ON THE GEOLOGY AND MINERALIZATION IN THE KHETRI COPPER BELT, JHUNJHUNU AND SIKAR DISTRICTS, RAJASTHAN*

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(Communicated by B. C. Roy, F.N.I.)

(*Received April 6, 1964*)

In the Khetri copper belt, a thick series of metamorphosed psammitic and pelitic rocks of the Alwar and the Ajabgarh series of the Delhi system has been thrown into a number of doubly plunging anticlines and synclines. With the increasing intensity of deformation the folds yielded to faults, thrusts and shear zones mostly at the contact of different rock formations. These faults and associated shear zones mainly confined to the schists and quartzites, acted as conduits for sulphide mineralization in the area. Sulphides represented by pyrite, pyrrhotite and chalcopyrite occur mainly as fissure fillings and have at places extensively replaced the country rocks. The wall rock alteration is characterized by the development of anthophyllite, cummingtonite, chlorite, biotite, actinolite and sericite. The relationship between deformation, metamorphism, intrusion and mineralization suggests that hydrothermal solutions were derived from the granite intrusives. Sulphide deposits show a fall in temperature from the northern to the southern part of the belt.

I. Introduction

General statement

Khetri (28° 0′ : 75° 47′) was a centre of copper mining activity in the historic past, long before the first geologist, Hacket (1877), examined the region towards the end of the nineteenth century. References to working of the deposits are found in *Ain-E-Akbari* written during the rule of the great Mughal Emperor Akbar. Extensive activity of the ancient miners in the region is evidenced from the old workings spread all over the belt, slag heaps [sometimes of enormous sizes, as for example, near Singhana (28° 06′ : 75° 50′)], and dumps of mine waste near the portals of all the old stopes. This paper presents the summarized account of the geology and sulphide mineralization, the details of which are being written up for the departmental monograph.

The Khetri copper belt lies within the Survey of India topo sheet Nos. 44 P/12, 16 and 45 M/NE and SW. It takes its name after the town of Khetri, which is situated about 170 kilometres south-west of Delhi.

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* Publication authorized by the Director-General, Geological Survey of India.

In some of the earlier unpublished reports of the Geological Survey of India, the Khetri copper belt has been described as extending from Singhana (28° 06′ : 75° 53′) to Babai (27° 53′ : 75° 46′), over a length of about 25 kilometres. But recent mapping of the areas further to the south has established that the belt stretches over a distance of 80 kilometres from Singhana (28° 06′ : 75° 50′) to Raghunathgarh (27° 39′ : 75° 21′) and probably even beyond, as one integrated copper belt with continuity of structural and geological features including copper mineralization.

Details of field-work

A total area of about 700 sq. km covering parts of the Jhunjhunu and Sikar districts of Rajasthan has been mapped on aerial photographs (scales 1 : 16,000 and 1 : 32,000), the details of which have subsequently been transferred to base maps. The resultant regional geological map (Fig. 1) provides the essential perspective background of the geology of the area.

Previous works

Hacket (1877, 1880, 1881) was the first geologist who studied the regional geology of the area. His work in this and in the adjoining areas was subsequently modified by Heron (1923, 1925) to whom goes the credit of most extensive study on the regional geology. In his presidential address to the section of Geology in the Indian Science Congress Dunn (1943) stressed the potentiality of the Khetri copper deposits. Deb (1948), Varma and Patni (1962), and Varma and Krishnanunni (1963) published abstracts of their papers on some limited aspects of the geology and mineralization of selected areas.

During the last one and a half decades the Geological Survey of India had conducted thorough field investigations in this belt. The work of Venkatesh and Das Gupta (1959*a*, *b*), Roy Chowdhury, Prasad Rao, Ramiengar and Das Gupta (1960), and Roy Chowdhury, Prasad Rao, Ramiengar, Das Gupta and Natarajan (1960, 1961) was preceded by the investigation of Crookshank (1948), Kerr-Cross (1948), Arogyaswamy (1949), Chandra and Aditya (1956), and Ramiengar (1956). West (1949) and Roy (1958, 1961*a*, *b*, 1962) published the main observations made by the earlier workers. The present knowledge on the geology of the Khetri copper belt is mainly based on the field and laboratory studies of the junior author of this paper.

