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Geophysical Prospection for Base Metal Sulphides in Gehab Prospect, Wadi Bidah, Kingdom of Saudi Arabia

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ABSTRACT. This paper presents the geophysical study of base metal sulphide deposit (of mainly Cu and Zn) in Gehab prospect using self potential (SP) and induced polarization (IP) methods. The interpretation of the geophysical data revealed that the mineralized zone can be divided into three distinct parts according to the subsurface extensions of this zone. The northern and central parts of this zone are associated with weak SP and IP responses, which reflect insignificant surficial mineralization represented by the gossan outcrops with very shallow depth extent. The southern part, which contains most of the proved reserves, is associated with relatively strong SP and IP anomalies caused by sulphide deposits which extend to considerable depths beneath the outcropping gossans. A distinguishable continuation of strong incomplete IP anomalous zone is observed in the extreme south of the prospect area. This extension is not associated with any gossan outcrops which suggests that a corresponding burried sulphide extension occurs in the extreme south and extends outside the surveyed area. This mineral extension would possibly increase the reserves in the prospect area. The study of the geophysical response also suggests that the subsurface configuration of the mineral zone is controlled by two distinguishable NE faults.

Introduction

Gehab prospect occurs in the northern part of Wadi Bidah district to the southwest of the Kingdom of Saudi Arabia (Fig. 1). The prospect area is covered by the Precambrian basement complex of the Arabian Shield which includes a NS striking zone of gossan outcrops. In addition to the iron and manganese oxides, the gossan outcrops have showings of copper and zinc minerals. The area was a subject of geological exploration and drilling investigations carried out by the U.S. Geological Survey (Earhart and Maawad 1970, Kiilsgaard *et al.* 1978). Additional geological work was later conducted by Riofinex Geological Mission (1979).

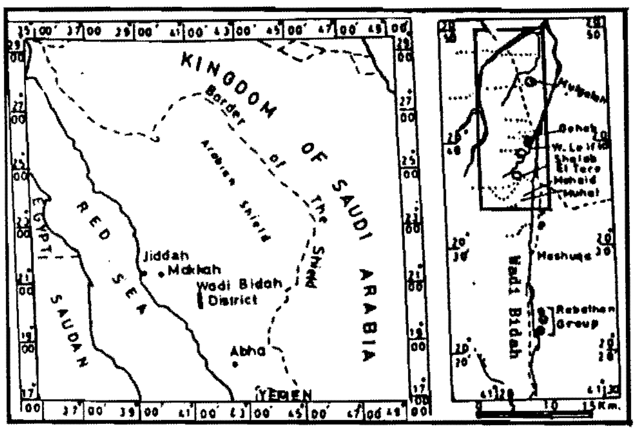

FIG. 1. Location map of Wadi Bidah district and Gehab prospect.

The previous studies revealed that the prospect is of base metal mineral interest of mainly Cu and Zn with traces of Ag and Au. It was reported that the mineral reserves occur mainly in the subsurface sulphide mineralization zone, beneath the southern gossan, and the reserves lie below the economic margin. They recommended further geophysical and drilling investigations in a trial to discover any subsurface extensions of minerals which tend to increase the reserves. At the same time, the detailed subsurface configuration of the mineralized zones will also be delineated.

This paper deals with the geophysical survey conducted in Gehab prospect in line with the previous recommendations. The survey was done as a part of an M.Sc. Thesis carried out by Ibrahim (1986) at King Abdulaziz University. However, the paper presents a reinterpretation of the geophysical data, included in the thesis, and reaches interesting and new conclusions about the mineral potential in the area.

Self potential (SP) and induced polarization (IP) surveys were conducted along a set of profiles which covers the gossan outcrops. The final geophysical data are presented in forms of SP maps, IP pseudosections and IP filtered maps. The reinterpretation of the data resulted in the discovery of a possible extension of the mineralized zones in the extreme south of the surveyed area, and revealed the approximate model of the subsurface configuration of these zones.

Geology

The regional geological setting of Wadi Bidah district, which includes the prospect area, is mainly drawn from Jackman (1972), Greenwood (1975) and Riofinex Geological Mission (1979). The district is mainly a NS trending anticline which plunges due south. The older metavolcanic rocks (Gharb Group) occur in the core, while a sequence of Bidah Group rocks and younger Sharq Group rocks crop out in the limbs. These proterozoic rock groups were later intruded by granitic stocks and overlain to the northeast by Tertiary basaltic rocks. The district suffered different phases of faulting trending mainly NS and NW-SE. Broad shears, showing signs of hydrothermal alterations, occur in the vicinity of ancient mines and outcropping gossans. A number of mineral prospects were discovered in the upper Gharb unit which crops out in the eastern limb of the anticline. They were a subject of several exploration studies as base metal targets of mainly Cu, Pb, and Zn minerals.

