NO.

REPORT
ON
THE MINERAL EXPLORATION
IN
THE YANQUL-GHUZAYN AREA
SULTANATE OF OMAN

FINAL REPORT

VOLUME II
(EXPLORATION RESULTS)

MARCH 2002

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

PREFACE

In response to the request of the Government of the Sultanate of Oman, the Japanese Government decided to conduct pre-F/S in order to investigate the possibility of mineral resources development in Yanqul and Ghuzayn areas and entrusted the project to the Japan International Cooperation Agency (JICA) and the Metal Mining Agency of Japan (MMAJ).

This investigation was carried out for two years from fiscal year 2000 to 2001.

The survey team exchanged views with the officials concerned of the Government of Oman and conducted a field survey in Yanqul area. After the team returned to Japan, further studies were made and present report was elaborated.

The results of these investigations are presented in a report consisting of 3 volumes: Volume 1: Summary, Volume 2: Exploration Results and Volume 3: Mine Development.

We hope that this report will serve for the development of the mineral resources in Oman and contribute to the promotion of friendly relations between Japan and Oman.

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

March 2002

Takao Kawakami
President
Japan International Cooperation Agency

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President
Metal Mining Agency of Japan

VOLUME 2

CONTENTS

CHAPTER 1　GEOLOGICAL SURVEY

1-1 Stratigraphy

Allochtonous unit (nappe) in the Oman Mountains forms two layered structure consisting of Hawasinah Nappe and Samail Nappe in ascending order.

Hawasinah Nappe is cropping out surrounded by Samail Nappe. It is also called Hawasinah Window and consists of sedimentary and volcanic rocks. Hawasinah Nappe is divided into four formations according to BRGM(1986) and from these formations, the two formations of Al Aridh Group and Umar Group are distributed in Yanqul area. These formations are formed during Middle Triasic and Late Cretaceous ages and suffered an intense structural deformation.

Samail Nappe, consisting of Samail Ophiolite, is widely distributed in the Yanqul area. The Samail Ophiolite generally consists of Tectonite, Cumulate sequence, High-level gabbro, Sheeted dyke complex, and Samail volcanic rocks in ascending order. Massive sulphide deposits in Oman Moutains occur in the Samail volcanic rocks. The Samail Volcanic Rocks are divided into three formations: Geotimes , Lasail and Alley units in Yanqul area, being the ore deposits situated near the boundary between Geotimes and Lasail units.

The geological map and profile are shown in Fig. II-1-1 and Fig. II-1-2, respectively. The general stratigraphy of the area is also shown in Fig. II-1-3.

Al Aridh Group, Umar Group, Samail Volcanic Rocks and Quaternary sediments widely outcropped in the area are described below in detail.

1-1-1 Al Aridh Group

Al Aridh Group is exposed on the hills in the central to southeastern part of Yanqul area. In the area the Group shows the lithology consisting of purplish red chert in 2-8 cm beds with 10-40 cm beds of lithoclastic limestone. It belongs to Late Triassic to Late Cretaceous age.

1-1-2 Umar Group

The upper formation of Umar Group is exposed in the area and consists mainly of red and green radiolarian chert in tabular 1-15 cm beds, in places with shale interbeds and grey to yellowish beds of micritic limestone. The age of this Group corresponds to Middle Triassic to Late Cretaceous.

1-1-3 Samail Volcanic Rocks

(1) Geotimes unit

The Geotimes unit consists of differential basaltic to andesitic lavas, and composed mainly of reddish brown colored pillow lava with large pillow size of 1m to 2m in diameter. It also consists of