II. Geological Setting

The main rock types of the area can be broadly divided into sedimentary metamorphites and intrusive rocks of pre-Cambrian age, and belonging to the Alwar and the Ajabgarh series of the Delhi system of Heron (*op. cit.*). The metamorphites include moderately metamorphosed schists, quartzites, marbles with intercalated calc-silicate rocks and amphibolites.

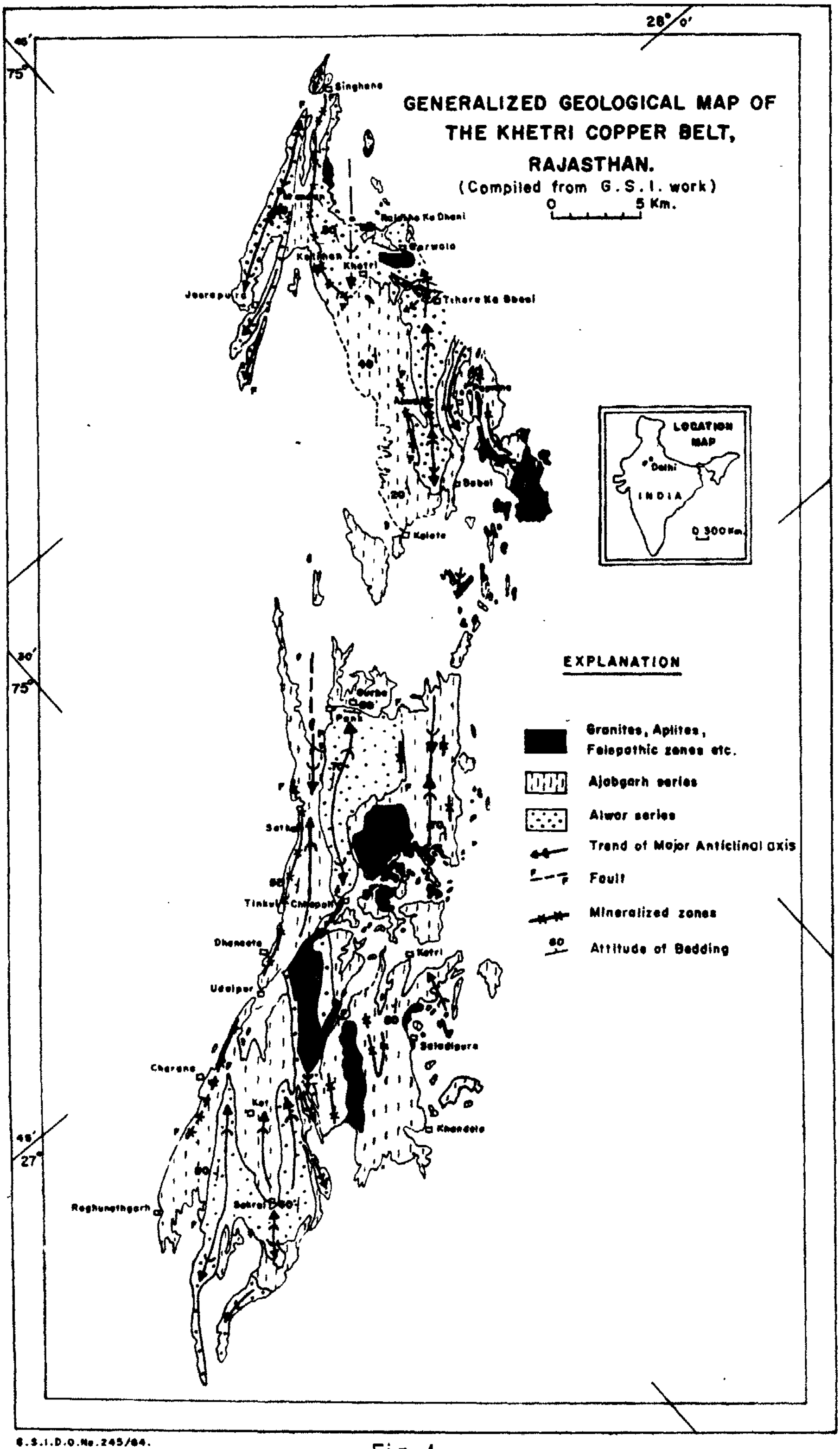
GENERALIZED GEOLOGICAL MAP OF
THE KHETRI COPPER BELT,
RAJASTHAN.
(Compiled from G.S.I. work)
0 5 Km.
28° 0'
75°
30'
27°
Singhana
Khetri
Jasrapura
Babai
Kolote
Tihara Ka Bhool
Gurha
Satkui
Tinkoi
Chhapoli
Dhanoota
Udaipur
Kotri
Saladipura
Charana
Khandela
Raghunathgarh
LOCATION MAP
Delhi
INDIA
0 300 Km.
EXPLANATION
Granites, Aplites, Felspathic zones etc.
Ajabgarh series
Alwar series
Trend of Major Anticlinal axis
Fault
Mineralized zones
Attitude of Bedding
G.S.I.D.O.No.245/64.

