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Simple Electrical Logging Technique for Base Metal Exploration

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Abstract—It is well known that electrical logs of boreholes can play a significant role in base metal exploration in identifying mineralised zones, especially when there is core loss or the borehole diameter is small or if drilling is by percussion. However, electrical logging is not widely utilised because of the additional burden on finances and time.

A simple electrical logging technique, based on a pole-pole (hole-to-surface) configuration with one borehole electrode and nearly akin to the single point method, for S.P., resistivity and I.P. parameters, is presented. It is shown that it has the resolution of the single point method and the penetration of a very long normal sonde which is helpful for detection. Besides these features, the main advantage of this technique is that it can be easily carried out using ground I.P. (time domain) equipment.

The electrical logs obtained in different base metal belts in Rajasthan, India, employing this technique and using ground I.P. equipment in connection with misc-à-la-masse surveys, illustrate the above features. A comparison with logs recorded by means of multi-electrode drill hole I.P. equipment of Scintrex, Canada, substantiates the same.

Key words: Electrical logging technique, base metal exploration, polarisability.

Introduction

It is well known that electrical logs of boreholdes drilled in base metal exploration play a significant role in (i) finding the depth and thickness of mineralised intersections, especially in zones of core loss or when the borehole diameter is small or if drilling is by percussion, (ii) correlation of mineralised zones from borehole to borehole, (iii) delineation of lithology and interpretation of surface geophysical data and (iv) planning borehole geophysical surveys.

Generally, self-potential (S.P.) and resistance/resistivity (or conductivity) are considered as the main parameters to confer conductive zones of metallic mineralisation in electrical logging. However, electrical polarisability is also important because the occurrence of base metal deposits in a disseminated form is quite common (BACON, 1965; SMITH, 1985).

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Although electromagnetic logging is increasingly employed, I.P. logging offers some possible advantages, even when the ore comprises massive sulphides and is a good conductor. This is because the target's size is frequently effectively increased by the surrounding zone of alteration and disseminated sulphides which is responsive to the I.P. method. Moreover, the target is in effect brought closer to the hole. In addition, experience has shown that some zones of a fairly high percentage of sulphides, which one would presume to be conductors, do not in fact respond to EM methods but appear clearly as I.P. targets (WAGG and SEIGEL, 1963). Thus, I.P. can provide a useful detection log for larger electrode spacings to detect anomalous zones away from the hole (Scintrex DHIP-2 drill hole I.P./resistivity logger manual).

I.P. logging of underground boreholes in the footwall zones of the Osceola Mine has provided an increased sample volume to detect the presence of copper mineralisation as well as information on geological contacts useful in the interpretation and planning of mining operations. This has been difficult from drill information alone due to the small diameter sample available from horizontal exploratory drill holes (BACON, 1965). The traditional logging tools viz., resistance, natural gamma, density, neutron, etc., which were primarily developed for petroleum exploration in sedimentary rocks are less useful in base metal exploration. Alternative tools such as magnetic susceptibility and I.P. do exist although they are not widely available. A large proportion of modern base metal exploration drilling uses percussion methods and only rock chips are available (at best) for geologic analysis and assay. Clearly, this can lead to poor identification of mineralised intersections and distortions in the geologic log (SMITH, 1985).

Despite these advantages, geophysical logging is not extensively utilised in base metal exploration as it involves additional expenditure due to separate equipment and personnel, and extra time necessary for this purpose. However, the economics can progress better if the ground I.P. cum resistivity equipment can also be used for borehole logging.

The simple electrical logging technique presented in the following is based on experience in base metal exploration carried out in the mineralised belts of Rajasthan, India. It has been employed mainly for identifying the conductive mineralised intersections to aid mise-à-la-masse survey (GUPTA and RADHESHYAM, 1993; SINGH and RADHESHYAM, 1994; unpublished reports of Geological Survey of India). Although geologist's lithology and assay provide the depth and thickness of the mineralised horizons, it is advantageous to detect the best part of the conductive zone to charge the conductor for carrying out mise-à-la-masse survey, which also safeguards from errors in depth, if any, in the geologist's log. This requirement is responsible for making use of surface I.P. (time domain) equipment meant for mise-à-la-masse survey for logging purpose. This technique with a single moving electrode has the advantages of both pole and pole-pole (hole-to-surface) methods with resolution of a single electrode system as well as penetration of normal sonde. Above all, it compensates for the lack of drill hole logger. Practical experience illustrates these advantages convincingly.

Theory

The simplest method of measuring electrical resistance of formations encountered in a borehole employs two electrodes, with one of them lowered into the hole while the other remaining fixed at the surface or at another convenient point (Fig. 1a). In this monoelectrode system, the total resistance depends on the size of the electrodes, the resistance of the connecting cables, the effective resistance of the formations relatively near the electrodes and the salinity of water around in the drill hole. The earth immediately adjacent to the electrodes contributes a major part of the total resistance to the current path. Excluding the material within a few feet of the electrode surfaces, the main mass of earth included between A and B (Fig. 1a) has a relatively low, or negligible, resistance due to its large cross-sectional area (JAKOSKY, 1950). Hence, the total resistance, R, of this circuit is given by

$$R = R_1 + R_2 + R' = (R_1 + R_2) + R' \tag{1}$$

where R_1 = resistance of the cable, R_2 = effective resistance of the fixed electrode 'B' and R' = effective resistance of moving electrode 'A'.

