REPORT
ON
THE MINERAL EXPLORATION
IN
THE HAOUZ CENTRAL AREA
KINGDOM OF MOROCCO

PHASE Ⅲ

MARCH 1990

JAPAN INTERNATIONAL COOPERATION AGENCY

METAL MINING AGENCY OF JAPAN

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PREFACE

In response to the request of the Government of the Kingdom of Morocco, the Government of Japan decided to conduct a Mineral Exploration Project in the Haouz Central Area and entrusted the survey to the Japan International Cooperation Agency (JICA) and the Metal Mining Agency of Japan (MMAJ).

The JICA and MMAJ sent to the Kingdom of Morocco a survey team headed by Mr. Jinichi Nakamura from September 12 to December 18, 1989.

The team exchanged views with the officials concerned of the Government of the Kingdom of Morocco and conducted a field survey in the Haouz Central Area. After the team returned to Japan, further studies were made and the present report has been prepared.

We hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries.

We wish to express our deep appreciation to the officials concerned of the Government of the Kingdom of Morocco for their close cooperation extended to the team.

February, 1990

Kensuke Yanagiya
President
Japan International Cooperation Agency

Gen-ichi Fukuhara
President
Metal Mining Agency of Japan

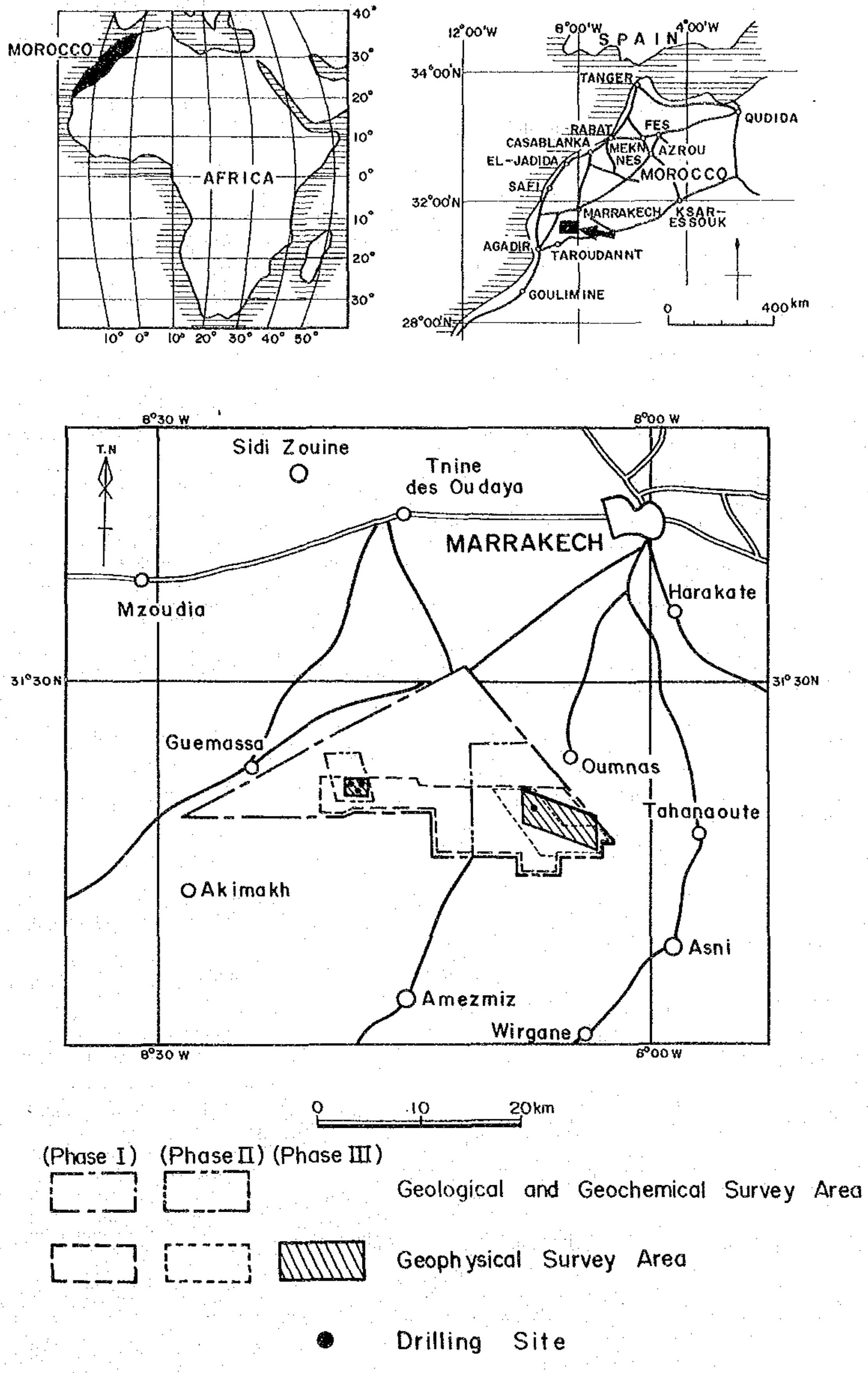


Fig. 1 Location Map of the Survey Area

Area	Measured Value		Analyzed Value		Magnetic Anomaly	Geological Structure
	PFE(%)	AR(Ωm)	PFE(%)	ρ(Ωm)		
Hajar SW Area	3-4	30-50	20	12	Medium	Southwest of Hajar orebody
Lamrah Area	3-5	20-40	5-15	15-20	Weak	Western extension of Hajar horizon
Frizem Area	5-6	20-40	10-25	10-20	Strong	Deeper part of Frizem west min. zone

(2) Drilling Exploration

Drilling exploration, 4 holes, each in 400m depth, total 1,600 m was carried out on the geophysical anomaly zones in the Lamrah area and in the Frizem west area.

As shown below, remarkable mineralized zones rich in copper, lead and zinc have been confirmed in every 4 holes. Main ore minerals are chalcopyrite, galena, sphalerite, pyrrhotite and pyrite.

No.	Rock Type	Depth (m)	No. of Ore	Mineralization				IP Anomaly	
				Type	Ore Min.	Width (m)	Grade	PFE (%)	AR (m)
MJMH-1	Sl-St	346-353	4	vlts	Py-Zn-Pb	0.1	Pb 6%, Zn 7%	3-4	20-40
MJMH-2	Ph-St	130-380	4	netw	Py-Zn-Cu	1.2	Pb 1%, Zn 2%	5-6	30-40
MJMH-3	Ph-St	120-340	5	netw	Py-Zn-Cu	1.3	Pb 1%, Zn 2%	4-6	50-90
MJMH-4	Ph-St	150-240	4	vein	Py-Po-Zn	0.3	Pb 1%, Zn 2%	4-5	30-60

Sl: Slate, Ph: Phyllite, St: Siltstone
Py: Pyrite, Po: Pyrrhotite

The confirmed mineralized parts are distributed widely, however, they show small-scale or low-grade dissemination, network ores and vein type ores, which are somewhat different from the massive sulfide orebody of Hajar and estimated to be difficult to develop economically.

SUMMARY

This report contains the Third Phase survey results of the Cooperative Mineral Exploration in the Haouz Central Area in the Kingdom of Morocco.

The purpose of this survey is to obtain comprehensive information on the condition of emplacement of mineral ore deposits through the elucidation of geological phenomena in the Haouz Central Area.

In this year, the following surveys were carried out in the Eastern Area and the Western Area which were selected for the promising areas in the First Phase and Second Phase surveys:

Geophysical prospecting IP method

Eastern Area:	14 lines, 20.2 km, 730 pts
Western Area:	3 lines, 6.0 km, 240 pts
Total :	17 lines, 26.2 km, 970 pts

Drilling exploration

Eastern Area:	400 m x 1 hole
Western Area:	400 m x 3 holes
Total :	400 m x 4 holes, total 1,600 m

(1) Geophysical Prospecting IP Method

Strong magnetic anomaly have been detected on the Hajar ore deposit and the ore shows strong IP anomaly and low resistivity (PFE = 10-20%, ρ = 10-20 Ωm).

In the Third Phase survey, IP prospecting was carried out on the concealed Hajar horizon in the Eastern Area and on the mineralized zone in the Western Area. As the results, several strong IP anomalies have been detected as shown below:

(3) Conclusion

A series of systematic surveys have clarified the following facts as to the features of mineralization and geophysical anomalies in this area.

1) Judging from the mode of occurrence and the ratio of ore minerals, the ores confirmed in the Lamrah area and the Frizem west area must be network ores formed in the lower part and in the peripheral zone of the sedimentary massive orebody.
2) The IP anomaly in the Lamrah area must be caused by the dissemination mainly of pyrite, accordingly, it is missing of strong magnetic anomaly.
3) The strong IP anomaly and magnetic anomaly in the Frizem west area must be caused by the network ore of pyrite and pyrrhotite. The network ore shows strong IP anomalous value equivalent to the massive ore.

(4) Outlook for the Future

1) To the southwest of the Hajar ore deposit, a weak IP anomaly has been confirmed. It is desirable to clarify the cause of the IP anomaly whether it depends on the occurrence of a concealed orebody or another reason.
2) In the Frizem area, it is difficult to expect a large-scale and high-grade massive orebody comparatively in the shallow underground. However, it is recommended to continue the study and survey concerning a possibility of orebody in the deeper places, judging from the increasing trend of IP anomaly to the deeper.

