CHAPTER 5 DISCUSSION ON THE SURVEY RESULTS

5-1 Ghuzayn-Doqal Area

5-1-1 Ghuzayn area

Two massive sulphide ore bodies were discovered during this survey, i.e., the Northern body intersected by the boreholes of MJOB-G3 and G13 and the Western body intersected by the boreholes MJOB-G5, G14, G15, G16 and G17. Table II-5-1 presents a summary of these results, including their scales and assays.

Geologic cross sections in bore hole sites located on the Northern and Western bodies are shown in Figs. II-5-1 and II-5-2, while theTDIP pseudo-sections containing the crossing boreholes are illustrated in Figs. II-5-3 and II-5-4. The distribution of the boundaries between Lower extrusive 1(V1-1) and Lower extrusive 2(V1-2) and the massive sulphide ore bodies detected in the above holes give more clarifications on the general geologic structure in Ghuzayn area. According to Figs. II-5-1 and II-5-2, the volcanic rocks and massive orebodies in this area, trend northeast to southwest and dips by 15° to 30° northwest.

Stockwork zone is known to accompany the Cyprus-type massive sulphide deposits as shown in Fig. II-5-5 of the schematic model of Daris and Rakah deposits. In Ghuzayn area, these stockwork ores are found in MJOB-G3 at Northern body and MJOB-G14 at Western body. Since a stockwork ore could be formed in and around a pass of hydrothermal solution which produced massive sulphide ore bodies, the main fault where a hydrothermal solution passed mainly through could be found nearby each of the boreholes G3 and G14. The results of drilling and TEM surveys on Western body support the idea that main fault is running in a north-south direction at the eastern edge of the body, in which the hydrothermal solution after being discharged, flowed towards northwestern direction while precipitating ore minerals and diffusing over sea floor.

The fact that intense chalcopyrite dissemination is observed in the Lower extrusives 2(V1-2) and on the hanging wall of massive ore, together with the fact that intense pyrite dissemination and silicification are also found in Lower extrusives 2(V1-2) at boreholes G1 and G10, suggest that the mineralization in Ghuzayn had continued sometime after the formation of massive sulphide ore bodies and that this mineralization was related to the early volcanic activity of Lower extrusive 2(V1-2).

As for the alteration associated with mineralization, silicification, bleaching and epidotization are observed in this area. They are found in both sides of the footwall and hanging wall and accompanied by pyrite dissemination, however, they are more intense in the footwall side. In addition, their intensities are increasing as approaching towards massive ore bodies. Both, silicification and bleaching, are widely distributed around ore bodies and bleaching covers a slightly larger extension. These extents coincide

Table II-5-1 Summary of results on drilling survey in Ghuzayn Area

Ore Body Name	Bore Hole NO.	Type of Ore	Depth (m)		Thickness (m)	Average Grade	
			from	to		Cu%	Zn(%)
Ghuzayn Northern Body	MJOB-G3	stockwork(upper)	115.15	133.00	17.85	0.22	0.01
		massive sulphide	133.45	138.60	5.15	4.85	0.04
		massive sulphide	140.00	142.80	2.80	3.77	0.06
		stockwork(lower)	142.80	166.65	23.85	0.40	0.11
		stockwork(lower)	167.15	179.90	12.75	0.59	0.03
		stockwork(lower)	185.35	233.50	48.15	0.27	0.02
		stockwork(lower)	246.10	247.25	1.15	0.30	0.17
		stockwork(lower)	279.50	288.20	8.70	0.15	2.66
	MJOB-G13	massive sulphide	152.80	154.40	1.60	0.17	0.04
Ghuzayn Western Body	MJOB-G5	stockwork	134.00	136.90	2.90	0.33	0.01
		massive sulphide	136.90	170.60	33.70	1.47	0.04
	MJOB-G14	massive sulphide	119.80	164.75	37.10	1.88	0.04
		stockwork	164.75	171.50	6.75	2.74	0.44
		stockwork	171.50	230.50	59.00	0.37	0.32
	MJOB-G15	(metaliferous sediment)	178.85	179.20	0.35	2.10	0.01
		massive sulphide	179.20	212.30	29.90	1.55	0.05
	MJOB-G16	stockwork	186.30	186.90	0.60	0.14	0.04
		massive sulphide	186.90	189.40	2.50	1.63	0.05
	MJOB-G17	massive sulphide	215.90	222.80	6.90	1.17	0.05

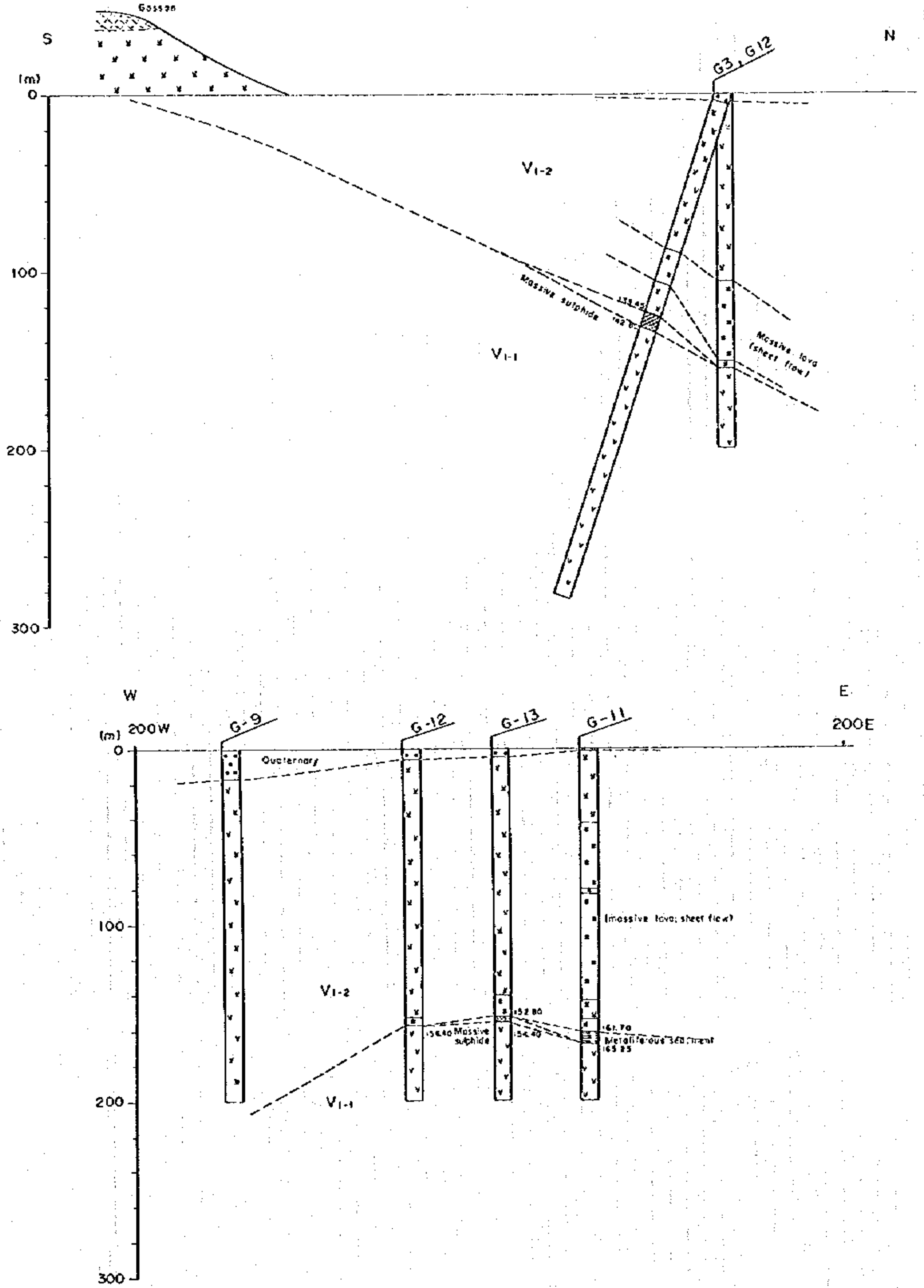


Fig.II-5-1 Cross section of borehole site in the northern body of Ghuzayn deposit