The moving electrode resistance (R') consists of the contact resistance between the electrode surface and the drilling mud filling the drill hole and the effective resistance of the earth material near the electrode. The contact resistance remains relatively constant if the borehole diameter and mud resistivity remain the same,

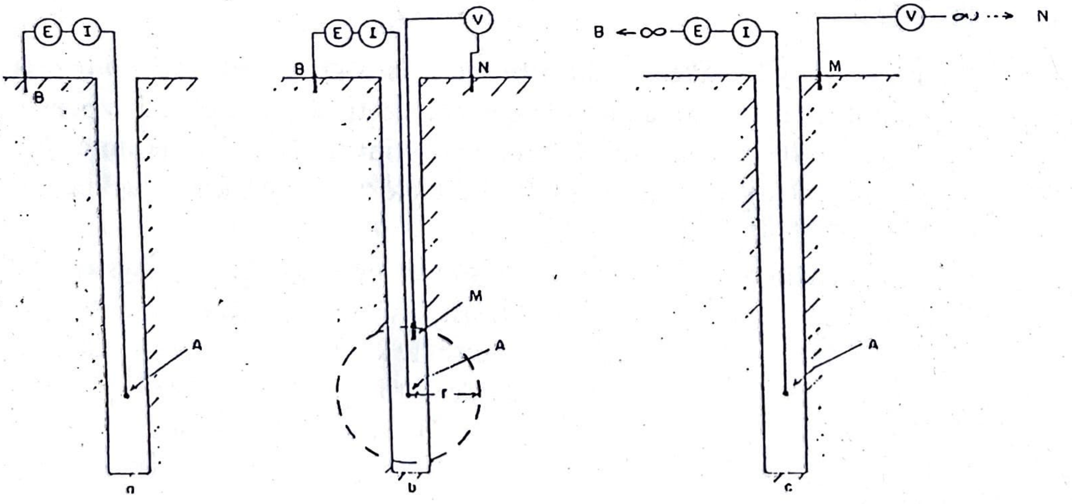

Figure 1
(a) Single point, (b) normal sonde, (c) proposed pole-pole (hole-to-surface) electrode systems.

while the effective resistance of the formation near the moving electrode varies (JAKOSKY, 1950).

Let $R_c = R_1 + R_2$, which remains the same as R_1 and R_2 are constant, and E be the impressed D.C. voltage between electrodes A and B. Then, the current, I, in the circuit is expressed as

$$I = \frac{E}{(R_c + R')} \quad \text{or} \quad \frac{E}{I} = R_c + R' = R_m \tag{2}$$

R_m being the resistance measured. Also,

$$\frac{1}{I} = \frac{R_c + R'}{E} = \frac{R_c}{E} + \frac{R'}{E}. \tag{3}$$

Hence the changes in monoelectrode resistance (R_m) or inverse of current (I^{-1}), if E is kept fixed, represent variations in lithology in the immediate vicinity of moving electrode 'A', being proportional to the resistance of the active electrode, which is dependent on the resistivity of the surrounding formation. If the moving electrode is of small size (a few inches of length), the single electrode system provides considerably better resolution than the multiple moving electrode system.

In the normal sonde, the effects of potential drop adjacent to the moving power electrode are removed by making resistivity measurements over a short section of the total current path which is sufficiently distant from the moving power electrode to be unaffected by minor variations in its vicinity (Fig. 1b) (JAKOSKY, 1950). It follows that the potential difference measured is equal to the potential, V, of the electrode 'M' as the other potential electrode is distant, and the apparent resistivity, ρ_a, assuming that the surrounding medium is not homogeneous, is given by

$$\rho_a = 4\pi AM\left(\frac{V}{I}\right). \tag{4}$$

Actually, ρ_a, may be taken as the average resistivity associated with the interval between the potential electrode and the current electrode. The effective penetration is twice the electrode spacing (AM) and varies inversely with the hole diameter (TELFORD *et al.*, 1976). Normal log may be blind to beds whose thickness is less than electrode spacing.

The present technique is effectively a single moving electrode system with a facility for the measurement of apparent resistivity and chargeability like a normal sonde but with the moving potential electrode kept fixed at the collar of the borehole (Fig. 1c). Therefore, it is equivalent to pole-pole (hole-to-surface) or normal sonde with spacing, AM, varying. This method has the advantage of detecting thin beds in the resistance log or current log, if impressed voltage is maintained constant, as in a single electrode system, as shown earlier (Eqns. (2) and (3), and the benefit of lateral penetration, similar to long normal or lateral techniques, because of large AM, though varying. The potential variations observed at a fixed point near the mouth of the borehole essentially reflect changes in current controlled by the resistivity of the formation surrounding the borehole electrode. But the potential is determined by the average resistivity of the lithology of the column between the borehole current electrode and the surface potential electrode. As such, the apparent resistivity log, obtained from current and potential measurements using eqn. (4), represents variations in lithology, akin to an elongated normal system probing side-ways with better resolution in the absence of 'adjacent bed effect'. This is amply indicated as some of the logs discussed in the following detected mineralisation occurring in fractured zones and have not been affected by borehole diameter variations. The same is also true of apparent chargeability log. An S.P. log is recorded by turning off the current source.