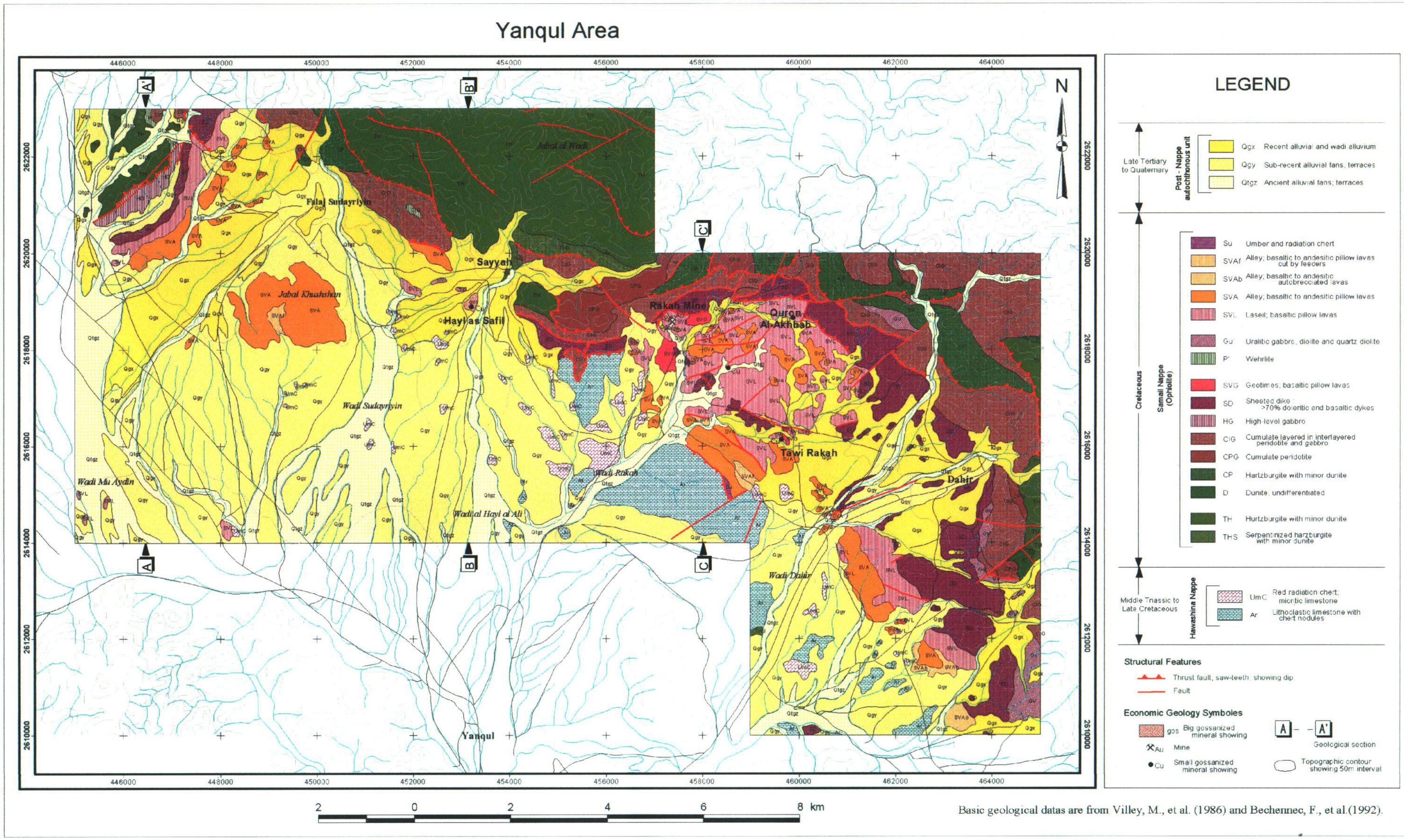

Fig. II-1-1 Geological map of Yanqul area

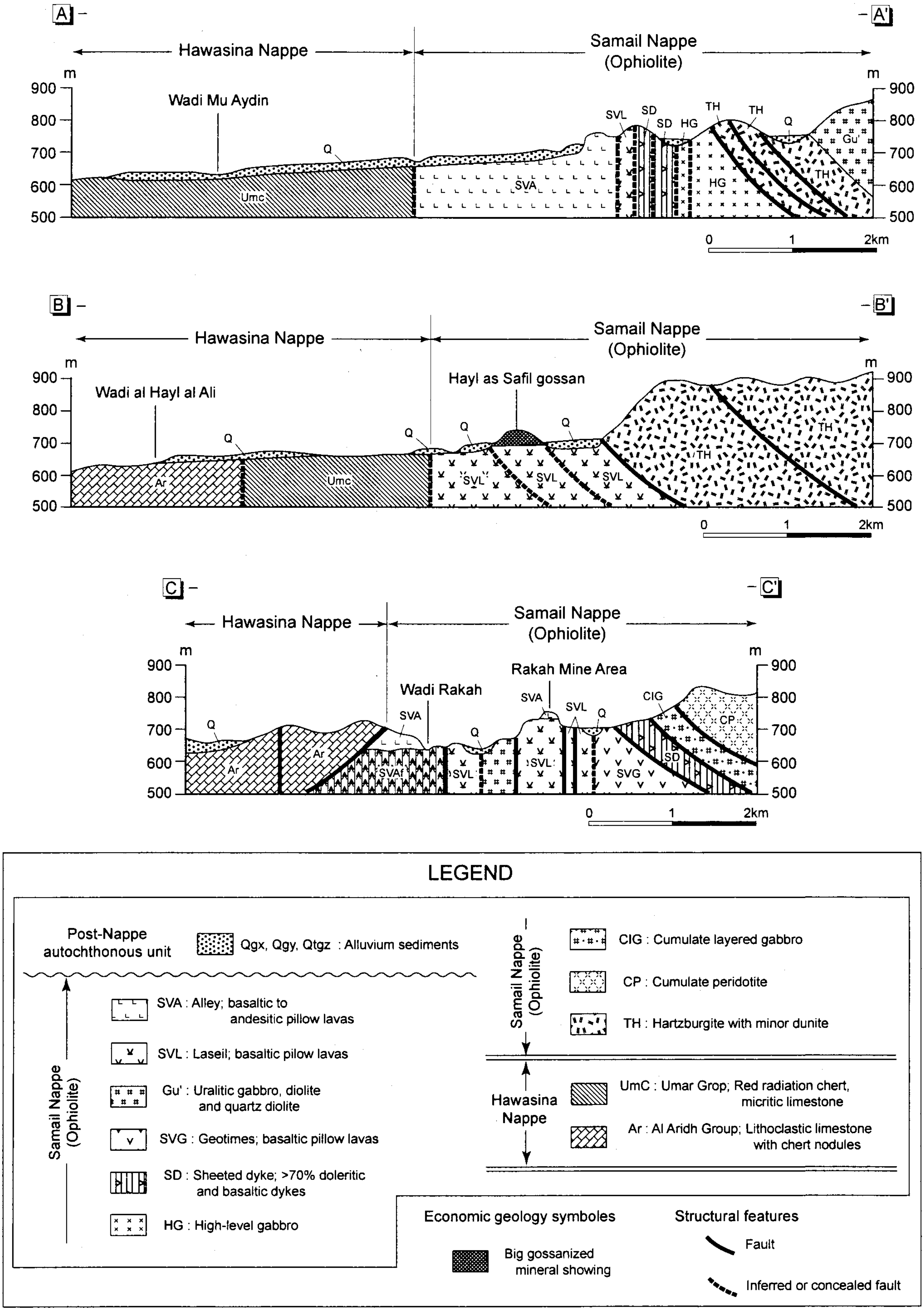

Fig. II-1-2 Geological section of Yanqul area.

