from time to time. We have estimated the ore reserves of the deposit on the basis of all diamond drill hole data, totaling 1,09,000 m in 267 holes, at various copper cut-off grades. The authors' estimates of "470 million tonnes averaging 0.9% Cu at 0.2% Cu cut-off grade" and "if mineralisation below 0.2% Cu is also taken into account, the total tonnage will be close to 900 million tonnes averaging around 0.5% Cu" are authentic figures till date. These figures will increase further if diamond drilling is undertaken below '0' mRL also, throughout entire strike length. Estimates of 600 million tonnes of 1.3% Cu grade, (Subhedar, 1986) were approximate and based on extrapolated geometry of the orebody during continued exploration stage. Worldwide bulk ore mining of porphyry copper deposits generally operates at low stripping ratio and at a grade of 0.3-0.7% Cu with associated metals like Mo, Au and Ag.

None of the earlier authors who had worked in this deposit produced any map of their own. The maps published by us involved extensive work through decades. To support the porphyry view, close observations in field, detailed core logging, mapping and continued observations of the mine workings are essential. We have supported the porphyry view only recently after intense field observations and detailed studies through decades in and around the deposit. Comments of Subhedar (1986) and Singh (1996) should not be used as conclusive evidence in characterizing the nature of the deposit.

Comments by the critics on the simple mineralogy and ore-chemistry, absence of high temperature minerals, traces of lead, similarity of mineralogy and mineral paragenesis, do not go against the porphyry view. Concentration of Cu, Mo, Au, Ag, etc and variation in Ca content are the characteristics of porphyry deposits. High abundance of Ni and less Co with other metals are conspicuously present in granitic rocks as is common in porphyry system. Sarkar et al. (1996) stated from their sulphur isotope studies that ore-fluid is similar to granite-associated copper deposit.

To support the contention that Malanjkhand deposit is not a porphyry type deposit, critics should have provided examples of a vein deposit which contains very large tonnage of around 900 Mt of 0.5% Cu grade with an average width of 200-300 m and 700 m depth (proven and mineralisation continues below -300 mRL depth also) over a known strike length of 2.6 km. Our data are based on regular observations of a deposit up to a depth of 448 mRL (130 m below valley level of 580 mRL) and more than 1,00,000 m logging of core.

Supportive Evidences for Porphyry Type

Commentators do not provide any proof that Malanjkhand is not a porphyry type deposit. On the contrary Rai and Venkatesh (1993) have described several features which are normally found in porphyry type copper deposits.

The presence of stringer type of ore in quartz veins, disseminated sulphide mineralisation associated with ferromagnesian assemblages, and quartz vein selvages in Malanjkhand deposit are indicative of porphyry type deposit. Jaireth and Sharma (1986) also concluded from their fluid inclusion studies that hydrothermal solutions were in boiling condition during deposition of quartz along with primary ore minerals and that boiling can be considered as main mechanism of copper porphyry deposit. Development of blanket of oxidation and supergene zones at Malanjkhand also favours the porphyry nature of the deposit.

Cu-Mo-Au METALLOGENY ASSOCIATED WITH PROTEROZOIC TECTONO-MAGMATISM IN MALANJKHAND PORPHYRY COPPER DISTRICT, MADHYA PRADESH by M. Bhargava and A.B. Pal. Jour. Geol. Soc. India, v.56(4), pp.395-414.

Rajesh K. Vishwakarma, Investigation Division, NMDC Ltd., Masab Tank, Hyderabad - 500 028 comments:

The study of Bhargava and Pal incorporates a detailed account of the geology of the Malanjkhand Cu-Mo-Au deposit and review of porphyry deposits. But, there are some contradictory statements while proposing genetic model, and many facts, which are enumerated in the following pages have not been given due cognizance. As a result it reminds us of an opinion by Panigrahi and Mookherjee (1997) that the ultimate origin of ore fluid is speculative due to absence of stable isotope data.