Equipment and Field Techniques

This logging method can be easily conducted by means of any I.P. cum resistivity (time domain) equipment used in ground surveys. A few inches long, say about 10", lead rod may be utilised as the active current electrode moving inside the borehole. The other current electrode and one of the potential electrodes presumed to be at infinity are located distantly from the borehole and apart from each other, as shown in Figure 1c, while the other potential electrode is fixed near the collar of the borehole. The wires to the remote electrodes are never side-by-side and generally in-line on either side of the borehole along the surface I.P. traverse across the strike of the formations. However they can be orthogonal to each other. The cable used for surface I.P. survey (4 mm^2 PVC insulated copper wire, current rating: 15A) is adequate as borehole electrode cable. If a winch with a counter is not available, the cable initially calibrated at 10 m interval is further calibrated at a closer interval while carrying out logging, depending on the requirement. This is not a major problem as boreholes for base metals, in general, are not very deep unlike those in petroleum and coal exploration.

The power input to the ground is chosen after checking the current and potential values noticed while lowering the borehole current electrode. Nonetheless logging is conducted bottom to surface; the observation interval varying from 0.25 to 10 m depending on the lithology and thickness of zones of interest. The parameters measured are current in the circuit and potential and chargeability at the collar of the borehole. Although the logs are from discrete measurements, they have been found to be comparable to logs recorded by regular electrical loggers (e.g., IRIS, France; Scintrex, Canada). In the case of drill hole I.P. cum resistivity loggers, observations have to be at intervals. This is the case with Scintrex DHIP-2 logger too. S.P. measurements are made separately, turning off the current and reading the potential difference between the borehole electrode and potential electrode located at the collar of the borehole.

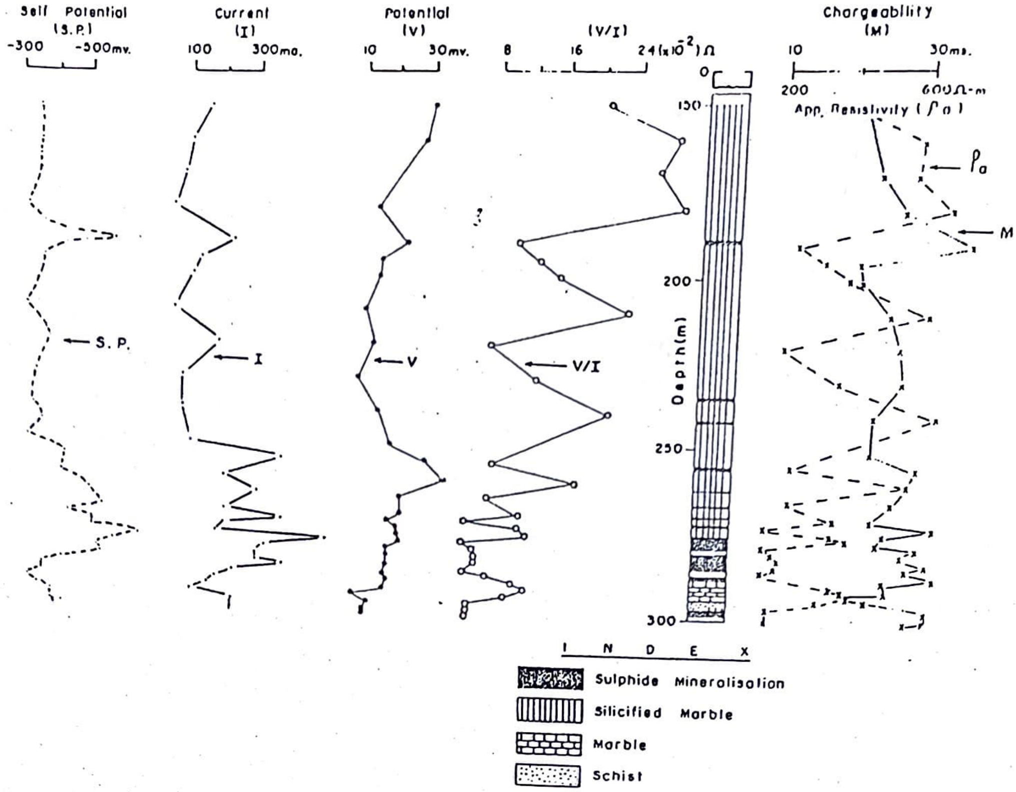

Figure 2
Electrical logs of a borehole in Sawar base metal belt, Ajmer district, Rajasthan (simple technique).

Discussion of Results

Numerous boreholes have been logged using this technique in different base metal belts of Rajasthan (India) to facilitate mise-à-la-masse surveys, as mentioned earlier.

