HYDROTHERMAL MINERALIZATION AT SEAFLOOR SPREADING CENTERS: ATLANTIC OCEAN AND INDIAN OCEAN

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Hydrothermal mineral deposits including polymetallic (Cu, Fe, Pb, Zn; associated Ag, Au) sulfides are formed by precipitation from hot aqueous (hydrothermal) solutions that convect through seafloor spreading centers driven by volcanogenic heat sources. Approximately 50 sites of hydrothermal mineral deposits including polymetallic sulfides are presently known along the approximately 54,000 km length of the globe-encircling system of oceanic ridges and rifts that extend through all the major ocean basins as seafloor spreading centers. The form of the deposits is closely related to their geologic setting. Stratiform sulfide bodies may form under conditions of restricted oceanic circulation at an early stage of opening of an ocean basin about a slow-spreading center, exemplified by deposits in basins of the Red Sea. Disseminated and stockwork sulfides may form beneath the seafloor where hot (350°), acidic, reducing primary hydrothermal solutions mix with cold, alkaline, oxidizing normal seawater that penetrates downward through fractures in the oceanic crust, exemplified by deposits beneath the slow-spreading Mid-Atlantic Ridge. Massive sulfide deposits may form on the seafloor where primary hydrothermal solutions discharge directly from vents into normal seawater, exemplified by deposits near the axis of the fast-spreading East Pacific Rise.

Nearly two-thirds of the 54,000 km length of the globe-encircling system of oceanic ridges and rifts are slow-spreading (half-rate $\leq$ 2 cm/yr) and are located in the Atlantic Ocean and Indian Ocean (Fig. 1). Systematic investigations for hydrothermal mineralization were performed along 1800 km-long portions of the Mid-Atlantic Ridge (MAR) crest between latitude 10° and 27°N in the central North Atlantic, and the Carlsberg Ridge (CR) crest between latitude 5°S and 10°N in the northwest Indian Ocean. Criteria developed and applied to locate hydrothermal mineralization include characteristic seafloor morphology, definitive magnetic signature, composition and mineralogy of sediments and rocks, and certain water properties (^{3}He; near-bottom water temperature). The two slow-spreading oceanic ridges investigated exhibit a segmented structure with linear sections of rift valley alternating with ridge-ridge transform faults at an average spacing of 75 km. The investigations revealed hydrothermal mineral deposits that were concentrated by high-intensity hydrothermal activity at localized sites of anomalously high thermal gradients and permeabilities within tectonic settings related to the segmented structure of the ridges as follows: (1) The wall along linear sections of the rift valley where normal faults act as conduits for deep-seated, long-lived hydrothermal activity, with deposition of disseminated, stockwork, and possibly massive polymetallic sulfides inferred beneath the seafloor as a consequence of subsurface mixing of high-temperature hydrothermal solutions with normal seawater, deposition of Fe-Mn oxides, hydroxides and silicates as layered bodies at the basalt/seawater interface, and precipitation of ferric hydroxide particles from the discharging solution reduced in temperature and depleted in metals; examples are the TAG Hydrothermal Field and five additional candidate sites identified along the MAR. (2) The intersection of the rift valley with ridge-ridge transform faults where thinning of oceanic crust and faulting has exposed disseminated and stockwork Cu-Fe sulfides; examples occur in the Vema and Romanche fracture zones of the MAR and the Vityaz fracture zone of the CR. (3) The axial zone of the rift valley constitutes an inadequately explored province with the possibility for the occurrence of massive sulfides. Evidence presented indicates that extensive hydrothermal mineralization occurs on slow-spreading oceanic ridges but, unlike that on intermediate- to fast-spreading ridges in the Pacific Ocean, the bulk of the high-temperature mineralization occurs beneath the seafloor.

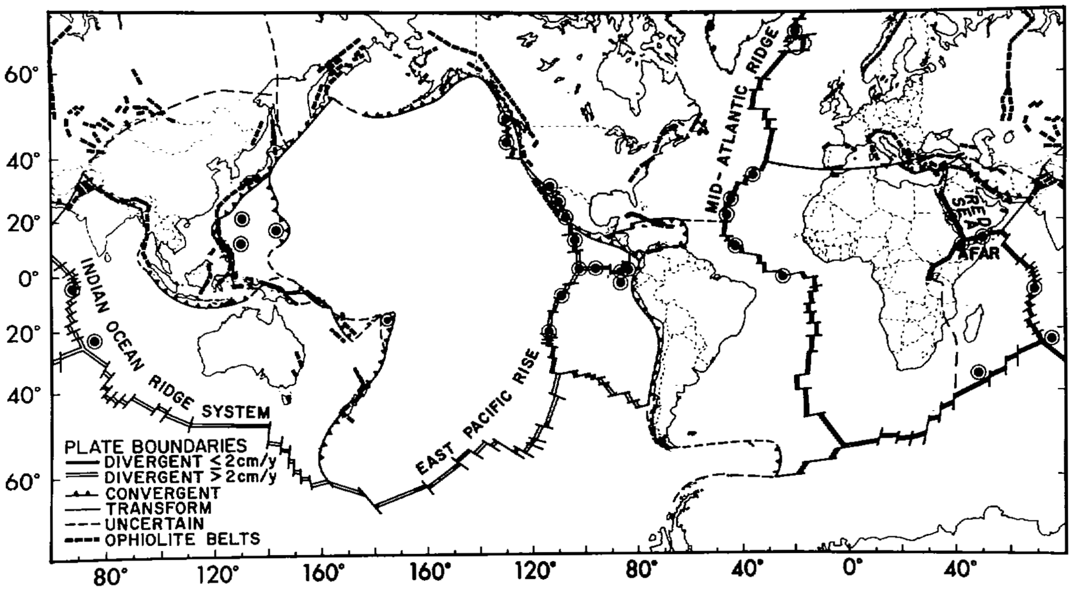

Fig. 1: World map showing boundaries of lithospheric plates (divergent plate boundaries are seafloor spreading centers), locations of known hydrothermal deposits (dots) at seafloor spreading centers, and belts of oceanic crust exposed on land (ophiolites) (from Rona, 1982, MTS Journal, v. 16, No. 3).