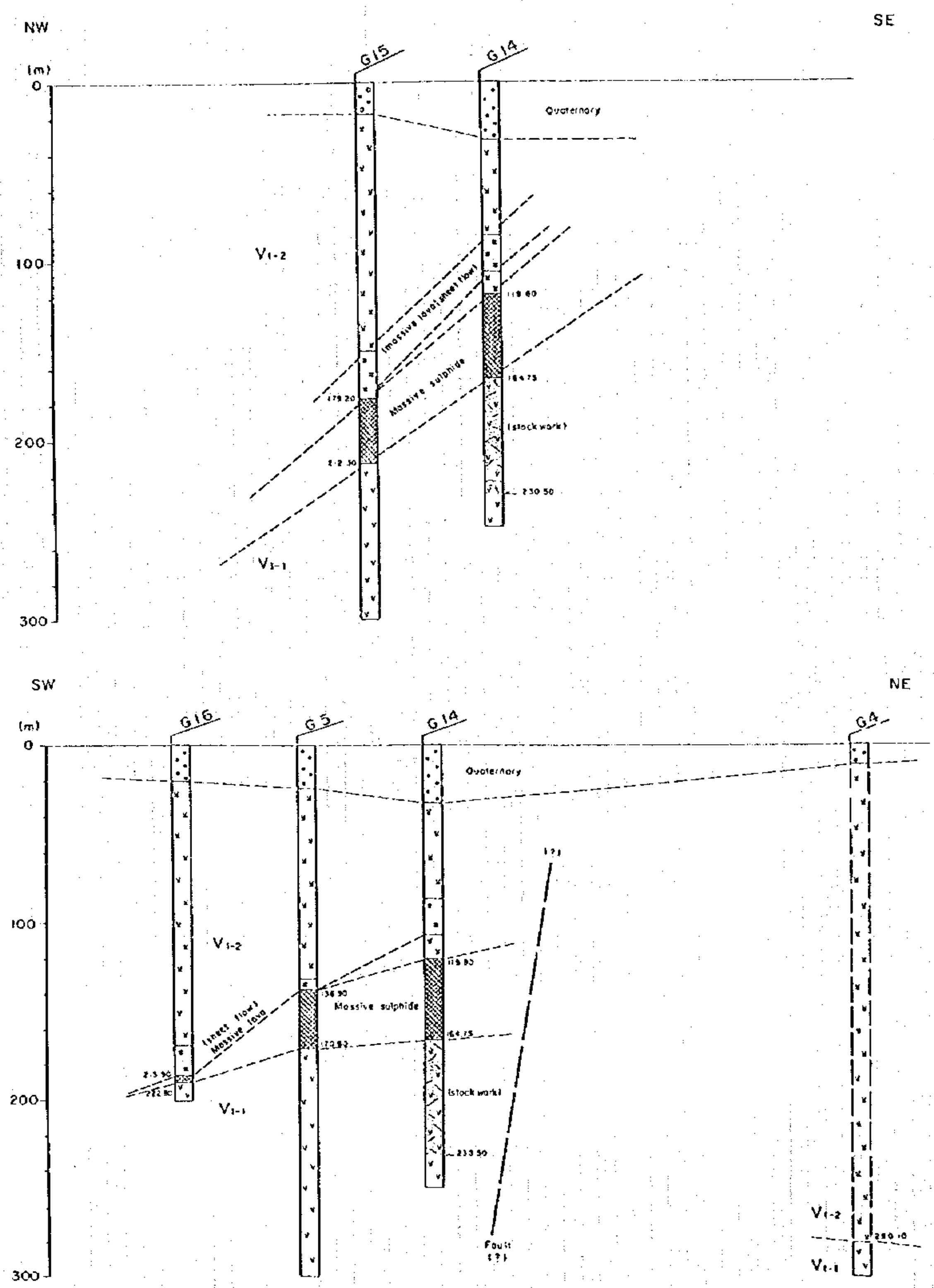


Fig.II-5-2 Cross section of borehole site in the western body of Ghuzayn deposit

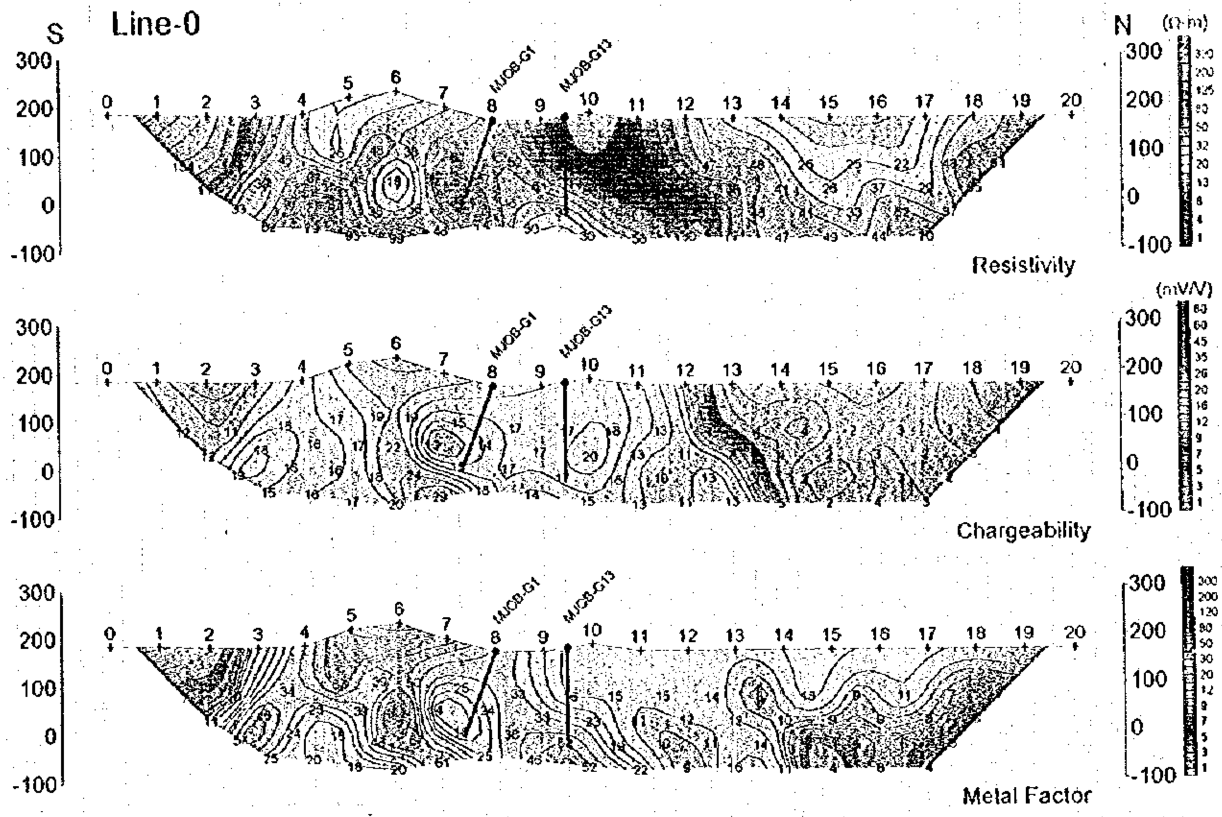


Fig.II-5-3 IP pseudo-section around northern body of Ghuzayn deposit

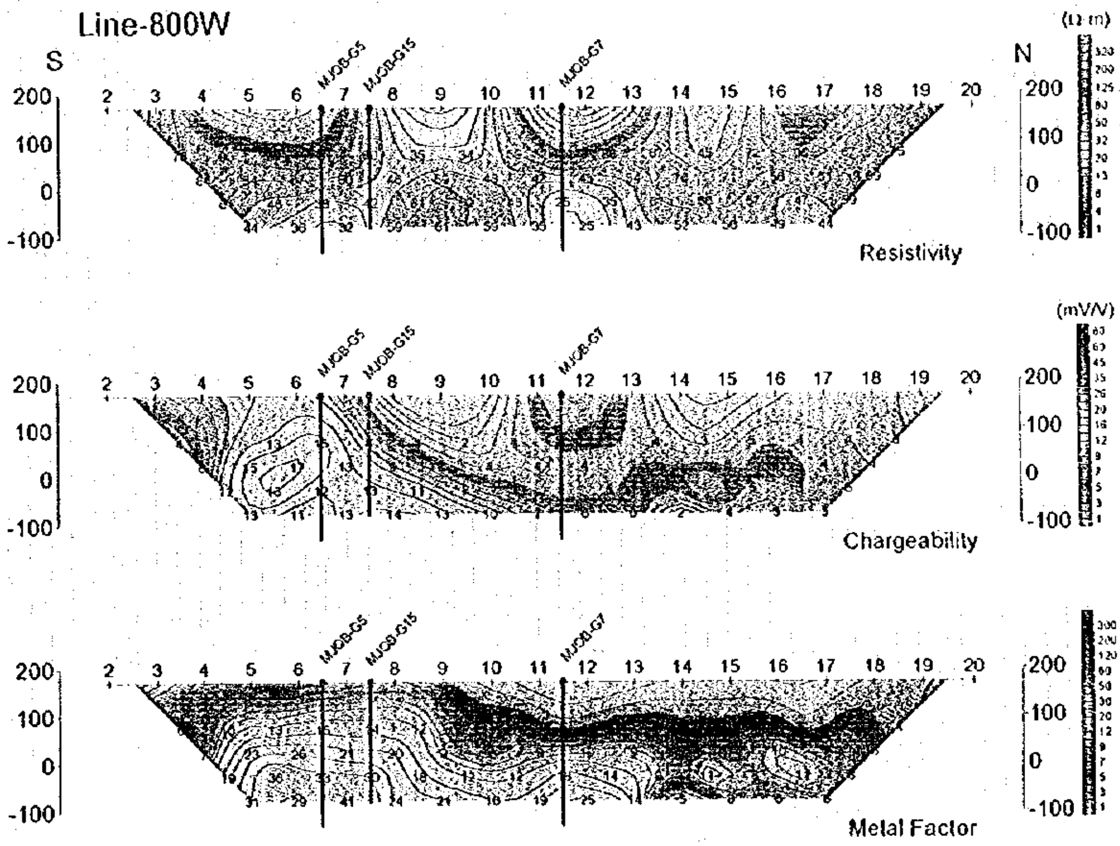
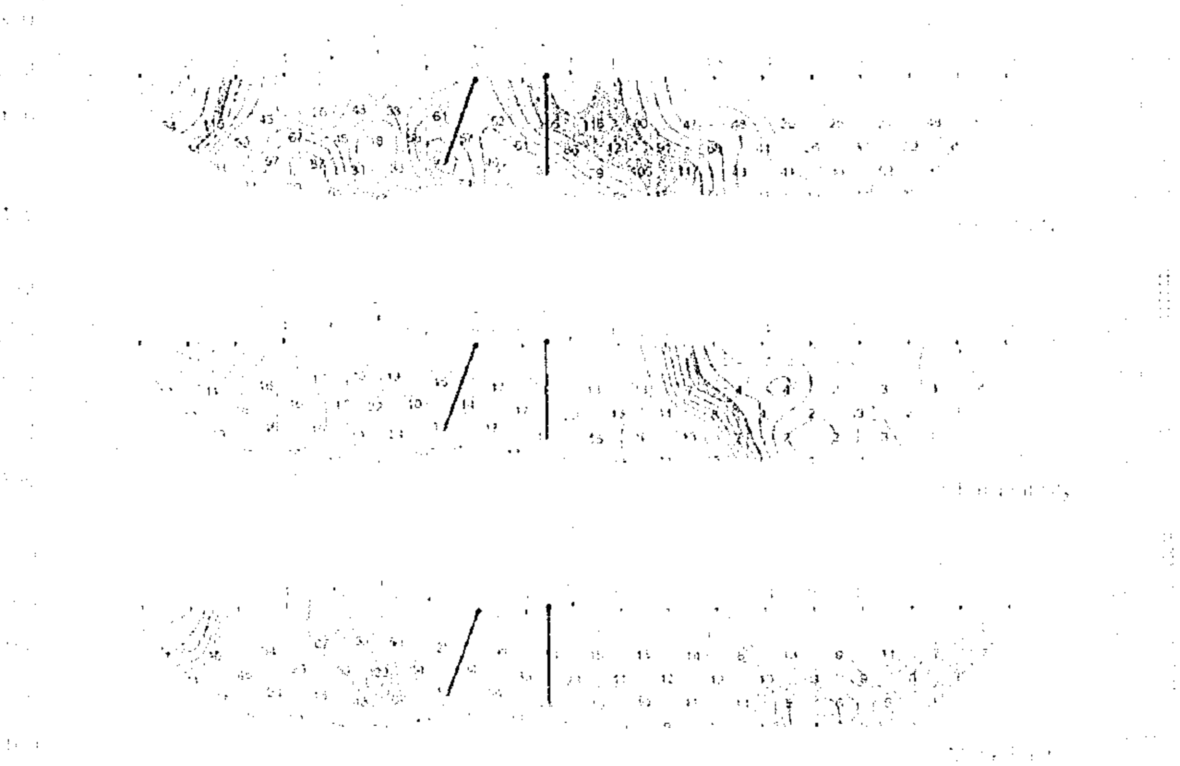
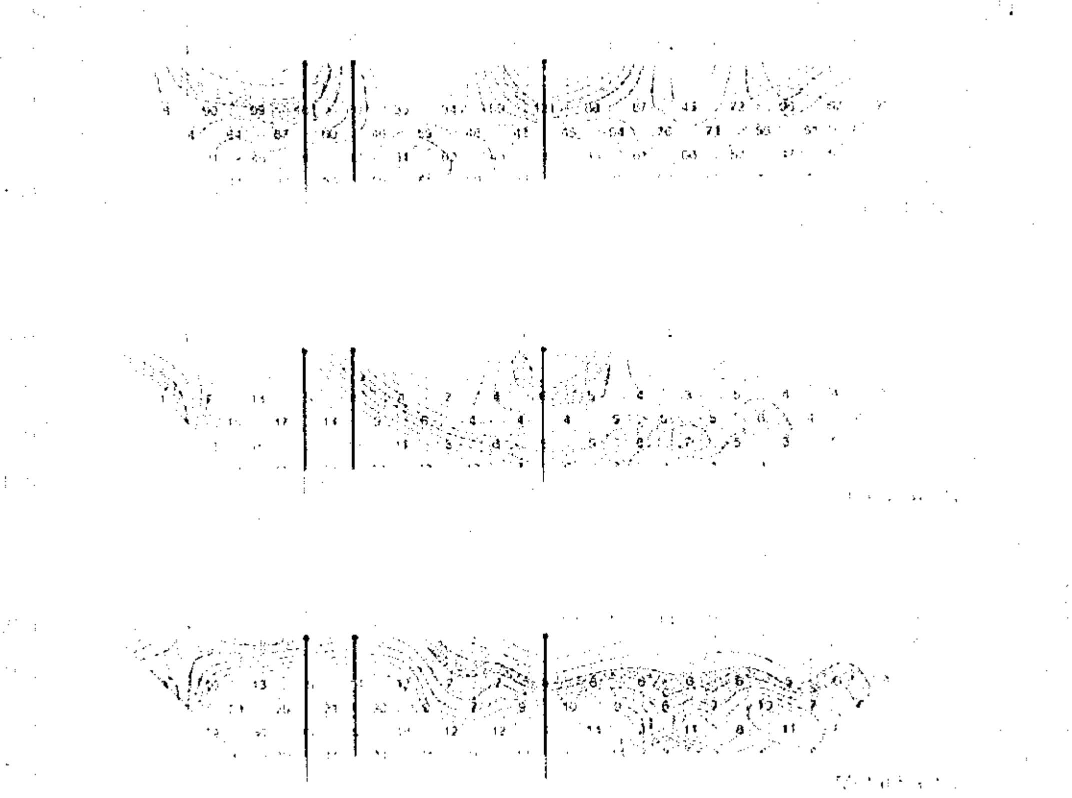