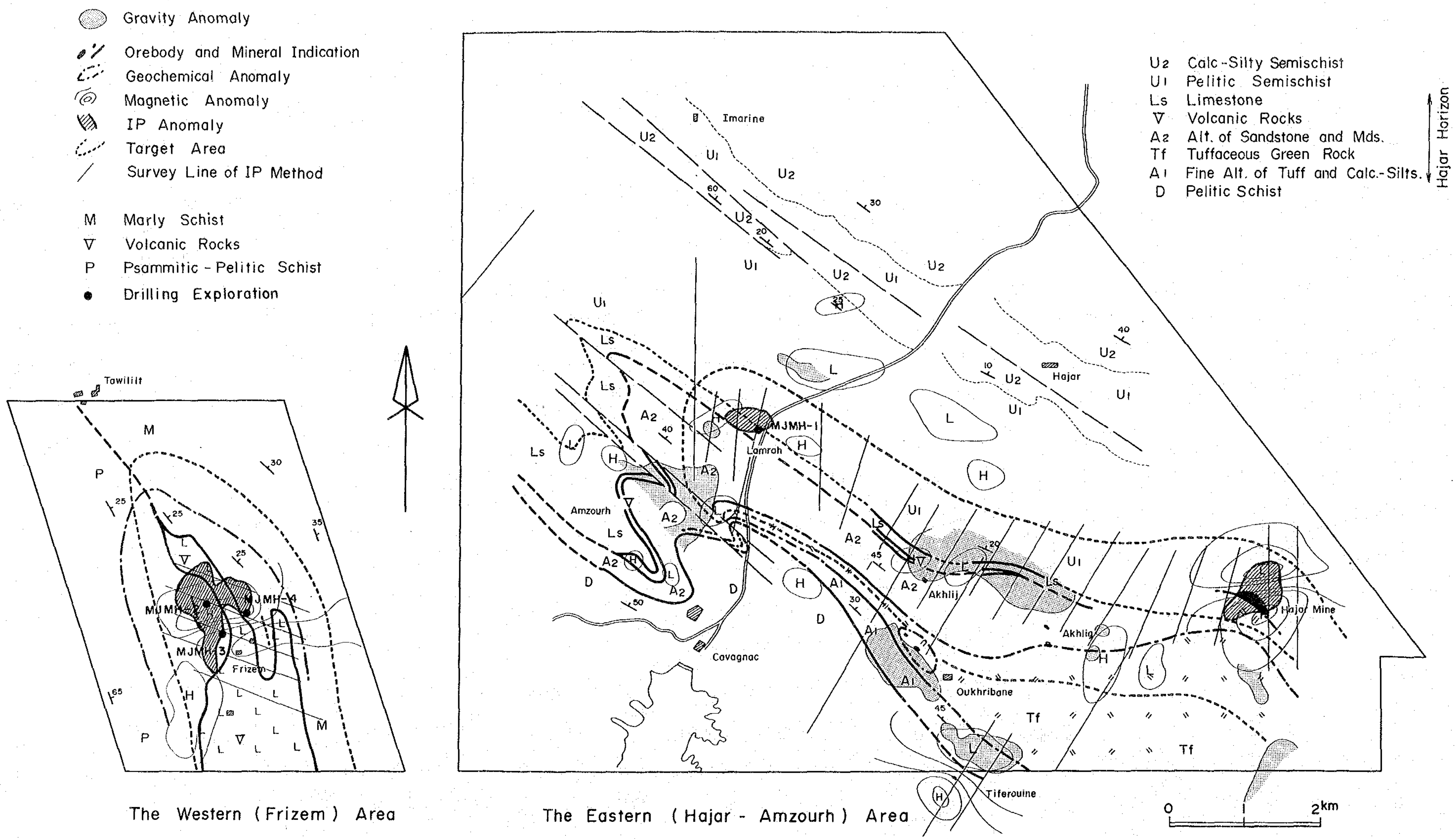


Fig. 2 Synthetic Map of the Exploration Results

CONTENTS

PARTICULARS

PART I GEOPHYSICAL SURVEY

PART II DRILLING EXPLORATION

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF PLATES

GENERAL REMARKS

CHAPTER 1 INTRODUCTION

1-1 Background of the Survey

The Kingdom of Morocco is rich in mineral resources and enforces a policy to develop mineral resources.

The Cooperative Mineral Exploration in the Haouz Central Area has been selected and agreed between the Bureau de Recherches de Participations Minieres (BRPM), the official organization of the Kingdom of Morocco, and the Project Finding Mission on November, 1986 and the Preliminary Survey Team on June, 1987, dispatched by the Government of Japan in response to the request of the Government of Morocco.

The survey of this year is corresponding to the Third Phase. In the First and Second Phase surveys, geological and geochemical survey, and geophysical prospecting by CSAMT method, IP method and Gravity method were carried out and two specific prosperous areas - the Eastern Area and the Western Area were picked up to enforce the detailed survey in the Third Phase (Fig. 1).

1-2 Conclusion and Recommendation of the Second Phase Survey

1-2-1 Conclusion of the Second Phase Survey

(1) Geological and Geochemical Survey

1) It was indicated that the ore deposits in this area were embedded in the two specific geologic horizons, namely Hajar horizon in the Eastern Area and Frizem horizon in the Western Area. The former is composed of acidic volcanic and pyroclastic rocks, siltstone, tuffaceous mudstone and limestone. The latter is composed of acidic volcanic and pyroclastic rocks.

2) The ore deposits represented by the Hajar ore deposit are submarine sedimentary type, formed in relation to the acidic volcanic activities. In the Hajar ore deposit, a large-scale and high-grade massive bedded orebody concentrated with lead, zinc, copper and silver has been formed at the upper part. And at the lower part of the mineralized horizon, a stockwork and vein-type orebody containing zinc and copper has been formed.
It was concluded that there was a high possibility for the occurrence of the other ore deposits of the same type to the Hajar orebody in the specific geologic horizons mentioned above.

(2) Geophysical Prospecting

1) By detecting the Hajar ore deposit as a low resistivity and strong IP zone, IP method was proved to be an effective technique for the exploration in this area.
2) The same low resistivity and strong IP anomalies were detected in the Lamrah and Frizem areas.
3) Several high gravity anomaly zones were detected by the gravity method. It was difficult to expect large scale massive ore deposit but a possibility of disseminated ore deposit was remained.
4) At the low resistivity and strong IP anomaly area found in Lamrah, a possibility of disseminated ore deposit was expected.
5) High resistivity and strong IP anomaly zone was found at Frizem. A possibility of the ore deposit similar to Hajar type was expected.

1-2-2 Recommendation of the Second Phase Survey

From the results of the Second Phase survey, several recommendations were proposed for the Third Phase survey as follows:

1) Detailed IP survey in the Frizem area to find out the structure and extension of the low resistivity and strong IP anomaly zone.
2) IP survey at the northern part of the line connecting the Hajar Mine, Akhlij, and Lamrah, where Hajar horizon is concealed below the surface. (The Second Phase IP survey was carried out in the area where the Hajar horizon was exposed on the surface.)
3) Drilling exploration for the low resistivity and strong IP anomaly zones in the Frizem and Lamrah areas.

1-3 Outline of the Third Phase Survey

1-3-1 The Survey Area

The Haouz Central Area is a triangular-shaped area of 350 km^2 located in the west central part of the Kingdom of Morocco, about 330 km south-southwest of Rabat.

As the results of the First Phase survey, two promising areas, the Eastern Area (Hajar-Amzourh Area about 100 km^2) and the Western Area (Frizem Area about 20 km^2) had been extracted for the extensive survey target of next stage. By the Second Phase survey, two important areas, the Concealed Hajar Horizon Zone about 15 km^2 and the Frizem West Mineralized Zone about 4 km^2 have been extracted for the extensive exploration target of the Third Phase survey.

1-3-2 Purpose of the Survey

The purpose of the survey is to clarify the details of geological successions and structure of mineralized horizons and the features of mineralization, and to confirm geophysical anomalous zones that suggest the existence of concealed orebodies.

1-3-3 Method of the Survey

Geophysical prospecting by means of IP method and drilling exploration were adopted for the Third Phase survey.
The details are as follows:

(1) Field Survey

Items	Eastern Area	Western Area
Geophysical Prospecting		
IP Method		
No. of lines (lns)	14	3
Length of lines (km)	20.2	6.0
No. of stations (pts)	730	240
Drilling Exploration		
Depth (m) × holes	400×1	400×3
Total length (m)	400	1,200

(2) Laboratory Test

Thin section:	20 pcs
Polished section:	10 pcs
X-ray diffraction:	20 pcs
Ore analysis (Ag-Cu-Pb-Zn):	62 pcs
Measurement of AR and PFE values:	10 pcs

1-3-4 Organization of the Survey Team

The members of the Third Phase survey team are as follows:

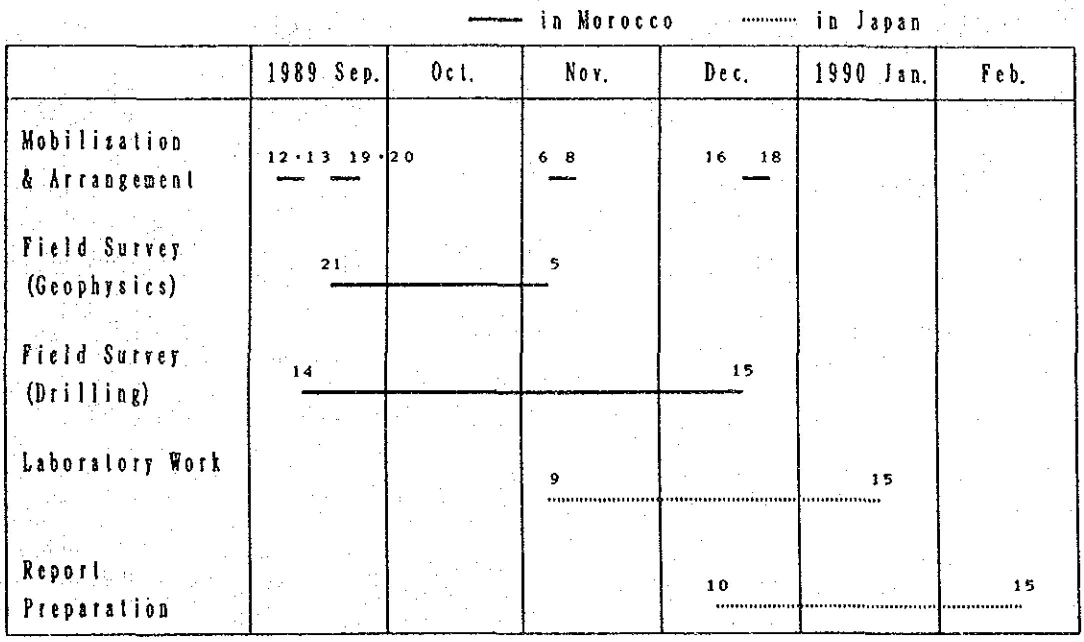
Japan Side			Morocco Side	
Coordinate	Naoki SATO	(MMAJ)	Assou LHATOUTE	(BRPM)
Coordinate	Koji KOIWA	(MMAJ)	Ali BENNANI	(BRPM)
			Ahmed LOUALI	(BRPM)
			El Bachir BARODI	(BRPM)
Leader Drilling	Jinichi NAKAMURA	(MINDECO)	Abderrahim CHBIHI	(BRPM)
Geophysic	Kazuhiko KINOSHITA	(MINDECO)	Mohamed BERRADA	(BRPM)
Geophysic	Tadashi OHASHI	(MINDECO)	Said QASRI	(BRPM)
Geophysic	Hirokazu MUTO	(MINDECO)		

MMAJ: Metal Mining Agency of Japan

BRPM: Bureau de Recherches et de Participations Minieres

MINDECO: Mitsui Mineral Development Engineering Co., Ltd.

1-3-5 Survey Schedule



CHAPTER 2 OUTLINE OF THE SURVEY AREA

2-1 Géography

Refer to the report of Phase I.

2-2 Previous Exploration

February 1988, the CMG (Companie Miniere des Guemassa) financed by both BRPM and ONA (Omnium Nord Africain) had been established to open the Hajar Mine and test operation in 200 t/d is currently running.

As for the detailed progress, refer to the report of Phase I.

CHAPTER 3 GENERAL GEOLOGY

The Haouz Central Area is located in the Paleozoic geosynclinal belt developed along the marginal parts of the Mauritanian Craton. The Carboniferous to Permian Systems are cropped out partly in the survey area, although the greater part of the survey area is covered extensively by the Quaternary and Neogene sediments (Fig. 3).

The Carboniferous to Permian Systems are mainly composed of pelitic and marly schist and semischist intercalated with acidic volcanic beds. Numerous schistosity faults and drag folds are developed in the schist and semischist. Although the geological structure is intensively deformed and complicated, the general trend of the formation is NNE-SSW or NW-SE directions dipping to the northeast (Fig. 4).

Ore deposit in the survey area is emplaced in the Carboniferous to Permian Systems and represented by the Hajar ore deposit in the Eastern Area and the Frizem mineralized zone in the Western Area. The Hajar ore deposit is a bedded sulfide deposit concealed in the ground at the depth of 150 m to 500 m below the surface. The Frizem mineralized zone is a lenticular and vein type gossan.

The mineralization in this area is intimately related to acidic volcanic activities and the ore deposits occurred in some specific horizons. The most important mineralization horizons are the Hajar horizon composed of an alternation of acidic volcanic and pyroclastic rocks, siltstone, sandstone, tuffaceous mudstone and limestone, and the Frizem horizon composed of acidic volcanic and pyroclastic rocks (Fig. 5).