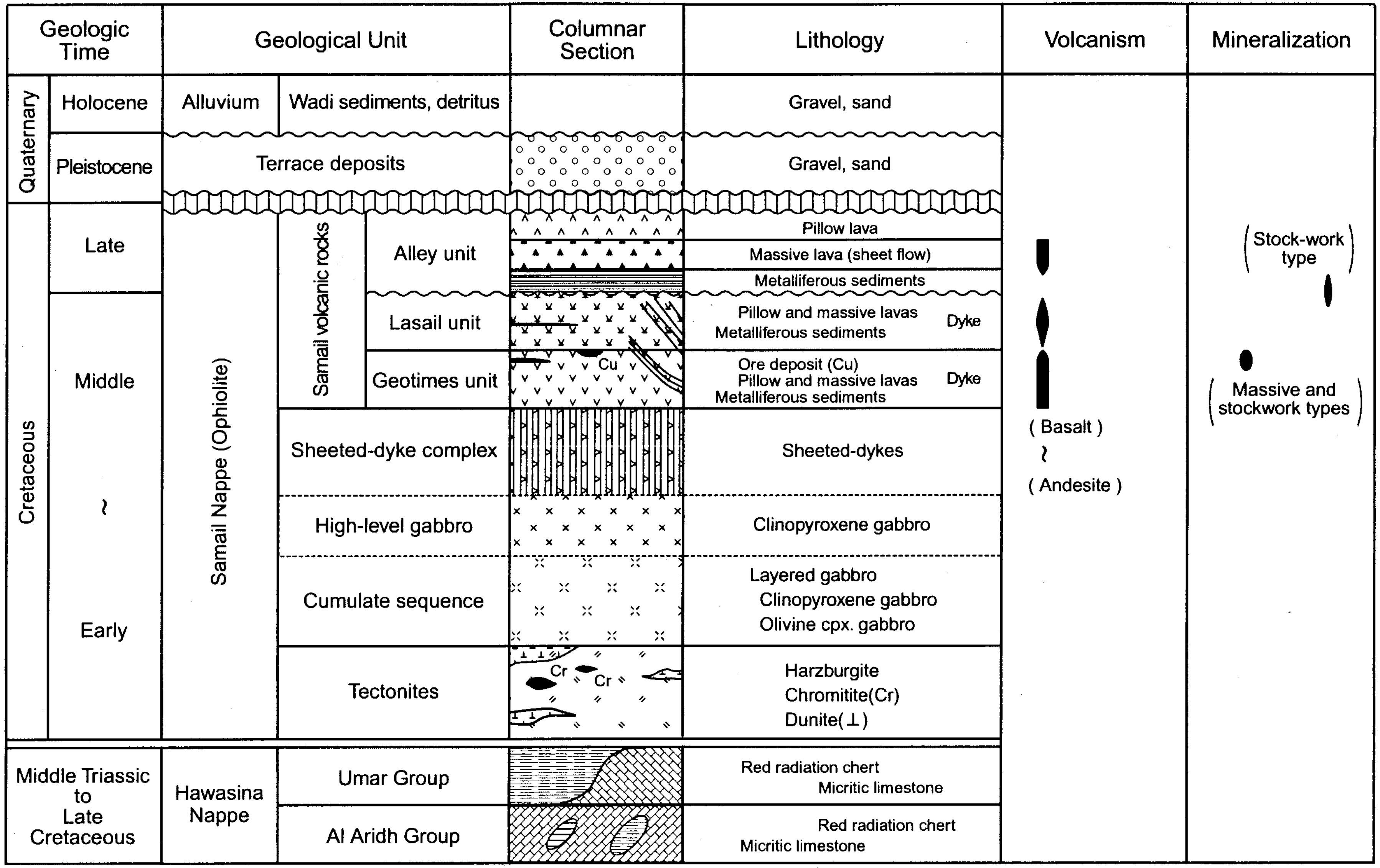

Fig. II-1-3 Geological columnar section of Yanqul area reddish brown to gray colored massive lava, hyaloclastite and pillow breccia. Characteristically, the pillow lava is aphanitic and accompanied with thick interpillows of 5cm to 40cm in thickness. The massive lava shows gray to brownish gray color with a thickness of several tenth centimeters to several meters. Columnar joints are developed in the thick massive lava.

(2) Lasail unit

The Lasail unit consists mainly of primitive basaltic lava composed of pillow lava accompanied with massive lava. The pillow lava shows light gray to purplish gray in color with pillow sizes mainly of 10cm to 1m in diameter and a maximum of 1.5m. It is characteristically accompanied with small sized pillow lavas of 10cm to 30cm in many places. Additionally, this pillow lava is porphyritic and shows a variole-like texture. Contrary to Geotimes unit, this pillow lava is accompanied with thin interpillows of 1cm to 5cm in thickness. Many basalt dikes intruded into the unit in the eastern part of the area. Metalliferous sediments and massive lava can be seen close by the boundary with Geotimes unit.