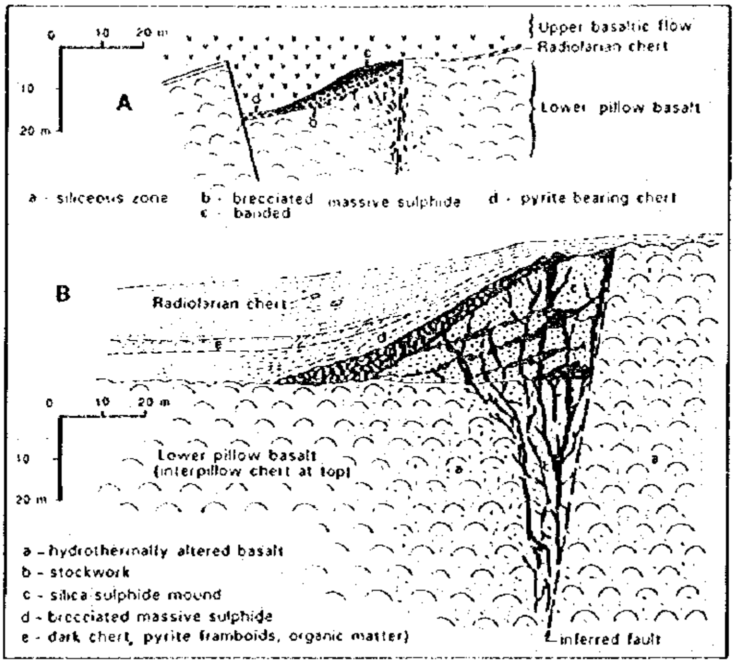
Fig.II-5-3 IP pseudo-section around western body of Ghuzayn deposit

Line 0



Line 800W





(Lescuyer *et al.*, 1988)

Fig.II-5-5 Schematic model of Daris and Rakah deposits

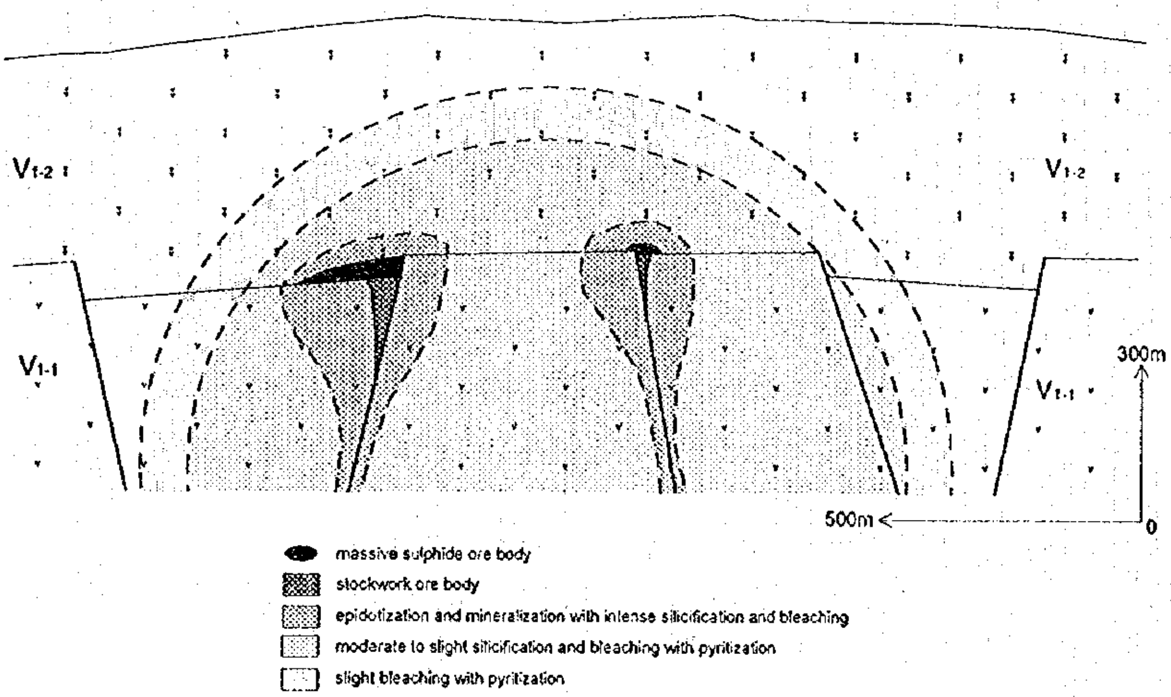


Fig.II-5-6 Schematic model of massive sulphide deposit in Central Batinah Coast almost with the area delineated as the high chargeability zone by TDIP survey. On the other hand, epidotization appears in a limited extension near ore bodies. Epidote associated with mineralization is mainly forming veinlets together with quartz or calcite, which is accompanied by pyrite, chalcopyrite and rarely sphalerite. Massive epidote is in places observed beside the massive ore bodies and is sometimes accompanied by disseminations of pyrite and chalcopyrite as seen in the hanging wall of G5 hole. Difference in alteration can be observed between the two bodies.The Northern body is characterized by a more remarkable silicification and bleaching and the Western body is characterized by a more remarkable epidotization.

Based on above facts and considerations, a model of Ghuzayn deposits can be schematically made as shown in Fig. II-5-6.

In addition, TEM data indicate also interesting anomalies which may correspond to high potential locations for massive sulphide mineralization in three places.

5-1-2 Doqal area

In Doqal area, TEM survey was conducted in order to investigate the high metal factor zone detected by TDIP. Since the TEM anomalies extracted in the area correspond well to the high metal factor zone, it became clear that this area may have a high potential for mineralization of massive sulphide deposits.

5-1-3 Other areas

Since no significant anomalous values of chargeability or resistivity were detected by TDIP survey in the areas such as Ghuzayn East, Ghuzayn West and Ghuzayn village North, these areas are considered to present very poor possibilities for finding economic mineral deposits.

5-2 Fardah-Sanah Area

5-2-1 Fardah area

In Fardah area, TDIP survey delineated a remarkable low resistivity anomaly, however, it was not accompanied by high chargeability. Accordingly, only oxidized ore bodies were expected in the area.

Since no significant mineralization was intersected by this drilling survey, the low resistivity anomaly is considered to be due to mudstone beds of Tertiary formation unconformably underlaying with Samail volcanic rocks. In addition, the gossan found in the Tertiary rocks seems to be formed by chemical weathering related to groundwater.

5-2-2 Sanah area

Because of the results in Fardah area and because same geological and geophysical features were found in Sanah area, it is considered that this area presents very poor possibilities for finding mineral deposits and no drilling survey was carried out.

5-3 Daris-Daris 3A5 Area

5-3-1 Daris area

Extensive high chargeability zone was detected by the TDIP survey in Phase I in the central part of the Daris area. Gossan and small massive sulphide ore bodies discovered by previous works are located in the southern edge of this high chargeability zone. Accordingly, TEM survey was carried out by using one loop around the known occurrences. The detected TEM anomalies were investigated by a drilling survey.

