GEOPHYSICS, VOL. 66, NO. 1 (JANUARY-FEBRUARY 2001); P. 70–77, 11 FIGS., 3 TABLES.

E-17

Case History

Mise-a-la-masse survey for an auriferous sulfide deposit

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ABSTRACT

A mise-a-la-masse survey was carried out in Bhukia area, Banswara district, Rajasthan, India for auriferous sulfide occurrences. This area was originally surveyed for copper mineralization. Exploratory drilling, however, proved it to be economically not viable. The area was reopened for geophysical surveys when grab samples indicated the presence of gold. Initial geophysical surveys for copper mineralization showed electromagnetic, induced polarization, and resistivity anomalies. At first, one borehole was drilled for gold exploration on the basis of initial geophysical surveys. It encountered massive sulfide mineralization in association with gold. Borehole logging and a mise-a-la-masse survey were carried out in this borehole. Three further boreholes drilled on the basis of the mise-a-la-masse results encountered massive sulfide mineralization in association with gold. One of the three boreholes, 100 m from the first borehole along strike, was used for another set of mise-a-la-masse measurements. A composite equipotential map was prepared using the results of mise-a-la-masse results of both the boreholes. The equipotential contours show a north-northwest–south-southeast trend of mineralization. The boreholes drilled on the basis of the mise-a-la-masse results have delineated a strike length of more than 500 m of gold-bearing sulfide mineralization. The sulfide content ranges from 10 to 40% and gold concentration ranges from 2 to 6 ppm. The dip and plunge of the lode, as anticipated from the mise-a-la-masse results, are toward the west and north, respectively. Mise-a-la-masse surveys are continuing in the adjoining areas.

INTRODUCTION

A number of old workings, in the form of wide and deep trenches running north-south along the western slope of the hill range, are seen between Jagpura-Taria and Lukia-Dilwara villages of the Banswara district, Rajasthan, India (Figure 1). Banswara district is in southern Rajasthan. The area is primarily a peneplain with rolling topography. The lowest level is 215 m and the highest 302 m above mean sea level.

Integrated geological and geophysical surveys together with follow-up drilling were carried out to locate copper mineralization. Economic mineralization was not found and, as such, the investigation was closed. Subsequent reexamination of the ancient mines and certain geological units under a detailed mapping program of the study area indicated the presence of visible, native gold in some of the grab samples (Grover and Verma, 1993). In light of this discovery, fresh drilling operations were started. The drilling has proved that the gold-bearing zones in the area are associated with pyrrhotite and arsenopyrite.

Saikia et al. (1977) conducted detailed electromagnetic (EM); resistivity, induced polarization (IP), self-potential (SP), and magnetic (vertical component) surveys in the area. EM surveys supported by resistivity and IP surveys delineated several conductors in the area. Subsequently exploratory drilling for gold mineralization was carried out (Grover and Verma, 1995). Borehole logging and mise-a-la-masse surveys in the boreholes drilled for the exploration of gold mineralization also were carried out (Gupta, 1996; Gupta et al., 1999).

REGIONAL GEOLOGY

The regional geological map after Grover and Verma (1993) is shown in Figure 2. Precambrian metamorphosed rocks occurring in the area belong to the Debari Group of the Aravalli

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Supergroup (Gupta et al., 1980, 1992). The lithostratigraphic succession is shown in Table 1.

Major geological units present in the area are (oldest to youngest) the Banded Gneissic Complex (BGC), Ghatol-Khamera Formation, Dagal Formation, Bamanpara-Kundli Formation, and Ganora Conglomerate with overlying Deccan Trap (Grover and Verma, 1993, 1995) (Figure 2). BGC is exposed in the northeastern part of the area and includes gneisses, amphibolite, quartzite, marble, graphite schist, etc. The Ghatol-Khamera Formation is represented by quartz mica schist, gneisses in the southern part, and chlorite phyllite in the northern part. The units belonging to the Dagal Formation include cherty quartzite, magnetite quartzite, carbon phyllite, amphibolite, chlorite schist, dolomite marble, and limestone. The Bamanpara-Kundli Formation exposed over a vast area is represented by garnetiferous amphibole schist, calcareous silicate, and quartzite. These units are migmatized in the western half of the area, separated by a major lineament along which an albitite-greisen zone is developed. The polymict Ganora Conglomerate outcrops in the western part. The geologic map of the Bhukia area is shown in Figure 3 (Grover and Verma, 1995). The survey boundaries for mise-a-la-masse surveys, with current electrodes in BHU-1 and BHU-8, are marked as zones I and II, respectively, on Figure 3. Other boreholes drilled in the area are also shown.

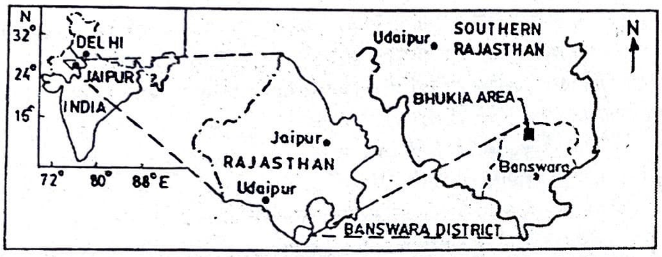

FIG. 1. Location map of Bhukia area, Banswara district, Rajasthan, India.