(a) Demonstration of Technique

A borehole logged in Sawar belt, Ajmer district, is considered for illustration of the technique. The rock types encountered in this borehole are mainly marble and quartzite of Delhi Super Group and gneiss and schist belonging to Aravallis of the Proterozoic belts of the northwestern Indian shield. The dip of the formations is steep to near vertical. The intersections of base metal sulphide mineralisation and their potential are known from the lithology of the borehole. Since the mineralised zones in the depth range 250–300 m are considered as significant, the observation interval of logging was reduced from 10 to 5 m and then to 1 m in this zone.

The left side in Figure 2 shows the self-potential, current I, impressed voltage being constant, potential V (measured near the collar) and resistance (V/I) logs. It can be seen by comparison with the adjacent lithology, how well the conductive sulphide intersections are indicated as high current and low resistance zones, as expected. The apparent resistivity ($= 4\pi d \cdot V/I$, using the geometric factor of conventional normal sonde, 'd' being the depth of the moving current electrode) and chargeability logs illustrated on the right side in Figure 2. clearly demarcate the conductive mineralised zones with high chargeability (GUPTA and RADHESHYAM, 1993, unpublished report of GSI). Some sulphide zones within 250 m have not been very well brought out in logs, mainly due to the large depth interval chosen between measurements in this region since they are not of interest.

Normally, only apparent resistivity and chargeability are recorded. However, keeping impressed voltage fixed, current, potential and resistance logs are also shown to demonstrate that current log at constant voltage is similar to point resistance, although with polarity reversed (Eqn. (3)), and potential measured at the borehole mouth for each current electrode depth enables resistance estimation and finally apparent resistivity leading to a log similar to that of normal sonde with large penetration.

Although the average resistivity of the litho-column between the borehole current electrode and the potential electrode at the collar of the borehole is expected to be on the lower side due to the presence of mineralised zones above, when the current electrode is in the depth range, 300–250 m, the average potential (V) is on the higher side as the average current is high because of several conductive zones. As such, in the mineralised sections, resistance/apparent resistivity is decreased as current is higher than the average value while it is increased in the zones separating them. However in the depth range, 180 to 150 m, the increase in potential has to be attributed to the high average resistivity, lithology being silicified marble, giving rise to high apparent resistivity.

Expressions for potential using images, when a dyke of anomalous resistivity and finite width is traversed, for different positions of one current electrode, have been derived (TELFORD *et al.*, 1976).

(b) *Comparison with Scintrex Drill Hole I.P. Logs*

For this purpose, a borehole in Kayar-Ghugra mineralised belt in the Ajmer district was logged employing this simple technique as well as DHIP equipment of Scintrex, Canada, for detection logging (GUPTA and RADHESHYAM, 1993, unpublished report, GSI).

The area adjacent to the borehole is part of the east Central Proterozoic regime of the Delhi Super Group and the lithological units comprise metamorphosed argillites, arenites and carbonates.

The self-potential, apparent resistivity and chargeability logs as observed with the surface I.P. equipment, using the present technique, are shown on the left side in both Figures 3 and 4 while the apparent resistivity and chargeability logs, also from discrete measurements obtained with drill hole I.P. equipment, are presented on the right side in the same figures. The drill hole I.P. employs the three electrode array with scope for several electrode separations ($AM = MN =$ 'a' or spacing $S = 1.5a$). The largest separation (a) possible is 40 m. Hence it is essentially detection logging. Of course, background I.P. parameter observed may supplement lithology delineation, provided the beds are adequately thick in comparison to separation, which is more likely in the case of smaller separations. In Figure 3, drill hole I.P. logs for electrode separations $a = 2.5$ and 20 m are shown and the same for separations $a = 10$ and 40 m are presented in Figure 4. This is to make figures legible for easy comparison.

It can be observed from the lithology that logs of simple technique have resolution comparable to single electrode method, except in zones of less importance covered by wide interval observations, and they match well with drill hole I.P. logs for the smallest separation ($a = 2.5$ m). This is because many beds satisfy the condition that if bed thickness is greater than twice the spacing, the lateral curve records the formation resistivity when MN is small (TELFORD *et al.* 1976; KAYAL,