Intense pyritization and thick gossan were encountered respectively by the boreholes MJOB-D2 and D4, however MJOB-D1 and D3 could not intersect any clear mineralization. The anomalies detected by TEM survey in the sites of MJOB-D1 and D3 are considered to be due to fracture zones accompanied by clay and pyrite.

The drilling survey conducted in the northern part of the area, no mineralization was encountered. In this hole (MJOB-R1), the Tertiary sedimentary rocks continued up to 131.85m before encountering Samail volcanic rocks, which is a calcareous sequence with intercalation of many mudstone beds. A considerable amount of pyrite were observed in the mudstone. These facts support the idea that the TDIP anomalies reflected the mudstone beds and pyrites in mudstone.

Since a high chargeability zone is seen widely distributed in Daris area, there is still a high possibility to find new deposits. However, ore bodies may be deformed by structural movements shown by the cataclastic texture in many parts of MJOB-D1.

5-3-2 Daris 3A5 area

Drilling survey of two holes was carried out to investigate the very low resistivity zone with moderate chargeability detected by TDIP survey of Phase I to the northwest of gossan and massive sulphide ore bodies. The two holes could not intersect any mineralization, except a slight gossanization in MJOB-A2. The geology of both holes consist mainly of slighly weathered and strongly montmorillonized hayaloclastite in shallow depth and strongly chloritized hayaloclastite and pillow lava in depth. Finely fractured cores were obtained in most of the parts at shallow to middle depth of both holes. Judging from the results of drilling survey, the intense resistivity anomalies detected by TDIP is considered to be due to a strong montmorillonization and ground water filling fractures.

CHAPTER 6 DISCUSION ON SURVEY METHODS APPLIED TO MASSIVE SULPHIDE DEPOSITS

6-1 Flow for Massive Sulphide Deposits Exploration in Batinah Coast

Based on the results of the ground geophysical surveys that we carried out not only during this year, but also in previous years in Sohar, we investigated on the suitable geophysical methods in order to implement an efficient exploration strategy in the search of massive sulphide deposits in Oman.

The massive sulphides distributed in Oman are of the Cyprus-type copper deposits, and which occur within the volcanic rocks conformed by basaltic pillow lava and associated to a stratigraphic control.

The selection of potential areas for massive sulphide deposits, can be achieved by first selecting the most suitable zones by tracing the pillow lava sequence through geological and airborne magnetic methods. The airborne magnetic method are useful to delineate demagnetized zones associated to mineralization.

The zones selected by the above methodology can be further investigated by appropriate ground geophysical methods in order to delineate in more detail areas with high potentiality.
The results of the geophysical methods can be finally confirmed by a suitable exploratory drilling program. Fig. II-6-1 illustrates a flow diagram for an efficient exploration strategy.

In Oman, one of the main difficulties to carry out mineral exploration is the existence of a very wide area covered by Quaternary sediments, and in this respect, it is important for future exploration works to effectively investigate blind deposits under the sediments. In particular, the flow chart described in Fig. II-6-1 illustrates the geophysical techniques that can be effective to find new deposits.

6-2 Suitable Ground Geophysical Methods for Massive Sulphide Deposits

6-2-1 Selection of the survey method

As illustrated by the schematic model for massive sulphide deposits in Central Batinah Coast (Fig. II-5-6), the massive sulphide deposits are also accompanied by sulphide dissemination. On this basis, the selection of the appropriate ground geophysical method should take into account not only the physical characteristics of the massive sulphide deposits but also the disseminated sulphides and their corresponding scale.

Flow for massive sulphide deposits exploration in Batinah Coast

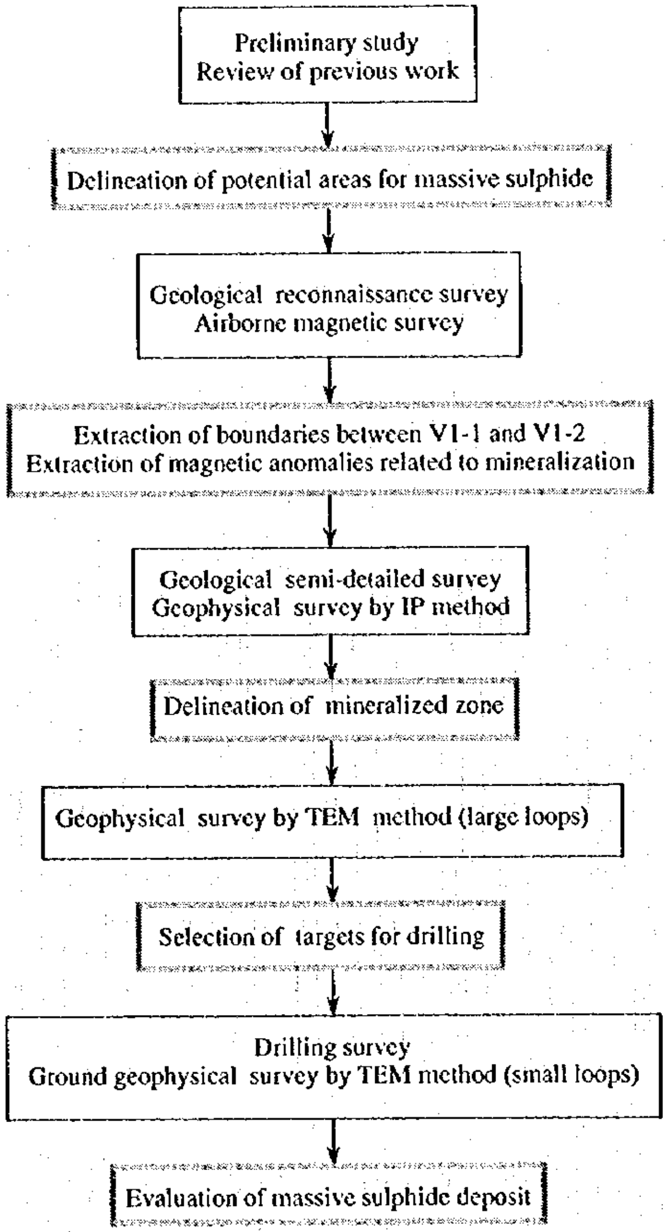


Fig. II-6-1 Flow for massive sulphide deposits exploration in Batinah Coast

In relation to the electrical properties of sulphide minerals massive deposits, it can be mentioned here that they present high chargeability and high conductivity (low resistivity). As the amount of sulphides increases, bigger electrical contrast differences can be detected between mineralized and non-mineralized zones.

For the case of exploration of Cyprus-type deposits in Oman and if we think of the scale of the deposits, it is quite complicated to find out directly massive sulphide deposits from the wide zone covered by Quaternary deposits. As such is the case, it would be also important to include within an exploration program, the search of disseminated sulphides which can be observed within a wide scope.

According to the flow diagram of Fig.II-5-1, the IP method is useful to search for high chargeabilities associated with sulphide mineralization. Simultaneously, underground resistivities are also measured. To confirm the IP results and to obtain resistivity in more detail and at deeper levels, the TEM method is also recommended after the IP survey results are known.

Among these two geophysical methods, IP can be useful to delimit the extension of the mineralized zone, by measuring chargeability as an electrochemical phenomena of the disseminated sulphide mineral. As mentioned previously, the IP method detects also low resistivity and as a result, another parameter called metal factor can be calculated. The metal factor is simply the ratio between chargeability and resistivity. High metal factor values are related to high possibilities for favorable mineral potential deposits, because higher contents of sulphide minerals can be associated to higher chargeabilities and lower resistivities of the rock.

Other geological environments which indicate also low resistivity, such as sedimentary rocks, e.g., mudstone, and layers containing saline water, can be distinghished from sulphide minerals signature by their low chargeability, which implies low metal factors. Accordingly, the IP method which is able to detect chargeability within a wide range can be useful to infer the disseminated sulphide distribution at a wide scale. At the same time, the ability to detect low resistivity distributions to extract high metal factors can be helpful to delineate even more the possibility to detect any existing sulphide mineralization within the area.

On the other hand, one of the weak points of the IP method is the ability to measure the IP parameters only along lines, however, if deeper exploration depth is wanted due to a deep target, the distance between electrodes can be increased longer, but as this is done, the scope of lateral influence gets wider, and as a result, the resolving power decreases more and becoming in this way, more difficult to decide the place of the source of the anomaly. On the contrary, by the TEM method although only the information of resistivity can be obtained, its value can be obtained directly below the observed point. To this it can be added that the sensitivity to extremely low resistivity bodies is higher as compared to another geophysical method.

Specially in Oman, the TEM method can be very effective, because in this case the host rock is compact and hard and therefore, a big contrast in resistivity can be seen if compared to the massive sulphides. The TEM response detected by the TEM method from hard rock is small and as such, a big TEM response can be expected from a massive sulphide deposit.

According to the above mentioned and for the case of the Cyprus-type deposits, massive sulphide targets can be discovered by first applying the IP method in order to extract a wide area where a wide high chargeability distribution with low resistivity can be detected under sediments, and as a second step, distributions with high chargeability and low resistivity values can be more precisely investigated by TEM method to delineate the most promising targets as defined by the most prominent TEM responses.

6-2-2 Results of Application

(1) Previous Survey in Sohar Area

From 1985 to 1990 geological regional surveys as well as detailed exploration surveys were carried out for about 6 years in the area of Sohar of the Sultanate of Oman. Within this period and at the beginning of the exploration survey, every kind of ground geophysical survey was tested, and as a result, the IP and TEM methods resulted specially effective for the exploration of massive sulphides in the area. In what follows and as a matter of example, we will very briefly mention the results obtained by using the above mentioned ground geophysical methods applied in Aarja and Bayda deposits and its surroundings, which had been discovered at the beginning of the survey.

Figs. II-6-2(1) and II-6-2(2) show the results obtained by the IP survey method near Aarja and Bayda deposits. As it can be clearly seen in these figures, both of these deposits are located in the edge of a high chargeability distribution and high metal factor (over 40). Around the deposits, there can be seen a zone of high chargeability distributed in a wide area.

Fig. II-6-3 shows in a plan map, the TEM responses of one of the results obtained by the TEM method applied around the Bayda deposit. In this map, high TEM responses are seen towards the south and north central direction of what is now the deposit. As compared with the result obtained by the IP method, the anomaly detected by the TEM method was able to delineate the location of the deposit in a more precisely way. It shows then, that the TEM method is effective to locate the massive sulphide deposit.

