DISCUSSION

1 ANATOMY OF A PORPHYRY COPPER DEPOSIT – MALANJKHAND, MADHYA PRADESH by M. Bhargava and A.B. Pal. Jour. Geol. Soc. India, v.53(6), pp.675-691.

2 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.

K.L. Rai, Department of Geology, Government Engineering College, Raipur - 492 010 and **H.K. Pandey**, Scientist 'B', Central Ground Water Board, State Unit Office, Allahabad, U.P., comment:

These contributions by Bhargava and Pal constitute a long-awaited and commendable effort that brings out several facts about the deposit, which were hitherto unknown. As rightly pointed out by the authors, many workers quoted by them do not support the view of porphyry copper deposit for Malanjkhand. This is a million dollar question having long-term repercussions on strategies for mineral exploration in the region. Hence, we consider it most opportune to debate its porphyry origin.

Absence of Wallrock Alteration

We have strong reservations regarding the pervasive or selectively-pervasive type of wallrock alteration on the following grounds:

The authors have identified silicification, potassic alteration, epidotisation, chloritisation and biotitisation as the main types of hydrothermal alteration and have produced a unique map showing "hydrothermal alteration zone (?) in the mine-pit area." (Fig.4 of Paper 1). The map depicts irregular, patchy and asymmetric alterations that cannot be considered as 'alteration zones' of large copper deposit. This kind of zonation has no analogue in any known porphyry type copper deposit of the world.

The authors claim that "hydrothermal alteration has affected the entire pluton, involving large rock volumes and extending into the wallrock far away from sulphide mineralisation. The post-mineralisation basic dykes close to mineralized veins have also been altered" (Paper 2). At the same time, the authors also conclude that "the effect of hydrothermal alteration is not intense and the original character of the granitoids is preserved to a large extent." Obviously, the authors have not distinguished between wallrock alteration related to sulphide mineralisation and mineral or rock alteration that may be related to other processes like regional prograde and/or retrograde metamorphism, deuteric alteration, activity of circulating meteoric waters etc. Much of what is observed and described by them as 'hydrothermal alteration' appears to be related essentially to pre- to post-mineralisation mineral/rock alterations.

After describing "hydrothermal alteration and broad (?) alteration zones of the Malanjkhand deposit," the authors have quoted Beane (1982), that "there are a large number of porphyry deposits which do not have such alteration zones." Does this not appear to be confusing or contradictory? Questioning our observation regarding the wallrock alteration, the authors have tried to justify their contention (Paper 1) on the basis that "distinct alteration minerals and assemblages have been identified (earlier) by Seetharam and Kalra (1983), Sikka (1989) and Sarkar et al. (1996)." We assert that none of the earlier researchers has been able to establish wallrock alteration or zoning related to sulphide mineralisation at Malanjkhand.

Our recent petrological, petrochemical and mineral-chemical studies on the wallrock granitoids of Malanjkhand (Rai et al. 1996; Pandey, 1998) are distinctly supportive of our earlier contention, the major observations being (i) wall-rock granitoids are remarkably uniform on ore-body scale and (ii) biotite compositions are uniformly consistent.

Tectonic Setting

Tectonic setting of the deposit in an island arc regime on the southern fringe of the Central Indian Suture Zone (CISZ), which represents "a plate boundary of late Archaean-early Proterozoic time" according to Yedekar et al. (1990), has been cited by the authors in support of their contention. Recent studies by Ramachandra and Roy (1999), Acharyya and Roy (2000), Jain et al. (1995) and Sharma (1995) have, however, seriously questioned the status of the CISZ as a suture between two protocontinental blocks.

Significantly enough, the deep continental geophysical studies by Agrawal et al. (2000) in Central India have revealed the existence of an isolated domain of Moho upwarps, defined by the triple-armed tectonic geometry of Son-Narmada-Godavari rift system with its apex near Pachmarhi. This highly fractured and sheared V-shaped domain between the arms of the dying Proterozoic Narmada-Son rift and propagating Permo-Carboniferous Gondwana rifts, according to them, contains twelve proven zones of U, Au, W, Cu, Mo mineralisation, the famous Malanjkhand copper deposits associated with the shear zones being one of them. The NNE-SSW trending Malanjkhand-Nandora Lineament comprising the shear zones referred to in this proposition is, according to Raina (1980), possibly "a branch of the N-S trending Kotri-Darekasa fault which represents a major curvilinear zone of the area."