Fig. 1

The rocks of the Alwar series are predominantly arenaceous, while the Ajabgarhs are mainly argillaceous. The Alwar rocks are characterized by current beddings and ripple marks but these features are almost always absent in the Ajabgarh series. Although the contact between the two series is not sharp, there is a narrow but distinct zone of transition showing widely varying mineralogical assemblages. The proportion of chlorite and biotite increases sharply from the Alwar series to the Ajabgarh series. The zone has been further complicated by shearing, faulting, and iron-magnesia metasomatism attendant with mineralization.

The oldest intrusive rocks are represented by a distinct group of amphibolites (metamorphosed dolerites) occurring as sheets and lenses. Granites and the related pegmatites contain inclusions of older amphibolites. The last phase of igneous activity is represented by basic dykes (now occurring as epidiorites and amphibolites) cutting across all the rocks and structural features of the area.

The geological succession of the area is as follows:

		Soil, dune sands
	Intrusives	Chert-ankerite veins Younger amphibolites (Period of mineralization) Granites, granite-gneisses, aplites and pegmatites, etc. Older amphibolites.
Delhi system	Ajabgarh series (about 1,300 m)	6. Quartzites, phyllites, schists, etc. 5. Marbles, dolomites, calc-gneisses, amphibolites, amphibole quartzites, etc. 4. Schists with or without garnet, staurolite, andalusite, etc.; phyllites, sandy phyllites, andalusite phyllites, etc.
		Gradational contact
	Alwar series (about 1,300 m)	3. Amphibole quartzites, marbles, amphibolites, etc. 2. Arkosic quartzites and intercalated phyllites and schists, magnetite and hematite quartzites, etc. 1. Phyllites and schists.
		Base not exposed.

Structure

Structurally the area is complexly folded and many folds show evidences of refolding. The general strike of the formations varies between NNE–SSW and NE–SW. But there are many deviations from these trends at several places. The dips are high and vary between 50° and 70° westerly or easterly, but locally the dips may be sub-vertical or sub-horizontal.

The most conspicuous structural feature of the region is a series of large scale doubly plunging anticlinal folds (Fig. 1), the core of which is occupied by the rocks of the Alwar series. The folds plunge either southwesterly or northeasterly with the axial traces trending generally NNE–SSW to NE–SW.