(2) Geophysical Survey Results in Ghuzayn area

In Ghuzayn area an IP survey was carried out during the first year of the project. Based on the IP results, a TEM survey was carried during the second year of the project. As a result of these geophysical investigations, drilling exploration carried out around the detected geophysical anomalies, discovered new massive sulphide deposits.

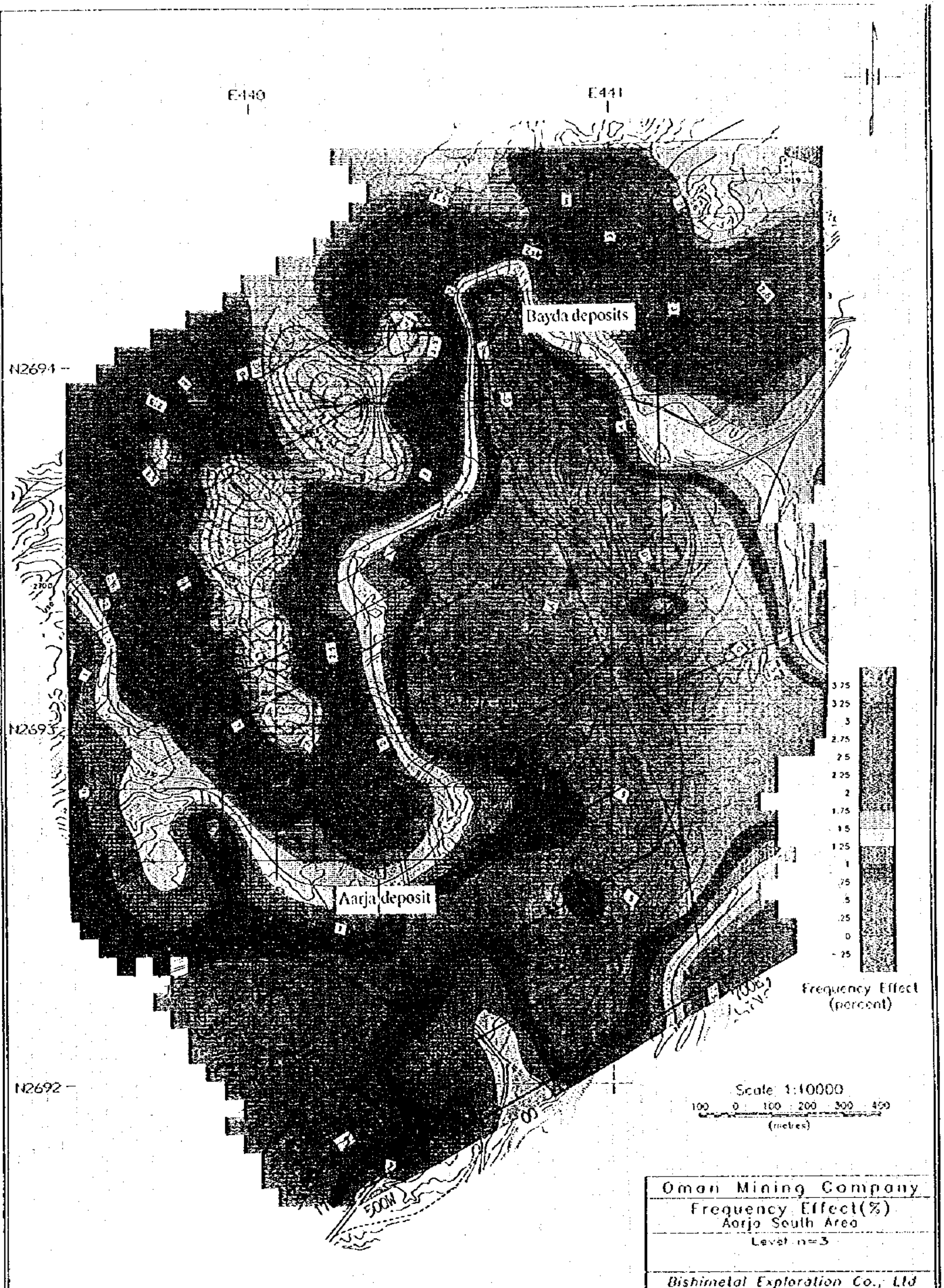
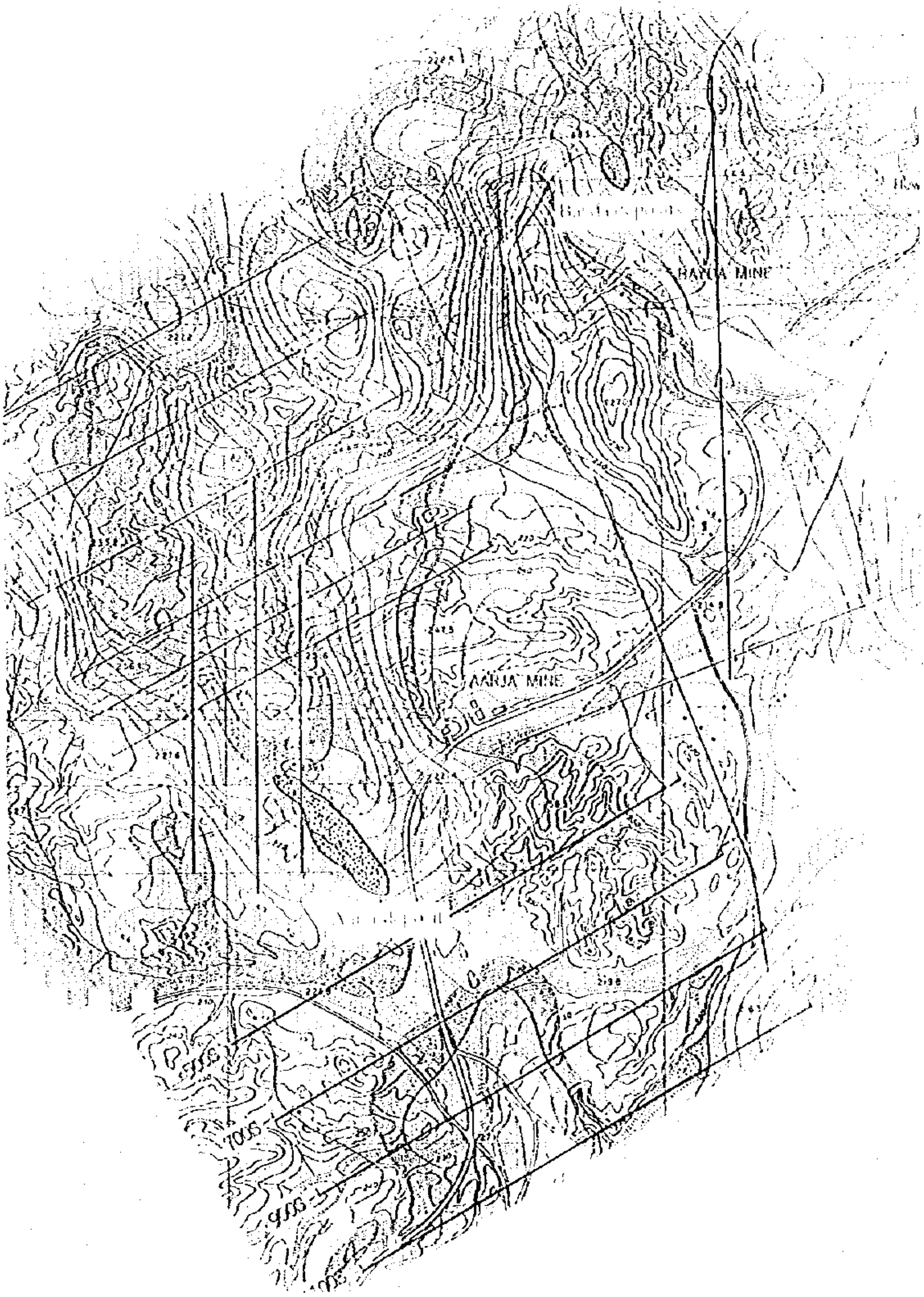