We agree with Agarwal's model that reflects a positive evolutionary correlation between the mineralisation, its host-rocks and the rift tectonics with particular reference to the Kotri-Dongargarh Rift Zone.

Stockwork Zone

The authors claim that a "stockwork zone of parallel (?) or cross-cutting mineralised quartz veins is definitely present" and that "it extends for hundreds of metres in the granitoids." This contradicts the observation of Sarkar et al. (1996) that the sulphide mineralisation at Malanjkhand is "more akin to the composite vein or lode-type as observed by Rai and Venkatesh (1990)."

Tenor/grade and Tonnage of Ore

Low tenor and high tonnage have been frequently cited as another supportive evidence of porphyry-type mineralisation at Malanjkhand by the authors and earlier workers like Sikka and Nehru (1997) and Sarkar et al. (1996).

By notable contrast, in the Middle Proterozoic copper mineralisation at Malanjkhand having 1.3% Cu as the grade of the run-of-mine ore with estimated reserves of over 600 million tonnes at 0.4% cut off, "the expected availability of ore and metal, per metre depth is the highest among the known copper deposits of India" (Subhedar, 1986).

The authors freely seek support for their debatable views from certain global-scale observations. In the process, they have conveniently overlooked several facts and number of other researchers (Subhedar, 1986; Singh 1996; Rai and Pandey, 2000) who do not subscribe to the porphyry view.

Several important observations which do not fit satisfactorily into the porphyry model are listed below:

(a) Very simple mineralogy and chemistry of the ores, marked by the conspicuous absence of high temperature minerals in them and/or the host-rocks, the presence of lead only in traces, and the absence of metalloids (As, Sb, Bi). Overall similarity of mineralogy and mineral paragenesis in all the observed ore types of the deposit, implying consistent physico-chemical conditions of ore deposition.

(b) Appreciably low temperature regime, well below 200°C, during the main stage of mineralisation, as revealed by fluid inclusions and mineralogical studies. Absence of any semblance to zonality or symmetry in mineral or metal distribution and also in temperature and salinity of fluids, as brought out by fluid inclusion studies.

(c) Concentration of several orders of magnitude of ore-forming metallic elements e.g. Cu, Zn, Mo, Au, Ag, Hg, W, Sn, etc. in the granitoids hosting mineralised veins *vis-a-vis* global averages in the acidic rocks (both high Ca and low Ca), as well as in the granitic rocks hosting typical porphyry copper deposits (Pandey, 1998). Fairly high abundance levels of basaltophilic elements e.g. Cr, V, Ti, Ni, Co etc. in the granitoids hosting the mineralisation. The observed consistency of abundances and patterns of REE distribution in the wallrocks and host rocks of mineralised quartz vein throughout the deposit. Characteristically, very narrow spread of δ^{34} S values, clustering around zero permil, in the sulphide minerals of the ore.

The feasible alternative models may include the one that takes due account of the regional geology and tectonics, marked by intimate spatial, temporal, and perhaps even genetic, linkages among mineralisation, host-granitoids and the volcano-plutonic complexes of Kotri-Dongargarh Rift Zone of which the Malanjkhand pluton is an integral peripheral part. This of course, implies volcanic affiliation of the mineralisation in primary genetic terms. Our research work in this direction is in progress.

