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Temporal and Spatial Evolution of Hydrothermal Deposits at the Maru Vent Field, Central Indian Ridge

SUN KI CHOI[1], JONGUK KIM[1], WONNYON KIM[1] AND RYOUNG GYUN KIM[1,2]

[1]Korea Institute of Ocean Science & Technology
[2]Pukyong National University

The Maru Vent Field (MVF), recently discovered on the western flank of an oceanic core complex at 15.3°S on the Central Indian Ridge, hosts H_2-rich, high-temperature (up to 316.7 °C) black smoker vents that produce Cu–(Zn–Co–Sn)-rich sulfide chimneys and mounds. Surrounding these active vents, clusters of inactive Fe–(Mo)-rich chimneys represent relict structures from an earlier phase of hydrothermal activity, likely formed by lower-temperature fluids. The contrasting mineralization styles indicate a temporal transition from an initial Fe-rich stage to the currently active Cu-rich mineralization. This multi-stage evolution is further evidenced by alternating Fe- and Cu-rich layers within chimney talus collected at the base of the mound. Additionally, a sediment core recovered 26 m from an active vent provides insights into post-depositional modifications of hydrothermal precipitates. The fine-grained metalliferous sediments exhibit metal concentrations comparable to those of active sulfide deposits, with systematic depth-dependent variations reflecting contributions from hydrothermal plume fallout and mass-wasting of sulfide debris during ongoing high-temperature venting.

In situ LA–ICP–MS analyses of sulfide minerals from chimneys, mounds, and metalliferous sediments reveal that trace element distributions are primarily controlled by physicochemical gradients in fluid conditions (temperature, fO_2, and fS_2) and seawater influx. The $\delta^{34}S$ values of sulfide separates vary significantly (+4.5 to +14.0‰), with notably higher values in Fe–(Mo)-rich chimneys and Fe-rich layers within chimney talus (+11.3 ± 2.1‰) compared to Cu–(Zn–Co–Sn)-rich chimneys and mounds (4.6 ± 0.1‰). These isotopic signatures suggest a greater influence of thermochemical sulfate reduction of seawater-derived sulfate during Fe-rich mineralization. Combined, the geochemical evidence indicates episodic shifts in fluid chemistry and venting conditions throughout the dynamic evolution of the MVF.

Our findings demonstrate a genetic link between chimney growth, structural collapse, and hydrothermal reworking, which collectively drive mound development through the progressive accumulation of sulfide precipitates. The mass-wasting of sulfide materials and subsequent seawater-induced alteration further redistribute metals, modifying the geochemical characteristics of the MVF. This study highlights the complex interplay between multi-stage hydrothermal mineralization and post-depositional processes, which together shape the long-term evolution of seafloor sulfide deposits at slow-spreading mid-ocean ridges.