

GEOLOGICAL SETTING AND STRUCTURAL STYLES OF VOLCANIC MASSIVE SULFIDE DEPOSITS IN THE NORTHERN APENNINES (ITALY): EVIDENCE FOR SEAFLOOR AND SUB-SEAFLOOR HYDROTHERMAL ACTIVITY IN UNCONVENTIONAL OPHIOLITES OF THE MESOZOIC TETHYS

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ABSTRACT

This paper is an overview of the geological setting and structural styles of Cu-sulfide deposits of the VMS-type, associated with Tethyan ophiolites (the Ligurides) in the northern Apennines (Italy). The Italian deposits represent a rare example of VMS associated with both the mantle-peridotite basement and the overlying volcanic pile, within a single ophiolite sequence. This peculiar feature is due to the particular geodynamic evolution of the Mesozoic Ligurian ocean that allowed the upper mantle to be exposed on the seafloor for a long period before the outflow of MORB-type lava and the deposition of pelagic sediments (cherts, Palombini shales and Calpionella limestones). Middle to Upper Jurassic uprising of the basaltic magma initially provided the heat source for convective circulation of hy-

drothermal fluids through the overlying mantle section, giving rise to sulfide deposition in crosscutting stockwork veins and seafloor-stratiform ore bodies within the serpentinized mantle peridotite and the serpentinite breccia formed by submarine erosion of the upper mantle. The setting and structure of VMS associated with the volcanic pile indicate that hydrothermal activity continued during and after the eruption of pillow basalts at the ocean floor, forming stockwork veins and conformable stratiform ore bodies within the basalt unit. Furthermore, hydrothermal activity formed seafloor-stratiform deposits, at the top of the volcanic pile,

covered with a thick horizon of cherts containing exhalative deposits of Mn.

MINERALS OF AU, AG AND U IN VOLCANIC-ROCK-ASSOCIATED MASSIVE SULFIDE DEPOSITS OF THE NORTHERN APENNINE OPHIOLITE, ITALY

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ABSTRACT

Ore samples from five copper sulfide deposits associated with Jurassic ophiolites in the Northern Apennine belt of Italy were found to contain gold, acanthite or argentite (Ag₂S), and freibergite (Ag,Cu,Fe)₁₂(Sb,As)₄S₁₃. These precious-metal minerals are part of a complex assemblage of microscopic to submicroscopic (<10 mm) accessory phases, including uraninite, barite, galena, smithsonite, siderite, a La–Ce carbonate and a Sn hydroxide, attributable to the rare mineral hydroromarchite Sn₃O₂(OH)₂. The textures of the sulfide host are indicative of metal deposition in a range of conditions, involving initial precipitation from hot, metal-charged solutions (syngensis), followed by post-depositional replacement of biological material and resedimentation of clasts, at low temperature (epigenesis). Syngenetic gold is Ag-rich and associated with uraninite in Fe–Cu-rich ore. The fineness of native gold increases by

loss of Ag into secondary Ag₂S during seafloor weathering of the sulfides. Freibergite forms during recrystallization of sphalerite in massive Zn–Fe ore. Hydroromarchite occurs in massive Zn–Fe ore, closely related with late deposition of siderite and secondary pyrite, possibly due to the action of neutral to basic and reducing waters flushing through the ore in the initial stages of seafloor diagenesis. The widespread evidence for seafloor resedimentation and for biogenic-activity-driven reworking of the sulfides suggests a transition from proximal VMS to a more distal type of deposit formed by resedimentation processes in a dynamic tectonic environment. This scenario seems to be consistent with the interpretation of the Jurassic Ligurian ocean as a narrow basin in the early stage of its opening, having its modern analogue in the Red Sea.