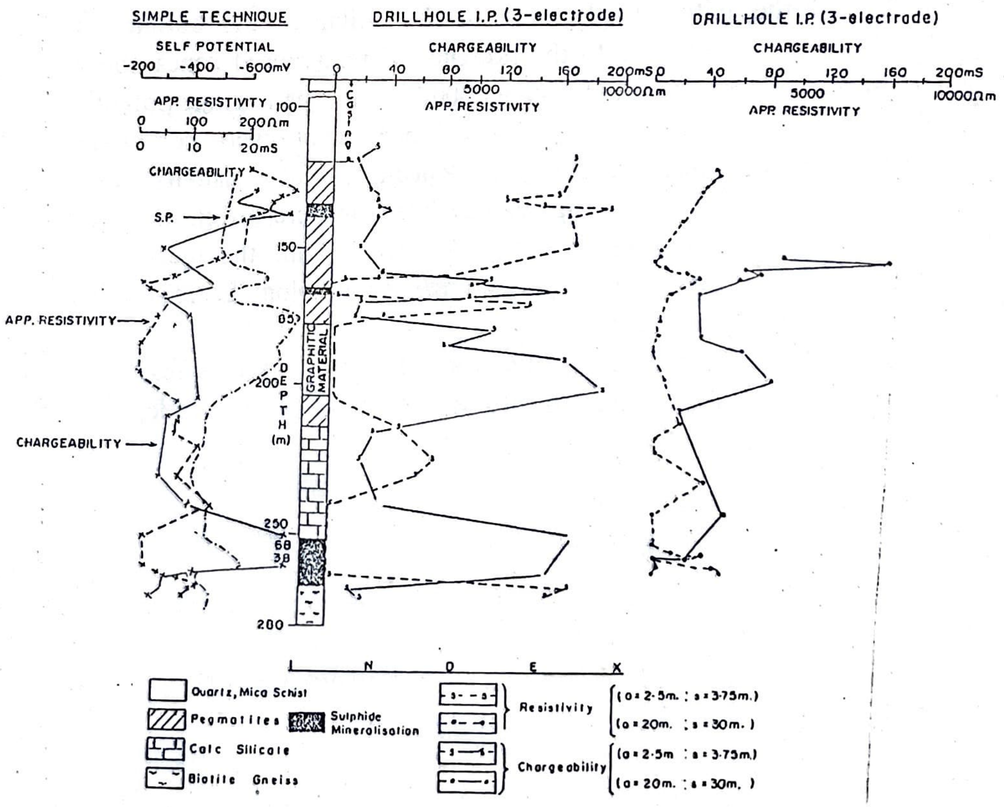

Figure 3
Comparison of electrical logs recorded by simple and drill hole I.P. ($a = 2.5$, 20 m) techniques, Kayar base metal belt, Ajmer district, Rajasthan.

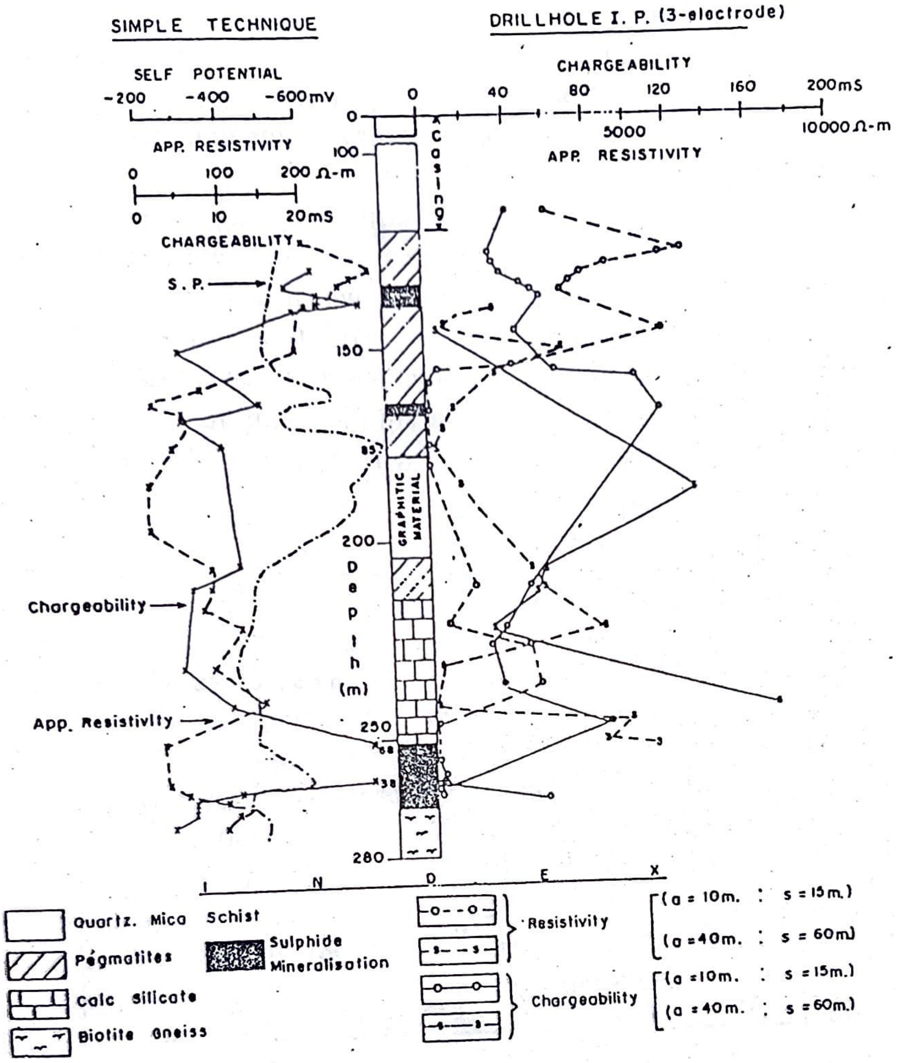

Figure 4
Comparison of electrical logs recorded by simple and drill hole I.P. ($a = 10$, 40 m) techniques, Kayar base metal belt, Ajmer district, Rajasthan.