The axes of culminations and depressions are not strictly at right angles to the axes of the main folds. Many minor fold axes run parallel to the trend of the axes of culminations and depressions. These latter folds appear to have been superposed on the earlier sets. This conclusion has been arrived at from the geometrical analysis of the structures.

Concomitantly with the folding, the area has also been subjected to intensive strike faulting, but there is not much of lateral shifts. Reverse faults are more common and the mineralization is associated with the openings produced by these faults. The major dip-slip faults are parallel to the strike of the formations or follow the contacts of quartzites and phyllites. Transverse faults trending across the major structure show minor displacement and are only locally mineralized.

Metamorphism

In an area subjected to repeated deformations and intrusions it is rather difficult to decipher the complex metamorphic history. The nature of metamorphism in the region is exhibited by the texture and mineral assemblages of phyllites, biotite schists, garnet-chlorite-quartz schists, sillimanite schists, kyanite schists, staurolite schists, andalusite schists, andalusite phyllites, anthophyllite-cummingtonite-bearing rocks, calc-gneisses and amphibolites. The distribution of the phyllites and schists containing critical metamorphic minerals is rather erratic and cannot be correlated exclusively with the definite structures or intrusives. However, the grade of metamorphism is higher on the eastern part of the belt where deformation is more intensive and the rocks, at places, are intruded by granitic rocks.

Where granitic rocks are absent, the grade of metamorphism is rather low, even when deformation is of higher intensity, although locally the deformed rocks show characteristic products of high grade metamorphism. Andalusite-bearing rocks in many places are restricted to the immediate vicinity of the amphibolites and were probably formed as a result of thermal effects induced by the intrusive basic rocks.

The spatial distribution of garnet, kyanite or sillimanite does not show any strict regularity in their occurrence. But the prevalence of these minerals in the neighbourhood of some of the exposed granite bodies is suggestive of the influence of these intrusives on higher grades of metamorphism. In many localized areas, structurally deeper parts show rocks of high metamorphic grades up to amphibolite facies (Turner 1949).

Metamorphism is accompanied and followed by metasomatism resulting in felspathization of schists in Jasrapura, Babai and Kotri; scapolitization of amphibolites (Das Gupta and Chakravorty 1962) in the area near Kot (27° 40′ : 75° 26′)-Sakrai (27° 38′ : 75° 24′) valley, Mandan, etc.; iron-magnesia metasomatism (Das Gupta 1961, 1962) of quartzites and schists, represented by the anthophyllite-cummingtonite and chlorite in the northern part of the Khetri copper belt. Iron-magnesia metasomatism, sericitization, biotitization, carbonatization and scapolitization are essentially connected with the wall rock alterations of the mineralized zones. These processes have been superimposed on the products of regional and thermal metamorphisms.

The metamorphic history has been further made complex by cataclasis and retrogression changing the texture, chemical and mineralogical compositions of the assemblages.

It is in this set-up the mineralizations took place mainly along the structurally weak zones around the fault and shear planes, in the moderately and low grade metamorphosed rocks like andalusite schist, garnet-chlorite schist, biotite schist and phyllites. The rocks of the sillimanite zones are not much affected by mineralization.

III. Mineralization

Sulphide-mineralization in the Khetri area is localized along a broadly defined linear belt which is traceable from Singhana in the north to Raghunathgarh (27° 39′ : 75° 21′) in the south including the prospects of Peeliwali (28° 4′ 30″ : 75° 47′ 45″), Ghatiwali, Mandan (28° 4′ 15″ : 75° 48′ 30″), Kudan (28° 4′ 15″ : 75° 47′ 25″), Masjidwali (28° 4′ : 75° 48′), Dumdumwali (28° 4′ 15″ : 75° 4′ 45″), Kolihan (28° 1′ : 75° 44′), Khetri (28° 0′ : 75° 47′), Akwali (27° 56′ : 75° 46′) in the northern part, and Satkui (27° 49′ : 79° 35′), Tinkui (27° 45′ : 75° 31′), Dhanaota (27° 44′ 45″ : 75° 30′) and Charana (27° 42′ : 75° 25′) ridges in the southern part.