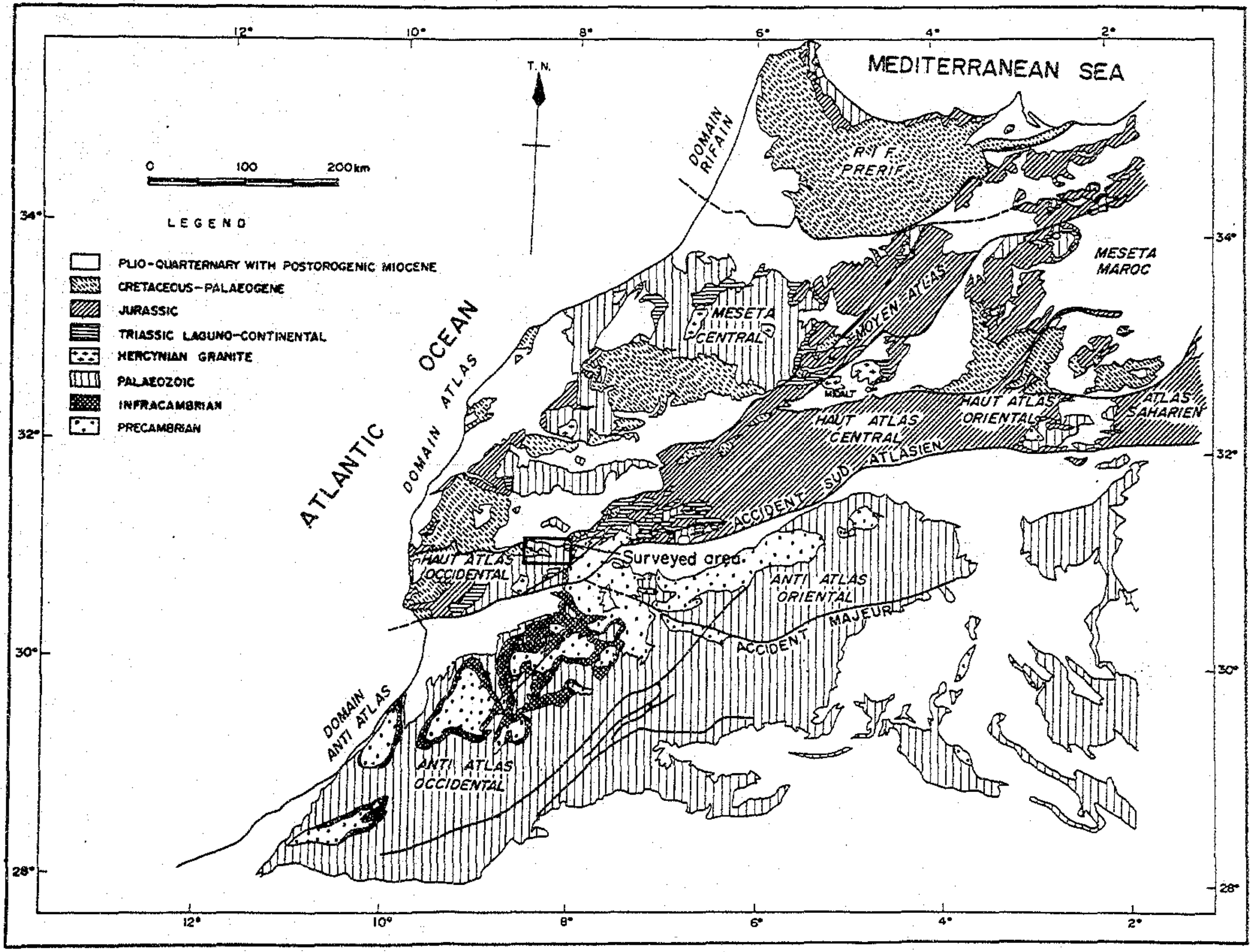
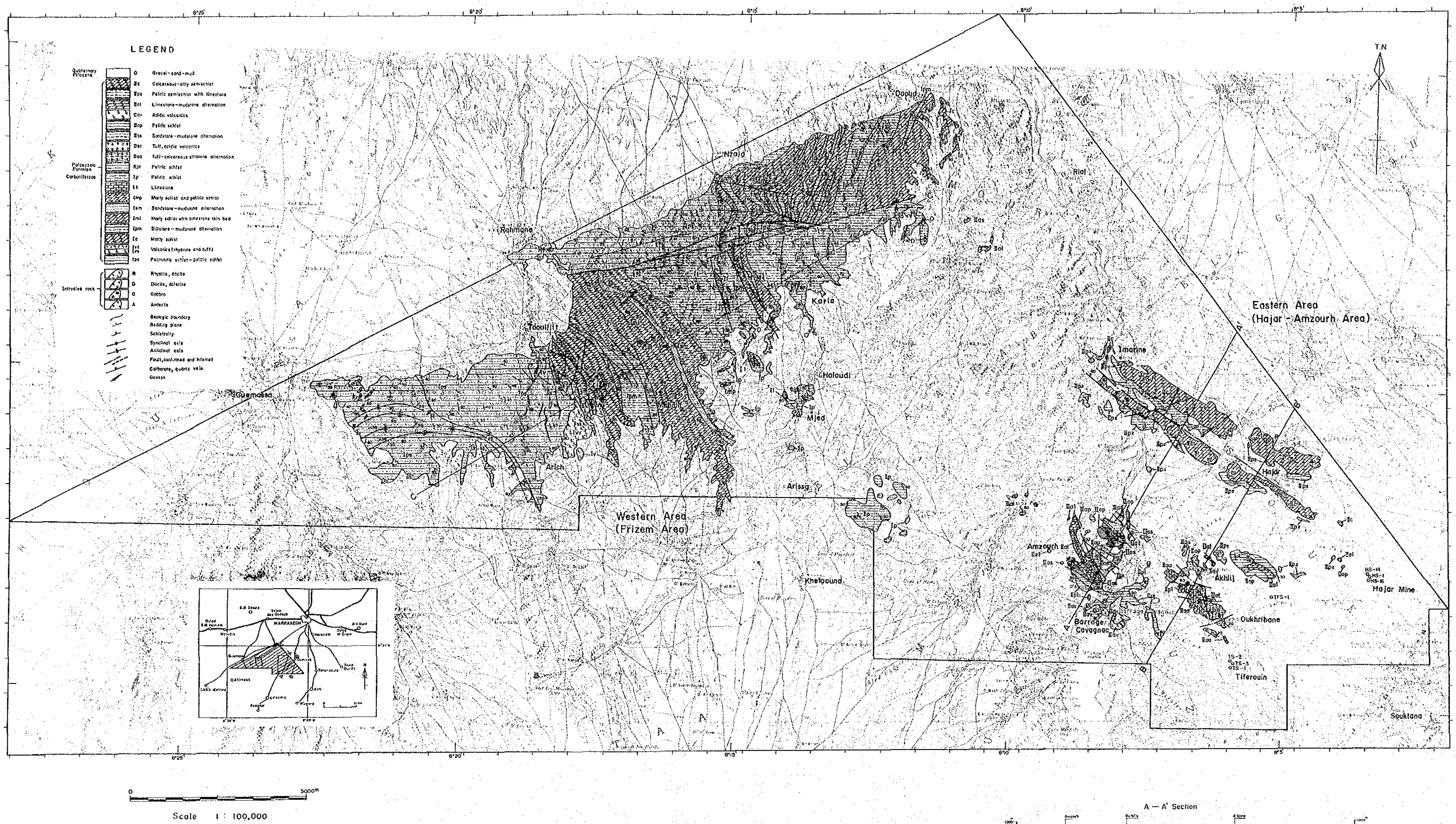
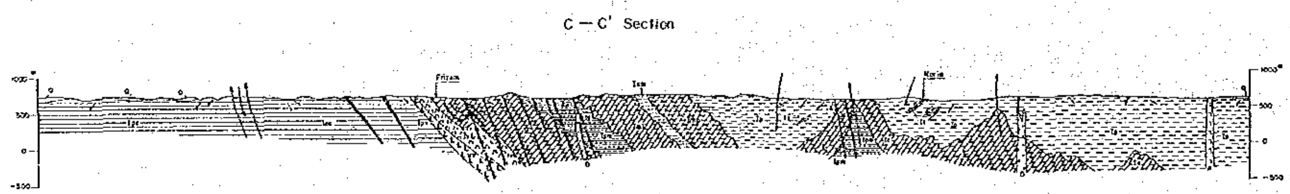


Fig. 3 Geotectonic Map of Northern Morocco





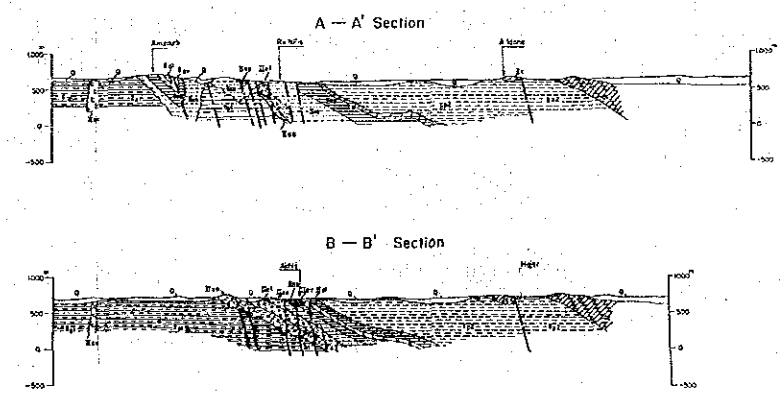


Fig. 4 Geological Map of the Haouz Central Area

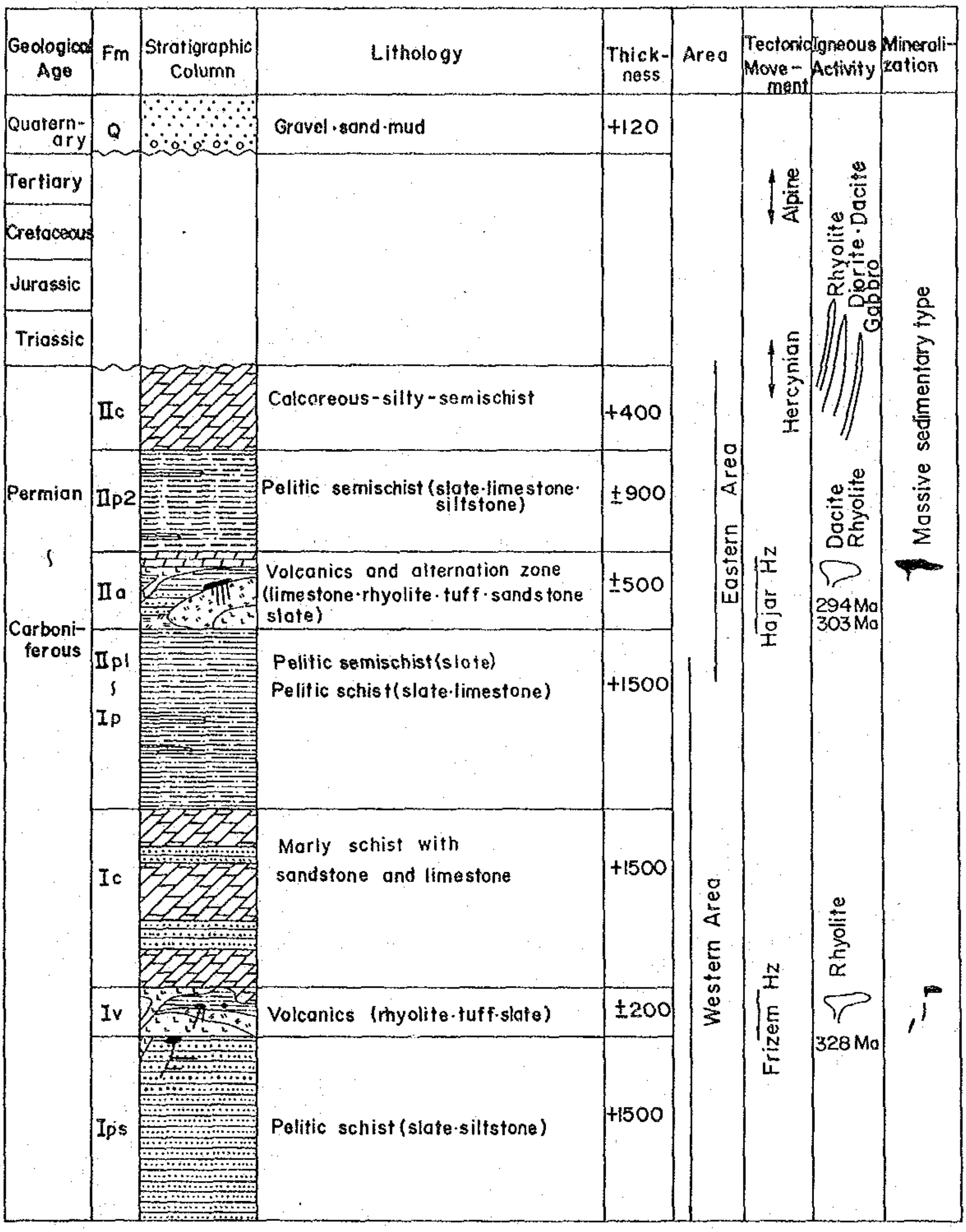


Fig 5 Schematic Geological Column of the Haouz Central Area

CHAPTER 4 SYNTHETIC INTERPRETATION

4-1 Results of Geophysical Prospecting IP Method

Strong magnetic anomaly have been detected on the Hajar ore deposit and the ore shows strong IP anomaly and low resistivity (PFE = 10-20%, ρ = 10-20 Ωm).