The detailed geological mapping of the Gehab prospect (Fig. 2) is mainly based on the previous geological exploration carried out by the U.S. Geological survey (Kiilsgaard *et al.* 1978) and Riofinex Geological Mission (1979). The prospect area is covered by the upper Gharb Group which is composed mainly of amphibolite-hornblende porphyry, sericite-quartz schist, jasperoid chert, and chlorite schist. These metavolcanic rocks were originally basaltic and andesitic to dacitic volcanoclastic rocks. A felsic dyke cuts through the middle of the mapped area in a NE trend, while quartz veins are observed in various places. The gossan outcrops are aligned in a NS direction in the middle of the prospect area where they are referred to as the southern, central, northwestern, and northeastern gossans.

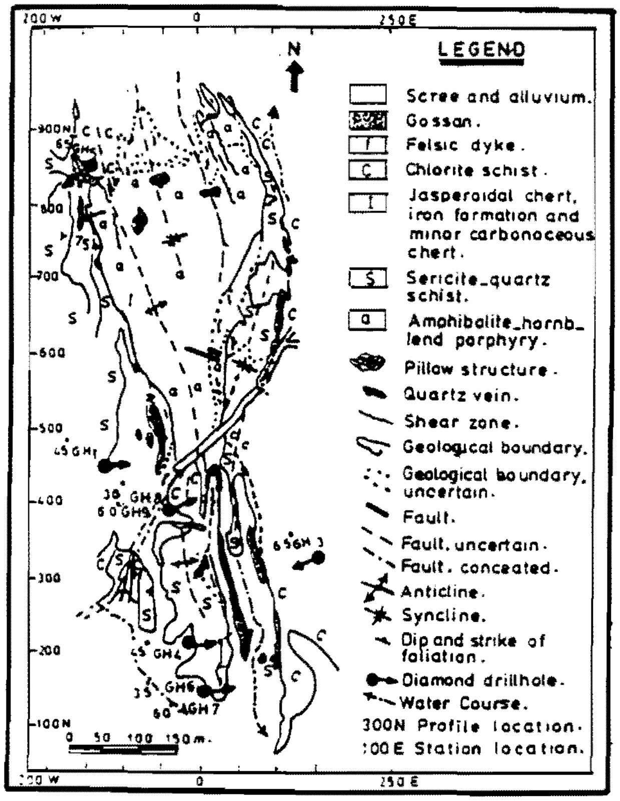

FIG. 2. Geologic map of Gehab prospect (after Ibrahim 1986).

Two fault systems trending NS and NE-SW are mapped in the area, as well as a number of NS trending shear zones.

The mineralized zones are believed to be associated with the gossan outcrops which represent the oxidized products of these zones. The gossans were detected in the subsurface by nine drill holes (Fig. 2) recommended from the geological exploration work. The drill holes succeeded to intersect a subsurface sulphide mineralization zone beneath the southern gossan only, while they did not intersect any significant mineralization beneath the other gossans. The discovered minerals were mainly pyrite, chalcopyrite, and sphalerite associated with traces of silver and gold. Therefore, the mineral reserves are located beneath the southern gossan where they were estimated as 1.3 million tonnes grading 1.56% Cu, 0.94% Zn, 0.09 gm/ton Au and 5.3 gm/ton Ag (Earhart and Maawad 1970). The origin of mineralization is still a subject of controversy. Roberts *et al.* (1975) concluded that the Gehab sulphide deposit is a post-volcanic replacement of an intrusive quartz porphyry sill. Kiilsgaard *et al.* (1978) regarded the deposit as strata bound conformable with the original sedimentary bedding, while the Riofinex Geological Mission (1979) assumed that the mineralization is essentially stratiform and resulted from chemical sedimentation in a volcanic-volcanoclastic succession.

Ground Geophysical Survey

The ground geophysical survey was conducted along a number of profiles set normal to the gossan outcrops and covers the whole prospect area. The profile separation was selected as 100 m, while the station spacing, along each profile, was set as 20 m. The self potential (SP) and the induced polarization (IP) methods were selected as the most convenient geophysical techniques to detect the sulphide mineralization at shallow and greater depths, respectively. A summary of the SP and IP techniques, survey specifications and data reduction is provided hereafter.