1979). For Scintrex drill hole I.P. this may be taken as '$4a$' since $AM = MN = a$. Regardless, differences are noticed, as can be seen against the calc-silicate zone between 200 and 250 m, though responses are similar. They may be attributed to a larger effective penetration of the present technique, as substantiated by the similarity to the response for larger separations, $a = 10$ and 20 m also, though three electrode logs are affected by asymmetry. In essence, this demonstrates that the pole-pole (hole-to-surface) method suggested has the dual advantage of the single point and long normal methods of logging, as mentioned while discussing theory. Besides, the problems of the apparent thinning and thickening of beds, depending on the resistivity in normal sonde logs, and the asymmetry of lateral arrangement, are not present.

Apparent resistivity and I.P. logs recorded with the Scintrex drill hole I.P. unit enable only qualitative interpretation for the detection of mineralised zones in and around the borehole. Zones of base metal mineralisation, in general, are thin and it is difficult to capitalize on multiparameter geophysical logging which involves quantitative interpretation carried out in sedimentary basins comprising very thick beds for coal and petroleum. However, the values of apparent resistivity and chargeability observed using the proposed technique, in general, are of the order obtained in surface I.P. cum resistivity profiles that indicate the presence of mineralised zone. This is demonstrated in Figure 5 which displays the surface I.P. and resistivity profiles observed for dipole-dipole array ($n = 3$, $a = 60$ m) over the transverse on which the logged borehole is located (GUPTA *et al.*, 1995). This further points to the greater penetration of the simple technique. But logs can be interpreted only qualitatively, which is the case with commercial borehole loggers also in the case of base metal exploration.

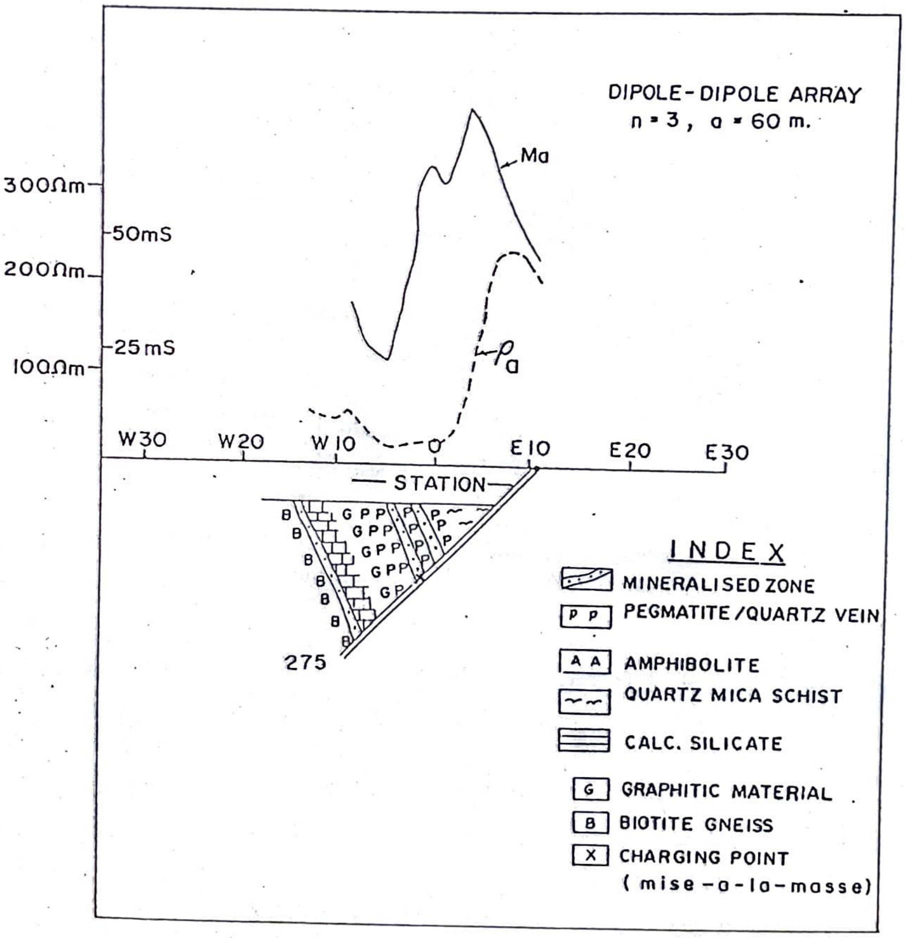

Figure 5
I.P. cum resistivity profiles along the traverse passing through Kayar–Ghugra borehole.

It may be mentioned that a few shallow measurements made with the Scintrex logger have been affected by casing (Figs. 3 and 4) as at least one potential electrode happened to be inside the cased part of the borehole. Probably, the shallowest observation with the current electrode about 4 m below casing, carried out with our technique, might have been influenced by the long casing column above.