It has been confirmed by the IP prospecting near the Hajar orebody in the 2nd Phase that the IP method, as well as magnetic survey, is effective for the exploration for the Hajar type orebody.

In the 3rd Phase, IP prospecting was carried out on the concealed Hajar horizon in the Eastern Area and on the Frizem mineralized zone in the Western Area. As the result, several anomaly zones were detected under the surface.

Hajar Area (HJ-1):	PFE = 5-6%, AR = 20-40 Ωm
Hajar SW Area (E-14):	PFE = 3-4%, AR = 30-50 Ωm
Lamrah Area (LM-2, E-2):	PFE = 3-5%, AR = 20-40 Ωm
Frizem West Area (W-1, FZ-1, W-2, W-3):	PFE = 3-5%, AR = 20-40 Ωm

The IP anomaly zone in the Frizem area is found in the western part. The intensity and size become stronger and larger in the deeper place to the east.

4-2 Results of Drilling Exploration

(1) The Eastern Area

Drilling, MJMH-1 was performed on the concealed IP anomaly zone (PFE = 3-5%, AR = 20-40 Ωm) in the Lamrah area.

As the drilling result, slate and siltstone belonging to a part of the Hajar horizon were confirmed, in which dissemination of pyrite was found widely and veinlets of lead and zinc were confirmed between the depth of 346 m and 354 m.

Average grade of the 4 veinlets was Ag 8 g/t, Cu 0.05%, Pb 6.39%, and Zn 6.91% in average width 15 cm.

(2) The Western Area

3 drillings, MJMH-2, MJMH-3, and MJMH-4 were performed on the IP and magnetic anomaly zones in the Frizem west area.

As the drilling results, phyllite and siltstone forming a fine alternation were found in every holes, in which remarkable mineralization of copper, lead and zinc was observed. The ores occur in the forms of vein, veinlet, network and dissemination with transitional relation to the host rock.

Ore minerals are mainly chalcopyrite, galena, sphalerite, pyrrhotite and pyrite. Gangue minerals are quartz, dolomite, siderite and calcite.

Siltstone, which forms a fine alternation with phyllite, is inferred to be originated in tuffaceous rock, judging from the mineral composition and texture.

The alternation is corresponded to the uppermost horizon in the pelitic schist located at the lower part of the acidic volcanic and pyroclastic rocks.

The assay results of the main ore parts are shown below.

DH No. DDH	No. of Sample	Av. Width(m)	Ag(g/t)	Cu(%)	Pb(%)	Zn(%)
MJMH-2	4	1.2	10	0.23	0.91	1.44
MJMH-3	5	1.3	6	0.17	0.99	1.62
MJMH-4	4	0.3	8	0.11	0.88	1.82

4-3 Synthetic Interpretation

(1) Measured Results of Rock Property

The measured values of the physical properties for the rock samples collected in this area are as follows:

Rock Type	No. of Sample	Resistivity (m)	PFE (%)	Density (g/cc)	Susceptivity (10-5cgs/emu)
Querternary	2	73(50-120)	1.1(1 - 2)	2.21(2.0-2.5)	2
Basement	18	510(300-800)	0.8(0.2-4)	2.70(2.6-2.8)	2
Ore (Hajar)	4	18(14- 23)	15 (12 - 20)	4.25(3.8-4.6)	530

(   ): distribution range

The ore samples taken from the Hajar orebody show considerably different properties from the rock samples taken from the basement group, that is to say, about 1/30 times in electic resitivity, about 20 times in PFE (frequency effect), 2.2 times in density, and 250 times in magnetic susceptivity.

(2) Summary of Each Geophysical Survey Results

The anomalies indicating the possibility of occurrence of ore deposit extracted by several different survey methods are shown below (Fig. 2).

Area	Magnetic Anomaly	AR Value	IP Anomaly	Gravity Value	Geoch Anomaly	Type of Ore
Hajar Ore Dep.	SSS	L	SSS	M	-	mass (Po-Pb-Zn)
Hajar SW Area	SS	L	SS	H	-	
Akhlig Area	W	M	W	M	-	diss (Po-Zn)
Akhlij Area	W	L	W	H	-	
Lamrah Area	W	L	SS	M	-	
Tiferouine Area	SSS	M	W	H	-	diss (Po-Py-Mg)
Oukhribane Area	W	M	W	H	SS	diss (Py-Cu)
Amazourh Area	SS	-	-	-	SS	vein (Py-Zn-Cu)
Frizem East Area	SSS	L	SS	-	SSS	mass (Py-Pb-Zn)
Frizem West Area	SSS	L	SSS	-	SSS	

SSS = very strong   H = high
SS = strong   L = low
W = weak   M = medium

Magnetic anomaly is principally caused by pyrrhotite and magnetite and IP anomaly is chiefly caused by sulfide minerals. Accordingly, the magnetic survey is thought to be very effective for the exploration for the Hajar type ore deposit, although the IP prospecting is considered to be more effective for the exploration for the ore deposit that is rich in pyrite instead of pyrrhotite.

After synthetic consideration on all of the survey results, the Frizem west area and the Lamrah area were selected as the target of drilling exploration in the Third Phase survey.

(3) Comparison of the Survey Results of Drilling and Geophysical Survey

Remarkable indications of mineralization have been confirmed widely in all the drilling total 4 holes carried out in the Lamrah and Frizem areas. However, every mineralized parts encountered by drill holes are low-grade or small-scale disseminated ore, network ore and vein-type ore, which are seemed to be difficult to develop economically for mining.

The comparison table of the drilling results and the geophysical data is shown below:

No.	Rock Type	Depth (m)	No.of Ore	Mineralization Type	Ore Min.	Width(m)	Grade	I P Anomaly PFE(%)	AR(Ωm)
MJMH-1	Sl-St	346-353	4	vlts	Py-Zn-Pb	0.1	Pb 6%, Zn 7%	3-4	20-40
MJMH-2	Ph-St	130-380	4	netw	Py-Zn-Cu	1.2	Pb 1%, Zn 2%	5-6	30-40
MJMH-3	Ph-St	120-340	5	netw	Py-Zn-Cu	1.3	Pb 1%, Zn 2%	4-6	50-90
MJMH-4	Ph-St	150-240	4	vlts	Py-Po-Zn	0.3	Pb 1%, Zn 2%	4-5	30-60

Sl: Slate St: Siltstone Ph: Phyllite
Py: Pyrite Po: Pyrrhotite

Then, several measured values concerning to the physical properties of the rock and ore samples collected from the drilling core are shown in the following table:

Area	Type (Ore Mineral)	No. of Sample	Resistivity (Ω m)	PFE (%)
Lamrah Area	Host Rock	4	1205 (550-2200)	2.6 (1.0-4.3)
	Diss Ore (Py)	1	230	5.6
Frizem Area	Host Rock	4	983 (110-1700)	0.8 (0.3- 1.2)
	Netw Ore (Py-Po-Zn-Cu)	3	166 (98-300)	11.5 (5.8-17.4)
	Vein Ore (Py-Po-Zn-Cu)	1	12	12.0

( ): range

Based on the above 2 tables and the measured data shown in the Tab. 4, the following inference on the relationship between physical property and mode of mineralization is induced.

1) Pyrite dissemination ore and pyrite-pyrrhotite network ore show extraordinally high PFE value nearly equal to the pyrrhotite-pyrite vein-type and massive ores.
2) The reason that IP anomaly in the Lamrah area is not associated with strong magnetic anomaly is depended on it's mineral assemblage composed mainly of pyrite.
3) The strong IP and magnetic anomalies in the Frizem west area are caused by pyrite-pyrrhotite ore. Accordingly, it is considered to be difficult to expect the existence of high-grade massive orebody comparatively in the shallow place.

CHAPTER 5 CONCLUSION AND RECOMMENDATION

5-1 Conclusion

(1) IP Prospecting

Strong IP anomalies were detected by the IP prospecting in the following areas. These IP anomalies were considered to indicate a possibility of the occurrence of sulfide orebody.

Area	Measured Value		Analyzed Value		Magnetic	Geological
	PFE(%)	AR(m)	PFE(%)	AR(m)	Anomaly	Structure
Hajar SW Area	3-4	30-50	20	12	Medium	Southwest of Hajar Orebody
Lamrah Area	3-5	20-40	5-15	15-20	Weak	West of Hajar Horizon
Frizem Area	5-6	20-4-	10-25	10-20	Strong	Frizem West Mineral Zone

(2) Drilling Exploration

Drilling exploration was carried out for the above mentioned geophysical anomaly zones, one hole in the Lamrah area, three holes in the Frizem area, 1,600m in total length. As the result, remarkable mineralized zones concentrating copper, lead and zinc associated with pyrrhotite and pyrite have been encountered widely by all of the 4 drilling holes.

However, all of the ore parts were low-grade or small-scale dissemination-type, network-type and vein-type, and it was thought they were difficult to develop economically.

It was estimated that the strong IP anomaly associated with weak magnetic anomaly in the Lamrah area are caused by extensive dissemination of pyrite in the host rock.

According to the measurement results of the ore samples taken from the drilling core, pyrite dissemination ore and pyrite-pyrrhotite network ore show extraordinally high PFE value equivalent to that of the pyrrhotite-pyrite vein-type and massive ores. This fact means that IP anomaly do not always indicate the existence of massive orebody. It is inferred that the strong IP and magnetic anomalies in the Frizem west area are caused by pyrite-pyrrhotite dissemination and network ores.

(3) Synthetic Discussion

The mineralized parts confirmed by drilling exploration are dissemination-type, network-type and vein-type orebodies containing copper, lead and zinc, and associated with pyrite and pyrrhotite, which are estimated to correspond to the lower parts and the peripheral zones of the massive orebody.

Remarkable mineralization indications and strong geophysical anomalies have been detected in the Hajar and Frizem horizons by the series of explorations. However, it could not be attained to confirmed the existence of high-grade and large-scale ore deposit.

An exploration system combined of some different methods were employed in this area. Magnetic propecting and IP prospectings must be most effective methods for the concealed ore deposit in this area, nevertheless, it became clear that magnetic anomaly did not always indicate sulfide orebody because magnetic anomaly was strongly controled by the contents of magnetite and pyrrhotite, and that by the IP method it was difficult to distinguish massive orebody from the dissemination-type and network-type orebody.