Self Potential (SP) Method

The self potential (SP) method is a geophysical exploration technique based upon the natural potential in the ground arising from sulphide bodies that extend in the oxidation zone. The SP phenomenon is attributed to the equilibrium potential of the chemical reactions which take place on the surface of the sulphide body (Sato and Mooney 1960). However, it was later formulated successfully in terms of nonequilibrium thermodynamics (Kilty 1984). The SP survey techniques have been widely used in the exploration of shallow sulphide deposits where they are marked by distinguishable voltage lows measured in millivolts (mV). Further details about the origin, field techniques and methods of interpretation are discussed in most of the geophysical text books, *e.g.* Telford *et al.* (1978).

The SP technique was applied in the prospect area as an economical reconnaissance tool of exploration for the shallow mineralized zones in the subsurface. The SP survey was carried out along ten traverses (100N - 1000N) using a station interval of 20 m (Fig. 2) to allow a reasonable coverage of the area under investigation. The SP response was measured by means of two porous pot electrodes connected to a sensitive SP meter model SP4 (a BRGM made) using the fixed electrode technique (Telford *et al.* 1978). The choice of the reference potential is entirely arbitrary, but a base station located in a non-mineralized environment was selected. The collected SP measurements at the different stations were then reduced to the reference base and displayed as an equipotential map at a 20 mV contour interval (Fig. 3).

Induced Polarization (IP) Method

The induced polarization (IP) is a current-simulated electrical phenomenon observed as a delayed voltage response in earth materials. In geophysical measurements, induced polarization refers to a resistive blocking action or electrical polarization in earth materials; the process being most pronounced in fluid-filled pores next to metallic minerals. The IP effect is, therefore, observed to be strong near rock containing metallic luster minerals. Accordingly, the IP method is considered as the primary electrical exploration tool for base metal deposits, specially copper-zinc or nickeliferous minerals. It has been remarkably successful in locating concealed bodies containing even small percentage of metallic-luster minerals in general. The origin, field techniques, and methods of interpretations are discussed in most of the geophysical text books, *e.g.* Telford *et al.* (1978), while some special volumes which discuss the IP method and its recent developments are now available in the literature, *e.g.* Summer (1976).

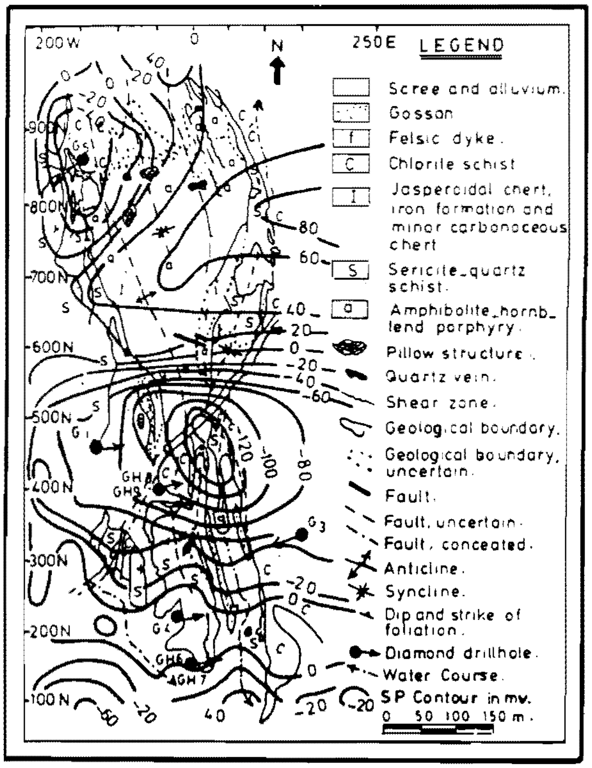

FIG. 3. Self potential (SP) map of Gehab prospect superimposed on geological map.

The IP measurements are made either in time-domain, as a voltage decay curve, or in frequency-domain as a voltage difference within variations in frequency. According to Seigel (1979), it is generally appreciated that the time-domain method has the advantage of higher potential sensitivity. It also provides the absolute measurements since the measurements are made after the cut-off of the current pulse. Thus, it is possible to improve the signal-to-noise of such measurements by increasing the transmitter power, thereby increasing the sensitivity of measurements for low IP response. In addition, the distortions introduced by the electromagnetic coupling on the measured IP signal are very weak in the time-domain technique. Therefore, the time-domain technique was applied in the present study of the prospect area.