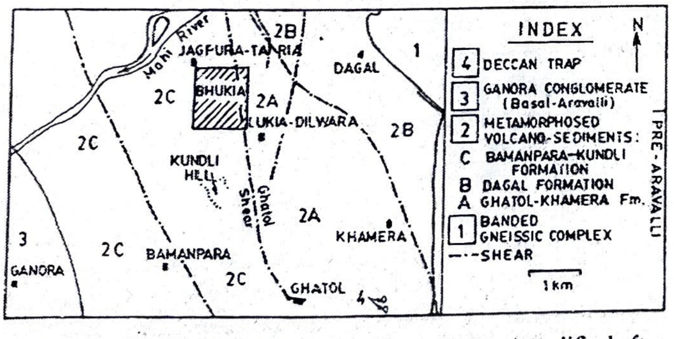

FIG. 2. Regional geological map of Bhukia area (modified after Grover and Verma, 1993).

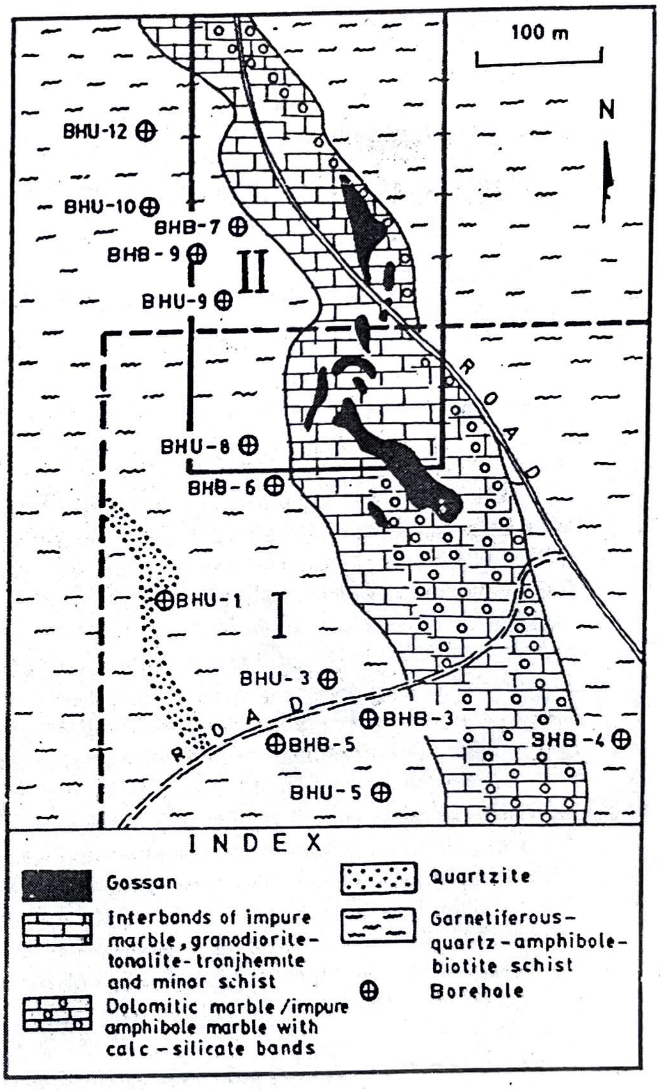

FIG. 3. Detailed geological map of Bhukia area (modified after Grover and Verma, 1995) with locations of boreholes. Regions I and II are mise-a-la-masse survey boundaries with current electrodes in BHU-1 and BHU-8, respectively.

Table 1. Simplified stratigraphy of the study area.

Supergroup	Formation	Lithology
	Recent	Alluvium/soil
	Deccan Trap	Basalts
	~~Unconformity~~~~~	
Post Aravalli Intrusives		Pegmatite, quartz vein, and calcite vein
Aravalli Supergroup	Ganora Conglomerate formation	Pebbles in schistose and siliceous matrix
	~~Unconformity~~~~~	
Pre-Aravalli Supergroup	Bamanpara-Kundli Formation	Garnetiferous-amphibole schist, calc. silicate, and quartzite
	......Tectonized contact......	
	Dagal Formation	Cherty quartzite, magnetite quartzite, carbon phyllite, amphibolite, chlorite schist, dolomitic marble, and limestone
	......Tectonized contact......	
	Ghatol-Khamera Formation	Quartz mica schist, gneisses, and chlorite phyllite
	Banded Gneissic Complex	Gneisses, amphibolite, quartzite, marble, graphite schist, etc.

MINERALIZATION

The area is affected by multiple phases of deformations. The control on mineralization is partly lithological and partly structural. Mineralized shears present in dolomitic marbles near Bhukia are subparallel to the Ghatol shear (shown in Figure 2 but falling outside the area covered by Figure 3). Indications of base metal mineralization in the form of malachite-azurite encrustations, gossans, and ancient mine workings are seen associated with quartz-epidote-garnet carbonate bands within chlorite schist. Fresh sulfide, mainly pyrite and pyrrhotite, and occasional chalcopyrite, gossans, and ancient mine workings are also present in marble, amphibole marble, sulfidic tuff, and quartzite. Ancient prospecting pits are also seen in the area. The search for gold in the area was based on the presence of blue quartz (veins), high arsenic values of Bhukia gossans, and presence of arsenopyrites in drill cores of the Bhukia prospect where large number of ancient mine workings exist. Visible native gold has been located in ancient mine dumps. Sulfide mineralization in the area is in the form of lenses and steeply dipping pipelike orebodies. Surface indications of mineralization found in the area are in old workings, gossans, and wall rock alterations. The mineral localization is along the axial shears and closures of mesoscopic folds. The dolomite marble is the most favored host, though mineralization also occurs in amphibole marble. The old workings generally follow the axial shear of north-northwest–south-southeast trending mesoscopic folds. Along the shears, these are in the form of steeply inclined trenches, which in the nose portions of the folds lead to inclines following the plunge of the folds. The shear fractures in gossans are filled with iron oxide. Studies of the gossans have indicated the presence of pyrite, pyrrhotite, arsenopyrite, and chalcopyrite, in conformity with the chemical analysis results.