5-2 Recommendation for the Future

1) To the southwest of the Hajar ore deposit, a weak IP anomaly has been confirmed. It is desirable to clarify the cause of the IP anomaly whether it depends on the occurrence of a concealed orebody or another reason.

2) In the Frizem area, it is difficult to expect a large-scale and high-grade massive orebody comparatively in the shallow underground. However, it is recommended to continue the study and survey concerning a possibility of orebody in the deeper place, judging from the increasing trend of IP anomaly to the deeper.

PART I
GEOPHYSICAL SURVEY

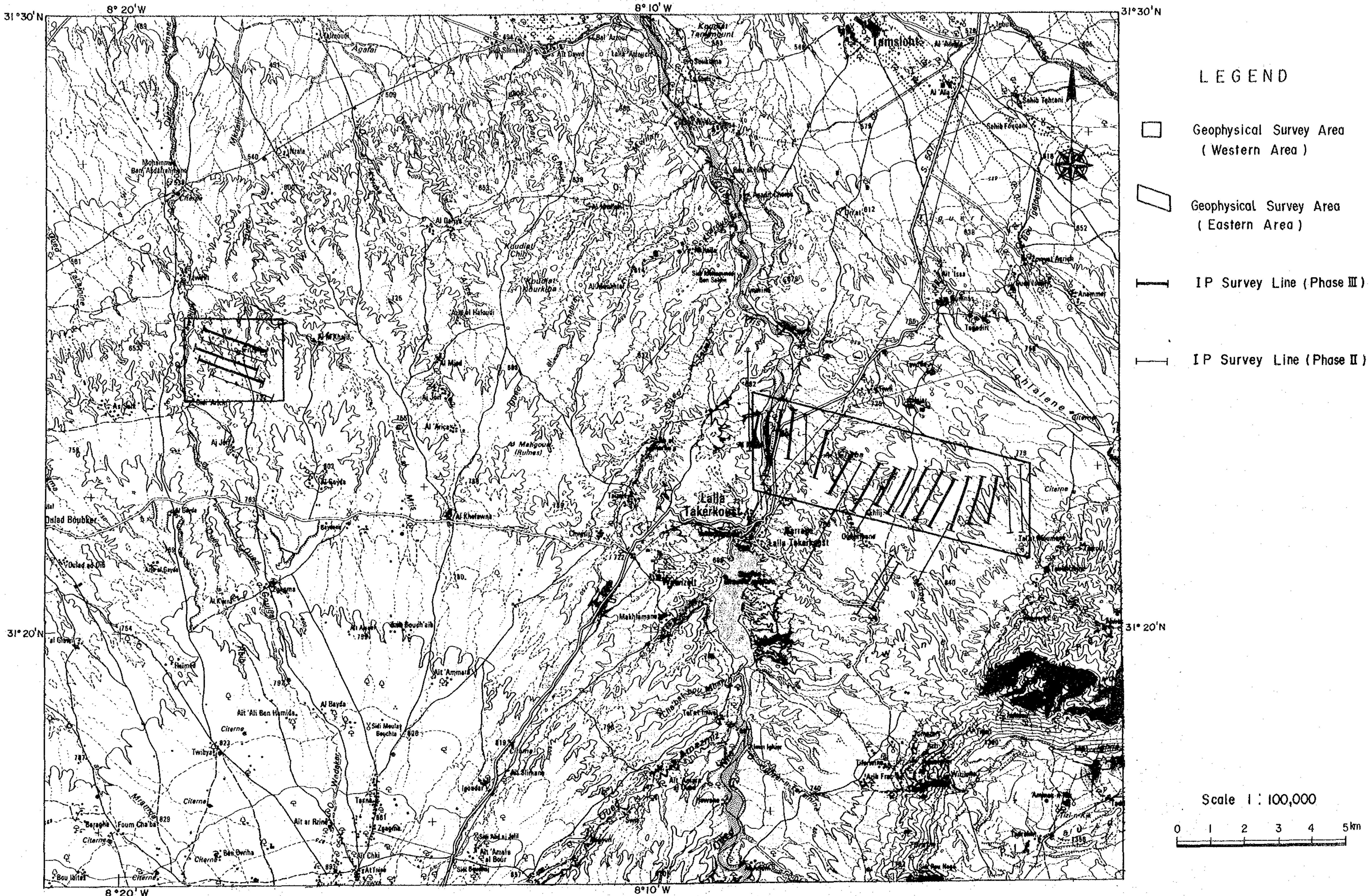


Fig. I−1 Geophysical Survey Area

CHAPTER 1 OUTLINE OF THE SURVEY

Airborne magnetic survey was carried out in this survey area and the resulting magnetic anomaly was the key to the discovery of the Hajar ore deposit. But since then there were quite a few geophysical survey techniques carried out in the area which lead to the discovery of new ore deposit. During the Phase I survey, CSAMT measurements were carried out to find several low resistivity anomalies.

From the rock sample measurements (the resistivity and frequency IP effect of the Hajar ore minerals were about 20 ohm-m and 20 % respectively), the IP method was considered to be one of the effective geophysical tools. The density difference between Hajar ore (about 4.5 g/cm^3) and the background (about 2.7 g/cm^3) was so big that the gravity survey was also considered effective in this area. Therefore, IP and gravity surveys were carried out in the Phase II.

For the Phase III, IP survey was carried out in the eastern area (Lamrah - Akhlij - Hajar) and the western area (Frizem area).

Principles, measurements and interpretation techniques of IP method are explained in this chapter in addition to the actual measurement procedures and equipments used for the survey.

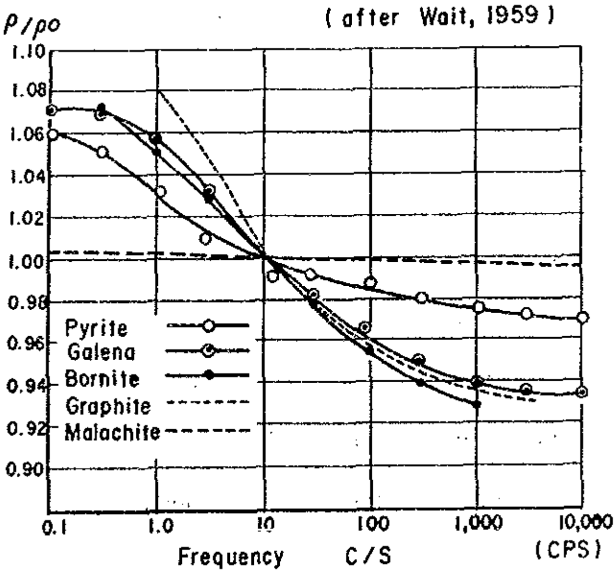
1-1 Principles of IP Method

The induced polarization method is an electrical prospecting technique based on the phenomenon called induced polarization (IP), which is the electrochemical polarization occurs across the interface between electron-conducting mineral and ion-conducting pore solution.

Upon the application of the DC currents into the ground, voltage difference arises between two potential electrodes. When the currents turned off, that voltage difference sometimes would not suddenly goes to zero but takes several seconds to minutes to decay to zero. On the contrary, when the currents are applied to the ground, it takes some time for the voltage difference to have constant value. This IP phenomenon is called time domain IP. And if IP effect is measured as a function of frequency, it is called frequency domain IP. Both time domain and frequency domain methods are equivalent theoretically, but have different features in practice. Since the frequency domain measurement was used for the project, the latter is explained mainly in this chapter.

The mechanism of IP phenomenon is not fully studied, but usually the explanation is done by the overvoltage and membrane polarization. The IP theory, measurement technique and interpretation methods are explained in detail by Sumner (1976) and Seigel (1967).

The frequency domain method is to measure the resistivities as a function of frequency. For example, the resistivities of sulfide minerals, graphite etc. are the functions of frequency as shown in the following figure.



Matrix andesite 2.0-0.84mm dia.

Electrolyte 5% 0.01N NaCl solution

Mineral 3% by solid volume 2.0-0.84 mm

ρ_0: DC resistivity

ρ : AC resistivity

Resistivity of minerals as a function of frequency

The IP value (frequency effect PFE) is defined by the two resistivity values measured by different frequencies as :

$$PFE = \frac{R_1 - R_2}{R_2} \times 100\ (\%) \quad \cdots\cdots (1)$$

where R1 : apparent resistivity measured at lower frequency

R2 : apparent resistivity measured at higher frequency

There are some discrepancy among literatures related to the definition of PFE, using R2 or $\sqrt{R1R2}$ as the denominator of equation (1), but no substantial difference exists.

The apparent resistivity values measured by a pair of potential electrodes are calculated by the following expression :

$$R = K \frac{\Delta V}{I} \quad (\Omega \cdot m) \quad \cdots\cdots (2)$$

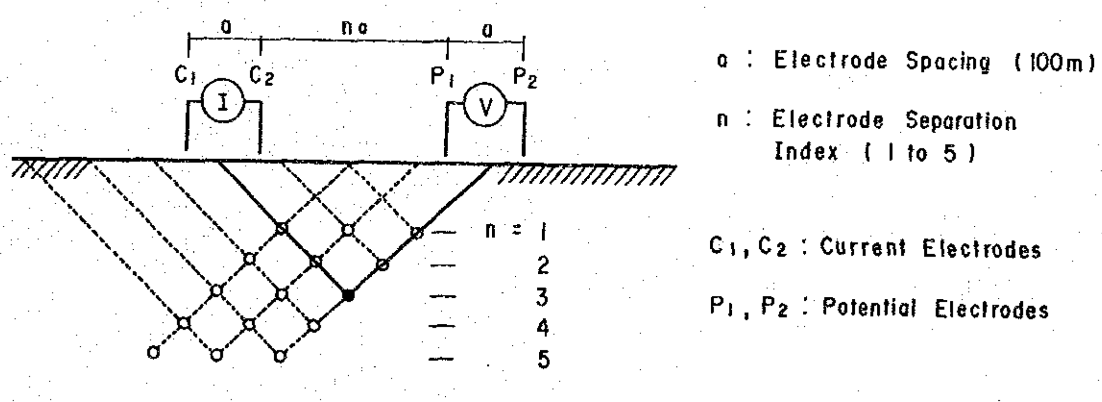
where R : apparent resistivity (ohm-m)

K : geometric constant

I : applied current (A)

ΔV : measured voltage (V)

The dipole-dipole array as shown in the following figure is used very often for the IP measurement.



Dipole - Dipole Configuration

By using the dipole-dipole array of electrodes, coupling between the transmitter and the receiver can be reduced. The dipole length (a) of 100 m, and the separation (n) of 1 to 5 were used for the survey. The depth of the investigations increases as n increases, and approximately expressed as follows :

$$\text{the depth of investigation} = \frac{n+1}{2}\,a \quad \cdots\cdots\cdots\cdots\cdots\cdots (3)$$

For example, the depth is about 100 m when n=1 and a=100 m, and about 300 m can be expected when n=5 and a=100 m.

It is possible to plot both apparent resistivity (as the function of n) and profiling data on a single two-dimensional diagram, giving a pseudosection of apparent resistivity along survey line. Resistivity values are plotted at the depth calculated from eq. (3) for the pseudo-section for this report.

And the electrode constant for the dipole-dipole array is calculated by the following equation :

$$K = \pi \cdot a \cdot n \cdot (n+1) \cdot (n+2) \quad \cdots\cdots\cdots\cdots\cdots\cdots (4)$$

1-2 Resistivity and IP Measurement

1-2-1 Measurement

Resistivity and IP values were measured in frequency domain using the dipole-dipole array of electrodes as stated earlier in this chapter. As the power source of the transmitter, a 50Hz engine generator was prepared for the survey. The generated 50Hz alternating currents were rectified and smoothed in the transmitter, and then transformed to very low frequency alternating currents by the SCR inverter circuits inside, which were applied to a pair of current electrodes.