The measured quantities in the time-domain IP technique are the chargeability (M), the apparent resistivity (ρ_a) and the metal factor (MF) which can be defined as

$$M = v_t / V \tag{1}$$

where V is the voltage between the potential electrodes during current flow
v_t is the voltage after the current is off by a time t

$$\rho_a = K \cdot V / I \tag{2}$$

where I is the current between the current electrodes
K is the geometric factor of the used array (dipole-dipole) and can be given as

$$K = \Pi na(n+1)\ (n+2)$$

where a is the dipole length
n is the number of dipole lengths which separates the current and potential dipoles

and $MF = 1000\, M / \rho_a$ (3)

Time-domain induced polarization technique was conducted along nine profiles (100N-900N) using the dipole-dipole array. The dipole length was 50 m, while the spacing between the transmitter and receiver dipoles was from one to six ($n = 1 - 6$) which allows considerable depth penetration. A powerful transmitter (3 K-Watt) model TSQ-3 and digital time domain receiver model IPR-10 were used throughout the field surveys. Such instrumentation provided relatively precise and consistent measurements regardless of the hard nature of the country rocks in the prospect area.

Vertical pseudosections, along the surveyed profiles (Fig. 4-6) were constructed for the chargeability (M), the apparent resistivity (ρ_a) and metal factor (MF). It should be realized that pseudosections give a highly exaggerated impression of depth of exploration and also that patterns produced are very different from the actual distribution of anomalous targets in the subsurface. Nevertheless, the results presented in this format can be used qualitatively (Sumner 1976) or can be compared with pseudosections from model experiments as described by Hallof (1970), B.R.G.M. (1975) and Hofmann (1977). Another disadvantage of the pseudosection is that the most anomalous values are displaced laterally and do not coincide with the source body. A modern technique of IP data filtering, suggested by Fraser (1981), was applied to each pseudosection to obtain a single value per station that reflects weighed data from all the subsurface levels of the pseudosection. If these values are plotted, the pseudosection data will be reduced to a profile with the most anomalous values which overlie the source body. The manual application of the suggested filters is complicated and time consuming; therefore, a computer program written by Sadek (1983) was used to apply the filtering technique automatically to the different pseudosections. The filtered data along each profile were put in plan and contoured to produce three maps for M, ρ_a and MF (Fig. 5).

Interpretation

Self Potential (SP)

It is well known that the differences in potential, in SP surveys, can arise where a variation in oxidation state exists between different parts of a conductive ore body. In such a case, a voltaic cell is established and a system of electric circuit is set up through and external to the deposit. The resulting SP values are generally measured in millivolts (mV), and over the top of the ore body they are always negative with respect to the surroundings.

The SP map (Fig. 3) reveals three distinct negative anomalies associated with the gossan outcrops in a NS trend. A well defined, but weak, anomaly with maximum negative value of –45 mV is almost associated with the northwestern gossan (station 900N/180W). The weak SP response may be attributed to the limited depth extent of the source body which may not reach beneath the oxidation zone. This confirms well with the drilling results where the drill hole GH-5 did not intersect any significant mineralization beneath the gossan.

A relatively stronger central anomaly with maximum negative magnitude of –160 mV is associated with the northern part of the southern gossan. This anomaly is attributed to a sulphide mineralization extension beneath the corresponding gossan outcrops. The sulphide mineralization zone detected by drill holes GH-8 and GH-9 supports this conclusion. The absence of any mineralization in drill hole GH-1 may be attributed to the fact that this hole was executed to test the subsurface of the central gossan, but did not reach the northern extension of the southern gossan as revealed from the SP anomaly.

