geology, v. 5, p. 339–368.

Binns, R.A., and Scott, S.D., 1993, Actively forming polymetallic sulfide deposits associated with felsic volcanic rocks in the eastern Manus back-arc basin, Papua New Guinea: Economic Geology, v. 88, p. 2222–2232.

Binns, R.A., Scott, S.D., Bogdanov, Y.A., Lisitzin, A.P., Gordeev, V.V., Gurvich, E.G., Finlayson, E.J., Boyd, T., Dotter, L.E., Wheller, G.E., and Muravyev, K.G., 1993, Hydrothermal oxide and gold-rich sulfate deposits of Franklin Seamount, western Woodlark Basin, Papua New Guinea: Economic Geology, v. 88, p. 2122–2153.

Cannon, W.F., 1986, Descriptive model of Algoma Fe, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 198.

Constantinou, G., and Govett, G.J.S., 1973, Geology, geochemistry and genesis of Cyprus sulfide deposits: Economic Geology, v. 68, p. 843–858.

Crowe, D.E., Nelson, S.W., Brown, P.E., Shanks, W.C., III, and Valley, J.W., 1992, Geology and geochemistry of volcanogenic massive sulfide deposits and related igneous rocks, Prince William Sound, south-central Alaska: Economic Geology, v. 87, p. 1722–1746.

Dashevsky, S.S., Schaefer, C.F., Hunter, E.N., 2003, Bedrock geologic map of the Delta mineral belt, Tok mining district, Alaska: Alaska Division of Geological and Geophysical Surveys Professional Report 122, 122 p., 2 pls., scale 1:63,360.

Dusel-Bacon, C., Wooden, J.L, and Hopkins, M.J., 2004, U-Pb zircon and geochemical evidence for bimodal mid-Paleozoic magmatism and syngenetic base-metal mineralization in the Yukon-Tanana terrane, Alaska: Geological Society of America Bulletin, v. 116, p. 989–1015.

Fouquet, Y., von Stackelberg, U., Charlou, J.-L., Erzinger, J., Herzig, P.M., Muhe, R., and Wiedicke, M., 1993, Metallogenesis in back-arc environments—The Lau basin example: Economic Geology, v. 88, p. 2154–2181.

Franklin, J.M., Gibson, H.L., Jonasson, I.R., and Galley, A.G., 2005, Volcanogenic massive sulfide deposits, in Hedenquist, J.W., Thompson, J.F.H., Goldfarb, R.J., and Richards, J.P., eds., Economic Geology 100th anniversary volume, 1905–2005: Littleton, Colo., Society of Economic Geologists, p. 523–560.

Gair, J.E., and Slack, J.F., 1984, Deformation, geochemistry, and origin of massive sulfide deposits, Gossan Lead district, Virginia: Economic Geology, v. 79, p. 1442–1478.

Galley, A.G., Hannington, M., and Jonasson, I., 2007, Volcanogenic massive sulphide deposits, in Goodfellow, W.D., ed., Mineral deposits of Canada: A synthesis of major deposit-types, district metallogeny, the evolution of geological provinces, and exploration methods: Geological Association of Canada, Mineral Deposits Division, Special Publication 5, p. 141–161.

Gibson, H.L., Kerr, D.J., and Cattalani, S., 2000, The Horne Mine: Geology, history, influence on genetic models, and a comparison to the Kidd Creek Mine: Exploration and Mining Geology, v. 9, p. 91–111.

Gilmour, P., 1971, Strata-bound massive pyritic sulfide deposits–A review: Economic Geology, v. 66, p. 1239–1249.

Glasby, G.P., Iizasa, K., Yuasa, M., and Usui, A., 2000, Submarine hydrothermal mineralization on the Izu-Bonin arc, south of Japan—An overview: Marine Georesources and Geotechnology, v. 18, p. 141–176.

Goodfellow, W.D., and Franklin, J.M., 1993, Geology, mineralogy, and chemistry of sediment-hosted clastic massive sulfides in shallow cores, Middle Valley, northern Juan de Fuca Ridge: Economic Geology, v. 88, p. 2037–2068.

Goodfellow, W.D., McCutcheon, S.R., and Peter, J.M., 2003, Introduction and summary of findings, in Goodfellow, W.D., McCutcheon, S.R., and Peter, J.M., eds., Massive sulfide deposits of the Bathurst mining camp, New Brunswick, and northern Maine: Economic Geology Monograph 11, p. 1–16.

Grenne, T., Ihlen, P.M., and Vokes, F.M., 1999, Scandinavian Caledonide metallogeny in a plate tectonic perspective: Mineralium Deposita, v. 34, p. 422–471.

Gross, G.A., 1980, A classification of iron formations based on depositional environments: Canadian Mineralogist, v. 18, p. 215–222.