Metalliferous sediments is the so-called umber that includes many radiolarians and predominant in iron oxides. It shows dark brown color and grades laterally into massive sulphide ore bodies in the case that the sediments contain many magnetite with clear stratification and copper mineralization. The sediments are well developed in the area of Hayl as Safil deposit and reach about 50m in thickness. In some places, they grade into a rock called Peperite which consists of basalt breccia and sediments and formed by the intrusion of basaltic magma into the sediments of unconsolidated condition.

(3) Alley unit

The Alley unit consists of pillow lava, massive lava and autobrecciated lava ranging from basaltic to andesitic composition and metalliferous sediments.

The pillow lavas show purple, green and greenish gray colors. Most of the pillow lavas present irregular pillow shapes with diameters of about 0.5 to 1.0m. Only this pillow lava shows a clear pillow structure among pillow lavas in three units in Yanqul. The massive lava shows various colors, such as gray, brownish gray, green, bluish gray and orange color on the weathered surface. In general the massive lava shows a doleritic texture.

Metalliferous sediments are the so-called umber and contains more radiolarians but less amounts of iron oxides than Lasail unit. They show a brownish black color.

1-1-4 Quaternary sediments

The Quaternary sediments exposed in the area consist of terrace deposits, debris and wadi sediments. Terraces are classified into the three levels of upper, middle and lower. These consist of gravel and sand.

1-2 Geological Structure

Structural geology in the Yanqul area is characterized by imbrication structure, consisting of thrust faults inclined to the northeast to north, and showing apparently an inverted structure due to thrusting. Normal fault system trends along two directions, namely E-W and N-S, and these faults are mostly steepy.

1-3 Mineralization

Two copper deposits of Rakah and Hayl as Safil were discovered in the Yanqul region. These are considered to belong to the Cyprus type copper deposits as same as the deposits in Sohar region and occur near the boundary between Geotimes and Lasail units.

The geological ore reserve of known 5 ore bodies of above deposits is shown in Table Ⅱ-1-1 according to OMCO(1995).

Table Ⅱ-1-1 Geologic ore reserves (sulphide ore) of known five bodies

Area	Ore Body	Geologic Ore Reserves (kt)	%Cu
Rakah	Rakah	5,094	0.83
Hayl as Safil	Hayl as Safil	5,958	1.13
	Al Jadeed	744	1.34
	Al Asghar	932	2.72
	Al Bishara	3,069	1.09

1-3-1 Rakah deposit

The geological map is shows in Fig. Ⅱ-1-4.

Rakah deposit is located in the upperstream of Wadi Rakah and was discovered under the small hilly gossan along the middle terrace surface. Ore body strikes northwest to southeast and dips northeast. The ore body is affected by the repetition from thrust faults and the blocking from normal faults (Fig. Ⅱ-1-5, Ⅱ-1-6).

Ore is classified in stockwork ore and massive ore, but stockwork ore type is predominant. Host rock of stockwork ore is markedly brecciated. Ore minerals are mainly pyrite, chalcopyrite and subordinate sphalerite, bornite, chalcocite, covelline, etc.

Oxided ore, so called gossan, is rich in gold and has been exploited since 1994 as Rakah gold mine. The mine produced aproximately 700,000 t of ore with an average grade of 6.37g/t Au and 6.9g/t Ag. By the end of 2001, the total produced gold and silver reached about 4.2 t and 2 t, respectively.

1-3-2 Hayl as Safil deposit

The geological map around the deposit is shown in Fig. Ⅱ-1-7.