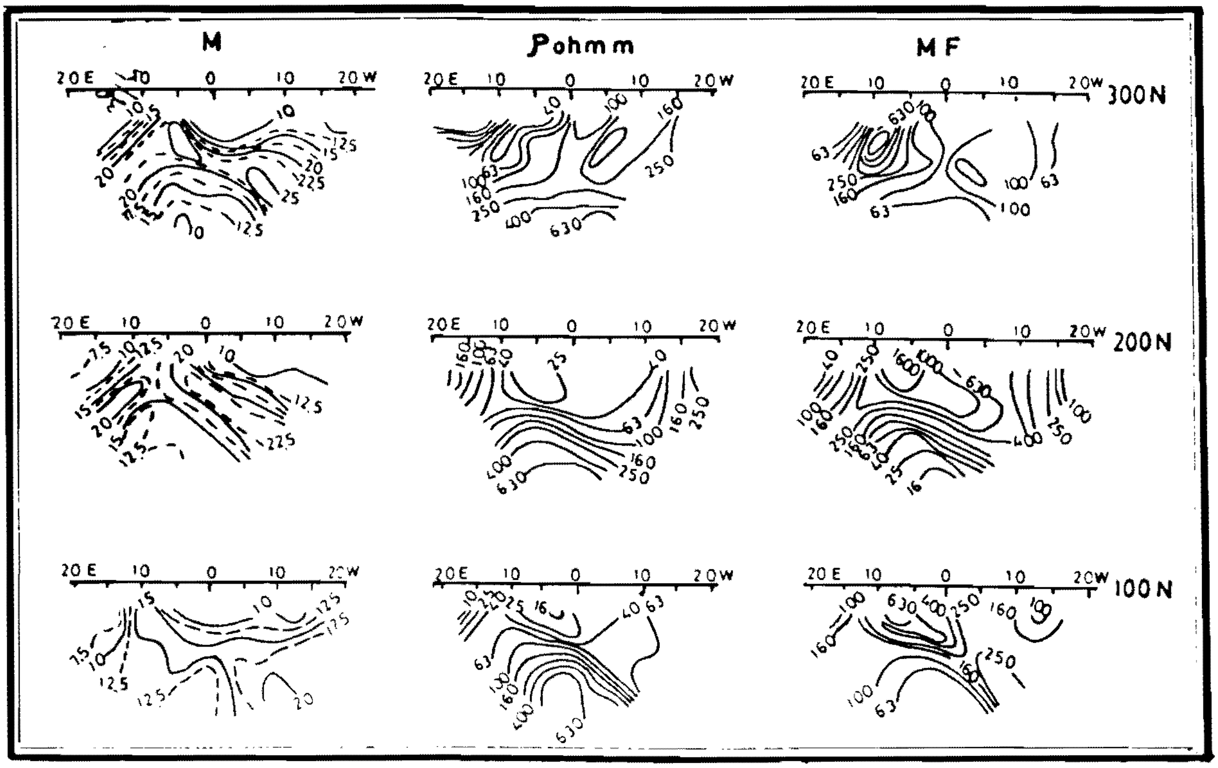

FIG. 4. Chargeability (M), apparent resistivity (ρ_a) and metal factor (MF) pseudosections of lines 100N-300N in Gehab prospect.

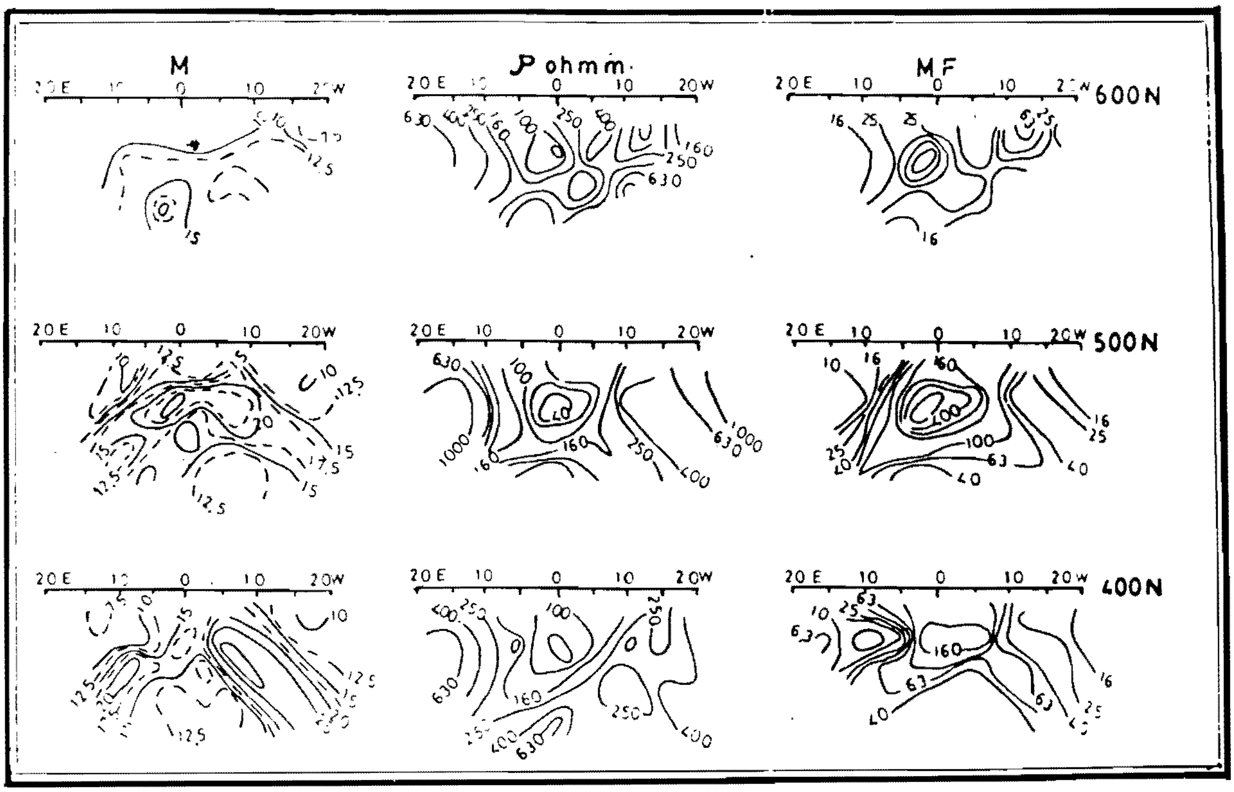

FIG. 5. Chargeability (M), apparent resistivity (ρ_a) and metal factor (MF) pseudosections of lines 400N-600N in Gehab prospect.