Gross, G.A., 1996, Algoma-type iron-formation, in Eckstrand, O.R., Sinclair, W.D., and Thorpe, R.I., eds., Geology of Canadian mineral deposit types: Geological Survey of Canada, Geology of Canada no. 8; Geological Society of America, Decade of North American Geology v. P1, p. 66–73.

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.

Halbach, P., Pracejus, B., and Maerten, A., 1993, Geology and mineralogy of massive sulfide ores from the central Okinawa Trough, Japan: Economic Geology, v. 88, p. 2210–2225.

Hannington, M.D., de Ronde, C.E.J., and Petersen, S., 2005, Sea-floor tectonics and submarine hydrothermal systems, in Hedenquist, J.W., Thompson, J.F.H., Goldfarb, R.J., and Richards, J.P., eds., Economic geology 100th anniversary volume 1905–2005: Littleton, Colo., Society of Economic Geologists, p. 111–141.

Herzig, P.M., and Hannington, M.D., 1995, Polymetallic massive sulfides at the modern seafloor–A review: Ore Geology Reviews, v. 10, p. 95–115.

Herzig, P.M., and Hannington, M.D., 2000, Polymetallic massive sulfides and gold mineralization at mid-ocean ridges and in subduction-related environments, in Cronan, D.S., ed., Handbook of marine mineral deposits: Boca Raton, Fla., CRC Press Marine Science Series, p. 347–368.

Humphris, S.E., Herzig, P.M., Miller, D.J., Alt, J.C., Becker, K., Brown, D., Brugmann, G., Chiba, H., Fouquet, Y., Gemmell, J.B., Guerin, G., Hannington, M.D., Holm, N.G., Honnorez, J.J., Iturrino, G.J., Knott, R., Ludwig, R., Nakamura, K., Petersen, S., Reysenbach, A.L., Rona, P.A., Smith, S., Sturz, A.A., Tivey, M.K., and Zhao, X., 1995, The internal structure of an active sea-floor massive sulphide deposit: Nature, v. 377, no. 6551, p. 713–716.

Hutchinson, R.W., 1965, Genesis of Canadian massive sulphides reconsidered by comparison to Cyprus deposits: Canadian Mining and Metallurgical Bulletin, v. 58, p. 972–986.

Hutchinson, R.W., 1973, Volcanogenic sulfide deposits and their metallogenic significance: Economic Geology, v. 68, p. 1223–1246.

Hutchinson, R.W., and Searle, D.L., 1971, Stratabound pyrite deposits in Cyprus and relations to other sulphide ores: Society of Mining Geologists of Japan, Special Issue 3, p. 198–205.

Kim, J., Lee, I., Halbach, P., Lee, K.-Y., Ko, Y.-T., and Kim, K.-H., 2006, Formation of hydrothermal vents in the North Fiji Basin—Sulfur and lead isotope constraints: Chemical Geology, v. 233, p. 257–275.

Koski, R.A., Lonsdale, P.F., Shanks, W.C., III, Berndt, M.E., and Howe, S.S., 1985, Mineralogy and geochemistry of a sediment-hosted hydrothermal sulfide deposit from the Southern Trough of Guaymas Basin, Gulf of California: Journal of Geophysical Research, v. 90, p. 6695–6707.

Lambe, R.N., and Rowe, R.G., 1987, Volcanic history, mineralization, and alteration of the Crandon massive sulfide deposit, Wisconsin: Economic Geology, v. 82, p. 1204–1238.

Large, R.R., McPhie, J., Gemmell, J.B., Herrmann, W., and Davidson, G.J., 2001, The spectrum of ore deposit types, volcanic environments, alteration halos, and related exploration vectors in submarine volcanic successions: Some examples from Australia: Economic Geology, v. 96, p. 913–938.

Leach, D.L., Sangster, D.F., Kelley, K.D., Large, R.R., Garven, G., Allen, C.R., Gutzmer, J., and Walters, S., 2005, Sediment-hosted lead-zinc deposits–A global perspective, in Hedenquist, J.W., Thompson, J.F.H., Goldfarb, R.J., and Richards, J.P., eds., Economic Geology 100TH anniversary volume, p. 561–607.

Leblanc, M., and Fischer, W., 1990, Gold and platinum group elements in cobalt arsenide ores–Hydrothermal concentration from a serpentinite source-rock: Mineralogy and Petrology, v. 42, p. 197–209.

Marques, A.F.A., Barriga, F.J.A.S., and Scott, S.D., 2007, Sulfide mineralization in an ultramafic-rock hosted seafloor hydrothermal system–From serpentinization to the formation of Cu-Zn-(Co)-rich massive sulfides: Marine Geology, v. 245, p. 20–39.

Mosier, D.L., Berger, V.I., and Singer, D.A., 2009, Volcanogenic massive sulfide deposits of the world: Database and grade and tonnage models: U.S. Geological Survey Open-File Report 2009–1034, 50 p.

