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Mode of occurrences and geochemistry of amphibole in the Kolihan-Chandmari copper deposits, Rajasthan, India: insight into the ore-forming process

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ABSTRACT

The Proterozoic Aravalli-Delhi Fold Belt in western India hosts some of the most important base metal sulfide deposits in the country, among which the Khetri group of deposits, North Delhi Fold Belt, is well known for its huge Cu repository. Copper mineralization in the Kolihan-Chandmari deposit, North Khetri Copper Belt, is hosted mainly by amphibole-bearing feldspathic quartzite and garnetiferous chlorite schist/quartzite. This study deals with mode of occurrences, textures and major and trace element geochemistry of amphiboles in amphibole-bearing feldspathic quartzite and their ore-genetic implications. Optically and geochemically different amphiboles, namely colorless A_1, green A_2 and blue A_3, occur in these deposits. While the A_1 amphiboles belong to Fe-Mg-Mn group (cummingtonite-grunerite), the A_2 (magnesio-ferri-hornblende) and A_3 (hastingsite, sadanagaite, tschermakite) amphiboles mostly belong to calcic group. The A_1 amphiboles commonly occur as disseminated grains and clusters of grains while the A_2 and A_3 amphiboles occur mostly as veins and pockets. Amphiboles in the veins and pockets are generally randomly oriented, commonly with radial arrangement of the grains, implying a late-/post-deformation origin. Based on mode of occurrences and mineral replacement textures, the relative timing of formation is established as $A_1 \rightarrow A_2 \rightarrow A_3$, A_1 being the oldest. The A_1 amphiboles may be metamorphic or hydrothermal in origin. However, the A_2 and A_3 amphiboles are entirely epigenetic hydrothermal in origin. Textural and geochemical characteristics demonstrate that the Na-Ca-poor, Fe-Mg-Mn-bearing A_1 amphiboles were replaced by the Ca-rich A_2 amphiboles, both of which in turn were replaced by the Na-Ca-K-Cl-rich A_3 amphiboles. This is evidence of Fe (-Mg) metasomatism followed by Ca-Na and finally by Na-K (-Ca) metasomatism. Based on their high Cl and Na contents and ubiquitous association with Cl-rich marialitic scapolite (in contrast to A_1 and A_2 amphiboles), the A_3 amphiboles are proposed to have crystallized from a hydrothermal fluid with a significant evaporite or basinal brine component. Calculated Fe^{3+} contents and Eu and Ce anomalies collectively indicate that the fluid parental to the A_3 amphiboles was more oxidized compared to those related to the other two amphibole types. Sulfide mineralization, represented by chalcopyrite-pyrrhotite-magnetite-pyrite ± uraninite ± allanite, is associated only with this alkali and Cl-rich hydrothermal A_3 amphibole veins and pockets. The mode of occurrences, mineralogy of the host rock and the mineralized veins in tandem with the geochemisty of amphibole suggests that the mineralization associated with the A_3 amphiboles is the consequence of epigenetic hydrothermal mineralization from a Na-K-Cl-rich fluid. Copper was likely transported as Cu-chloride complexes and precipitated as Cu-sulfide due to destabilization of chloride complexes during precipitation of Cl-rich amphibole and Cl-rich marialitic scapolite. The A_3 amphiboles, associated with sulfide mineralization, are characteristically enriched in Cu, Ni and most other trace elements compared to the A_1 and A_2 amphiboles. This study thus suggests that the major and trace element compositions of amphibole can be used in differentiating mineralized vs. non-mineralized systems. Involvement of high salinity oxidized brine in mineralization, abundant Na-K (-Ca) alteration, ubiquitous presence of magnetite in the ores, and other circumstantial evidence indicate that the epigenetic hydrothermal sulfide mineralization associated with the A_3 amphibole veins and pockets in the Kolihan-Chandmari deposits has many characters akin to iron oxide copper gold (IOCG) style mineralization.

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1. Introduction

There are several base metal sulfide deposits in the Proterozoic Aravalli-Delhi fold belt in western India. While in most deposits, Pb and Zn are recovered as the main commodities, Cu is the main commodity in the Khetri group of deposits, located in the northern part of the fold belt (Sarkar and Gupta, 2012 and references therein). The origin of the Cu deposits in the Khetri Cu-belt is controversial. Sarkar and Dasgupta (1980) proposed that the ores were initially deposited by sedimentary-diagenetic process and were subsequently modified during deformation and metamorphism presumably involving mobilization. They did not entirely reject the involvement of an exhalative component. Das Gupta (1974) proposed a dual mode of origin; an initial syngenetic mineralization followed by subsequent mobilization. While these models advocate a major syn-genetic, syn-sedimentary component, likely with later fluid-mediated mobilization, Roy Chowdhury and Das Gupta (1965), Banerjee (1976), and Knight et al. (2002) suggested entirely epigenetic hydrothermal origin of these deposits. In all these models, it is apparent that fluid played important role in mineralization, mobilization or both. However, none of these studies have described in details the nature and source(s) of the hydrothermal fluid(s) and its/their physico-chemical-temporal evolution. Deciphering the source(s) of the fluid(s) and the progressive evolution of its/their chemistry is crucial for understanding the source-transport-sink possibilities of mineralization that involve hydrothermal fluid in one way or the other.