Three phases of rock deformations have been identified in the area. The sulfide-hosted gold mineralization is associated mainly with the second phase of deformation and related shearing and shear zones. The gossans, formed by oxidation and leaching of primary massive sulfides, are enriched in gold, which at places is visible in the native form. The major part of the primary sulfides consists of pyrite followed by pyrrhotite, arsenopyrite, and chalcopyrite. The gold is also observed to be closely associated with the arsenopyrite in the primary sulfide.

GROUND GEOPHYSICAL SURVEYS

Detailed ground geophysical surveys were carried out with the objective of locating copper mineralization in the area. The methods employed were SP, IP, resistivity, magnetic (vertical component), and EM surveys. Fifteen conductive zones were located in the Bhukia region, mainly on the basis of EM surveys (Saikia et al., 1977). Figure 4 shows the anomaly axis of conductor 1 which can be divided into a western unit 1a and an eastern unit 1b. Both the units extend from line S4 to line N16 (Figure 4) for a strike length of more than 1 km. Good and moderate conductors have been marked by solid and dashed lines, respectively, on the basis of in-phase and quadrature anomalies. The conductors 1a and 1b have high in-phase to quadrature ratio up to traverse N10; then, the EM response decreases on the northern side. Figure 5 shows SP, magnetic (vertical component), and EM profiles, respectively, for the section with boreholes BHB-3 and BHB-5 (bottom of figure) intersecting mineralized zones at two different levels. Figure 6, for the same section, shows pseudodepth sections for resistivity, frequency-domain IP [percent frequency effect (PFE)], and metal content factor (MCF), respectively. A very strong in-phase EM anomaly is observed over the conductor. Resistivity and IP pseudosections confirm the presence of a good conductor in this zone.

These geophysical surveys were carried out for the exploration of copper ore. The results were subsequently applied to the search for gold-bearing pyrite and arsenopyrite in the same area.

BOREHOLE GEOPHYSICAL SURVEYS

The BHB boreholes in Figure 4 were drilled on the basis of the initial ground geophysical surveys. Subsequently, it was decided to study the possibility of occurrence of gold in the sulfide deposits. Borehole BHU-1 at a nearby site (N4, W90) was drilled to intercept the interpreted sulfide lode within the conductors 1a and 1b identified previously (see Figure 4). Borehole logging and mise-a-la-masse were carried out first in BHU-1. On the basis of the results of the borehole geophysical surveys for BHU-1 as well as the previous ground EM results, BHU-8 was drilled to intercept the same mineralized zone. It encountered five massive sulfide zones. The results of borehole logging and mise-a-la-masse measurements for the boreholes BHU-1 and BHU-8 are discussed below.

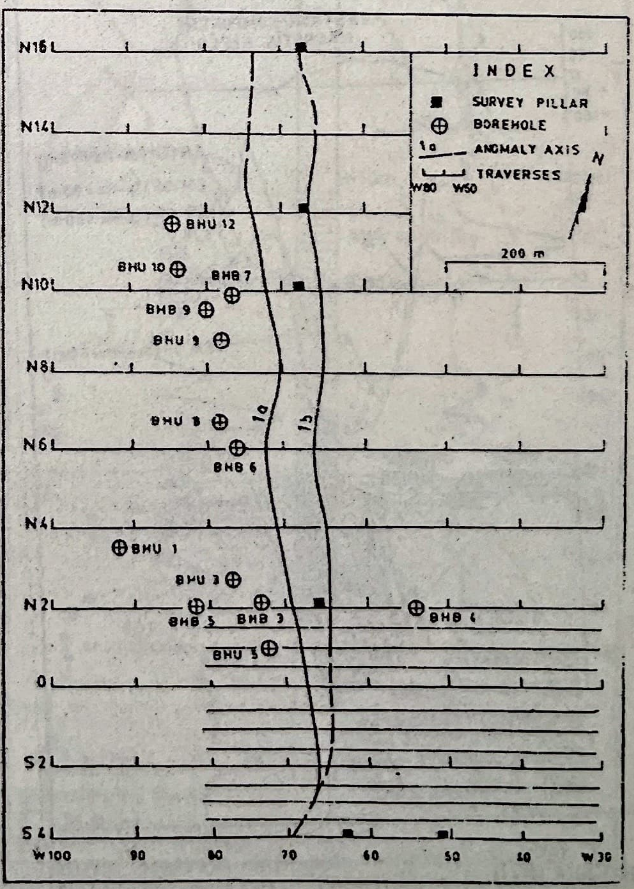

FIG. 4. Anomaly axes of conductors 1a and 1b (modified after Saikia et al., 1977).