Mosier, D.L., and Page, N.J, 1988, Descriptive and grade-tonnage models of volcanogenic manganese deposits in oceanic environments: A modification: U.S. Geological Survey Bulletin 1811, 28 p.

Ohmoto, H., and Skinner, B.J., eds., 1983, The Kuroko and related volcanogenic massive sulfide deposits: Economic Geology Monograph 5, 604 p.

Page, N.J, 1986, Descriptive model of Limassol Forest Co-Ni, in Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 45.

Panayiotou, A., 1980, Cu-Ni-Co-Fe sulphide mineralization, Limassol Forest, Cyprus, in Panayiotou, A., ed., Ophiolites—International Ophiolite Symposium, Cyprus, 1979, Proceedings: Republic of Cyprus, Geological Survey Department, p. 102–116.

Peter, J.M., and Scott, S.D., 1988, Mineralogy, composition, and fluid-inclusion microthermometry of seafloor hydrothermal deposits in the Southern Trough of Guaymas Basin, Gulf of California: Canadian Mineralogist, v. 26, p. 567–587.

Peter, J.M., and Scott, S.D., 1999, Windy Craggy, northwestern British Columbia—The world's largest Besshi-type deposit, in Barrie, C.T., and Hannington, M.D., eds., Volcanic-associated massive sulfide deposits—Processes and examples in modern and ancient settings: Reviews in Economic Geology, v. 8, p. 261–295.

Prokin, V.A., and Buslaev, F.P., 1999, Massive copper-zinc deposits in the Urals: Ore Geology Reviews, v. 14, p. 1–69.

Rona, P.A., Hannington, M.D., Raman, C.V., Thompson, G., Tivey, M.K., Humphris, S.E., Lalou, C., and Petersen, S., 1993, Active and relict seafloor hydrothermal mineralization at the TAG hydrothermal field, Mid-Atlantic Ridge: Economic Geology, v. 88, p. 1989–2017.

Schmidt, J.M., 1986, Stratigraphic setting and mineralogy of the Arctic volcanogenic massive sulfide prospect, Ambler District, Alaska: Economic Geology, v. 81, p. 1619–1643.

Schulz, K.J., and Ayuso, R.A., 2003, Lithogeochemistry and paleotectonic setting of the Bald Mountain massive sulfide deposit, northern Maine, in Goodfellow, W.D., McCutcheon, S.R., and Peter, J.M., eds., Massive sulfide deposits of the Bathurst mining camp, New Brunswick, and northern Maine: Economic Geology Monograph 11, p. 79–109.

Shanks, W.C., III, and Bischoff, J.L., 1980, Geochemistry, sulfur isotope composition, and accumulation rates of Red Sea geothermal deposits: Economic Geology, v. 75, p. 445–459.

Sillitoe, R.H., Hannington, M.D., and Thompson, J.F.H., 1996, High sulfidation deposits in the volcanogenic massive sulfide environment: Economic Geology, v. 91, p. 204–212.

Steinmüller, K., Abad, N.C., and Grant, B., 2000, Volcanogenic massive sulphide deposits in Peru, in Sherlock, R.L., and Logan, M.A., eds., Volcanogenic massive sulphide deposits of Latin America: Geological Association of Canada Special Publication No. 2, p. 423–437.

Stephens, M.B., Swinden, H.S., and Slack, J.F., 1984, Correlation of massive sulfide deposits in the Appalachian-Caledonian orogen on the basis of paleotectonic setting: Economic Geology, v. 79, p. 1442–1478.

Tornos, F., 2006, Environment of formation and styles of volcanogenic massive sulfides–The Iberian Pyrite Belt: Ore Geology Reviews, v. 28, p. 259–307.

Upadhyay, H.D., and Strong, D.F., 1973, Geological setting of the Betts Cove copper deposits, Newfoundland—An example of ophiolite sulfide mineralization: Economic Geology, v. 68, p. 161–167.

Wright, I.C., de Ronde, C.E.J., Faure, K., and Gamble, J.A., 1998, Discovery of hydrothermal sulfide mineralization from southern Kermadec arc volcanoes (SW Pacific): Earth and Planetary Science Letters, v. 164, p. 335–343.

Zierenberg, R.A., Koski, R.A., Morton, J.L., Bouse, R.M., and Shanks, W.C., III, 1993, Genesis of massive sulfide deposits on a sediment-covered spreading center, Escanaba trough, southern Gorda Ridge: Economic Geology, v. 88, p. 2069–2098.

Zierenberg, R.A., Shanks, W.C., III, Seyfried, W.E., Jr., Koski, R.A., and Strickler, M.D., 1988, Mineralization, alteration, and hydrothermal metamorphism of the ophiolite-hosted Turner-Albright sulfide deposit, southwestern Oregon: Journal of Geophysical Research, v. 93, p. 4657–4674.