MINERALOGY AND CHEMICAL COMPOSITION OF VMS DEPOSITS OF NORTHERN APENNINE OPHIOLITES, ITALY: EVIDENCE FOR THE INFLUENCE OF COUNTRY ROCK TYPE ON ORE COMPOSITION

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ABSTRACT

In the ophiolites of the Italian northern Apennines, mantle rocks were exposed on the seafloor and eroded prior to the extrusion of pillow basalt and the deposition of pelagic sediments. Various types of VMS deposits occur at different stratigraphic positions in the ophiolite sequence. Stockwork-vein and seafloor-stratiform ore bodies are associated with serpentinitized mantle peridotite and serpentinite breccia. A second group of sulfide deposits consist of crosscutting stockwork or conformable stratabound ore bodies emplaced into the pillow basalt, and seafloor-stratiform deposits located at the top of the volcanic pile, in contact with the sedimentary cover. Geochemical and mineralogical differences are observed in the ore and gangue assemblages of the deposits that were formed before the outflow of pillow basalt, and those precipitated during and after basalt extrusion. Compared with basalt-hosted sulfide deposits, the ores associated with serpentinite have a higher Cu/Zn ratio due to a

low modal proportion of sphalerite and are enriched in the compatible elements Ni, Cr, and Mg. The Co and Ni of the ores reflect those of pyrite. The Co/Ni ratios of pyrite range from 0.29 to 1.79 (av.=0.74) in serpentinite-hosted deposits and from 1.09 to 8.0 (av.=2.59) in basalt-hosted deposits. The composition of chlorite varies from Cr-rich, Mg-clinocllore, in serpentinite-hosted deposits, to Fe-clinocllore with relatively high Mn contents, in basalt-hosted deposits. The sulfides in serpentinite contain accessory chromite that is compositionally similar to chromian spinels from abyssal peridotites. The observed geochemical variations among the various ore types are due to the interaction of the oreforming fluids with different types of country rock (ultramafic vs. mafic), which involves hydrothermal leaching of metals from the substrate, rock-fluid reactions at the site of ore deposition and the mechanical transfer of detrital material from the country rock to the ore forming-system.

INVESTIGATION OF DATOLITE ($\text{CaB}[\text{SiO}_4/(\text{OH})]$) FROM BASALTS IN THE NORTHERN APENNINES OPHIOLITES (ITALY): GENETIC IMPLICATIONS

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ABSTRACT

Datolite, ideally $\text{CaB}[(\text{OH}/\text{SiO}_4)]$, from hydrothermal veins crosscutting pillow basalt in 10 different localities of the Northern Apennine ophiolites was investigated with regard to mineral chemistry and fluid inclusion microthermometry. Bulk analyses of datolite crystals show REE contents below chondritic, except for La and Ce. With respect to host rock, datolite is occasionally enriched in La, Rb, Cs, Be, and shows relatively high contents of chalcophile elements (Cu, Zn, Pb, Ni) when occurring in contact with sulfide-mineralized basalt. Volatiles escaped during the decomposition in the temperature range 600 and 700 C. The main component is water. The temperature maximum of water release is different and frequently with a shoulder or a second maximum. Together with water, sulfur species as H_2S and SO_2 and traces of boron species escaped. The CO_2 release by the decomposition especially of datolite from Castellaro and Cinghi has a maximum in the range of

500–580 C and is different from the decomposition of calcite. Together with CO_2 a boron species escaped. Chlorine does not detect. Two-phase (L+V) fluid inclusions texturally identifiable as primary and secondary were observed, yielding average homogenization-temperatures of 236 and 173 C, respectively. Fluid inclusion cooling data yield calculated salinity in the range of 10–16wt% NaCl equivalents, thus relatively higher compared with seawater. The results are compatible with those reported for fluids formed under diagenetic conditions, but differ from those observed in seafloor hydrothermal systems and/or emanating from magmas. Distribution of trace elements between datolite and host basalt indicates enrichment with respect to the host rock limited to a few elements such as La, Rb, Cs, Be, Ni, Cu, Zn and Pb. The lithophile elements can be hosted in the datolite lattice, whereas the chalcophile metals and Ni are probably carried in sub-microscopic inclusions.