9. Hypogene Gangue Characteristics

By John F. Slack

Volcanogenic Massive Sulfide Occurrence Model

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Contents

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Mineralogy

All nonsulfide components of VMS deposits are generally considered to be gangue. In this section, discussion is limited to hypogene gangue minerals that occur within sulfide ore and sulfide-rich wall rocks, excluding occurrences in surrounding alteration zones. Minerals within this gangue category vary greatly depending on several factors including metamorphic grade, age, and geologic setting of the deposits (see Lydon, 1984; Franklin, 1993; Franklin and others, 2005). For deposits that occur at or below lower greenschist facies, the hypogene gangue may consist of quartz, carbonate, barite, white mica, and (or) chlorite, together with lesser amounts of magnetite, sodic plagioclase, epidote, tourmaline, analcime, and montmorillonite; fluorite, celsian, hyalophane; greenalite, stilpnomelane, hematite, anhydrite, and gypsum may be present locally. At higher metamorphic grades, chloritoid, garnet, amphibole, cordierite, gahnite, staurolite, kyanite, and andalusite are common gangue constituents, with minor rutile and (or) titanite occurring in places.

Ages of VMS deposits are linked broadly to the presence or absence of some gangue minerals. Notable among these is barite, which occurs in several Archean orebodies (Reynolds and others, 1975; Vearncombe and others, 1995; Li and others, 2004) but typically is absent in younger Precambrian deposits (for example, Franklin and others, 2005). Barite is relatively common in Phanerozoic deposits that contain abundant felsic volcanic rocks in footwall sequences, owing to generally high Ba concentrations in K-feldspar within such lithologies and their availability for leaching of this Ba by deeply circulating hydrothermal fluids. Anhydrite and gypsum occur in some weakly metamorphosed deposits, such as the Miocene Kuroko orebodies in Japan (Ogawa and others, 2007), but are generally unknown in more metamorphosed older deposits, mainly because of the retrograde solubility of anhydrite and its ease of dissolution by later fluids (see Hannington and others, 1995).

Mineral Assemblages

Assemblages of gangue minerals in VMS deposits vary widely as a function of several parameters such as fluid composition, fluid/rock ratio, P–T history, and postore recrystallization. In the sulfide-rich zones of greenschist-facies deposits, common assemblages are quartz + chlorite + sericite ± carbonate ± barite ± albite; more strongly metamorphosed deposits may contain quartz + garnet + amphibole ± rutile as typical assemblages.

Paragenesis

The original hydrothermal paragenesis of gangue minerals is generally impossible to discern owing to postdepositional deformation and metamorphism. However, some well-preserved VMS deposits, at or below lower greenschist facies with minimal penetrative deformation, reveal apparently primary sequences of gangue mineralization. In the Ordovician Bald Mountain deposit in Maine, seven stages of mineralization have been recognized: early massive pyritic sulfide; massive pyrrhotite; vein quartz; massive pyrite, magnetite, and Fe-silicates; quartz-siderite-sulfide veins; and two sets of late quartz ± sulfide veins (Slack and others, 2003). Some VMS deposits of Silurian or Devonian age in the southern Urals of Russia preserve primary paragenetic relationships (Herrington and others, 2005). Gangue minerals in footwall feeder zones also may retain a premetamorphic paragenesis, such as at the Archean Kidd Creek deposit in Ontario (Slack and Coad, 1989; Hannington and others, 1999) and the Cambrian Hellyer deposit in Tasmania (Gemmell and Large, 1992). At the Archean Mons Cupri deposit in Western Australia, carbonate gangue occurs both in early and late assemblages, bracketing in time the deposition of semimassive sulfide (Huston, 2006).

Zoning Patterns

Mineralogical zoning is recognized in many VMS deposits (see Lydon, 1984, 1996; Franklin and others, 2005). Zoning of sulfide minerals is well documented, but gangue mineral zoning (excluding in exhalites) is seldom discussed. A few generalizations nevertheless can be made. First, in well-preserved Phanerozoic deposits, the gangue in cores of sulfide mounds is predominantly quartz, whereas the margins locally contain abundant barite and (or) anhydrite (Large, 1992; Galley and others, 2007). Chlorite and white mica may be concentrated in the lower or upper parts of sulfide mounds.

Carbonate minerals tend to be widely distributed, but in some deposits such as Ruttan in Manitoba occur preferentially in the stratigraphically higher parts of the sulfide zone (Barrie and others, 2005).

Grain Size

Gangue minerals show a range of grain sizes depending on the extent of post-depositional processes such as subsurface zone refining and metamorphic recrystallization. Typically, gangue minerals are less than 1 mm in maximum dimension. Although grain sizes typically are larger in more strongly deformed and metamorphosed VMS deposits, some ancient deposits below greenschist facies may contain gangue minerals as much as several centimeters in size. Much coarser grains are well documented in amphibolite- and granulite-facies deposits, where equant minerals like garnet and cordierite may be 5–8 cm in diameter, and prismatic minerals like amphibole and kyanite can be tens of centimeters long.

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