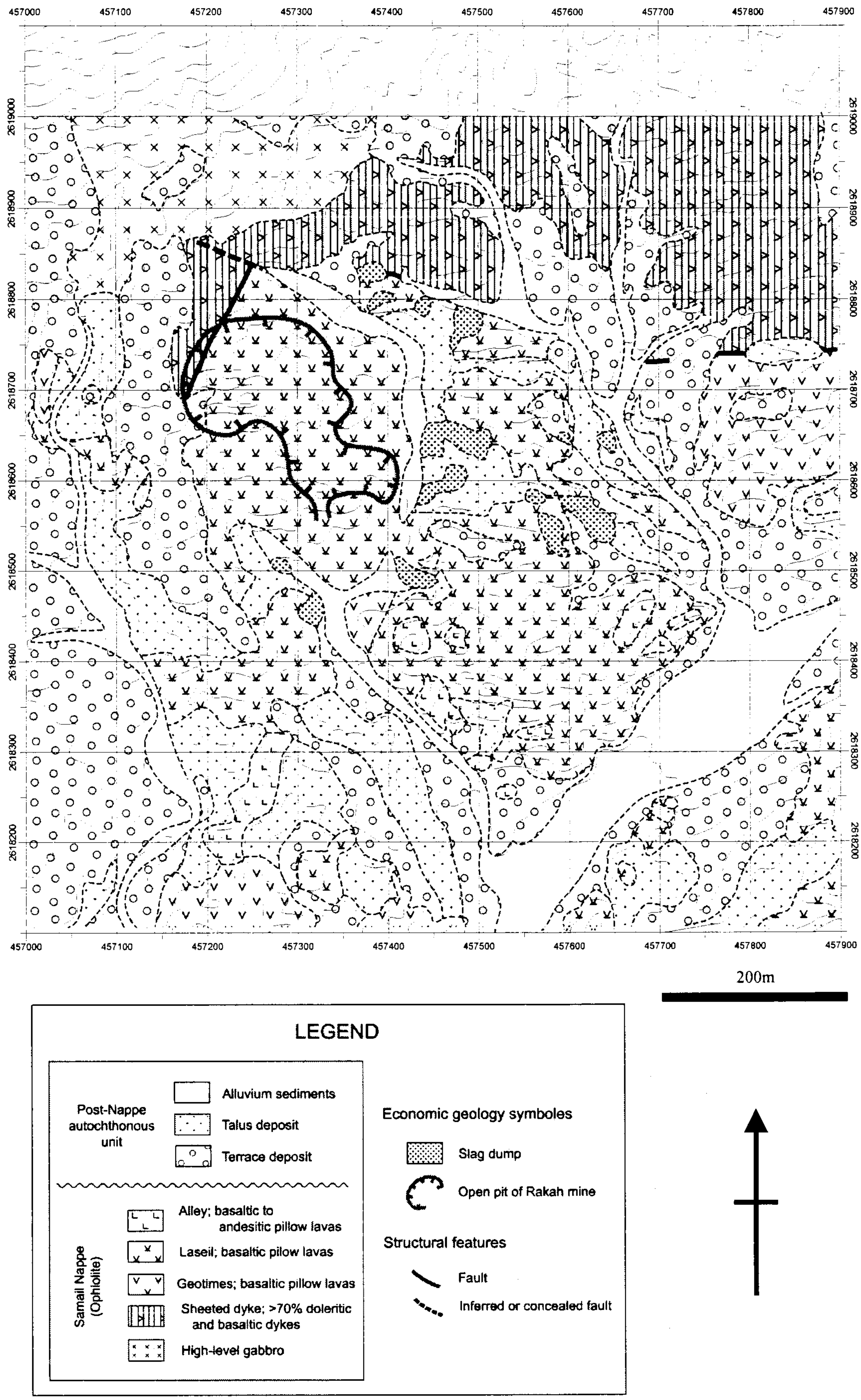

Fig. II-1-4 Geological map of Rakah Mine area

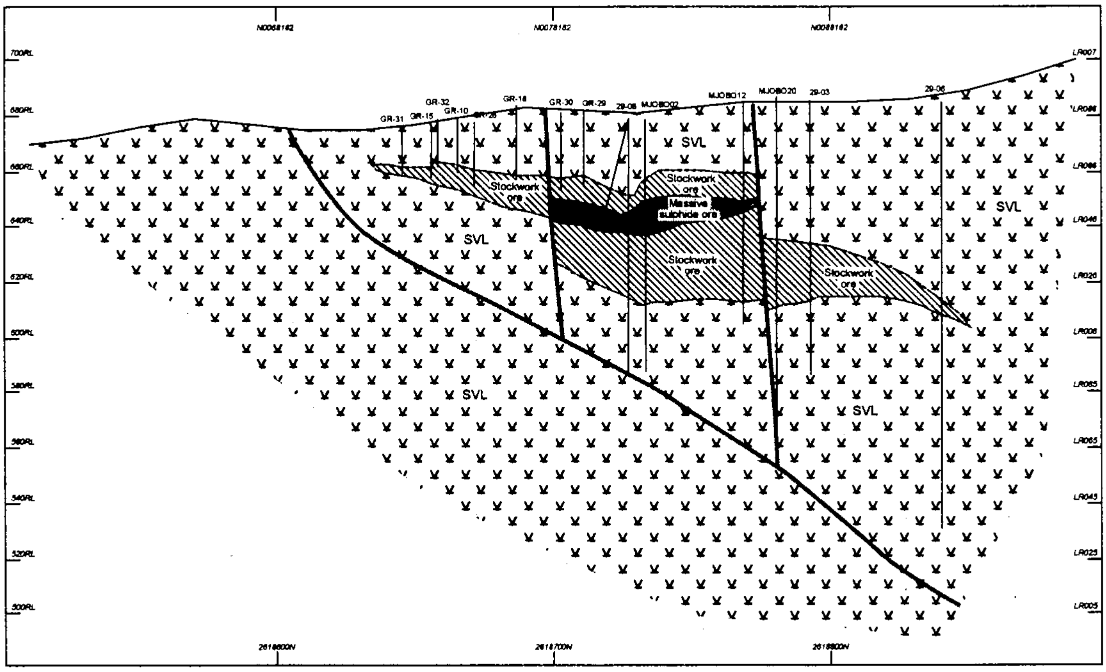

Fig. II-1-5　Rakah borehole and domain outline of cross section 290E

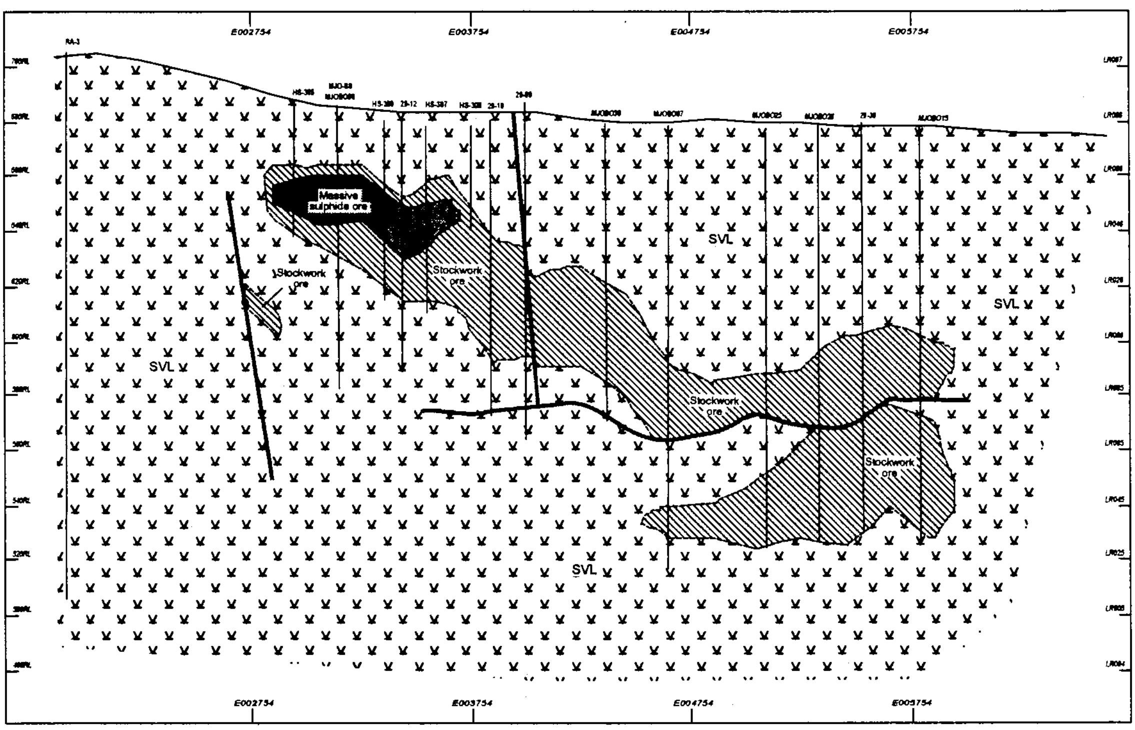

Fig. II-1-6　Rakah borehole and domain outline of cross section 750N

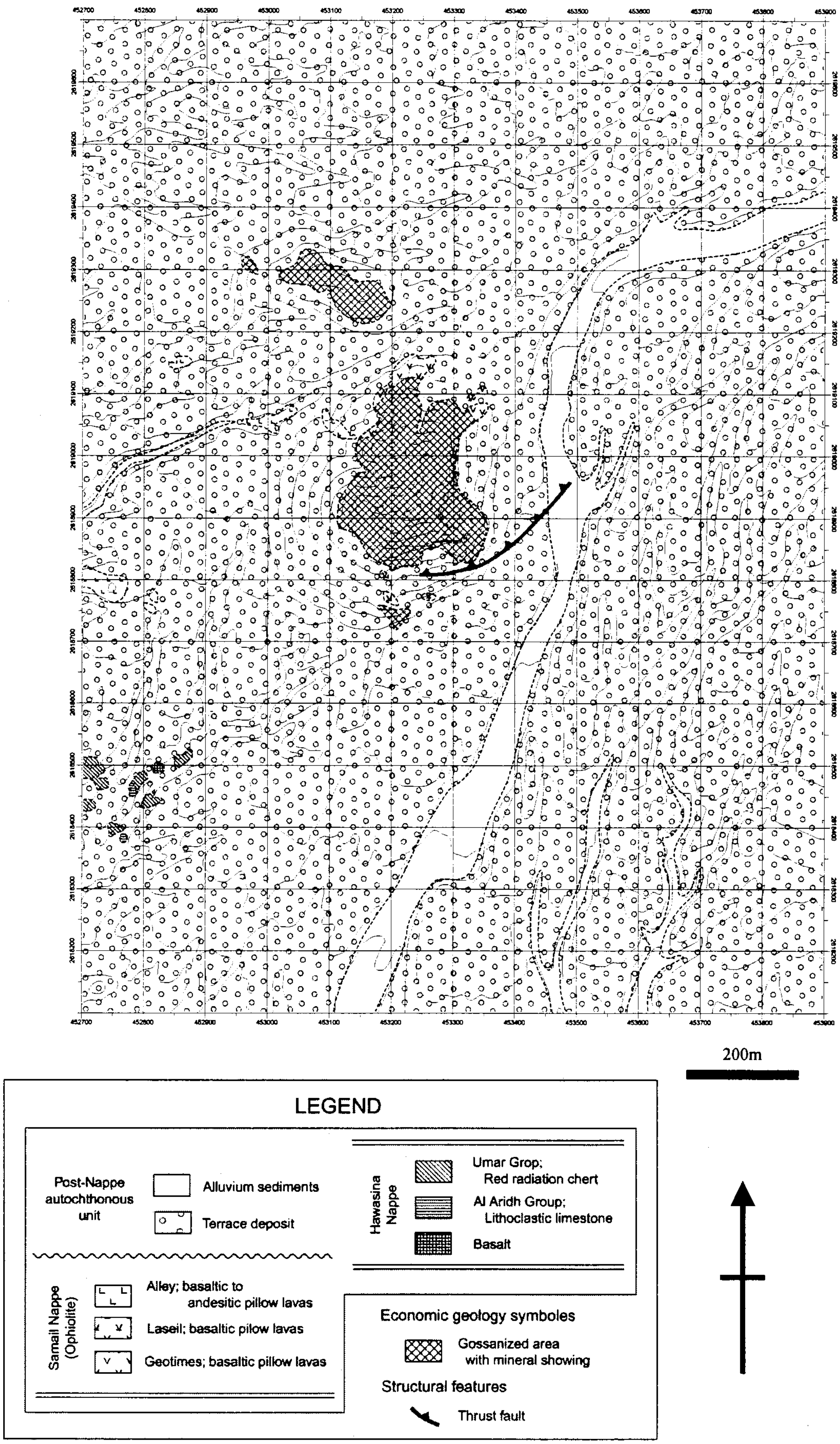

Fig. II-1-7 Geological map of Hayl as Safil area

Hayl as Safil deposit consists of 4 ore bodies; namely, Al Ashgar, Hayl as Safil, Bishara and Al Jadeed ore bodies from northwest to southeast. Large scaled gossan is prominent in the center of the deposit. These ore bodies belong to a large scale continuous mineralized zone of 500m wide and 1,500m long. All of them are concealed bodies. Surface features of mineralization are gossan, intense silicification around gossan, silicified parts with dense quartz veinlets and copper oxide along fractures.

