Abstract

The Malanjkhand granitoid complex dominantly comprises a coarse grained hornblende and biotite bearing granodiorite displaying variations in proportions of modal QAP (quartz - alkali feldspar – plagioclase) from granite to tonalite. The complex has been studied in an area of ~300 Km^2 around a copper-molybdenum deposit of (1.8 x 0.8 Km^2) area, nearly centrally located in the complex. The granitoid within the area of study is dominantly gray, coarse grained, often faintly gneissose, whereas in the mine pit it is pink, and coarse grained, visibly enriched in K-feldspar. The mine pit pink granitoid encloses a fracture controlled, arcuate or hook shaped N-S trending mineralized quartz reef of 1.8 Km strike length and 70m average width. A leucocratic medium grained granite exposed in much smaller volume occurs in one major outcrop proximal to the mineralized zone and as bands and pockets within the gray-granitoid in the area referred to as 'leucogranite' or 'microgranite' in the literature. Though the 'pink granitoid' and 'the gray granitoid' were considered as temporally equivalent sharing many commonalities in petrographic and chemical features, there were opposing views on their time relationship and implications to the genetic affinity of the deposit. Zircon dating by U-Pb method using SHRIMP RG technique furnished almost identical age of 2475 / 2476 $\pm$9 Ma ($^{207}Pb^*/^{206}Pb^*$) for the two granitoid types thus resolving the controversy, though the temporal relationship between the granitoid complex and mineralization is still under debate. The Rb-Sr dates available from earlier work for the leucogranite indicated a younger age that needs to be substantiated by better dating technique. On the basis of the new age data, the Malanjkhand granitoid complex is tentatively divided into two – Malanjkhand Granitoid Complex Phase-I (MGC-I) comprising the gray and the pink granitoids and MGC-II (leucogranite / microgranite). Petrographically, MGC-I is a coarse grained hornblende, plagioclase and biotite bearing, where quartz is also coarse grained and interstitial to other major phases. Apatite, zircon and Sphene are the minor phases. Pervasive alteration in the form of saussuritization of plagioclase, chloritic alteration and break down of hornblende to biotite + epidote ± sphene and chloritization of biotite are conspicuous. Replacement of altered plagioclase by fresh K-feldspar (microcline) is extensive in MGC-I exposed in the mine pit where intense chloritization of biotite and replacement of almost all preexisting phases by quartz is observed. This microclinization and silicification is incipient in MGC-I outside the confines of the mineralization zone. Association of opaques (magnetite, pyrite and chalcopyrite) with the altered ferromagnesian clots and chloritized biotites is consistent in MGC-I in the mine pit. The deuteric alterations, in all probabilities, have only been instrumental in redistributing silica, potash and Fe, without disturbing other major elemental species. The major elemental species largely retain the original interrelationship from which amphibole or amphibole + biotite fractionation trend is discernible. Deformation grades assigned on the basis of elementary deformation textures (EDT) in quartz, biotite and plagioclase fail to indicate any spatial regularity in deformation in MGC-I in the study area. The rare earth element distribution pattern is also presumably undisturbed, shows moderate fractionation indicating dominance of hornblende in the residue and in turn, an amphibolitic source for MGC-I. Model calculation assuming an amphibolitic source with 60 % plagioclase and 40 % hornblende and taking concentration ratios of P_2O_5 and other less incompatible elements (HREEs) indicate that MGC-I could have resulted from about 5-8 % partial melting of the source. Zircon saturation thermometry yields a

temperature of ~852 ^oC and hornblende barometry (from existing data) indicate a pressure of about 4.5 Kb. The maximum and minimum water content of the MGC-I melt has been calculated to be 2.6 to 7.8 wt %.

Mineralization in a 1.8 Km long fracture controlled quartz reef is considered unique to the Malanjkhand deposit. Distribution of mineralized quartz / quartzofeldspathic veins / stringers in the enclosing granitoid is non uniform and do not resemble stockwork. The deposit significantly lacks a zonal pattern of alteration and also does not display any zoning in metal distribution that is characteristic of almost all porphyry-copper deposits occurring in young continental arc settings. Earlier work indicated a dominantly low temperature of the ore fluid. Biotites and chlorites furnish temperatures in the range of 236 to 384 ^oC and 261 to 349 ^oC that agrees well with temperature of ore fluid deciphered earlier. Reconstruction of physicochemical environment has been attempted through chemical characterization of biotites and chlorites and consideration of mineral fluid equilibria from various sub-assemblages of magnetite, pyrite, chalcopyrite, chlorite, biotite and K-feldspar. The inferred paragenetic sequence of deposition of early magnetite and magnetite + pyrite (in presence of biotite + K-feldspar and also chlorites) changed to a chalcopyrite dominated stage (+ chlorite) with increase of fugacity of H_2S followed by decrease of temperature. This increase of fugacity of H_2S possibly was brought about by coupled redox reaction of Fe and sulfate to produce magnetite and HS^- that was an outcome of mixing of two fluids inferred earlier from fluid inclusion studies. Copper is inferred to have been transported dominantly through chloride complexing in the fluid.

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The leucogranite, with its distinctive petrographic and chemical features and suspected later emplacement, also has a difference in the characteristic of late-stage fluid compared to MGC-I. The late-stage fluid there was CO_2-bearing and also was enriched with a sulfurous species, possibly SO_4^{2-}. On the basis of proximity of the leucogranite to the mineralization zone and the chemical signature of fluid, it stands as a possible contributor to the ore fluid.

A working model of ore genesis can be formulated on the basis of new data generated and existing data on characteristics of fluid in the ore zone and MGC-I. The model visualizes that the pervasive fluid phase in MGC-I evolved to a low-temperature condition through incursion of meteoric fluid, caused the deuteric alterations, carried enough silica and potash, scavenged copper and Fe through fluid-rock interaction under subsolidus conditions and converged to the fracture zone where it continued precipitating quartz and K-feldspar. The leucogranite was possibly emplaced round about the same time and exsolved S and CO_2-rich fluid that mixed with the main component of the MGC-I derived ore fluid and triggered mineralization. This model explains the quartz reef formation, the unique style of mineralization and associated alterations elegantly. However, the model remains speculative in the absence of (i) exact age of emplacement of the leucogranite, (ii) stable isotopic signature to trace the ancestry of the fluids and (iii) precise quantitative estimates. Crude estimates of the volume of MGC-I required to contribute silica and a feasible time frame for deposition of silica in the fracture zone has been attempted taking a 1-D dissolution and diffusive transport model.