It is well known that routine electrical logging is not conducted in the cased portions of the borehole.

(c) Effect of Environment, Depth and Thickness

The electrical logs shown in Figures 2 and 3 clearly reflect the resistive nature of the formations which comprise rock types such as silicified marble, pegmatite, quartz mica schist and calc-silicate in which sulphide mineralisation occurs. The sulphide zones have been picked by the logs irrespective of the depth of burial and thickness. For comparison, we refer to Figure 6 in which logs recorded in a borehole in the Bhukia gold prospect area, Banswara district, are presented. The litho-units in the area are marble, dolomitic marble, quartzite, amphibolite, sulphidic tuff, gossans, etc. The apparent resistivity log reveals the highly conductive nature of the host medium (impure marble), the maximum apparent resistivity being 27.6 ohm-m. It is interesting to observe that more conductive sulphide zones occurring in the conductive host environment have been brought out in the logs, though measurements could not be made below 190 m depth due to very low potentials occasioned by the highly conductive formations which also made I.P. measurements unfeasible (SINGH and RADHESHYAM, 1994, unpublished report, GSI). The shallowest observation at less than 30 m depth appears to have been influenced by the boundary effect of the insulating ground surface, resulting in an increase of resistivity. In such situations, it may be advisable to keep the potential electrode at a radial distance of 40 m from the borehole, instead of locating it at the collar of the borehole, and repeat the observations from 40 m depth upwards (LEE and DAMIATA, 1995). This may promote understanding of the ground effect from the observations in the unaffected overlapping part so as to arrive at the acceptable apparent resistivity for depths less than 30 m.

Figure 7 presents the electrical logs recorded in a borehole in Pindwara-Watera mineral belt in the Sirohi district (GUPTA and RADHESHYAM, 1993, unpublished report, GSI). The noteworthy feature of these logs is the delineation of a very thin sulphide band very well by all the three logs, namely, S.P., resistivity and I.P.

It is evident from the logs illustrated that electrical logs recorded, employing the proposed simple technique and using the ground I.P. (time domain) equipment, have good resolution and are not influenced by host rock resistivity or depth of burial, barring possibly the insulating ground surface influence at very shallow depths.

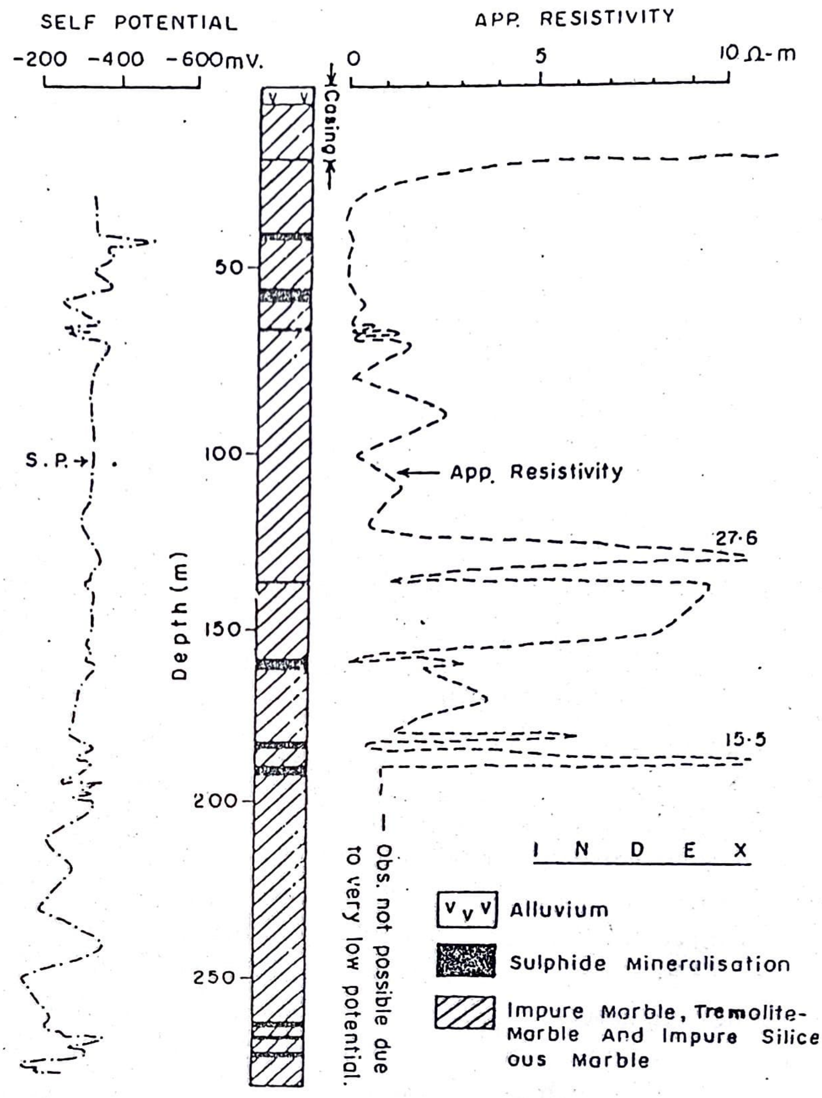

Figure 6
Electrical logs of a borehole in the Bhukia gold prospect area, Banswara district, Rajasthan (simple technique).