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

Indeed we agree with the commentators' statement "This is a million dollar question having long-term repercussions on the strategies of mineral exploration". Replies to their objections are given below:

Wallrock and Hydrothermal Alteration

We totally disagree with their statement about "the absence, in general, of any semblance to pervasive alteration or alteration zoning on the ore-body scale", without citing any substantial work of their own. Selectively pervasive alteration is restricted to specific minerals of the host rock. Development of selectively pervasive biotite alteration is of pre-ore stage and is the earliest recognized alteration effect at Malanjkhand. Early biotite alteration is observed in most of the porphyry deposits of the world (Titley, 1982). Pervasive alteration is also of pre-ore type but slightly later than biotite alteration, brought about mainly by chloritization, epidotization, sassuritization, sericitization and microclinization of the wallrocks. At Malanjkhand, selectively pervasive alterations are mostly controlled by fractures and veins systems forming aureoles of potassic alteration. Superposition of alteration mineral assemblages at various stages of hydrothermal activity caused the irregular pattern of alteration zones. This has caused alteration patterns that are "irregular, patchy and asymmetric types of such alterations". Wallrock alteration and hydrothermal alteration are synonymous. Hydrothermal fluids cause wallrock alteration.

The authors' identification of alteration patterns, alteration assemblages and zones in the pit are based on extensive database such as detailed mapping of the entire mine workings up to a depth of 448 mRL (130 m depth from valley level), 2.2 km length and 600 m width of pit, diamond drilled core data of 1,09,136 m in 262 holes, XRD analysis of 150 samples from the deposit area and hundreds of petrochemcial and mineralogical studies in and around the deposit.

Intensity of hydrothermal alteration mainly depends on permeability of the host rock and wallrock in the same manner as mineralisation. The overlapping character of alterations is mostly controlled by fracturing, introduction of K-feldspar-quartz veins, intense silicification and mineralisation, hydrothermal condition of ore forming fluid and superposition of hydrothermal alterations due to introduction of basic dykes, younger veins as well as oxidation and supergene processes. Therefore, effect of alteration is not uniform and the original grain characters of granitoid are preserved at places.

Hydrothermal alteration has affected large volumes of rock due to formation of stockwork veins involving introduction of large amount of K-feldspar and silica preceding mineralization. This has altered biotite, hornblende and plagioclase which occur as relics at the core. The post-mineralised basic dykes have also been altered due to continued hydrothermal activity, as evidenced by occurrence of chalcopyrite and pyrite disseminations in the dykes and pervasive chloritic alteration associated with them. Chlorite is pervasively found in either of the ore zones and wallrocks. Epidote occurs more in the altered wallrocks than in the ore zones. Sericite is pervasive and present more in the altered granitoids than in the ore zones. Basic rocks and granitic wallrocks are affected by pervasive chloritic alteration due to later hydrothermal solutions related to intrusion of dykes, and this chloritisation has overlapped all the earlier alterations. Hydrothermal alteration model described in Fig.5 and deposit formation model in Fig.8 in our second paper have explained the overlapping and continued hydrothermal activity in relation to alteration and mineralisation.

These observations undoubtedly prove that there is no ambiguity regarding wallrock alterations and alteration mineral assemblages observed by present authors.

We accept the classical hypogene concentric zoning of the alterations like propylitic, argillic, phyllitic, potassic and ore-shell as in a typical porphyry deposit is not found in Malanjkhand. Such typical concentric zoning is also not found in many other porphyry deposits of the world.

Uniform composition is not an *a priori* reason for non-porphyry nature of the deposit. Extensive and long term alterations can and often lead to uniform compositional trends of host rocks. This only shows that alteration has been prolonged, pervasive and extensive.

Tectonic Setting

The commentator's statements about the suture zone in Central India are outside the data collected by the authors and were only used as supporting evidence.

Stockwork Zone

Stockwork zone consisting of parallel or cross-cutting mineralised quartz veins with K-feldspar at the peripheral contacts are conspicuously present, forming low grade ore (< 0.8% Cu), locally termed as granite ore. This stockwork zone has been superimposed by the late N-S shear, occupied by Stage-II vein system. A close look at geological map of the Malanjkhand mine area (Pal and Bhargava, 1998) will reveal the stockwork appearance of the main ore body even at much reduced scale. Stringer type of ore is only found in stockworks. Development of thick blanket type oxidation and supergene enrichment of sulphide ore zones at Malanjkhand deposit is a characteristic of stockwork ore deposit. Breccias are absent in Malanjkhand deposit as in other stockworks.

Tenor and Tonnage of Ore

In the Malanjkhand deposit, the "mineable reserves" at various economic cut-off grades are quoted by many authors 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