Ore is classified in stockwork ore, massive ore and brecciated ore which consist of reworked and brecciated massive ore. Stockwork ore is especially developed in Hayl as Safil deposit. Al Ashgar ore body mostly consists of massive ore, but Bishara and Al Jadeed ore bodies consists mainly of reworked and brecciated ore and partly accompanied by massive ore.

Ore minerals are mainly composed of pyrite, chalcopyrite and subordinate sphalerite, bornite, chalcocite, covelline, etc.

Cross sections across the ore bodies are shown in Fig. II-1-8 ～II-1-11. Al Jadeed body shows a simple structure dipping gently towards west. Hayl as Safil body consists mainly of stockwork ore and does not show any clear structural control. To the contrary, Al Ashghar and Bishara ore bodies are characterized by the displacement of faults. Al Bishara body is a complex formed by small lenticular bodies situated within thick metalliferous sediments.

1-3-3 Quron Al-Akhbab mineral showing

The geological map is shown in Fig. II-1-12.

This area is located 2.5km to the east of Rakah deposits and forms a small hill trending E-W. Ground surface shows dark brownish color and is in general, weakly gossanized. Gossanized quartz veinlets accompanied by copper oxide are recognized in many parts. Testimony of ancient exploration activities such as galleries, depressions and waste dump are observed in several places.

As shown in Fig. II-1-12, this mineral showing is situated over Lasail Unit. Sheeted Dike is thrusted over in the north and contact with non-mineralized Lasail Unit by the normal fault in the south.

1-3-4 Tawi Rakah mineral showing

The geological map is shown in Fig. II-1-13.

This showing is located 3.5 km to the southwest of Rakah deposits. Abundant slag, left after smelting activities several thousand years ago, is observed around the showing, while waste dump of brownish to yellowish argillaceous gossan still remains in the south. The silicified zone with slightly gossanized quartz network is exposed in the north and a copper oxide is accompanied with quartz veinlets in places.

In this showing several exploration works were conducted in the past. Prospection Ltd. during 1973 to 1977 and Bishimetal Exploration Co. Ltd. in 1991 detected low grade copper mineralization.

1-3-5 Najaid area

The geological map is shown in Fig. II-1-14.

This showing is located about 2.5km to the east of Rakah deposits. Small-scale gossanized zone is observed with scattered quarts-epidote veinlets. Remarkable high chargeability zone was detected by IP survey in Phase I.