In locating the mineralized zones several criteria have been adopted. These are: (1) shear zones often showing stains of hydroxides of iron and rarely secondary copper minerals like malachite and azurite, (2) gossans of diagnostic colour showing boxwork of limonite, (3) old mines, prospect pits, debris of waste material, slag heaps, and (4) wall rock alterations. Though faithful guides, these criteria have obvious limitations in the case of buried deposits and in establishing the continuity, nature and intensity of mineralization in the intervening areas of the different prospects. In such cases more reliance had to be placed on the regional guides like lithological, stratigraphical and structural controls in locating the ore-bearing horizons.

Lithological-stratigraphical controls

There is no particular host rock or rocks of mineralization but the most favoured rocks are schists and phyllites in the northern part of the belt, and quartzites and phyllites in its southern part. Locally, marble and amphibolites are also mineralized but the concentration of sulphide in them is of poor order only.

There is no definite stratigraphic control on mineralization in the belt but in the northern part the mineralization is at the contact of the Alwar and the Ajabgarh series, whereas in the central part and near Akwali, the mineralization is in the schistose rocks of the Ajabgarh series and in the southern part it is mainly confined to quartzites of the Ajabgarh series.

Structural control

The chief controlling feature of mineralization is a series of fairly large scale faults, both normal and reverse, and the accompanying shear zones as observed at Peeliwali, Dumdumwali, Kolihan, Khetri and Akwali. The mineralized zone at Satkui and Dhanaota in the southern part of the belt is mostly along a persistent fault zone. At Dhanaota, the structure appears to be further complicated by post-mineral faults, as a result of which the ore body is probably missing at a deeper level in spite of a thick gossan zone on the surface.

The faults are sub-parallel to the strike of the formations and mostly they are at the contacts of two different lithological units such as the Alwar quartzites and the Ajabgarh schists. As a consequence of faulting numerous shear zones were developed parallel to these faults which acted as good channel-ways for ore-bearing solution. Shear zones are of various pattern, the most important of which is the horse-tail structure developed at Madan and Kudan hills. It has been commonly observed that the shear planes are mostly mineralized wherever they are parallel to the bedding or foliation. Although the metalization is mainly restricted to the fault or shear zones, the mineralizing solutions permeated to varying widths from these zones as marked by the disseminated ores.

Less commonly (i) the zones of intersection of strike faults and transverse faults, *e.g.* at Mandan, (ii) nose of folds, *e.g.* at Suradi (27° 54′ 30″: 75° 46′ 30″), Ponk (27° 48′ 45″: 75° 37′ 45″), (iii) folds, *e.g.* at Saladipura (27° 38′ : 75° 31′) and (iv) joints, *e.g.* at Peeliwali form loci for sulphide bodies.

Wall rock alteration

Ore-bearing horizons have been made more conspicuous by the presence of a suite of rocks formed as a result of wall rock alteration. In the northern part of the belt, quartzites and schists show three distinct types of iron-magnesia metasomatism. These are: (1) amphibolization indicated by the anthophyllite-cummingtonite and actinolite, (2) chloritization and (3) biotitization. The zones of such metasomatism can only be broadly delineated as these generally show irregularity in their distribution.

Amphibolites have been mostly biotitized. The profuse development of biotite and sericite is characteristic of the wall rock alterations of the Akwali region. Chlorite and biotite are either absent or less commonly developed in the southern part of the belt.

Besides these, conspicuous silicification and local development of ankerite and other carbonates are noticed at places, which are usually later than the early phases of wall rock alteration represented by iron-magnesia metasomatism. At Dhanaota, supergence kaolinization has been superposed on the hypogene alterations.