A pair of non-polarizable potential electrodes were used to detect ground voltage differences, which were measured by a potentiometer inside the receiver after the filtration of unnecessary frequency noise components. Dry batteries were used for the power source of the receiver to minimize the noise.

IP and resistivity measurements consist of two parts, namely the land survey of measurement lines and actual measurements, and explained as follows :

(1) Land Survey of the Measurement Lines

Laying out of the survey lines was carried out with an Ushikata pocket compass and measuring tapes. The intervals between measuring points were measured with the measuring tape, while azimuth and dipping angle were measured with the pocket compass. Each station sites was marked with a pile of stones, having corresponding painted station numbers on it.

(2) Resistivity and IP Measurements

(a) Preparation of Current Electrodes and Wiring

As a current electrode, an aluminum plate of about 40 cm and 40 cm in dimensions was buried for each station at 50 cm to 1 m depth. By surrounding the electrode plate with the mixture of salt water (20 to 40 liters) and bentonite, the grounding resistance was reduced to 100 to 500 ohms.

Due to very hard ground surface, one crew of 3 persons could dig only average 3 electrode holes a day, the dimension of which is about 1 m wide, 1 m long and 50 cm to 1 m deep. 3 to 4 crews of 3 persons were organized to make the holes in advance to the actual measurement process.

At the electrode site where the ground resistance was high, additional efforts were made like enlarging the holes and putting more salt water until the resistance was reduced to 100 to 500 ohms.

In order to minimize the measurement errors due to coupling between current and potential cables and leakage of currents, very careful wiring techniques like no intersection nor approach of cables, careful connections of cables to keep the insulating resistance maximum were performed at the field site.

(b) Potential Electrodes

Non-polarizable electrodes which had spiral copper wire submerged with copper sulfate solution was used as a potential electrode. Electrode polarization can be minimized by using the copper ions as the charges carrying currents at the copper electrode. Potential electrodes were also buried in the current electrode holes with 1 to 5 l of copper sulfate solution to reduce contact resistance between the electrode and ground to about 100 ohms to 1 kohm.

1-2-2 Measuring Equipment

The specifications of measuring equipment used for the survey were as follows :

(a) Transmitter

Model MI-5609, Manufactured by Yokohama Electric Lab.

Input power voltage	AC 90 V to 130 V
Output voltage	50 V to 800 V
Output currents	0.01 A to 4 A
Frequency	0.1, 0.3125, 1.25, 2.5, 5.0 Hz
output impedance	200 ohm to 40 kohm

(b) Receiver

Model DF-58Z, Manufactured by Yokohama Electric Lab.

Sensitivity	100 microvolts to 10 V 5 ranges
input impedance	2 Mohm
Resolution	sensitivity 0.1 to 1 %, PFE 0.1 %
Noise	5 microvolts p-p input equiv.
Error	0.5 % PFE 1 mV to 10 V

(c) Generator

Model EC2000X, Manufactured by Honda

Output power	2 kVA (60 Hz), 1.7 kVA (50 Hz)
Running time	2.5 hours continuous
Fuel capacity	3.3 l
Weight	37 kg (dry)

1-2-3 Laboratory Measurement of Rock Samples

Thirteen rock samples were collected from drilling cores as follows:

DDH No.	Depth in meter	Number of samples
MJMH-1	101, 201, 255, 301, 400	5
MJMH-2	141, 183, 220, 247, 317	5
MJMH-3	92, 126, 141	3

The rock samples were shaped to cylinder, and immersed in the water for about 24 hours before the measurements of rock properties. Samples were held between a pair of copper electrode plates. And the filter papers soaked in saturated copper sulfate solution were inserted between the sample and the electrode plate to minimize the contacting resistance. The current density within a rock sample was kept as close as possible to the actual current density, but minimum value was about 3 microampares/cm^2 to maintain reasonable S/N ratio. The measured rock properties measured during the phase III are shown in Table I-2, and those of the phase II are listed in Table I-1.

The average resistivity and PFE values of Hajar ore samples were about 18 ohm-m and 15 % respectively. There are significant differences between those values of other rock samples like Quaternary rocks (73 ohm-m, PFE 1.1 %) and older rocks (510 ohm-m, PFE 0.8 %). The resistivity of pyrrhotite is as low as 2.0*10 to 1.6*10 ohm-m (Keller 1966). Due to the high resistivity matrix like quartz in which very conducting minerals are dispersing, total rock resistivity seems to be as high as 20 ohm-m.

Resistivity and PFE of rock samples, in Table I-2, show that the minimum resistivity is 12 ohm-m (MJMH-3, 126m), the maximum resistivity is 2,200 ohm-m (MJMH-1, 301m), the minimum PFE is 0.3 % (MJMH-2, 183m), and the maximum PFE is 17.4 % (MJMH-2, 141m). The results of rock sample test are concordant with the Table I-1. Mineralized rock samples, like sample No. 12 (MJMH-2, 126m), are high in PFE and low in resistivity.

1-3 Interpretation of Resistivity and IP data

1-3-1 Pseudosection Plotting

Resistivity values were plotted at the midpoint of dipole-dipole array into five lines, to which the electrode separation n is corresponding. For example, the first line of apparent resistivity pseudosection is for n=1, and the second line is for n=2 and so on.

Topographic correction technique by computer 2D simulation is common to compensate the terrain effects in case of steep topography. This correction can not be applied in case of complicated or 3D topography, or not necessary for flat topography, which is the case of this survey area.

1-3-2 Compilation of Data

Apparent resistivity values and PFE values are plotted on plan for each separation constants (n) with those of the Phase II survey. Apparent resistivities and PFE's are contoured 10, 15, 25, 40, 60, 100 etc. (ohm-m), and 1, 2, 3, etc. (%) and divided into three zones as follows.

APPARENT RESISTIVITY

40	250 ohm-m	
L	M	H

PFE

2	4 %	
L	M	H

1-3-3 Computer 2D Simulation

Computer 2D simulations were carried out for the survey lines which showed low resistivity and high IP anomalies. 2D finite element programs were used to interpret those survey lines.

At first, an initial model was introduced from the corresponding pseudosection, taking into account the results of past work including literatures, numerical calculations, water tank experiments and so on.

Then numerical calculations were carried out for the model and construct the second model by comparing the results to the field data. The same process was continued until reasonable model, the numerical calculation of which created well represented the field data, was found. Sometimes, the results of these numerical simulation would not create the reasonable numerical model because of the 3D geological structure.

1-4 Specifications of the Measurements

Figure I-2 and Plate I-1 show 17 survey lines (26.2 km) measured during the survey period. Length and the number of measurement points for each line are shown in the following table.

	Location	I P Line	Line Length	Number of Stations
Eastern Area	Lamrah	E－1	1.0 km	30
		E－2	1.3	45
		E－3	1.5	55
		E－4	1.4	50
	Akhlij	E－5	1.4	50
		E－6	1.6	60
		E－7	1.2	40
		E－8	1.6	60
		E－9	1.6	60
		E－10	1.6	60
		E－11	1.6	60
	Hajar mine	E－12	1.6	60
		E－13	1.4	50
		E－14	1.4	50
Western Area	Frizem	W－1	2.0	80
		W－2	2.0	80
		W－3	2.0	80
Total		17 Liens	26.2 km	970 Stations

As for the electrode array, dipole-dipole array was used with the electrode separation a=100 m, and separation constants (n) were varied from 1 to 5. Maximum currents were tried to put into the ground, but average values of the currents were about 1 ampere.

2.5 Hz and 0.3 Hz were used for the measuring frequency, and apparent resistivities were calculated using the higher frequency.

Tab. I − 1 Rock Properties in Phase II

No.	Formation	Rock Name	Resistivity (Ω・m)	mean	mean	PFE (%)	mean	Density (g/cc)	mean
1		Sand	61			2.3		2.27	
2		〃	53			1.7		2.30	
3		〃	27			2.1		2.16	
4	Quaternary	〃	89		73	0.9	1.1	2.44	2.21
5		Tuff	150			0.3		2.01	
6		〃	76			0.8		1.86	
7		Mud	120			1.3		2.48	
8		Mudstone	240	330		1.9		2.70	
9		〃	460			1.5		2.73	
10		Siltstone	1000	880		0.2		2.68	
11		〃	780			0.9		2.67	
12		Carbonatic Schist	710			0.7		2.71	
13		〃	550			0.2		2.73	
14		〃	520			1.4		2.67	
15	Permian	〃	670			0.2		2.78	
16		〃	650			0.1		2.64	
17	|	Pelitic Schist	480	520	510	4.3	0.8	2.76	2.70
18		〃	500			0.6		2.70	
19	Carboni-	〃	420			0.2		2.79	
20	ferous	〃	290			0.6		2.65	
21		〃	510			0.9		2.74	
22		Dacite	230			1.1		2.73	
23		〃	700	340		3.0		2.70	
24		〃	250			2.1		2.61	
25		Quartz vein	1100			1.5		2.61	
26		Pb-Zn-Pyrr. ore	21			29.5		4.32	
27		〃	15			15.4		4.49	
28		〃	14			18.7		4.34	
29	Ore of	〃	11		18	11.9	15.4	3.95	4.25
30	Hajar mine	〃	23			13.8		3.89	
31		〃	35			8.5		3.74	
32		〃	17			13.2		4.56	
33		〃	20			19.8		4.83	
	Mean				150		1.7		2.89

※ mean … Geometrical Average

Tab. I－2 Rock Properties of Boring Core Samples

Sample No.	Location & Depth	Resistivity (Ω・m)	mean	PFE (%)	mean	Rock Name
1	MJMH-1 101 m	1,400		2.6		Pelitic Schist Intc.Silts.
2	〃 201 m	230		5.6		Pelitic Schist (Py Diss.)
3	〃 255 m	550	760	1.0	2.7	Pelitic Schist
4	〃 301 m	2,200		4.3		Pelitic Schist Intc.Silts.
5	〃 400 m	670		2.3		Pelitic Schist
6	MJMH-2 141 m	98		17.4		Py-Po Network Ore
7	〃 183 m	1,700		0.3		Psammitic Schist
8	〃 220 m	920	560	1.2	2.3	Pelitic Schist
9	〃 247 m	300		11.4		Py Network Ore
10	〃 317 m	1,200		0.9		Pelitic Schist
11	MJMH-3 92 m	110		0.9		Pelitic Schist
12	〃 126 m	12	51	12.0	4.0	Py-Po Massive Ore
13	〃 141 m	100		5.8		Py Veinlet Ore
Mean		360		2.8		

CHAPTER 2 RESULTS OF THE SURVEY

2-1 Results of Apparent Resistivity and IP Survey

2-1-1 Apparent Resistivity along Each Line

Average apparent resistivities measured for this phase were shown in the following table for each survey line and each electrode separation, "n". Total average values in addition to the maximum and minimum values for each survey line are also tabulated.

Line	Apparent Resistivity (Ω・m)								Standard
	n=1	n=2	n=3	n=4	n=5	Ave.	Max.	Min.	Dev. σ_n
E-1	28	37	47	58	79	47	130	17	26
E-2	35	50	61	71	69	56	180	14	32
E-3	32	43	56	69	93	57	310	20	44
E-4	30	41	50	63	75	51	110	21	18
E-5	53	74	94	100	130	90	210	22	49
E-6	64	100	120	120	140	110	310	22	80
E-7	120	140	150	150	160	150	340	20	83
E-8	58	110	120	140	160	120	250	10	68
E-9	29	47	64	81	100	63	230	18	37
E-10	19	30	43	56	71	42	94	14	19
E-11	25	40	53	62	71	49	110	18	20
E-12	23	31	40	54	61	41	110	13	18
E-13	25	34	45	50	60	42	93	17	17
E-14	33	40	43	45	46	41	78	22	11
W-1	120	130	120	120	120	120	280	20	61
W-2	110	120	140	160	180	140	490	32	88
W-3	130	180	210	230	230	190	700	32	150
Ave.	55	73	86	96	110	83			

Average apparent resistivity

Average (Ave.), maximum (Max.) and minimum (Min.) values of resistivity along the all survey lines are shown in addition to the standard deviation (σ_n). For example, the average resistivity value of E-1 line in the eastern area is 28 ohm-m for "n"=1, and the average for n=1 to 5 is 47 ohm-m, with the maximum of 130 ohm-m and minimum of 17 ohm-m.