Fig.II-6-2(1) IP plane map near Aarja and Bayda deposits


AARJA MINE

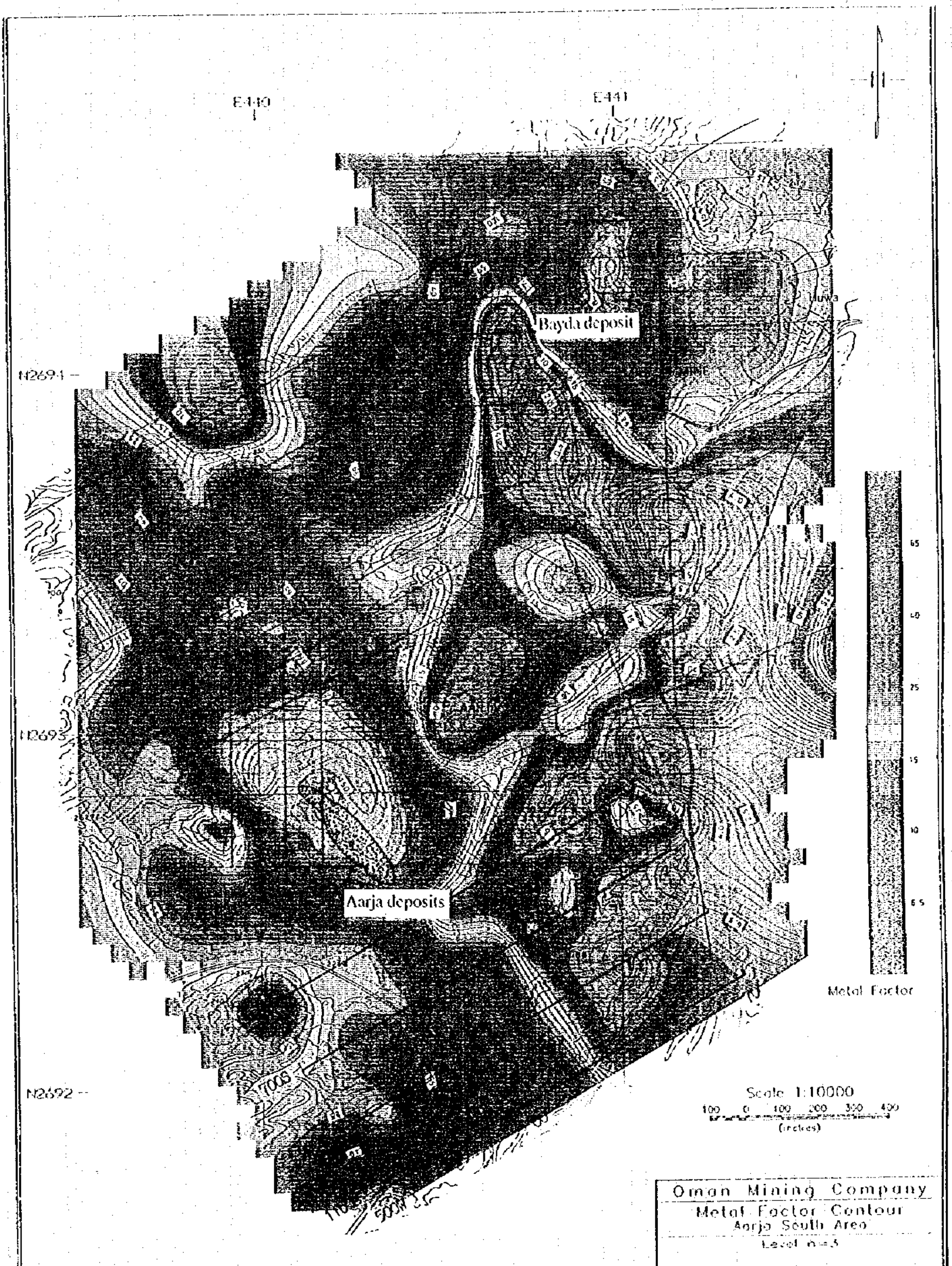
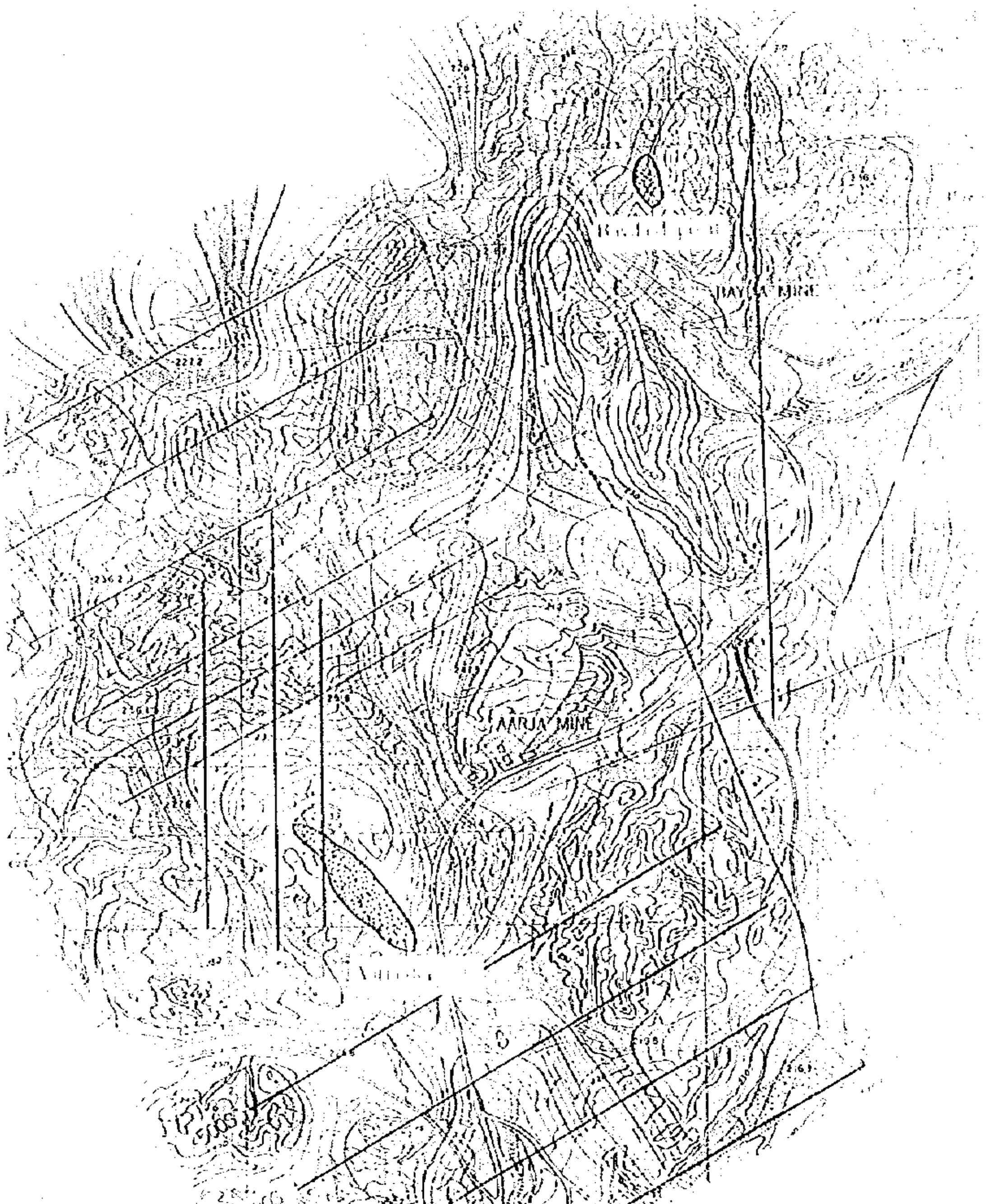


Fig.II-6-2(2) IP plane map near Aarja and Bayda deposits


AARJA MINE

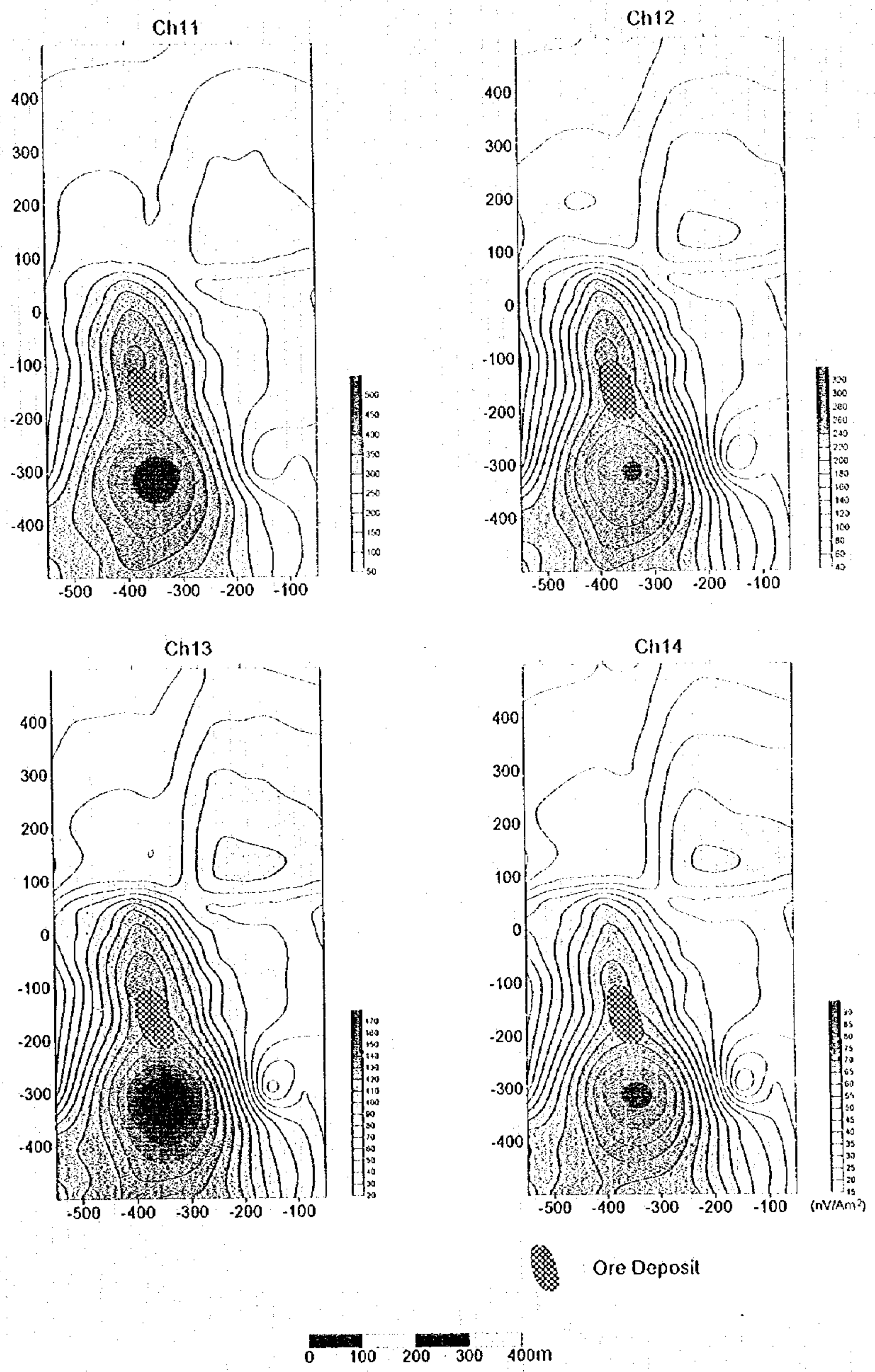


Fig.II-6-3 TEM response plane map in Bayda deposit

(a) IP Survey Results

Fig. II-6-4 shows the results in a plan map of resistivity, chargeability and metal factor distributions obtained from the IP survey. The exploratory drilling carried during the Phase II survey indicated good agreement with the high chargeability anomalies and massive and disseminated sulphide mineralization encountered in the boreholes.

The confirmed Western and Northern orebodies (Fig. I-4-6) are located in a low resistivity zone with high chargeabilities, which implies that probabilities to discover sulphide mineralizations can be high in places where metal factors resulted with high values.

(b) TEM Survey Results

The TEM survey was conducted by taking into consideration the location of anomalies extracted by means of high metal factors detected around the central area of the zone where the IP survey was carried out. The location of the area where the TEM transmitter loops were deployed as shown in the Fig. II-6-4.

Fig. II-2-11(2) summarizes in a compiled map the results obtained from the TEM survey. According to the results, five TEM anomalies, including the Western and Northern orebodies, were detected in the area.