Form of ore-bodies

It is rather difficult to determine the size and shape of the ore-bodies without sufficient sub-surface data. But fortunately in the Khetri copper belt, old stopes and other forms of underground workings, and recent drilling data provide an opportunity to form an idea about the nature of ore-bodies. Even then in a metalliferous deposit like Khetri copper, where the controls are so variable, accurate determination of the shape of the ore-bodies must await the sufficient advance in the development work. However, the data collected so far indicate that the ore-bodies are lens-shaped or tabular in nature. Within these lenses or tabular bodies there are many septas of barren country rocks. The direction and amount of plunge of such ore-shoots vary from 10° to 40° southwesterly or northwesterly. The length of the individual ore-shoots varies from a few metres to several hundred metres and the most persistent of them being located at Mandan, Kudan and Kolihan prospects.

Mode of formation

The sulphides are mostly emplaced in the shear zones as fissure fillings both in the schistose rocks and in the quartzites. But in the northern part of the belt, replacement has, however, played a considerable role in the mineralization, especially along fracture zones traversing the favourable host rocks. Disseminated sulphide in the margins of the shear zones as also the mineralization in the unsheared rocks are predominantly the results of pore space fillings.

Mineralogy

The main sulphides in the ores are pyrite, pyrrhotite and chalcopyrite in their order of abundance and also in paragenetic sequence. These occur in the form of irregular patches or as discontinuous veins and stringers in the host rocks.

The proportion of pyrrhotite gradually decreases towards south, and at Satkui and Dhanaota this mineral is totally absent. In the northern part of the belt and at the main mineralized zones on the Mandan-Kudan hill, the proportion of pyrrhotite locally increases with depth and occasionally sulphides are made up of pyrrhotite only.

Besides these, cobaltite, danite (Mallet 1881), chalcocite, arsenopyrite and leuco-pyrites have been reported but their occurrence is so restricted that their paragenetic relations cannot be worked out.

Of the secondary copper minerals the most important ones include malachite, azurite, covellite, chrysocolla, chalcanthite and brochantite. Native copper is found in Satkui and rarely in the northern part of the belt.

The chief gangue minerals are quartz, chlorite, scapolite, albite, tourmaline, anthophyllite, cummingtonite, actinolite, andalusite, garnet, magnetite, biotite, dolomite, calcite, etc.

IV. Origin

The mineralogy, mode of occurrence and wall rock alterations clearly point out that the deposit belongs to the upper part of the mesothermal or lower part of hypothermal class (Lindgren 1933) of hydrothermal deposits (Roy Chowdhury, Prasad Rao, Venkatesh, Ramiengar, Das Gupta and Natarajan 1962). The general absence of pyrrhotite in the southern part and the presence of low temperature mesothermal fluorspar are indicative of change in temperature and composition of the ore fluids.

From the time relation amongst the deformation, igneous activity, metamorphism and mineralization, it appears that granite is post-faulting and probably the mineralizing solutions rich in iron, magnesia, soda, potash, chlorine, fluorine, boron, carbon dioxide, H_2O and sulphur were expelled from the granite magma. The late phase of granite has formed pegmatites or aplites which are poor in sulphides. The ore fluids maintained a critical composition for the deposition of sulphides. Such fluids altered the wall rocks extensively. The general nature of the Khetri ore-bodies, their persistency along fault or shear zones in depth and the character of the mineral constituents suggest that the condition of deposition was guided by a gradual fall in temperature from north to south.

Definite mineral barometry is lacking but texturally the earlier minerals are compact, fractured and crushed, suggesting that during initial stages the pressure was quite high. The later minerals appear to have formed under low pressure and their occurrence in vugs is more common.

Acknowledgements

The authors wish to acknowledge the works of Messrs. G. H. S. V. Prasad Rao, A. S. Ramiengar, V. Venkatesh and W. K. Natarajan of the Geological Survey of India.

Thanks are due to Messrs. V. K. S. Varadhan and M. Narasimhan of the Indian Bureau of Mines for showing many sub-surface features.

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