The apparent resistivity increases as "n" increases (like 55 ohm-m for "n"=1 and 110 ohm-m for "n"=5 which are averages of all survey lines) and the average of all apparent resistivity values is 83 ohm-m.

From the comparison of the average apparent resistivities among all the survey lines, those of the lines E-1 and E-10 to E-14 in the east area are low, less than 50 ohm-m, and those of the lines E-6 to E-8 in the eastern area and the lines in the western area are high, over 100 ohm-m. Thus average apparent resistivity varies from line to line.

The standard deviation shows the variation of each values from the mean value, and the value increases when the variation of data is large. The standard deviations along the survey lines of which average resistivities are over 100 ohm-m are large.

2-1-2 Results of IP Measurements

Average IP values measured for this phase were shown in the following table for each survey line and each electrode separation "n". Total average values in addition to the maximum and minimum values for each survey line are also tabulated.

The average PFE value as apparent resistivity increases with the increase of "n" and the average value of the measurenent is 1.6 %. That in the eastern area is small and in the western area is large. Over 4 % of PFE values were obtained along the six survey lines, E-2, E-3 and

E-14 in the eastern area and three lines in the western area.

The standard deviation is relatively small. Only four lines, E-2 in the eastern area and three lines in the western area show the standard deviation over 1 %.

Line	PFE (%)								Standard
	n=1	n=2	n=3	n=4	n=5	Ave.	Max.	Min.	Dev. σ_n
E-1	0.7	1.0	1.2	1.7	2.2	1.3	3.0	0.4	0.6
E-2	1.2	1.7	2.2	2.7	3.7	2.2	5.1	0.3	1.0
E-3	1.1	1.3	1.7	2.1	2.6	1.7	4.2	0.6	0.7
E-4	0.9	0.8	1.0	1.3	1.6	1.1	2.1	0.4	0.4
E-5	0.8	1.2	1.3	1.5	1.9	1.3	2.5	0.3	0.5
E-6	0.7	0.9	1.0	1.4	1.6	1.1	2.8	0.4	0.5
E-7	1.0	1.2	1.6	1.8	1.9	1.5	3.1	0.0	0.9
E-8	1.0	1.1	1.3	1.5	2.2	1.4	3.1	0.0	0.8
E-9	0.5	0.7	0.6	0.9	1.2	0.8	2.0	0.1	0.4
E-10	0.5	0.5	0.6	0.8	1.0	0.7	1.5	0.2	0.3
E-11	0.6	0.7	0.8	1.1	1.2	0.9	2.0	0.3	0.4
E-12	0.6	0.8	0.9	1.1	1.3	0.9	2.2	0.3	0.4
E-13	0.9	1.1	1.3	1.6	2.0	1.4	2.7	0.5	0.5
E-14	0.8	1.0	1.4	2.3	2.8	1.6	4.2	0.2	0.9
W-1	2.6	3.5	3.9	4.2	4.6	3.7	6.6	1.5	1.0
W-2	2.1	2.9	3.1	3.4	3.8	3.0	5.4	0.2	1.3
W-3	2.2	2.5	2.8	3.1	3.2	2.8	5.5	0.0	1.3
Ave.	1.1	1.3	1.6	1.9	2.3	1.6			

Average PFE

2-2 Pseudosection of Apparent Resistivity and PFE

Pseudosections of apparent resistivity and PFE along each survey lines are shown in figures I-3 to I-19. Apparent resistivity values and

PFE values are divided into as follows.

Low apparent resistivity (L)...... under 40 ohm-m

Medium apparent resistivity (M)... from 40 to 250 ohm-m

High apparent resistivity (H)..... over 250 ohm-m

Low PFE (L)...................... under 2 %

Medium PFE (M)................... from 2 to 4 %

High PFE (H)..................... over 4 %

Generally apparent resistivity and PFE in the eastern area are low and the both in the western area are high.

The results of the survey for each area are explained in the following paragraph :

2-2-1 Eastern Area (Fig. I-3 to I-16)

Fourteen survey lines are surveyed in the eastern area which is from Lamrah, north of Barrage Cavagnac, to Hajar mine. Survey lines are numbered from west, E-1, to east, E-14.

Apparent resistivity distribution and PFE distribution are explained as the two areas, vicinity of Lamrah (E-1 to E-4) and Akhlij-to-Hajar Mine area in the following sections.

(1) Vicinity of Lamrah (Fig. I-3 to Fig. I-6)

The four survey lines, E-1 to E-4, in the vicinity of Lamrah are along the both banks of N'Fis river which flows from Barrage Cavagnac. The average apparent resistivity of the area is about 40 ohm-m and lower than that of other areas. Apparent resistivity values in some places of the shallow part become below 25 ohm-m. PFE values in the vicinity of Lamrah are relatively higher among the eastern area.

Apparent resistivity values along the survey lines E-1 and E-2 are higher at the depths of the southern part and become lower at the surface of the northern part of the survey lines. A low apparent resistivity zone of below 40 ohm-m is at the surface of the northern part of the survey lines. PFE values are small at the shallows (n=1) and become larger with depth. Those at the depths between stations 4 and 5 of the survey line E-2 are as high as 4 to 5 %.

Along the survey line E-3, the low apparent resistivity zone between the stations 5 and 7 extends to depth and medium to high apparent resistivity zones distribute at the south of the low apparent resistivity zone. PEF values are generally low but are over 3 % at the depths of the northern part of the survey line of which the relatively high PFE zone corresponds to the IP anomaly in Lamrah area obtained by the phase II survey.

Along the survey line E-4, a low resistivity zone at shallow gradually change to a medium apparent resistivity with depth. PFE values along the line vary slightly and are low.

(2) Akhlij-to-Hajar Mine Area (Fig. I-7 to Fig. I-16)

Akhlij-to-Hajar Mine area is large, from Akhlij, about 3 km southeast of Lamrah, to Hajar mine, the east end of the survey area. This area can be divided into three zones by the distributions of apparent resistivity and PFE, the three zones, between the lines E-5 and E-8, between the lines E-9 and E-12, and between the lines E-13 and E-14.

In the zone between the four lines E-5 and E-8, near Akhlij, the average apparent resistivities are high and vary significantly. The average apparent resistivities along the three lines E-6 to E-8 are especially high over 100 ohm-m and high apparent resistivity zones are at near the surface in the center to the north of the three survey lines. The high apparent resistivity zones at near surface corresponds to high gravity anomaly detected by the phase II survey. PFE values along the four lines are mostly about 1 % with some over 2 %.

In the zone between the lines E-9 and E-12, the average apparent resistivities are low and low apparent resistivity zone at near the surface gradually change to medium apparent resistivity zone at depths. PFE values are low and under 1 % down to depths.

In the zone between the lines E-13 and E-14, low apparent resistivity zone extend to depths eastward with increasing PFE values. At the survey line E-14 which is about 500 m west of Hajar mine, PFE values become as high as 4 % at depths.

The survey revealed that a resistive basement is shallow near Akhlij village and a conductive surface layer over the resistive basement becomes thicker at the east of the survey line E-9. We assume that a conductive zone with high PFE along the survey line E-14 is a reflection of either mineralization or an alteration associated with Hajar ore deposit.

2-2-2 Western Area (Fig. I-17 to Fig. I-19)

In the western area, there are one survey line at the north of Frizem, which is 16 km west-northwest of Barrage Cavagnac, and two survey lines in the south. All of the survey lines run west-northwest to east-southeast direction and 2 km long.

Apparent resistivity and PFE distributions in the western area differ largely from those in the eastern area. Apparent resistivity values and PFE values in the western area are about double of those in the eastern area and their variations are large.

The average apparent resistivity and the average PFE along the survey line W-1 are 120 ohm-m and 3.7 % which are the lowest apparent resistivity and the highest PFE in the western area. A low apparent resistivity zone of below 40 ohm-m is at near surface of the station 13 and with high PFE zone of over 5 %. The similar conductive -high PFE zones are found at depths of the station 5 and the station 11 where the highest PFE value of this survey, about 6 %, is recorded.

The average apparent resistivity and the average PFE along the survey line W-2 are 140 ohm-m and 3.0 %. The west half of the survey line is medium apparent resistivity with high PFE and the east half is high apparent resistivity with medium PFE. High PFE zones of about 5 % are with a low apparent resistivity zone at the station 6 and a high resistivity zone at depths of the station 10.

The average apparent resistivity along the survey line W-3 is the highest, 190 ohm-m among the all lines. The average PFE value is 2.8 %. This line is high apparent resistivity and low PFE value. West of the station 5 is a low apparent resistivity zone with high PFE. At depths of the station 7 there is a high PFE zone with apparent resistivity of 100 to 200 ohm-m.

2-3 Apparent Resistivity Plan and PFE Plan

Apparent resistivity values measured for this survey are compiled with those of the phase II into apparent resistivity plans.(PL. I-2 to PL. I-6) PFE values are compiled with those of the phase II into PFE plans. (PL. I-7 to PL. I-11) All the plans are made for each electrode separation, "n"=1 to 5.

Apparent resistivities and PFE values on the plans are divided into three zones as the pseudosections.

Low apparent resistivity (L)...... under 40 ohm-m

Medium apparent resistivity (M)... from 40 to 250 ohm-m

High apparent resistivity (H)..... over 250 ohm-m

Low PFE (L)...................... under 2 %

Medium PFE (M).................... from 2 to 4 %

High PFE (H)...................... over 4 %

The features of apparent resistivity distribution and PFE distribution in the eastern area and the western area are as follows:

1) Apparent resistivity and PFE are low in the eastern area and the both in the western area are high.

2) Apparent resistivities in the eastern area are very low at shallow and increase with depth. Those in the western area are high and do not change with depth.

3) PFE values in the both areas increase with depth.

2-3-1 Eastern Area

(1) Apparent Resistivity Plan (PL. I-2 to PL. I-6)

Plate I-2 is an apparent resistivity plan (n=1). A high resistivity zone of over 250 ohm-m is around Akhlij at the center of the eastern area. Most of the area except the above-mentioned high resistivity area is low resistivity of under 40 ohm-m. Apparent resistivity of this plan (n=1) is generally low. Very low resistivity zones of under 25 ohm-m are from the southern part of the survey line E-6 to the survey line E-13, and near Lamrah in the western part of the survey area and the center of Hajar mine.

On the plate I-3 (n=2), a high apparent resistivity zone is similar to that of "n"=1, but an area of low resistivity zones is less. There is almost no low apparent resistivity zone from the southern part of the survey line E-6 to the survey line E-13. Only small low apparent resistivity zones are near Lamrah and Hajar mine and extending E-W direction.

On the plates I-4 to I-6 (n=3 to 5), contour lines of apparent resistivity generally extends E-W direction. relatively high apparent resistivity zones of over 100 ohm-m with small area of over 250 ohm-m increase their area in near Aklij, south of Lamrah and in the southeast of Hajar mine. Low resistivity zones decrease their area. There are some very low resistivity zones of under 25 ohm-m at near Lamrah and Hajar mine on "n"=3 and only one at near Lamrah on "n"=4 and 5. There are only three low resistivity zones at near Lamrah, south of Akhlij and Hajar mine for n=5.

(2) PFE Plan (PL. I-7 to PL. I-11)

In the eastern area, PFE generally increases with "n" value, depths. High PFE of over 4 % are recorded at depths of Lamrah and Hajar.

