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Thesis Title: Origin and geochemical evolution of the metamorphosed SEDEX Zn-Pb deposit at Kayad, western India: constraints from texture, hydrothermal alteration, major and trace element geochemistry and stable isotope systematics.

Abstract:

Sedimentary exhalative (SEDEX) deposits belong to an intriguing and important class of sediment-hosted zinc and lead deposits that contribute approximately 50% of the world's zinc and lead resources. These stratiform to stratabound deposits are known to be formed through the exhalation of hot, metalliferous fluid from submarine vents onto the seafloor contemporaneously during sedimentation. Despite the apparently straightforward definition of its genesis, SEDEX deposits are observed to have varied mechanisms of formation in terms of source of metals and fluids, physicochemical conditions of the mineralizing fluid, and timing of mineralization with respect to the host sediments. Most SEDEX deposits are metamorphosed and deformed which variably alters the tell-a-tale geological, mineralogical and geochemical signature of the deposits and thereby pose challenges in interpreting their origins. The present work integrates field relations, mineralogy, texture, sulfide geochemistry, and sulfur and boron isotope systematics to address some of the key issues of SEDEX mineralization, using Kayad Zn-Pb deposit in Aravalli Delhi fold belt (ADFB), western India as a case study.

The ADFB is home to some of the oldest and richest Pb-Zn deposits in the world that are confined in the Bhilwara belt (Rajpura-Dariba, Rampura-Agucha etc.) and in the Aravalli belt (Zawar). The Kayad Zn-Pb deposit near Ajmer in Rajasthan is a part of the Ghugra-Kayad mineralized belt of the North Delhi fold belt. Based on morphology, mineralogy and textural attributes, three different styles of sulfide mineralization are recognized: i) a *laminated/disseminated* type where sphalerite and pyrrhotite, with minor galena and chalcopyrite occur as lamina/bands parallel to the schistosity of quartz mica schist, and as disseminations in quartzite, ii) a *massive* type consisting of sphalerite, galena, pyrrhotite, chalcopyrite and arsenopyrite which occur in large masses disrupting and replacing the general foliation of the schists and accumulating primarily at the fold hinge, iii) a *vein-hosted* type represented by pyrrhotite + chalcopyrite ± sphalerite ± galena in pegmatites, and sphalerite + galena ± chalcopyrite ± pyrrhotite in K-feldspar and quartz veins.

Based on mode of occurrence and mineralogy, the laminated/disseminated sulfide ores are interpreted to represent the original syn-sedimentary/diagenetic SEDEX mineralization in the area. On the other hand, several lines of evidences suggest that the massive high-grade ores and the vein-hosted ores are the products of remobilization of the existing SEDEX ores. Presence of durchbewegung texture, accumulation and attenuation of ores at the fold hinge and the limb respectively, and piercement veins suggest that syn-metamorphic plastic flow played important role in the formation of massive ores. Furthermore, very low dihedral angles between sphalerite and galena wherein galena displays cusps and carries texture in tandem with locally preserved re-equilibrated melt textures indicate remobilization through sulfide melting also played significant role in the formation of massive ores. The massive ores are enriched in low melting chalcophile elements (LMCEs) such as Ag, Sb, As, Bi, Tl, and Se, evidenced by ubiquitous intergrowths of sulfides with sulfosalts such as Ag-bearing tetrahedrite, gudmundite, pyrargyrite, breithauptite, inclusions and exsolutions of sulfosalts in sulfides and high

concentrations of LMCEs in the sulfide minerals. The LMCEs facilitated sulfide melting by lowering the melting temperature and in turn were fractionated in the massive ores. The Fe-Cu dominant mineralization associated with pegmatite show pervasive replacement of pegmatitic plagioclase and muscovite by albite + orthoclase + chamosite + biotite ± clinochlore suggesting a K + Na + Fe metasomatism. On the other hand, microcline in Zn-Pb dominated K-feldspar rich veins is replaced by prehnite + pumpellyite + clinochlore ± fluorite suggesting overprinting of K-metasomatism by a later Na + Ca metasomatism.

Major and trace element compositions of tourmaline (dravitic composition, oxydravite compositional trends, enrichment in Ti, V, Cr, depletion in granitophile elements, and strongly positive Eu anomaly), negative $\delta^{11}B$ of tourmaline (-13‰ to -10.7‰; avg. -11.8±0.7 ‰) in conjunction with highly positive $\delta^{34}S$ (+4.3 ‰ to 11.3‰) of sulfide precludes involvement of marine fluids and suggests fluids derived from continental evaporite were responsible for the SEDEX mineralization. Sulfide precipitation occurred via thermochemical sulfate reduction of sulfate as suggested by positive $\delta^{34}S$ and minor deviation of $\Delta^{33}S$ and $\Delta^{36}S$ from mass dependent fractionation line. Similarity of $\delta^{34}S$ values of massive and vein-hosted ore with the laminated SEDEX ore implies that the sulfur from the original SEDEX mineralization was recycled and remobilized to form the massive and the vein-type ores. Tourmalines associated with pegmatite-hosted Fe-Cu mineralization, connote magmatic/magmatic-hydrothermal origin based on its Fe-rich schorl nature, Al-Fe-Mg composition and lightest $\delta^{11}B$ value of -13.1‰ to -15.2 ‰. Tourmaline associated with K-feldspar vein-hosted Zn-Pb mineralization occurs as outsized clots of dravite having major and trace element compositions similar to SEDEX tourmaline and boron isotope compositions intermediate between SEDEX tourmaline and pegmatitic tourmaline. Based on these observations and similar alteration types of pegmatite-hosted Fe-Cu and K-feldspar vein-hosted Zn-Pb mineralization, it is proposed that the magmatic fluid responsible for pegmatite-hosted Fe-Cu mineralization also recycled boron, sulfur and metals from existing SEDEX mineralization and locally formed fluid-mediated remobilized Zn-Pb mineralization. In summary, the Kayad laminated/disseminated Zn-Pb deposit initially formed by thermochemical reduction of sulfate-rich fluids derived from the dissolution of continental evaporites in euxinic basins in the North Delhi fold belt. During regional deformation and metamorphism, the Zn-Pb ores were remobilized primarily via mechanical transport and partial melting and subordinately by hydrothermal fluids forming the massive mineable ore lodes. The mobilizing fluids were derived from a magmatic source that recycled ore constituents from existing SEDEX ores to form vein-type mineralization associated with hydrothermal alteration.

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