Borehole logging

Borehole BHU-1.—The first borehole BHU-1 drilled on the basis of surface manifestations in the area and ground geophysical surveys carried out earlier intersected a 28 m zone of 10–40% sulfide. Its collar inclination is 40° and azimuth N70°E. The borehole was drilled to a depth of 365 m. The massive mineralized zone mainly contains pyrrhotite along with chalcopyrite and arsenopyrite in dolomitic marble. Borehole SP and pole-pole IP (chargeability)-cum-resistivity logging was carried out. In the mineralized zone related to conductor 1a, a low SP (on the order of 200 mV) was recorded from 205 to 245 m (Figure 7). The apparent resistivity log indicates a gradual decrease in values from 141 m depth downwards, and it saturates at a low resistivity value of about 50 ohm-m in the mineralized zone. The logging was carried out only in the shallower part of the borehole and could not be continued for a deeper level much beyond the mineralized zone. Chargeability increases to 26 ms at the start of the mineralized zone. Also, two low resistivity zones are observed between 55 and 74 m and between 127 and 141 m. The lower zone is also characterized by a moderate increase in chargeability. Mineralization has not been encountered in this part of the borehole. The presence of a resistivity and one-point IP anomaly between 127 and 141 m may be indicative of sulfide mineralization in the neighborhood, but this has yet to be confirmed by drilling.

Borehole BHU-8.—Borehole BHU-8 was drilled with a collar inclination of 65° and azimuth N73°E. It intersected five mineralized zones. It was drilled to a depth of 265 m. The sulfide mineralization mainly consists of pyrrhotite, chalcopyrite, and arsenopyrite hosted by impure marble. SP and pole-pole IP (chargeability)-cum-resistivity logging was carried out in the borehole between 20 and 250 m depth (Figure 8). A broad resistivity low on the order of 250 ohm-m is observed over the mineralized zone between 135 and 190 m as compared to 1500–2500 ohm-m of the adjacent rocks. The chargeability response is also moderate to high over the mineralization. A conspicuous high chargeability on the order of 31 ms was recorded at 161 m, which correlates with the richer part of mineralization. The SP response is also anomalously low in the

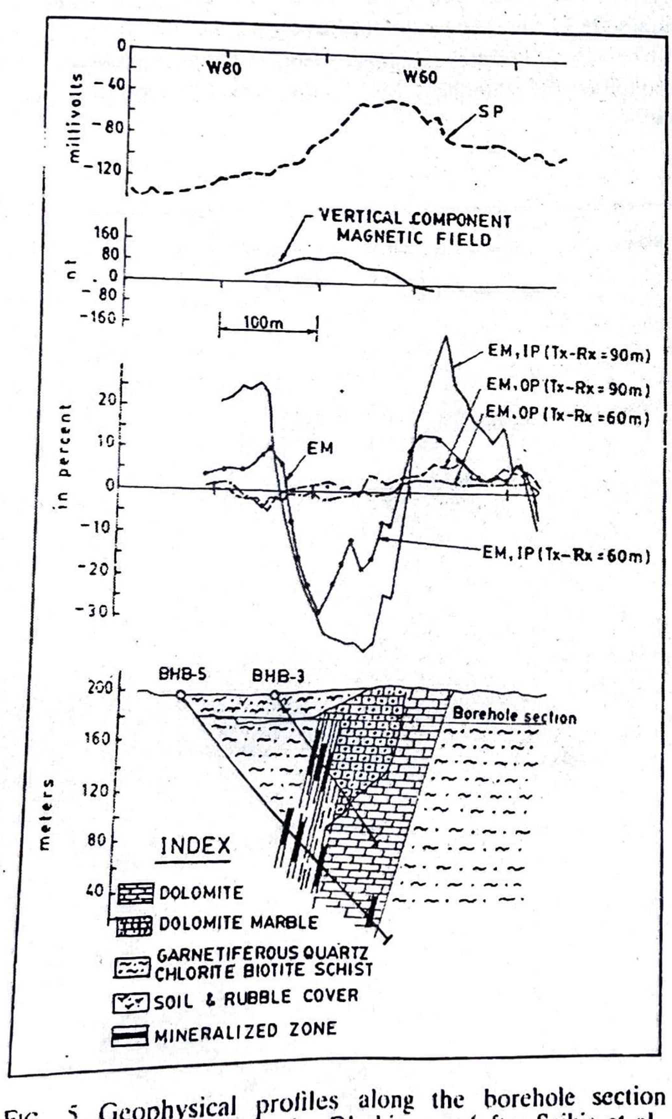

FIG. 5. Geophysical profiles along the borehole section (BHB-3 and BHB-5) in the Bhukia area (after Saikia et al., 1977). The EM profiles were obtained using a horizontal co-planar (Slingram) coil configuration with a transmitter frequency of 2400 Hz.

