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Critical Metals in Base Metal Mineralization of the Otavi Mountain Land and the Kunene Region, Namibia

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Carbonate-hosted base metal deposits, notably those in the Otavi Mountain Land (OML) of Namibia, particularly at Khusib and Tsumeb mines, are renowned for their complex unique mineralogy rich in critical metals like Cd, Co, Ni, Ga, Ge, Mo, Se, and In. Both deposits are dominated by tennantite, galena, and associated pyrite with accessory bornite, chalcocite, enargite, chalcopyrite, and sphalerite with accessory Ag-Pb-Ge-sulfosalts. At Khusib Springs mine tennantite and chalcopyrite are the most important carriers of trace elements such as Zn, Ag, Sb, and Pb and Ag, respectively. Additionally, Khusib Springs ore reveals a diversity of Ag-bearing minerals. Conversely, Kombat mine has a similar macro-sulfide assemblage with chalcopyrite as the primary carrier of Ga, Ge, and In but negligible Ge-sulfides or complex sulfosalts and higher proportions of acanthite and molybdenite. Mineralization in the Kunene region is older than that in OML and displays significantly lower proportions of Zn-sulfides, higher proportions of Cu-sulfides, Co, Ni, and Mo. Fluid-inclusion geochemistry and mineral geothermometry indicate Kombat and Kunene mineralisation were formed at higher temperatures and from lower salinity solutions than those responsible for mineralization at Tsumeb and Khusib Springs. Geochemical data reveal a positive correlation occurs between Cd, Ga, Ge, In, and Zn concentrations and between Ag, Mo. An antipathetic relationship may occur between Co and Ga and Ge. Reconnaissance Zn isotope data (–0.19 to 0.14‰) delineate Tsumeb ore as typical Zn-rich massive sulfide ore, with values overlapping with Irish MVT deposits (–0.17 to 1.33‰). Cu isotopes are comparable to isotopic data of hypogene mineralisation for Tsumeb ore, and a potential magmatic source as well as a hydrothermal fluid for Kunene mineralisation. These variations reflect differences in fluid sources, temperatures of hydrothermal fluids, and multi-mineralisation events, with implications for exploration targeting different critical metals based on their relationships with major metals or mineralogy.