Geology

The stratigraphic sequence of Malanjkhand area

(Table 1) needs inclusion of meta-conglomerate that is known to occur right atop the granitoid body. There is possibility of the presence of Precambrian platformal sedimentary rocks between the lower Chilpi Group and the Malanjkhand granitoid. A recent study on the Malanjkhand deposit indicates that since polymict meta-conglomerates overlying granitoid contain abundant quartzite, chert, phyllite (at places highly carbonaceous) and lack granitic pebbles, presence of metasedimentary unit over granitoid pluton of Malanjkhand area cannot be ruled out. In all probability there was an extension of Sausar Group rocks up to Malanjkhand area which got eroded away prior to deposition of the younger Chilpi (Vishwakarma, *in press*).

Sarkar et al. (1996) have not identified Malanjkhand as a porphyry deposit. They have clearly stated in the very first line of the abstract that Malanjkhand is a lode-type copper (-molybdenum) deposit.

Ore Zone

The complete absence of multidirectional stockwork, magmatic-hydrothermal breccia and predominance of arc volcanism associated with ore deposition, collectively make porphyry nature of mineralisation quite equivocal. The mineralised quartz veins interpreted as small stockworks (surprisingly only on centimetre scale as shown in Fig.2) might represent cross-cutting veins that are normally found in fractured and sheared zones. It is also possible that the so-called stockwork is of secondary origin due to remobilisation of quartz. If not, why the stockwork of first generation veins (Stage I) are generally less than 1 m thick, and are absent in the main second generation veins (Stage II) which form mostly parallel mineralised vein system on the regional scale? Usually stockwork includes veinlets of large enough scale.

When it had been assessed that the effect of hydrothermal alteration is not intense (p.403), then it would not be possible to support (a) extensive pervasive silicification of granitoids with replacement of silicate minerals and quartz veining (with chalcopyrite and pyrite) (p.404), and (b) hydrothermal alteration with intense silicification and precipitation of sulphides producing rich mineralisation (p.408). Hydrothermal alteration appears to be mainly secondary and partly due to emplacement of silica-bearing hydrothermal ore-fluid.

The authors propose the orthomagmatic model to explain the source of huge quantity of silica and ore elements (p.409). In that case, the granitoid in close proximity to mineralised quartz veins should roughly, if not exactly, correspond with the age of the mineralization. On the contrary, by taking note of authors' own assessment (p.408), the age of granitoid is between 2243±217 Ma and 2467±22 Ma, whereas the age of mineralisation is too young (1737±49 Ma and 1818±73 Ma; Sikka and Nehru, 1997). Consequently, Malanjkhand may not belong to the category of intrusion-related deposit.

Tectonics

It is discussed (p.408) that most known Cu±Mo±Au porphyry deposits have formed above the zone of subduction and the regional tectonic environment of the Malanjkhand pluton is, therefore, favourable for the Malanjkhand Cu-Mo-Au mineralization. But in the same discussion section (p.411), it is interpreted that the Malanjkhand pluton probably represents rift-related activity by virtue of the fact that the structural elements conform to the Kotri-Dongargarh rift. How can two diverse tectonic settings ascribe the metallogeny to the same Cu-Mo-Au deposit at Malanjkhand?

There are evidences to suggest that the northern Bundelkhand and the southern Deccan blocks characterize rifting, and subsequent to which compression and suturing events took place during Mesoproterozoic time (Ravi Shanker, 1991). The rift palaeoenviroment is consistent with the inference (Acharyya and Roy, 2000) that the Sausar mobile belt, just beneath the Central Indian Suture Zone, shows a geophysical feature of an extensional tectonic regime represented by normal faults/ductile shear zones. Thus, such zones do not define sutures between two continental blocks (Ramachandra, 1999). Obviously the tectonic setting of subduction as favourable environment for Cu-Mo-Au mineralization has little significance. Rift appears to be the potential localizer of ore-fluid at Malanjkhand (Vishwakarma, *in press*).

Mineralisation

While advancing the concept of mineralization from the most differentiated microgranites (p.409), emphasis is laid down particularly on the homogenization temperature varying from around 160° to 400°C (p.410). However, considering the studies on the very high temperature origin of ores (e.g. around 700°C; Dubey and Singh, 1999) it seems that the most differentiated microgranites under 160°-400°C temperature cannot be linked with mineralisation. This opinion is further supported by the following:

The mineralisation is of lode-type. Such origin first of all involves formation of fractures and then their filling by the ores after a long interval of time. Similar temporal relationship exists at Malanjkhand in the light of the younger age of molybdenite mineralisation (1924±14 Ma, Vishwakarma, *in press*) as compared to the much older granitoid. This reflects on the different origin of ores and granitoids that is also apparent from the exceptionally high $^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ in ores and quartz veins as compared to relatively less radiogenic Pb-isotopes in the granitoid (Vishwakarma, 2000). The very high radiogenic Pb cannot be linked with mantle reservoir, because mantle-derived granitoids at Malanjkhand and other parts of the world do not exhibit such feature. Rather, suitable premise of the Pb in ores and quartz vein is consistent with an old U-enriched upper crustal source. At this point, it is worth mentioning that the isotopic difference between ore and rock is due to difference in source and not due to difference in post-mineralisation U/Pb ratio (Vishwakarma, *in press*). Often it is conceived that the extremely low lead content might cause elevated U/Pb for radiogenic isotopic signature. It is not always applicable for the highly radiogenic molybdenite from Malanjkhand which shows high lead value of 115 ppm. Furthermore, petrography of all the analysed samples did not reveal presence of U-rich minerals, which can affect lead isotopic composition of everything including ores, quartz veins as well as granitic rock. Absence of U-rich mineral phase was also confirmed by GM count at the Bhabha Atomic Research Centre, Hyderabad.

Since Malanjkhand deposit does not fit into the category of igneous intrusion-related deposit, the role of sedimentary process akin to exhalative activity due to sea-water convection in the spreading-ridge environment may hold good to account for metallogeny (Vishwakarma, 2000; Vishwakarma, *in press*). This may also be evidenced by the presence of elevated manganese content in large number of quartz vein samples. The higher Mn-content may be explained as due to exhalative-hydrothermal process (Raith, 1991). This model is in keeping with the observation that the sedimentary rocks of the Sausar Group present over the conduit zone, i.e., mineralised quartz vein within fractured parts of granitoid, had been eroded away.

A.B. Pal, Hindustan Copper Ltd., Malanjkhand - 481 116, Madhya Pradesh replies:

We agree with the statement of Panigrahi and Mookherjee (1997) that without stable isotope data the origin of ore fluid would be speculative. From their fluid inclusion and thermobarometry studies they suggested a genetic linkage between the granitoids and mineralisation. They have inferred a two-stage model of evolution, "the first (steam heating and mixing) being the cause and the second (CO_2 unmixing) being the effect of mineralisation". However, they have ruled out its direct magmatic derivation due to low density and proportion of the F1 component and circulating meteoric water. Fluid inclusion studies of Jaireth and Sharma (1986) showed that "quartz along with primary ore minerals was deposited from hydrothermal solutions that were boiling". Boiling is one of the main mechanisms of ore deposition in many ore deposits particularly in copper porphyry deposits. Hence boiling phenomenon also favours the porphyry view. Sulphur-isotope studies by Sarkar et al. (1996) from Malanjkhand ores also suggest magmatic origin of the ore fluid and its host rocks derived from mantle. Oxygen isotope studies by them in gange-quartz is similar to most volcanic and plutonic rocks. However, further work on this aspect is needed.

Geology

Table 1 in our paper shows the stratigraphic position of the conglomerate marking the basal part of upper Chilpi sequence. It is clearly observed that the basal conglomerate of upper Chilpi directly overlies pink granitoids in the south of Malanjkhand mine area. Another metasedimentary sequence of rocks, identified in the eastern part away from the Malanjkhand area, directly overlies granitoids and is represented by carbonaceous phyllite, shale and phyllite without basal conglomerate and arkosic grit and is identified as lower Chilpi. Sausar Group is exposed far away from the deposit area and occupies northwestern part in the map beyond the suture zone. Hence no modification in our stratigraphic sequence is needed.

The authors have never asserted that Sarkar et al. (1996) have "identified Malanjkhand as a porphyry deposit". Rather, we have stated that "Sarkar et al. (1996) noted that Malanjkhand deposit satisfies most of the characteristics of a porphyry deposit, except that a stockwork zone is absent".

We totally disagree with the critic's statements about presence of "polymict meta-conglomerates" and "lack of granitic pebbles". The conglomerate consists pebbles and cobbles of granitoid, quartzite, quartz vein, chert and phyllite in an arkosic to gritty matrix. The granitoid pebble/cobble includes both biotitized hornblende-bearing granitoids and micro-granitoids, besides presence of schistose and gneissic rocks.