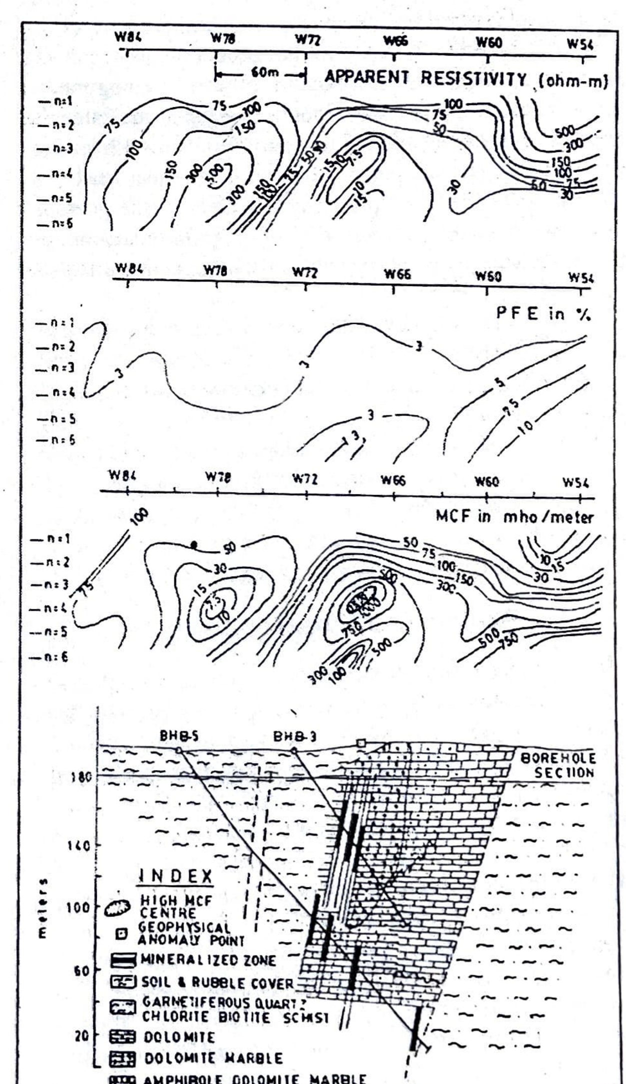

FIG. 6. Resistivity and IP pseudosections along the borehole section (BHB-3) and (BHB-5) in the Bhukia area (after Saikia et al., 1977).

mineralized zones. High magnetic susceptibility values are observed at 168 and 175 m, corresponding to the pyrrhotite rich zones.

Mise-a-la-masse-measurements

The mise-a-la masse method was first attempted by Schlumberger in 1920 (Parasnis, 1966). Only very limited case histories are available for this method (e.g., McMurray and Hoagland, 1956; Garner, 1963; Callaghan and McMurray, 1967; Parasnis, 1967, 1974; Ketola, 1972; Pelton and Hallof, 1972; Cowen et al., 1975; Mansinha and Mwenifumbo, 1983). The mise-a-la-masse measurements were carried out using a Scintrex TSQ-3 (3 kW) transmitter and IPR 10 receiver. The positive current electrode was always planted in the mineralized part of the borehole. The negative current electrode, on the other hand, was located more than 1 km away from the borehole on the updip side. The reference potential electrode was always kept at a great distance (infinity) from the borehole on the opposite side of the negative current electrode. The potentials were measured at stations located in a 10 m × 50 m grid around the boreholes with respect to the reference potential electrode located at infinity. The current electrode in the borehole, consisted of a lead rod attached to an insulated flexible copper wire. The mise-a-la-masse equipotential maps have been prepared by normalizing the potential values for 1 A current (i.e., units are volts/amps).

Borehole BHU-1.—For the purpose of the mise-a-la-masse survey, the sulfide lode was charged at a depth of 230 m along the hole at a point of maximum conductivity as obtained by