Since outside of this anomalies, disseminated mineralization was intersected by the drilling exploration, it is very likely that three of the above mentioned five anomalies find massive sulphide deposits with a high probability of success.

(3) Guidelines for Future Geophysical Exploration Surveys

According to the ground geophysical results obtained in Oman for the exploration of Cyprus-type massive sulphide deposits, the first step towards the search of these deposits is the utilization of the IP method to cover a wide range. The distribution of prominent IP anomalies permits the extraction of a possible mineralization, which in turns, leads to the second step, i.e., the implementation of a TEM method within the areas delineated by IP method.

The results of the TEM survey add more probabilities to discover massive sulphide deposits by clarifying the distribution of high TEM responses.

In this survey and in order to increase the speed and efficiency during the survey, it was selected a large fixed transmitter loop with a receiver moving within the area. On the other hand, through tests carried out, it was found that the lateral and vertical resolution of the measured data can be improved by using loops small to some extent. The data processing for the case of small loop configurations is also less complicated.

The above mentioned fact can be further illustrated by the Fig. II-6-5, which shows a comparison of the TEM results around the borehole G5 by means of large configution loops (600 X 600m) as well as small central loop (50 X 50m) soundings. The left side of this figure indicates the TEM results by using the large configuration loop, while the rigth side shows the results of the small loop.

The results presented here are based on TEM data taken around the Western deposit: one plane map around the deposit and two sections (E-W and N-S directions respectively).

According to the TEM responses indicated in the plane maps at the top of this figure, it appears evident in the small loop case that the massive sulphide becomes thin around the borehole G16 and in G17 where the TEM responses suddenly become weak.

As can be seen in this figure, both of the two loop configurations detected the orebody, and specially, the small loop showed better resolution, and as such, the location of the orebody could be made clearer.

Assuming that less than 10 Ωm correspond probably to the massive sulphide orebody, the Section 325S shows the probable depth of the deposit and indicating that the deposit deepens to the west of G17 and east of G14. Additionally, the Section 775W, shows the orebody dipping gradually to the north.

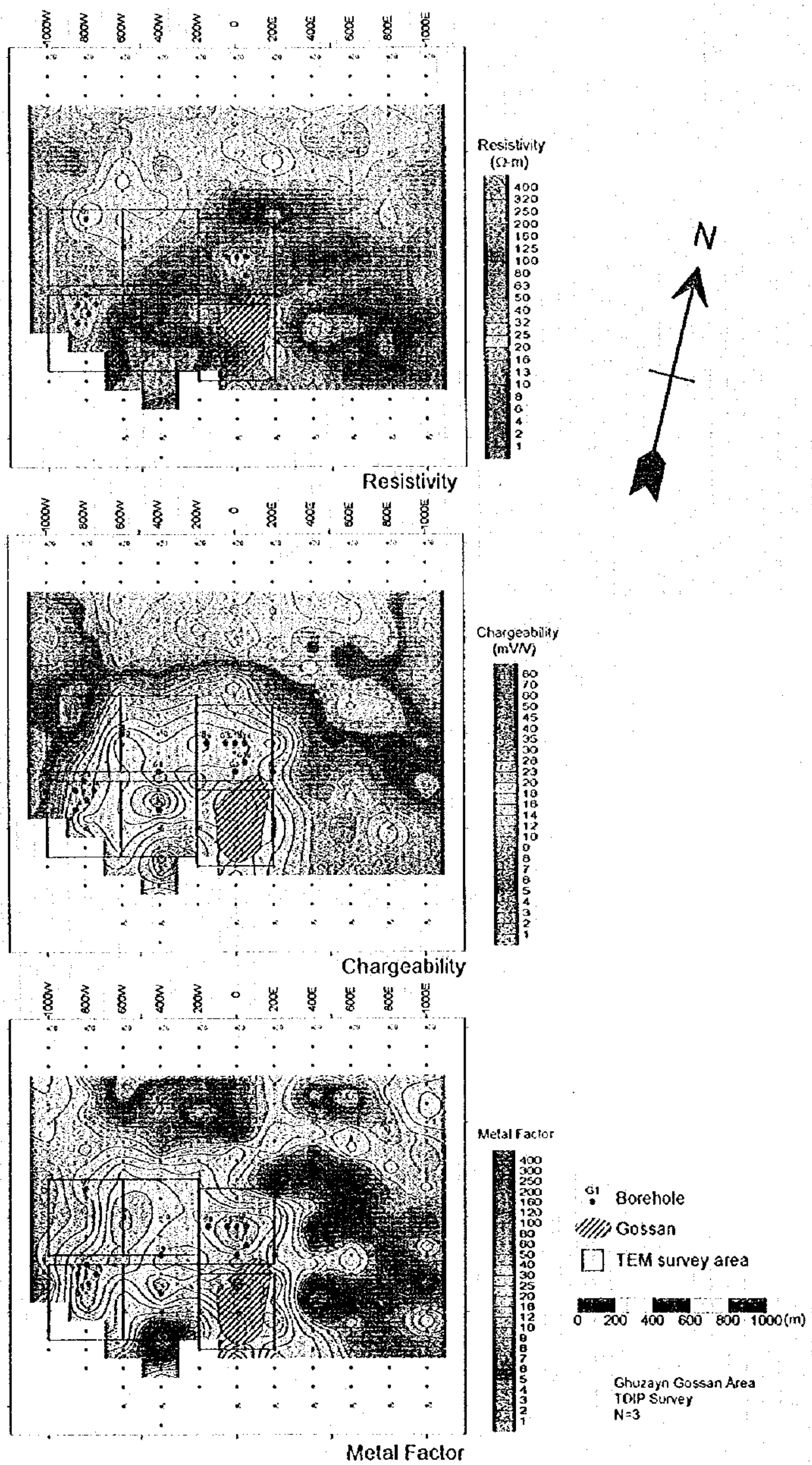
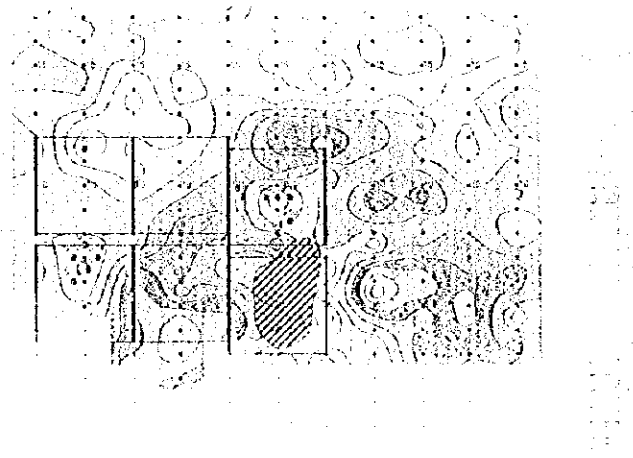
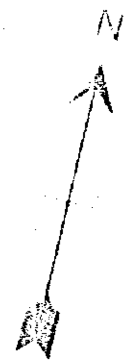
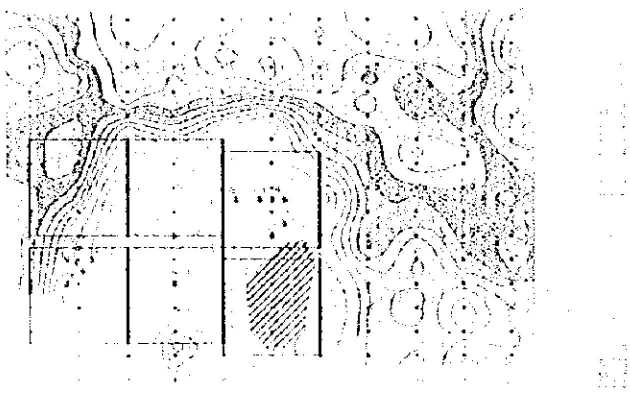