On the plans "n"=1 and 2 (PL. I-7 and I-8), most area is covered with low PFE of under 2 % and PFE values vary slightly. Medium PFE zones over 2 % are in three areas, near Lamrah, near Akhlij and Hajar mine.

On the plans "n"=3 and 4 (PL. I-9 and I-10), there are high PFE zones, 4 % at "n"=3 and 5 % at "n"=4, at Hajar mine, and the area of medium PFE zone at near Lamrah increases its area.

On the plan "n"=5 (PL. I-11), high PFE of over 6 % is seen at Hajar mine with southwest-northeast extension being over 4% and it of over 5 % is at near Lamrah with east-west extension.

The above is summarized as follows:

1) Very low apparent resistivity zones with high PFE are only at near Lamrah and Hajar mine.

2) Very low apparent resistivity zones other than the above-

mentioned two zones in shallow (n=1 to 3) are with low PFE.

3) A widely extending high apparent resistivity zone near Akhlij is with high PFE.

2-3-2 Western Area

(1) Apparent Resistivity Plan (PL. I-2 to PL. I-6)

In the western area, apparent resistivity is generally high, and anomalous apparent resistivity zones both high and low extend north-south direction. Apparent resistivity distribution pattern does not change significantly depending on "n" values. All five apparent resistivity plans show that a high apparent resistivity zone of over 250 ohm-m extends north-south direction and is accompanied in its both sides by low apparent resistivity zones of under 40 ohm-m.

The above-mentioned low apparent resistivity zones west of the high apparent resistivity zone are in small scale between the station 8 of the survey line W-2 and the station 3 or 4 of the survey line W-3 for all "n" (n=1 to 5). The centers of those low apparent resistivity zones tend to move westward with depths, greater "n" value. The low apparent resistivity zones east of the high apparent resistivity zone changes its center depending on the "n" value. It is between the stations 16 and 18 of the survey line W-3 for "n"=1, at the station 13 of the survey line W-1 for "n"=2 and 3, and at the south of the station 11 of the line W-1. Apparent resistivity at the station 16 of the line W-2 is low at the surface and changes to high at depths.

(2) PFE Plan (PL. I-7 to PL. I-11)

PFE values in the western area varies very much. High PFE zones of over 4 % are in all plans. Area of high PFE zones increases with depth.

On the plans "n"=4 and "n"=5, the western half of the area is occupied by high PFE. High PFE zones in depths are generally with high apparent resistivity.

On the plans "n"=1 and "n"=2, there are high PFE zones at the station 13 of the survey line W-1 and the stations 5 to 7 of the survey lines W-2. The both high PFE zones are with low apparent resistivity. On the plan "n"=3, those high PFE zones increase their area and cover the western half of the western area on the plans "n"=4 and "n"=5.

The highest PFE to 6 % is recorded at the station 5 and the stations 8 to 9 of the survey lines W-1 for "n"=5.

The above is summarized as follows:

1) Generally, high PFE zones are with low apparent resistivity and high apparent resistivity zones are with low PFE.

2) Apparent resistivity anomalies show narrow strip shape, but PFE anomalies are rather wider strip shape.

3) Apparent resistivity does not change largely with depth but PFE increases with depths in especially the western half.

2-4 Results of Two Dimensional Simulation

The IP survey of this phase discovered low apparent resistivity zones with high PFE along the survey lines E-2 and E-14 in the east area and all three survey lines in the western area. For interpreting resistivity structures along all five survey lines, we calculated response of forward models by finite element method and the results are shown in Fig. I-20 to I-24 and PL. I-12.

Two dimensional simulation is done as follows:

1) An initial model is inferred from apparent resistivity and PFE

pseudosections.

2) Apparent resistivity and PFE response are calculated by a computer and the results are compared with the field data.

3) The model is adjusted to give better matching with the field data.

4) The process of 2) and 3) are repeated until getting better matching.

The results are as follows:

(1) Eastern Area (Fig. I-20 and Fig. I-21)

Because low apparent resistivity zones with high PFE are detected along the survey lines E-2 near Lamrah and E-14 the west of Hajar mine in the eastern area, we simulated the anomalies by two dimensional finite element method.

The E-2 simulation result reproduced the apparent resistivity features of the data where apparent resistivity is high at depths in the south and low at the surface of the north. PFE is not reproduced as well as apparent resistivity, but the both show low at near the surface and high at depths. The resulted structure model shows low resistivity layer of 30 ohm-m being at the surface and resistive body of 100 ohm-m and resistive basement of 200 ohm-m are under the conductive layer. A conductive body (15 to 30 ohm-m) with high PFE (5 %) is inferred centered at the station 4. The exploratory well, MJMH-1, is drilled this year and found weakly ore-disseminated basement rock, slate.

Fig. I-21 shows the result of two dimensional simulation along the survey line E-14. The apparent resistivity distribution and the PFE distribution of the collected data along the survey line E-14, Fig. I-16, are well reproduced on the simulation results. The resulted resistivity structure shows a conductive layer of under 25 ohm-m resting over a resistive basement of 150 ohm-m. A conductive body (12 ohm-m) with extremely high PFE (20 %) is inferred between the stations 10 and 11. This conductive high-PFE body is assumed to be an extension of an alteration zone surrounding Hajar mine, because Hajar mine is only 500 m east of the survey line.

(2) Western Area (Fig. I-22 to Fig. I-24)

Computer simulation was performed for all three survey lines, W-1, W-2 and W-3, in the western area, since there found high PFE anomaly of over 5 %. The simulation results along the three survey lines are generally well reproduced the field data.

The resulted structures are explained in the following paragraphs.

The structure model along the survey line W-1, Fig. I-22, shows that resistive bodies of 100 to 300 ohm-m with medium PFE of 2 % are with some local small conductive bodies and high PFE bodies. Two conductive high PFE bodies (20 ohm-m and 10 %) are found at the stations 5 and 13.

The structure model along the survey line W-2, Fig. I-23, is similar to that along the survey line W-1. There are resistive (150 to 500 ohm-m) and medium PFE (2 to 5 %) body with local small changes of resistivity and PFE. There found conductive high PFE body (20 ohm-m and 10 %) at the shallow part of the station 10. The location of this conductive high PFE body is about the same as it of a mineralized zone in alternating beds of phyllite and siltstone being cut by the borehole, MJMH-3.

The structure along the survey line W-3, Fig. I-24, shows resistive (200 to 500 ohm-m) and medium PFE (3 %) body with a very resistive zone of 500 ohm-m at the center of the survey line dominates the area. There are some small conductive bodies. A conductive high PFE body (20 ohm-m and 10 %) is found at the stations 5 and 6.

CHAPTER 3 SUMMARY AND DISCUSSIONS

3-1 Summary of the Results

The results derived from IP are summarized as follows :

(1) The Hajar ore deposit was analyzed to be the zone of low resistivity, strong IP effect, high density and high magnetic permeability. Especially, IP method could effectively distinguish sulfide ore deposits in the low resistivity zones.

(2) The distributions of apparent resistivity and PFE differs largely in the eastern area and the western area. Apparent resistivity and PFE are low in the eastern area and high in the westernern area. In the eastern area apparent resistivity increases with depths, but that in the western area does not depends on depth.

(3) Apparent resistivity distribution and PFE distribution in the eastern area are summarized as follows:

1) High PFE zones well correspond to low apparent resistivity zones only near Hajar mine and Lamrah.

2) Low apparent resistivity zones are at the surface, except near Akhlij at the center of the area where a resistive basement rock outcrops.

3) There are not found any high PFE zone in the eastern area except the above mentioned, 1).

(4) Apparent resistivity distribution and PFE distribution in the western area are summarized as follows:

1) PFE values in the western area vary significantly. High PFE zones of over 4 % are found in all depth. Low apparent resistivity zones are generally with high PFE.

2) Apparent resistivity anomalies tend to extend north-south direction and PFE anomalies spread out of apparent resistivity anomalies.

3)Apparent resistivity does not depend on depth but PFE generally increases with depth. It is more significant in the western half of the western area.

(5) Low apparent resistivity and high PFE zones like Hajar ore deposit are found in the following places.

1) In the eastern area: At the depths of the stations 4 and 5 of the survey line E-2 near Lamrah and at depths of the stations 9 and 10 of the survey line E-14, west of Hajar mine.

2)In the western area: At the depths of the stations 5 and 11 and near surface of the station 13 of the survey line W-1, near surface of the station 6 and at depths of the station 10 of the survey line W-2, and at depths of the stations 7 of the survey line W-3.

(6) The resulted resistivity structure of the two dimensional simulation show high PFE (10 to 20 %) and conductive (12 to 20 ohm-m) bodies, like Hajar ore deposit, at the following places:

1) In the eastern area: Around the station 10 of the survey line E-14.

2)In the western area: Around the stations 4 to 6 and 12 to 13 of the survey line W-1, around the station 10 of the survey line W-2, and around the stations 5 and 6 of the survey line W-3.

3-2 Comparison of IP Results and the Other Studies

3-2-1 Comparison with Geology

In the eastern area, Quaternary covers basement Palaeozoic, alternating beds of schist, slate and siltstone. Geological structure dips north to northeast and faults extends NW-SE to E-W ward. Rock sample study shows that Palaeozoic rocks are resistive and low PFE and Quaternary rocks are medium resistivity and low PFE. The physical property of rock samples seem to be inconsistent with the fact that apparent resistivity near the surface of the eastern area is very low except at the center of the area. However we assume that Quaternary rocks over the resistive Palaeozoic are filled with water and become very conductive. Most rocks in the area are low PFE.

The western area consists by Palaeozoic, alternating beds of schist, phyllite and siltstone with interbedded pyroclasic rocks. They dip east with some faults extending NNW-SSE ward. Apparent resistivity in the western area is generally high, but low apparent resistivity strips extend N-S direction and PFE in the area is high. Especially, PFE in the western half is higher with depths. We assume that this fact is because resistive and low PFE rock underwent mineralization along N-S faults and formed conductive and high PFE zone.

3-2-2 Comparison with Magnetic Survey

For interpreting IP result with magnetic survey, we compiled the map, Fig. I-25 and PL. I-13, with the following data:

1) Low resistivity zones

The eastern area: resistivity under 40 ohm-m in n=5.

The western area: resistivity under 60 ohm-m in n=5.

2) High PFE zones

The eastern area: PFE over 4 % in n=5.

The western area: PFE over 5 % in n=5.

3) Magnetic anomalies.

The magnetic anomalies in the area are one pair of high and low anomalies over Hajar ore body, two high anomalies at the northwest and the southwest of Frizem in the western area. Low apparent resistivity anomalies and high PFE anomalies except those at near Lamrah and near Akhlij have close relation to the magnetic anomalies.

If we assume magnetic anomalies in the area mainly caused by ferromagnetic mineral, pyrrhotite, the low apparent resistivity and high PFE anomalies over Hajar ore body and in Frizem area are caused by IP phenomenon associated with pyrrhotite, and those near Lamrah and Akhlij are caused by other IP phenomena.

The relation among IP anomalies, magnetic anomalies and geology of drill cores is summarized in the following table.

Area	Mag. Anomaly	Resistivity	PFE	Mineralization	Mineral
Hajar Mine	very strong	low	high	massive	Cu,Pb,Zn,Po
Lamrah	weak	low	high	disseminated	Pb,Zn,Po,Py
Frizem	strong	weakly low	high	vein, dissem.	Cu,Pb,Zn,Po,Py

Po: pyrrhotite, Py: pyrite

Type of mineralization varies for different area, but magnetic anomalies, conductive anomalies and high PFE anomalies have close relation. Thus for delineating Hajar type ore deposit in the area, combination of magnetic survey and IP survey including resistivity survey is proved to be very powerful.

Magnetic anomalies are at Tiferouine area as Hajar deposit where IP