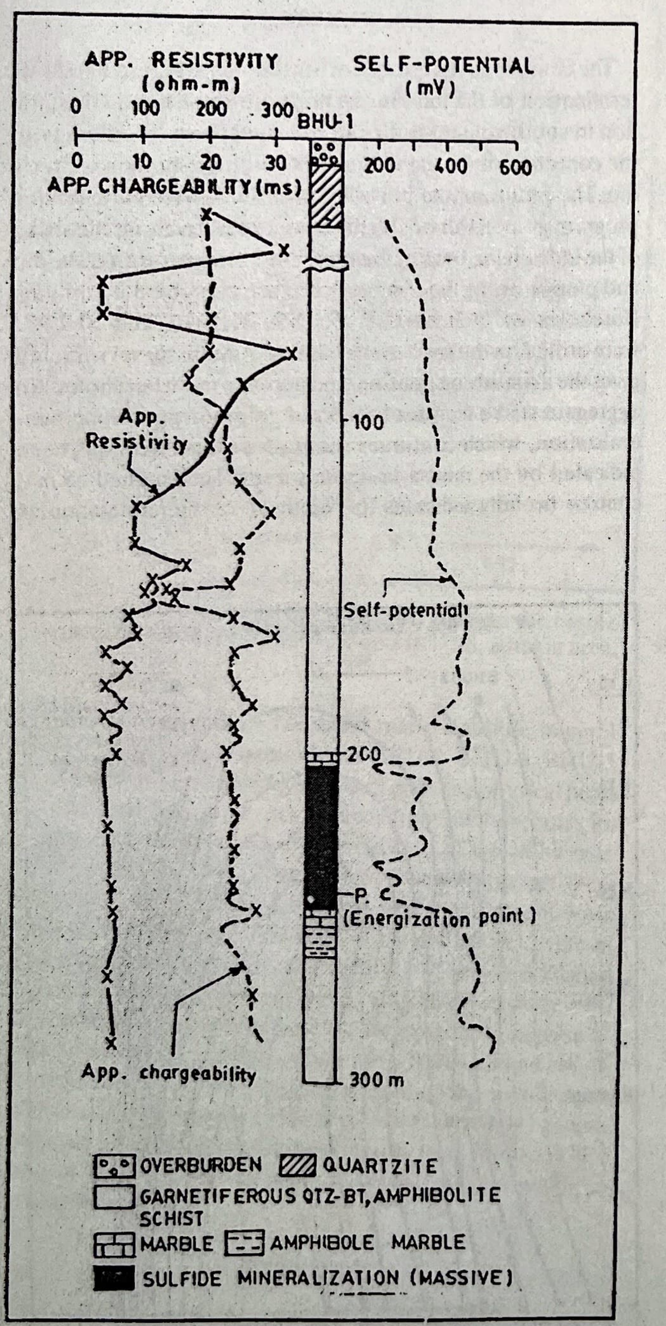

FIG. 7. SP, IP, and resistivity logs in borehole BHU-1, Bhukia area.

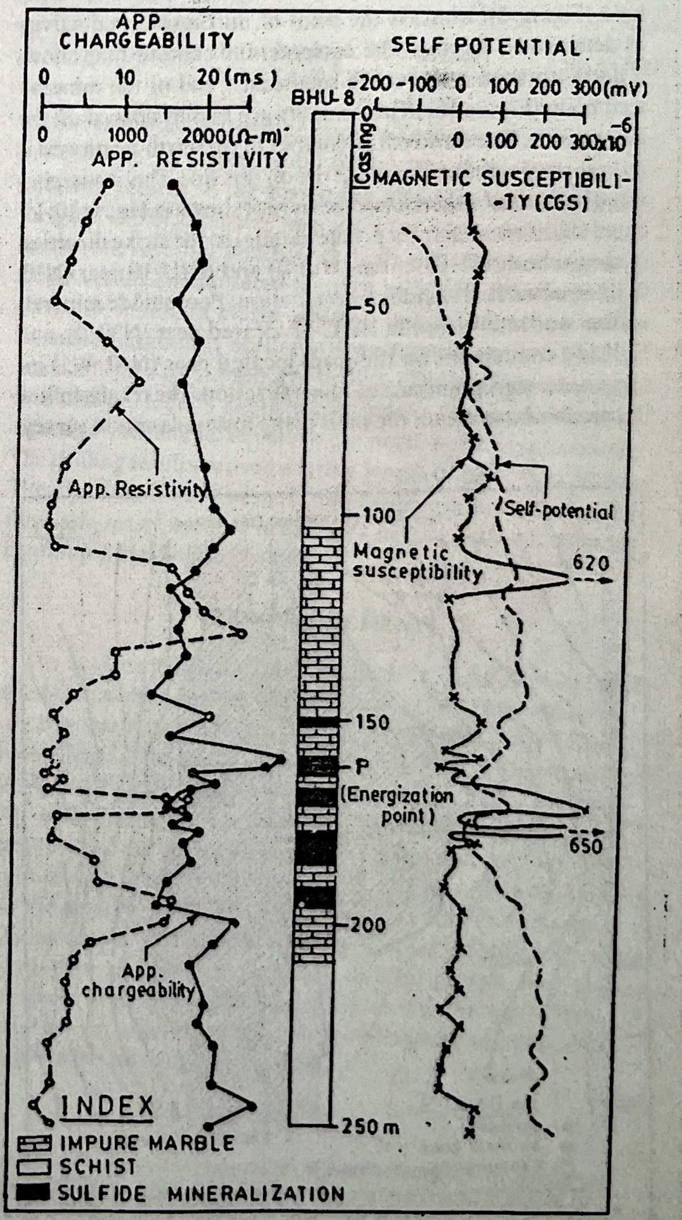

FIG. 8. SP, IP, resistivity, and magnetic susceptibility logs in borehole BHU-8, Bhukia area.

logging. The equipotential contour map indicates a broad anomalous zone (Figure 9). The contours are open towards north as well as south beyond traverses N20 and S20, respectively, indicative of extension of the mineralized lode intersected in borehole BHU-1 for a distance of more than 400 m. The hatched contour envelope of 55 mV roughly delineates the width of the body as projected to the surface. The density of contours on the eastern side also indicates a westerly dip of the body. Gold has been found to be associated with the sulfide mineralization in this borehole. On the basis of the mise-a-la-masse results, boreholes BHU-3, BHU-5, and BHU-8 were drilled to intercept the ore body suggested by the hatched lines in Figure 9. All three boreholes intersected sulfide mineralization.

Borehole BHU-8.—For the purpose of the mise-a-la-masse survey, the mineralized body was charged at 162 m down the hole (Figure 8), which is the point of maximum conductivity as detected by logging. The equipotential contour map shows a north-northwest and south-southeast trend of the mineralized body (Figure 10). The contours are closely spaced on the eastern side. The trend of the contour in the north-northwest is indicative of termination of the ore on this side. This is corroborated by four subsequent boreholes (not shown in Figure 10) located 100 m apart along a profile parallel to the strike direction of the orebody. BHU-9 near (N10, 0) and BHU-10 near (N20, 0) intersected rich sulfide mineralization. Poor sulfide mineralization was intersected in BHU-12 located near (N30, 0), and BHU-14 (not shown on the map) located near (N40, W5) intersected insignificant sulfide mineralization. The results follow the prediction made on the basis of the mise-a-la-masse survey.

