The Shale-hosted Las Cruces VMS, Iberian Pyrite Belt, Spain: Not a Brine Pool Deposit

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Las Cruces is a shale-hosted volcanogenic massive sulfide (VMS) deposit located in the southeast Iberian Pyrite Belt, Spain. The pre-mining resource (M+I) included 38.9 Mt of hypogene ore at 1.3% Cu, 1.2% Pb, 2.5% Zn, and 30.6 g/t Ag; and 14.2 Mt of supergene ore at 5.7% Cu. Previous studies concluded shale-hosted VMS deposits in the Iberian Pyrite Belt, including Las Cruces, formed via exhalation of saline, sulfur-deficient, metal-bearing hydrothermal fluids into the sea. These fluids were considered immiscible in seawater, and to have ponded in bathymetric lows forming reduced and acidic brine pools from which metal sulfide minerals precipitated.

Footwall rocks at Las Cruces are andesites and basalts that comprised a submarine caldera, overlain by a shale unit that thins over the volcanic edifice. A dense sulfide vein stockwork is present in the volcanic rocks and the shales. The shales also contain stacked, bedding-parallel, massive sulfide lenses concentrated in a middle, organic-rich sub-unit. Distal shales contain pyrite nodules with strongly negative $\delta^{34}S$ values indicative of bacterial sulfate reduction of seawater. Sulfide minerals within the deposit display positive $\delta^{34}S$ values, with massive sulfides averaging +6.2‰. Lithostratigraphy and palynology suggest the middle, organic-rich shale represents the ~358.9 Ma Hangenberg Mass Extinction Event. However, paleo-redox indicators including Mo, Fe/Al, and TOC all suggest conditions were weakly anoxic to oxic. Visual kerogen typing, C/N ratios, and $\delta^{13}C_{org}$ of the shale confirms mixed types of organic matter, but nitrogen stable isotopes ($\delta^{15}N$) show no evidence of abundant bio-available nitrogen venting as seen in some modern vents. None of the attributes of the shale are consistent with pockets of restricted water column circulation in a brine pool. Therefore, mineralization was most likely epigenetic with fluids derived from magmatic sulfur (~0‰) and seawater (~+20‰) in a ratio of ~2:1.