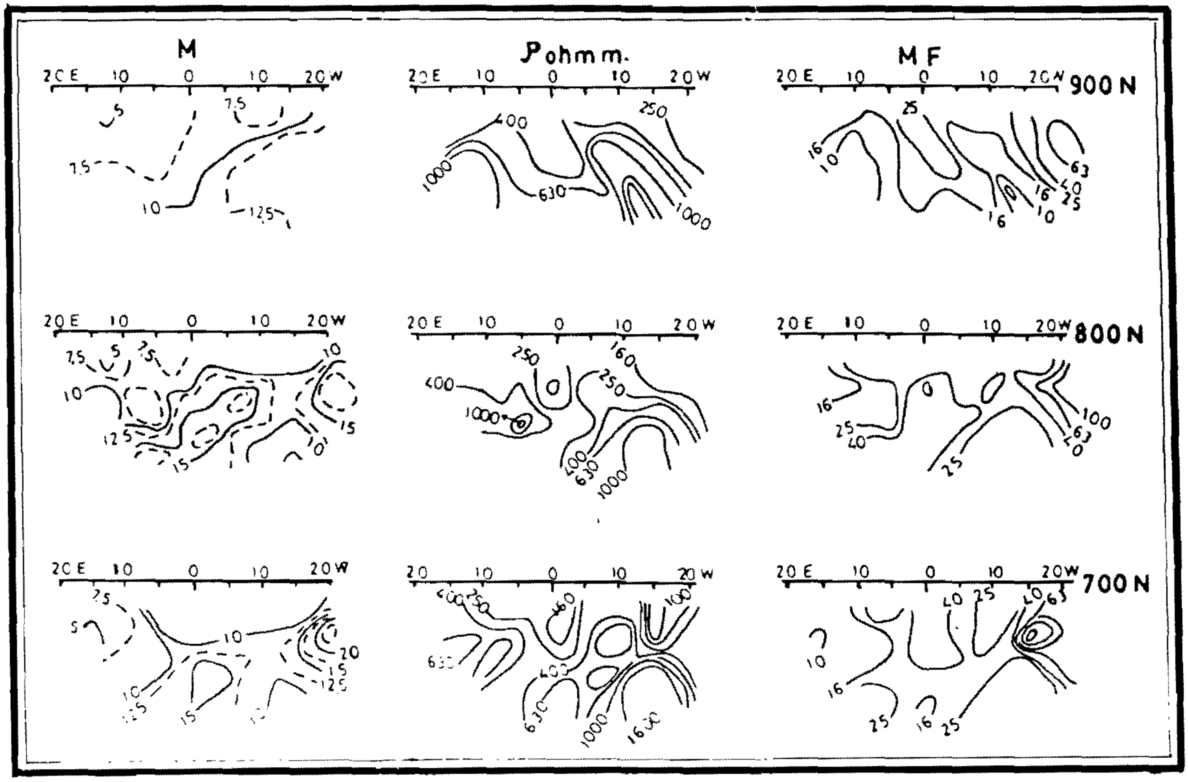

FIG. 6. Chargeability (M), apparent resistivity (ρ_a) and metal factor (MF) pseudosections of lines 700N-900N in Gehab prospect.

The extreme southern part of the prospect area is associated with a bimodal and ill-defined SP anomaly as observed on lines 100 N and 200 N. This anomaly has bimodal negative peaks with magnitudes of –60 and –40 mV and is not associated with any gossan outcrops. The deeper sulphide mineralization detected in holes GH-6 and GH-7 gives the impression that the ore body lies deeper in this part of the area but its upper part only lies in the zone of detection of the shallow SP method. In addition, this bimodal anomaly is incomplete from the south which bears a strong evidence that the associated deep ore body extends to the south of the surveyed area.