Since the intersections in boreholes BHU-1 and BHU-8 lie 100 m apart on the same strike profile, an attempt has been made to prepare a composite equipotential map (Figure 11) based on the data of mise-a-la-masse surveys in both the boreholes. These two surveys were not carried out on the same grid, but, a part of the area overlapped both the surveys. The equipotentials obtained over the overlapping zone of the two surveys were used for applying corrections in the preparation of the composite map. Corrections were applied for matching the equipotential contours over the common area of the survey and for shifting the coordinates of the grid for BHU-8 with respect to a common reference of BHU-1.

RESULTS

The composite equipotential contour map (Figure 11) shows termination of the lode in the north-northwest and continuation in south-southeast directions respectively. The density of the contours on the eastern side of this map shows a westerly dip. The plunge of the body is northerly. A systematic drilling program at intervals of 100 m was undertaken along the strike of the lode on the basis of these mise-a-la-masse results. The dip and plunge of the lode as described are confirmed by drilling. Boreholes BHU-3, BHU-5, BHU-9, BHU-10, and BHU-12 were drilled on the basis of the mise-a-la-masse surveys. Table 2 gives the azimuth, inclination, and depth of these boreholes. An aggregate strike length of 550 m of gold-bearing sulfide mineralization, which continues south of traverse S20, has been indicated by the mise-a-la-masse survey. The hatched 55 mV contour broadly indicates the width of the mineralization as

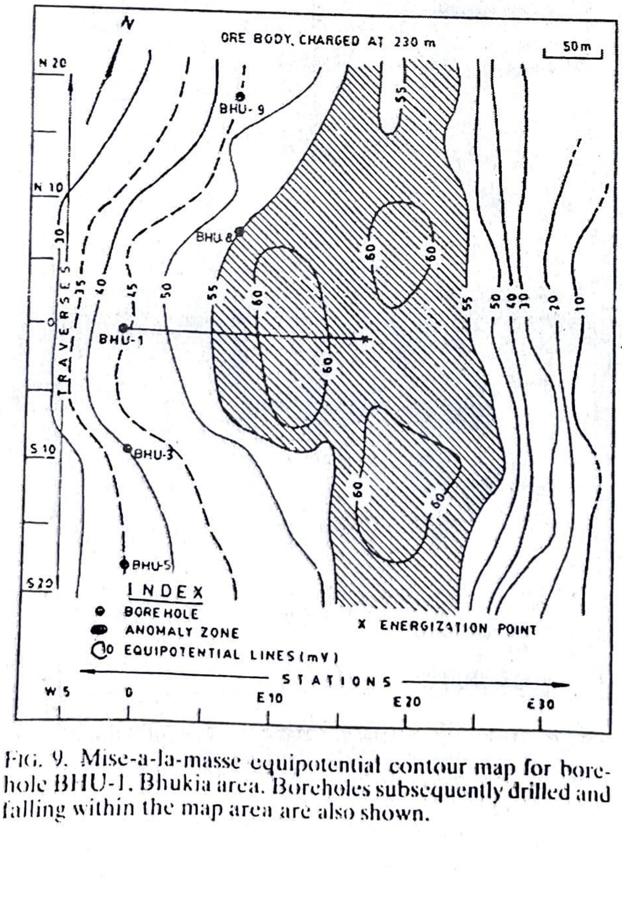

FIG. 9. Mise-a-la-masse equipotential contour map for borehole BHU-1, Bhukia area. Boreholes subsequently drilled and falling within the map area are also shown.

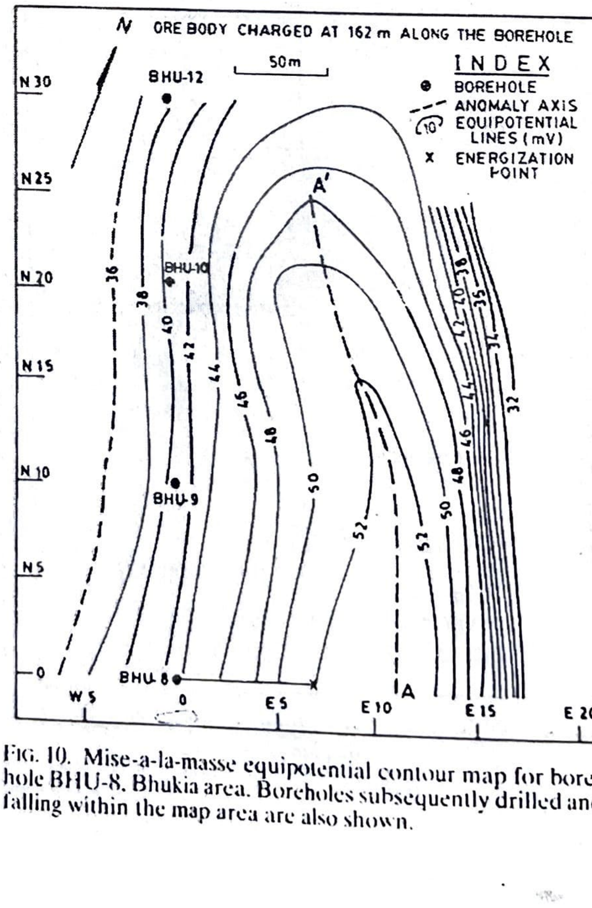

FIG. 10. Mise-a-la-masse equipotential contour map for borehole BHU-8, Bhukia area. Boreholes subsequently drilled and falling within the map area are also shown.