The stockwork zones of mineralised quartz veinlets are present not only near the main shear zone, but are also widespread throughout the pluton and cannot be of secondary origin. The first generation vein-forming stockworks in granitoids are deformed, display tight folding in both the walls of thick Stage II veins. The early Stage I vein formation is followed by the main stage of shearing and emplacement of thick Stage II veins which are intensely mineralised and are common in a porphyry deposit. The Stage I veinlets are also present within Stage II quartz veins in granitic patches. In many porphyry deposits, hydrothermal breccia is not present. Arc volcanism is one of the environs associated with porphyry deposit.

Hydrothermal alteration is not so intense, but all the alterations are not pervasive in nature, but only selectively pervasive to specific minerals. The alterations in relation to mineralisation described in Fig.5 and Fig.8 include propylitisation at the pre-potassic alteration stage, and potassic alteration followed by silicification and mineralisation.

We have reviewed the various ages determined by different authors and assessed the age of granitoid after establishing field relationship of fractures, vein- and dyke systems in relation to alteration and mineralisation. The younger age determination by Sikka (1989) from granitic rock of the pit has been remarked by Panigrahi and Mookherjee (1998) as "later event and not the age of granite" which we have regarded as the age of last mineralization.

Tectonics

Tectonic activity marked by subduction zones is very commonly associated with many porphyry copper deposits. Initiation of subduction is caused due to late Archaean Mahakoshal rift activity (Nair et al. 1995), and Kotri lineament is an uplifted fault lineament. Data about subduction and Kotri lineament of Central India are used as supporting evidences of porphyry environs. N-S trending linear structural elements present in pluton may be related to the Kotri lineament.

Mineralization

Intrusion of weakly mineralized micro-granitoid body in the central barren zone of the deposit (see longitudinal section in Fig.7, Bhargava and Pal, 1999) and high pyrite/chalcopyrite ratio located at the deeper part of the microgranitic body suggests that the magmatic activity, which brought the intrusion, might have played an important role in the genesis of the ore deposit. The intrusion of magma at deeper levels might have caused the circulation of hydrothermal solutions and consequently the mineralisation. After the main mineralization event, the microgranitoid has intruded the upper levels as a late phase magmatic differentiation product, carrying disseminations of pyrite, chalcopyrite and molybdenite.

The homogenization temperature of fluid inclusions in the ore minerals present in microgranitoid has not been studied so far. The Pb content in K-feldspar-rich pink granitoid, aplite and quartz veins shows the same value as the mill feed ore. Hence the critic's observations of high radiogenic Pb in ore and low Pb in granite cannot be accepted. The younger age of molybdenum determined by Vishwakarma as 1924±14 Ma was not known earlier to the authors. Molybdenum occurs as specks with sulphides in pink K-feldspar-rich quartz veins and along fractures in quartz and granitoids. Occurrence of Mo in the microgranitoid at Malanjkhand and Devgaon as disseminated type also indicates its syngenetic nature. The age of microgranitoid (Gr-I of Panigrahi et al. 1993) is determined as 2106±102 Ma. Hence we doubt about the source and type of Mo sample used for age determination. Younger age of Mo may represent a similar later event as described earlier. Pb isotopic studies on the Palaeoproterozoic Malanjkhand deposit may not give correct age data due to very low content of Pb in ore and host rock. The system has been disturbed by a younger event and interpretation can be made only with support of appropriate geological evidences. U and Th mineralisation is reported by many authors in the adjoining Proterozoic Dongargarh Supergroup of Central India. It is well established now that both Malanjkhand and Dongargarh granitoids are emplaced during the same tectonomagmatic event. Elevated Mn content in quartz vein as remarked by the critic is not true. Mn content in ore is much less than in basic rocks, microgranitoid and both pink and grey granitoids. Sarkar et al. (1996) also noted that there is no evidence at present for the view that the ore elements were contributed by an external source. Panigrahi and Mookherjee (1997) suggested from their discussion on fluid evolution that "ore fluids *vis-a-vis* fluid characteristics in the granitoids prompt the suggestion of a genetic linkage between the granitoids and mineralisation." Therefore the critic's hypothesis of the "role of sedimentary process akin to exhalative activity due to seawater...... ridge environment" cannot be sustained.

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