Induced Polarization (IP)

The IP pseudosections (Fig. 4-6) show valuable information about the subsurface mineralization zones in the prospect area. These zones are generally associated with low resistivity (ρ_a), high chargeability (M) and high metal factor (MF) anomalies as indicated by their respective pseudosections. It is clear that the lowest ρ_a values are observed in the southern pseudosections (from 100 N to 500 N), while the corresponding anomalies in the M and MF sections are of the higher magnitudes. These anomalies are almost associated with the southern gossan which reveals that the sulphide mineral potential occurs beneath this gossan and extends to the south of it. The filtered IP maps (Fig. 7) offer further support to this conclusion where corresponding high M, low ρ_a and high MF anomalies occur in this part. These anomalies, which strike NS, are incomplete from the south and southwest giving a strong evidence that the associated sulphide mineralization extends to the south outside the surveyed area. The drilling investigations proved that the northern part of this anomalous zone has most of the mineral potential in the prospect area, according to the results obtained from holes GH-3, GH-4, GH-6, GH-7, GH-8 and GH-9. There is a strong belief that considerable mineralization will be intersected beneath the geophysical anomalies observed to the south of line 200 N and outside the surveyed area regardless of the absence of gossan outcrops. The absence of any gossan outcrops in this part may be attributed to down faulting of the mineralized zone or the southern plunge of the anticline.

The surveyed part in the north (on lines 600 N to 900 N) did not show significant anomalies associated with the northwestern, northeastern and central gossans. This suggests the absence of any significant mineralization beneath these gossans. This conclusion was

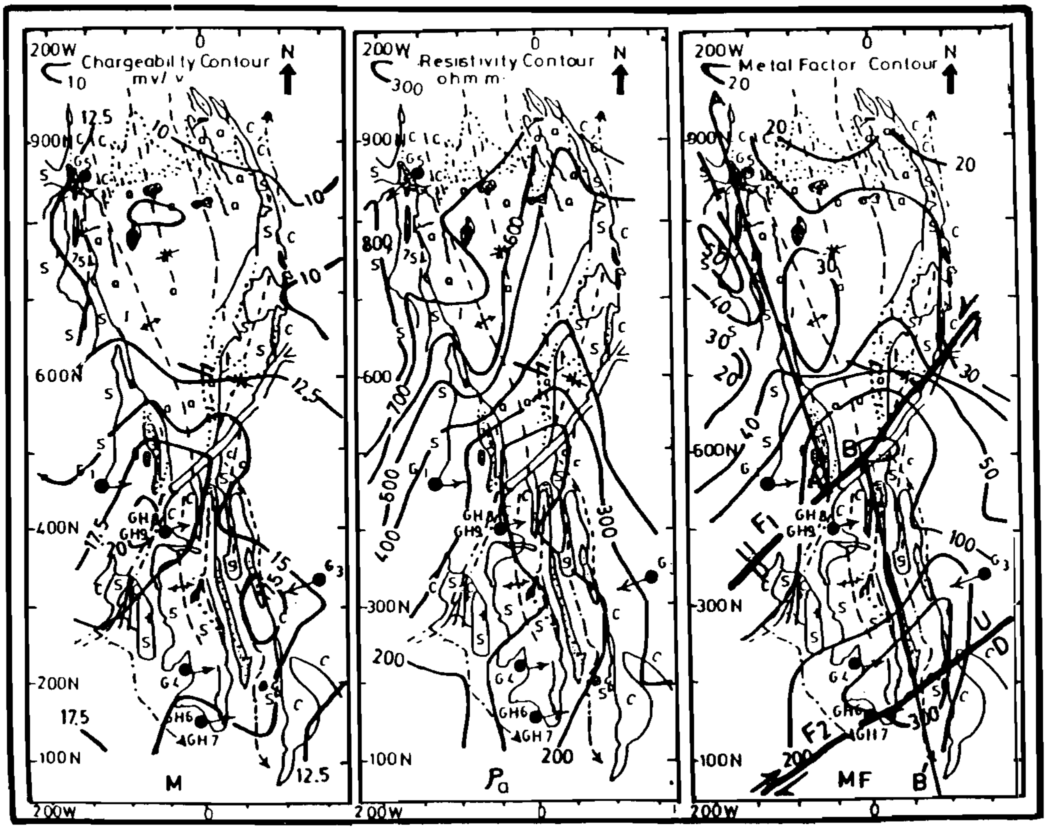

FIG. 7. Chargeability (M), apparent resistivity (ρ_a) and metal factor (MF) maps of the filtered IP data superimposed on the geological map of Gehab prospect (for geological index see Fig. 2).

confirmed by the drilling results since drill hole GH-1, and GH-2 and GH-5 did not intersect any significant mineralization.