This study is conducted in and around the Kolihan-Chandmari deposits of the North Khetri Copper Belt. One of the important host rocks for copper mineralization in the study area is amphibole-bearing feldspathic quartzite containing ubiquitous amphibole (this study; Roy Chowdhury and Das Gupta, 1965; Sarkar and Dasgupta, 1980; Knight et al., 2002; Chen et al., 2015). However, there is no detailed investigation on the mode of occurrence, texture, and geochemistry of amphibole from these deposits. The general formula of amphibole is $AB_2C_5T_8O_{22}W_2$, where A = □, Na, K, Ca, Pb, Li; B = Na, Ca, Mn^{2+}, Fe^{2+}, Mg, Li; C = Mg, Fe^{2+}, Mn^{2+}, Zn, Ni^{2+}, Co^{2+}, Fe^{3+}, Mn^{3+}, V^{3+}, Sc, Al, Ti, Zr, Li; T = Si, Al, Ti, Be; W = (OH), F, Cl, O^{2-} (Hawthorne et al., 2012). It is evident from the formula that amphibole can incorporate a variety of cations, including some common ore metal ions, and anions depending on the physical and chemical environment they crystallize

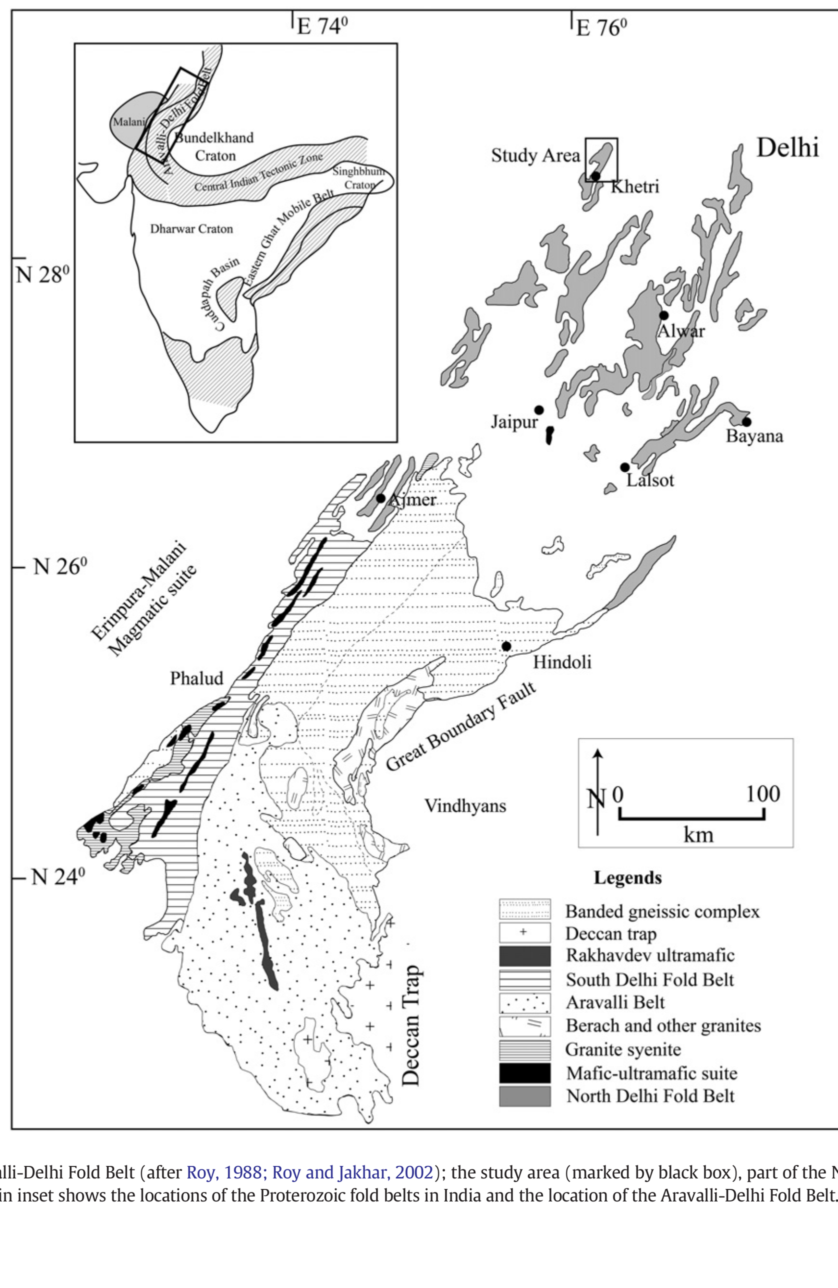

Fig. 1. Geological map of the Aravalli-Delhi Fold Belt (after Roy, 1988; Roy and Jakhar, 2002); the study area (marked by black box), part of the North Delhi Fold Belt, is located in the northeastern part of the belt. Map in inset shows the locations of the Proterozoic fold belts in India and the location of the Aravalli-Delhi Fold Belt.