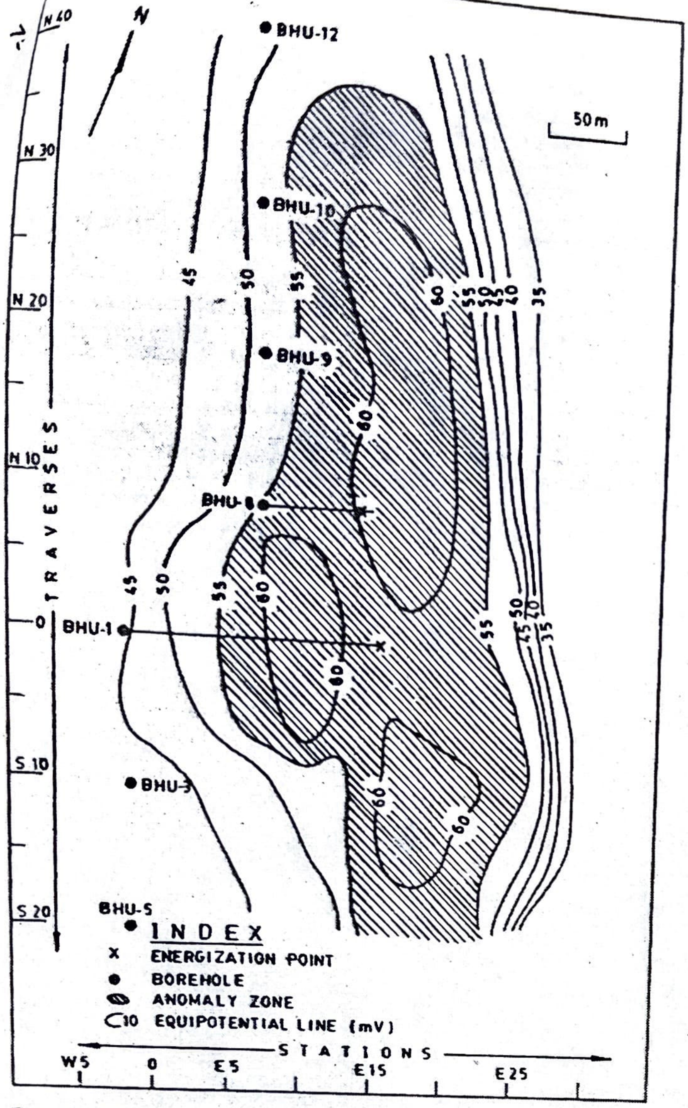

FIG. 11. Composite equipotential contour map on the basis of mise-a-la-masse survey in BHU-1 and BHU-8, Bhukia area.

projected to the surface. The same massive sulfide mineralization was intersected in boreholes BHU-1, BHU-3, BHU-5, BHU-8, BHU-9, and BHU-10. Table 3 gives the physical properties measured from 33 core samples from the boreholes for the mineralized zones and the host rock (i.e., dolomite marble) (Singh et al., 1997). The sulfide mineralization in these boreholes ranges from 10% to 40%, and gold concentration ranges from 2 to 6 ppm. The lode is parallel to the strike of the geological formation. Borehole BHU-12, which is located outside the shaded zone on Figure 11, intersected poor mineralization as was expected from the interpretation of mise-a-la-masse survey carried out for boreholes BHU-1 and BHU-8. Borehole BHU-1 shows presence of gold in the sulfide mineralization and hence the entire conductive zone has become significant for exploration of gold mineralization (Gupta, 1996; Gupta et al., 1999). Mise-a-la-masse surveys are continuing in the adjoining areas.

CONCLUSIONS

Old workings and other surface manifestations (such as gossans, etc.) led to the discovery of the copper mineralization in the area. Subsequent drilling following detailed geophysical surveys showed that the copper deposit was not economically viable. Re-examination of the area showed that native gold was present in the gossan samples. One borehole drilled for gold exploration was also used for mise-a-la-masse measurements. Another borehole drilled on the basis of mise-a-la-masse results encountered massive sulfide in association with gold. The mise-a-la masse contours indicate that the strike of the mineralization is north-northwest–south-southeast, which was confirmed by subsequent drilling. The contours also indicate that the lode is likely to continue in the south-southeast direction and may terminate in the north-northwest direction. The drilling results proved a strike length of more than 500 m. The dip of the lode is westerly and the plunge is northerly. The mise-a-la-masse method in this area has been successful and is continuing in adjoining areas.

Table 2. Details of the boreholes drilled on the basis of mise-a-la-masse measurements.

Borehole	Azimuth	Inclination	Depth (m)
BHU-1	N70°E	40°	365
BHU-3	N73°E	55°	165
BHU-5	N73°E	65°	210
BHU-8	N73°E	65°	265
BHU-9	N73°E	65°	256
BHU-10	N73°E	65°	244
BHU-12	N73°E	65°	276

Table 3. Physical properties from core samples (Singh et al., 1997).

Rock type	Magnetic susceptibility $\times 10^6$ (SI units)	Chargeability (ms)	Resistivity (ohm-m)
Dolomite marble with mineralization	100–4500	18–162	1–2000
Dolomite marble	10–160	10–30	550–95 000

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