The geophysical interpretation also introduces probable modifications on the structural configuration of the prospect area. The previous geological information indicated that the Precambrian rocks are folded in a NS anticline plunging due south and the sulphide deposits are strata bound which occur in steeply dipping limbs of the anticline. The interpretation of the collected geophysical data, supported by drilling results, suggests the mapping of two faults (faults F1 and F2, mapped in Fig. 7) trending almost NE and have the downthrown to the south. The first fault separates between the southern gossan which has considerable depth extension and the other gossans in the north which have insignificant depth extension. The second fault separates between the southern gossan and the suggested mineral extension, to the south and outside the surveyed area, which was recognized from the interpretation of geophysical data. The absence of any gossan outcrops to the south of line 200 N may be attributed to the downfaulting or the plunge of the anticline or both. According to the previous geophysical interpretation, the subsurface configuration of the mineralization and the host rock along profiles AA' and BB' (see Fig. 7) is illustrated in Fig. 8.

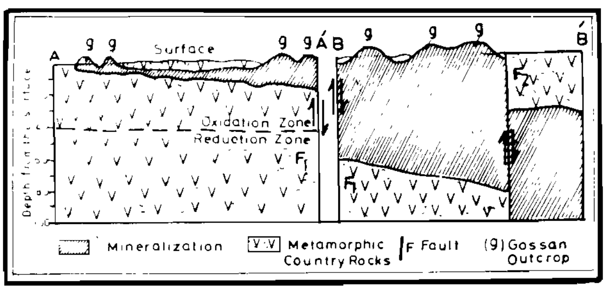

FIG. 8. Subsurface configuration of the mineralized zone and the host rock along profiles AA' and BB' as expected from the interpretation of the geophysical data.

Conclusion

The interpretation of the SP and IP data succeeded to reveal the subsurface configuration of the mineralized zones in the prospect area. The northern part of the area (from line 600 N to 1000 N) has a weak response which is associated with insignificant mineral deposit. The southern part (from line 200 N to 500 N) has a relatively stronger SP and IP responses associated with the southern gossan which reflect considerable subsurface mineralization beneath this gossan. The strong IP response extended to the south of line 200 N bears a strong evidence for considerable subsurface extension of the sulphide deposits to the south of the surveyed area. The weak SP response detected over this extension reveals that the expected sulphide body is completely burried, and its upper surface only lies at the depth of detection of the shallow SP method. The discovery of the southern subsurface mineral extension will certainly increase the estimated reserves in the Gehab prospect. However, the estimation of the additional reserves requires additional IP surveys in the south to delineate the mineralization extensions in this part. Subsequent exploration drilling, based on the geophysical data is recommended to test the thickness, depth extent and grade of mineralization.

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الاستكشاف الجيوفيزيائي لكبريتيدات معادن القاعدة في موقع تمعدن قِهاب بوادي بيدة بالمملكة العربية السعودية

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المستخلص . يقدم هذا البحث الدراسة الجيوفيزيائية لكبريتيدات معادن القاعدة في مستكشف قِهاب باستخدام طريقتي الجهد الذاتي والاستقطاب المستحث . ولقد أوضح تفسير البيانات الجيوفيزيائية أن نطاق التمعدن يمكن أن يقسم إلى ثلاثة أجزاء واضحة طبقًا للامتدادات التحتسطحية لهذا النطاق . ويصاحب الجزء الشمالي والأوسط من هذا النطاق استجابات ضعيفة من الجهد الذاتي والاستقطاب المستحث كما يعكس تمعدنًا سطحيًا غير ذي جدوي ويمثل التأكسدات المعدنية الظاهرة على السطح ذات الامتدادات الضحلة في الأعماق . الجزء الجنوبي الذي يحتوى على معظم الاحتياطيات المعدنية يصاحبه شاذات قوية نسبيا من الجهد الذاتي والاستقطاب المستحث والتي تسببت عن وجود تمعدنات كبريتيدية تمتد إلى أعماق جوهرية تحت التأكسدات المعدنية الظاهرة على السطح . ولقد لوحظ وجود امتداد لشاذات قوية متميزة وغير كاملة في الجزء الجنوبي الأقصى من منطقة المستكشف . وهذا الامتداد غير مصاحب بوجود مخارج سطحية لتأكسدات المعادن مما يُرجح وجود امتدادات كبريتيدية مدفونة والتي يمكن أن تمتد إلى الجنوب من المنطقة التي تم مسحها . هذه الامتدادات سوف تزيد بالتأكيد من احتياطيات المعـادن في هذه المنـطقـة . وترجح الدراسة الجيوفيزيائية أن الشكل التحتسطحي لنطاق التمعدن محكوم تمامًا بصدعين متجهين شمال شرق .