Conclusions

It is shown that the pole-pole (hole-to-surface) method in which the current pole moves in the borehole while the potential pole remains fixed on the ground near the collar of the borehole, can be a very effective and simple method for electrical logging in base metal exploration. This method has the capabilities of both single electrode and long normal methods, in the form of resolution of the former and penetration of the latter which may be useful in the detection of mineralised zones in the area adjacent to the borehole. However, the major advantage is that it can be easily conducted with ground I.P. (TD) equipment for the three parameters viz. S.P., electrical resistivity and I.P.

The above features of the method have been demonstrated by logs recorded by means of this simple technique, using ground I.P. equipment in different base metal belts of Rajasthan, India, as well as by a comparison with logs obtained employing multi-electrode drill hole I.P. equipment of Scintrex, Canada.

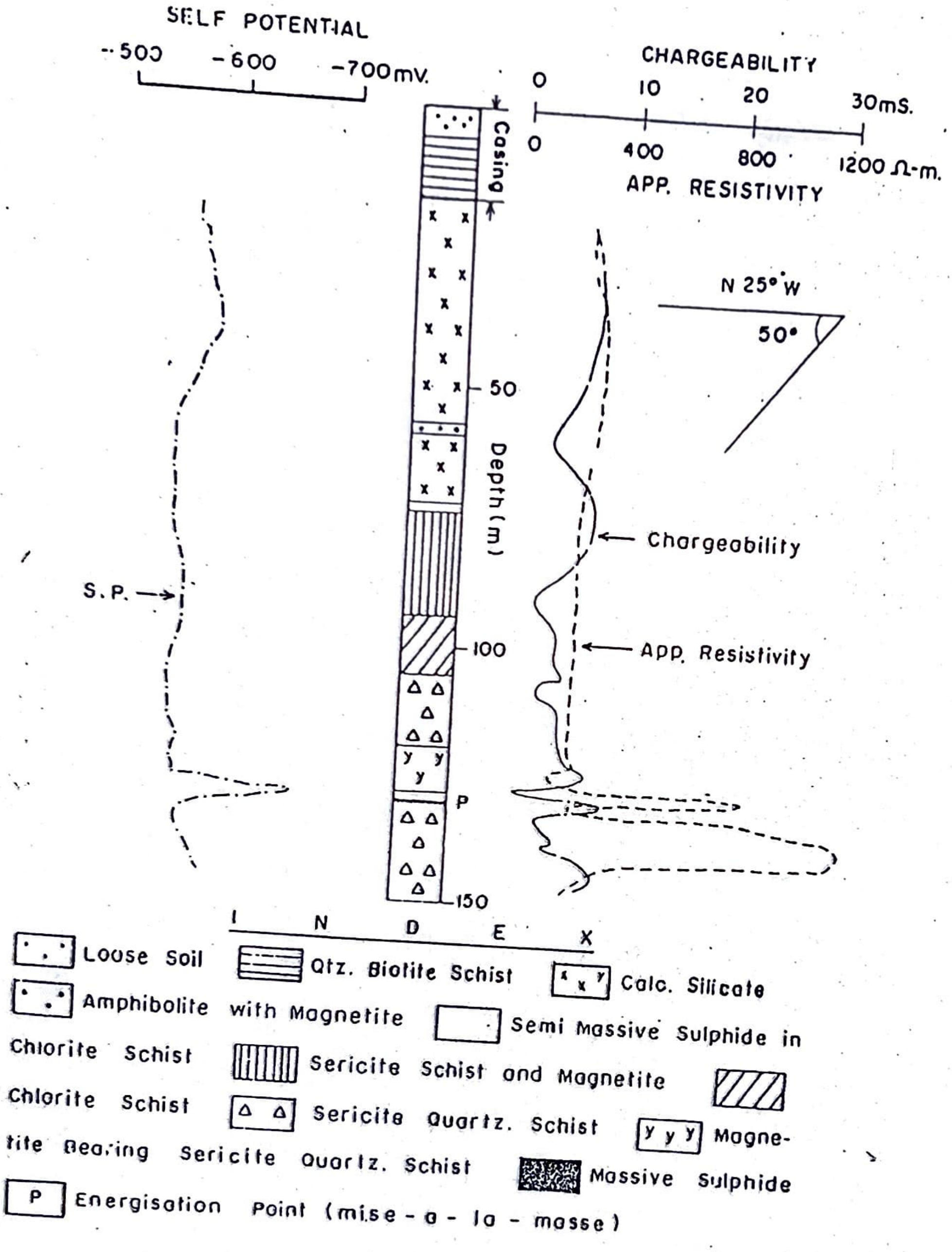

Figure 7
Electrical logs of a borehole in the Pipela area, Pindwara-Watera base metal belt, Sirohi district, Rajasthan (simple technique).

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