Fig.II-6-4 IP plane map in Ghuzayn gossan area

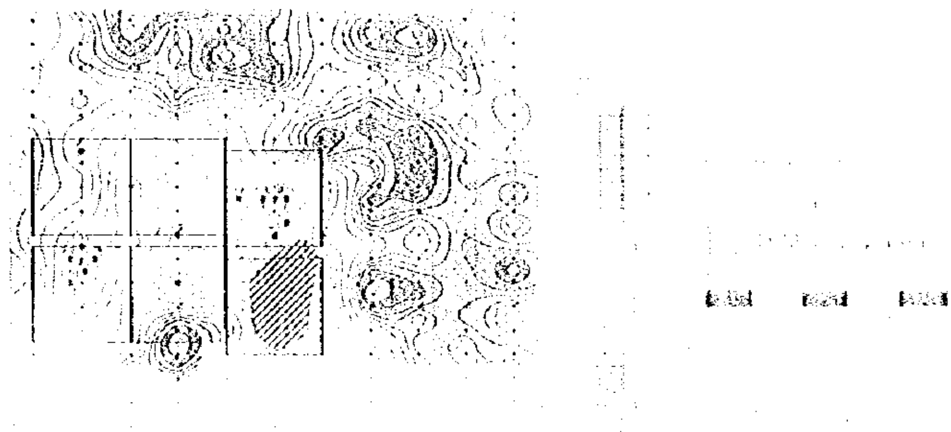


Resistivity





Chargeability



Metal Factor

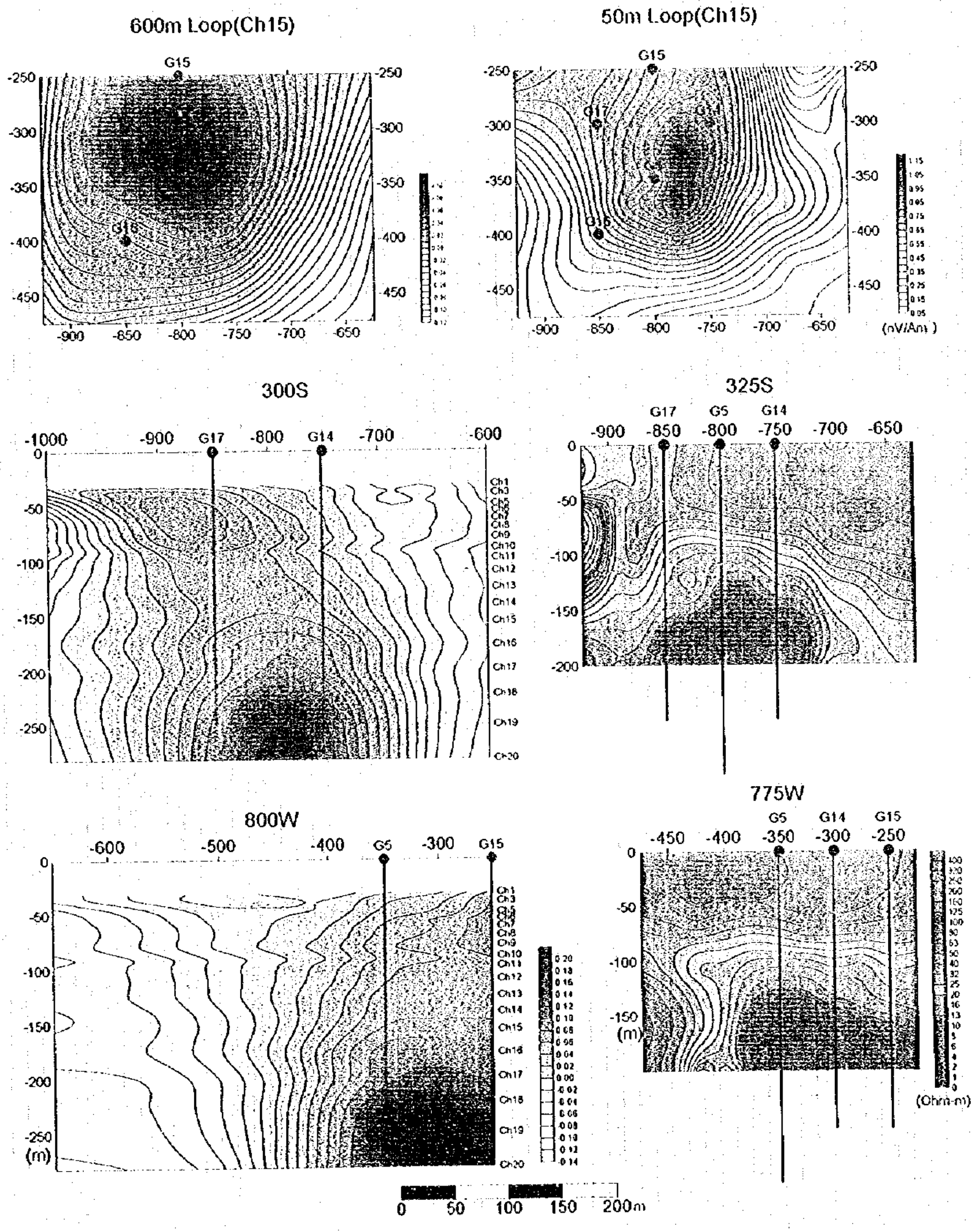


Fig.II-6-5 Comparative TEM results between 50m and 600m loops configuration

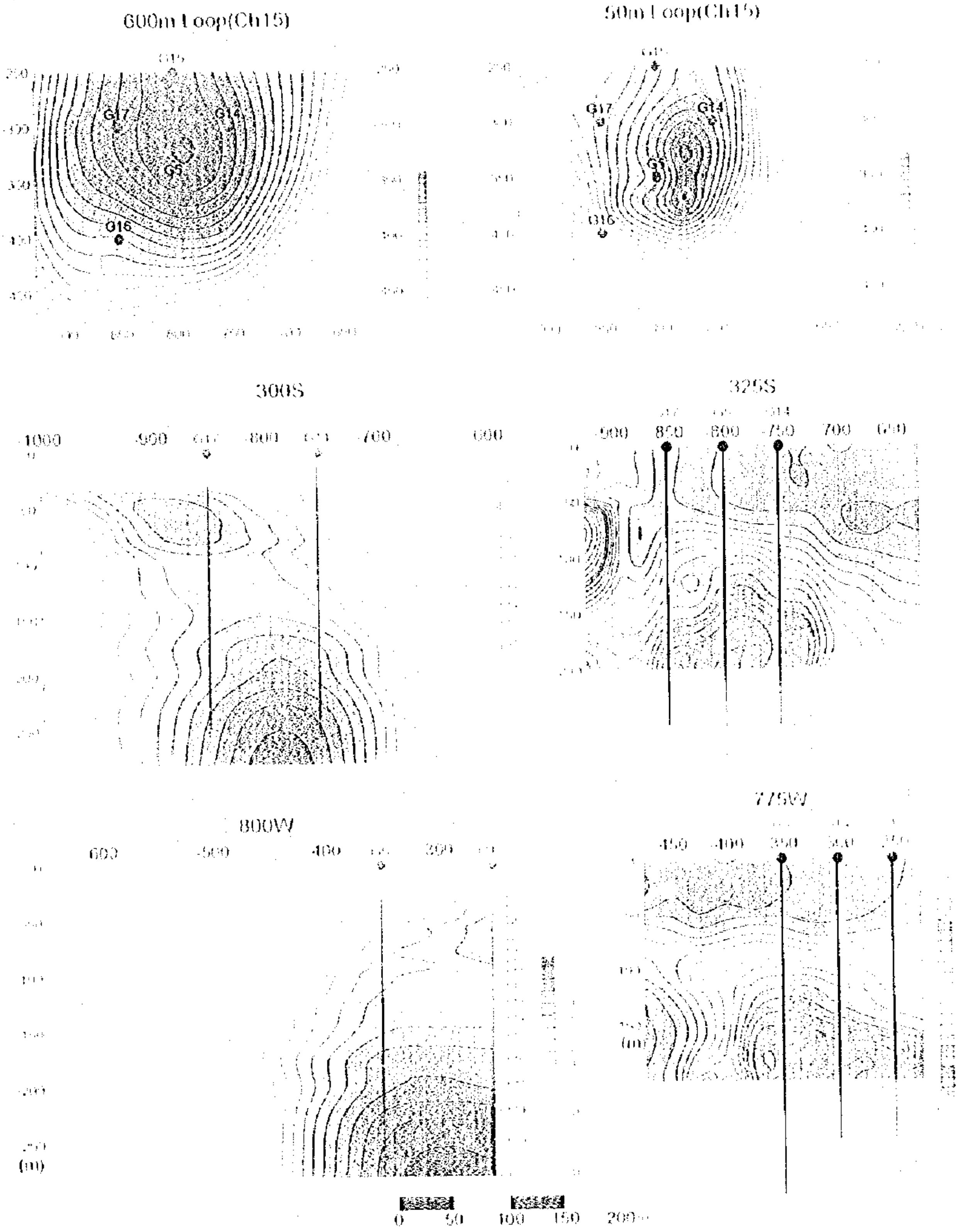


Fig II-6-5 Comparative TEM results between 50m and 600m loops configuration

PART III

CONCLUSIONS AND RECOMMENDATONS

CHAPTER 1 CONCLUSIONS

The survey results of two years from 1995 to 1996 can be summarized as follows:

(1) Drilling survey conducted in Ghuzayn area discovered massive sulphide bodies in two places, i.e., in the northern and western part. The Northern body located to the north of gossan, shows a maximum core length of 7.95m with average assays of 4.66% Cu in MJOB-G3 hole. The Western body located to the west of gossan, shows a maximum core length of 37.1m with average assays of 1.88% Cu in MJOB-G14 hole.

(2) TEM survey in Ghuzayn area highlighted the extension of massive sulphide ore bodies which were intersected in two places by drilling conducted in Phase II. The TEM data show also that the Western body has an extension of 150m wide in east-west direction and 300m long in north-south direction and that the Northern body extends 150m wide in east-west and 100m long in north-south. In addition, TEM data reveal also three interesting anomalies which may give indications of high potential locations for massive sulphide mineralization.

(3) In Doqal area, TEM survey was conducted in order to investigate the high metal factor zone detected by TDIP. Since the TEM anomalies extracted in the area correspond well to the high metal factor zone, it became clear that this area may have a high potential for mineralization of massive sulphide.

(4) In Daris area, drilling survey conducted in the central and northern part of the area, could not intersect any significant sulphide mineralization. However, a distinctive high chargeability zone was widely distributed to the north of the gossan and several high metal factor locations were delineated at the margin of a high chargeability zone. Accordingly, there is a possibility for the existence of massive sulphide deposits.

(5) Because of the thick coverage of Quaternary sediments, a ground geophysical survey seems to be the most important and effective tool for the exploration of copper deposits in Oman. According to the survey of two years in Central Batinah Coast for the exploration of Cyprus-type massive sulphide deposits, it is safe to say that the utilization of the TDIP method as a first step, is very effective to delineate a promissing sulphide mineralized zone while covering a wide area, and as a second step, the implementation of a TEM method is a powerful technique to delineate the most promissing locations for drilling. TEM surveys by means of small loop(50m x 50m) along with the drilling survey can delineate in more detail the extension of ore bodies and allocate better the drilling targets.

CHAPTER 2 RECOMMENDATIONS

Results of two years surveys show that the Central Batinah Coast area has a high potential for bearing massive sulphide deposits. As a continuation to the exploration program for the project, drilling and geophysical surveys are required in the areas of Ghuzayn, Doqal and Daris area as follows:

(1) Ghuzayn Area

1) Drilling survey is recommended to clarify the details of Northern and Western ore bodies found in this Phase II, along with TEM survey by using small loops(50m x 50m) to delineate in more detail the extension of bodies and to allocate drilling targets.

2) Drilling and TEM small loop surveys are recommended to investigate other anomalies detected by the TEM large loop survey carried out in this phase II.

3) TDIP survey is recommended around the area where TDIP was carried out in Phase I, in order to evaluate the total potential for mineralization in Ghuzayn area.

(2) Doqal Area

1) Drilling survey is recommended to be carried out to investigate the mineralization on the anomalies detected by TDIP and TEM surveys in this Phase.

2) Since TEM anomalies still continue towards north beyond the Phase II TEM survey area, it is neccessary to conduct a TEM survey in northern part in order to trace the detected anomaly zone. In addition, TEM survey is recommended to be carried out in the western part where IP anomaly was detected.

3) TDIP survey is recommended around the area where TDIP was carried out in Phase I, in order to evaluate the total potential for mineralization in Doqal area.

(3) Daris Area

1) Since the high metal factor zone detected in Phase I during the TDIP survey needs of further claryfication, it is recommended to continue TEM survey in selected locations defined by high metal factors detected in the central-western part of this area.

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