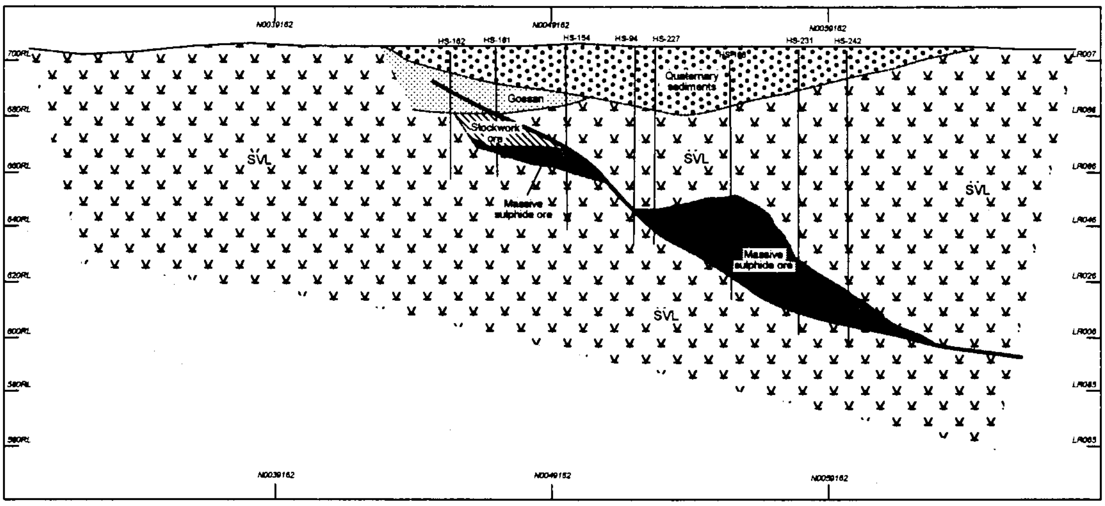

Fig. II-1-8 Al Ashgar borehole and domain outline of cross section 3000E

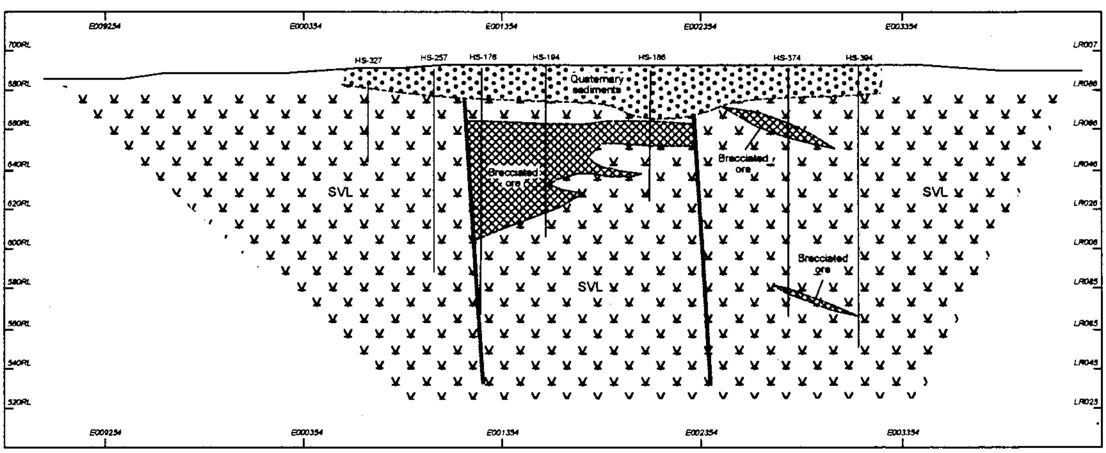

Fig. II-1-9 Al Bishara borehole and domain outline of cross section 525N

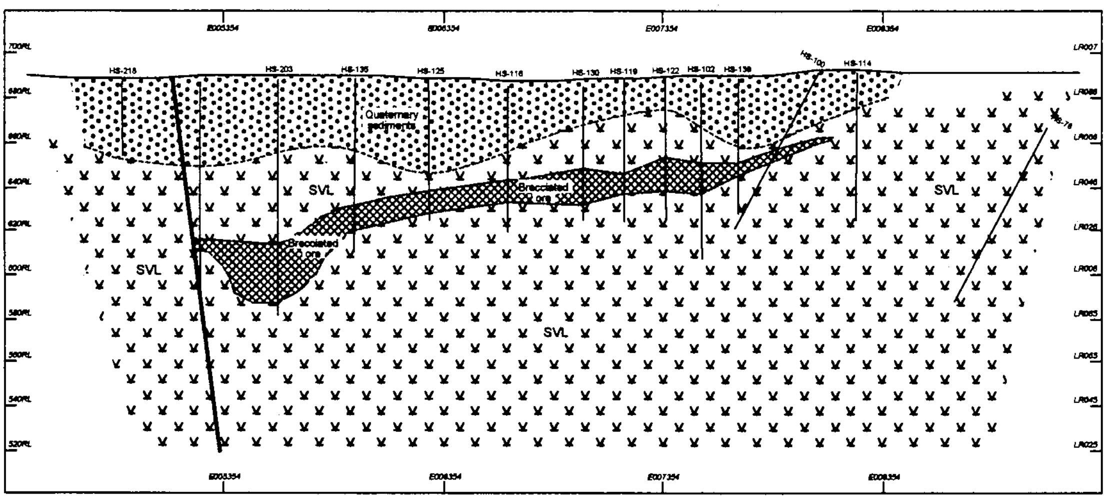

Fig. Ⅱ-1-10　Al Jadeed borehole and domain outline of cross section 240N

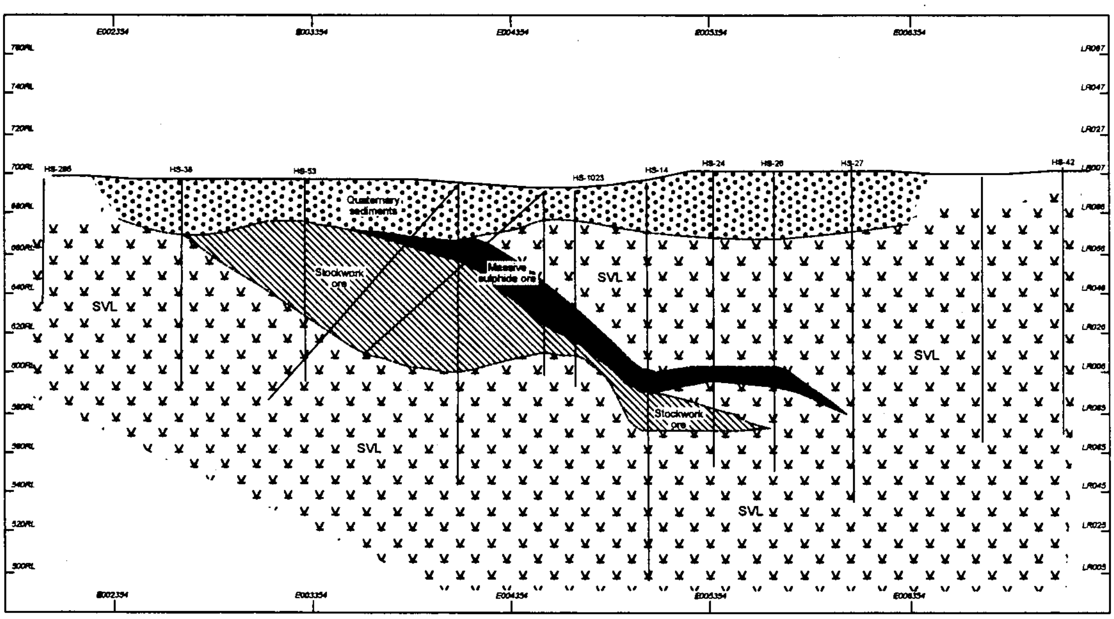

Fig. Ⅱ-1-11　Hayl as Safil borehole and domain outline of cross section 700N

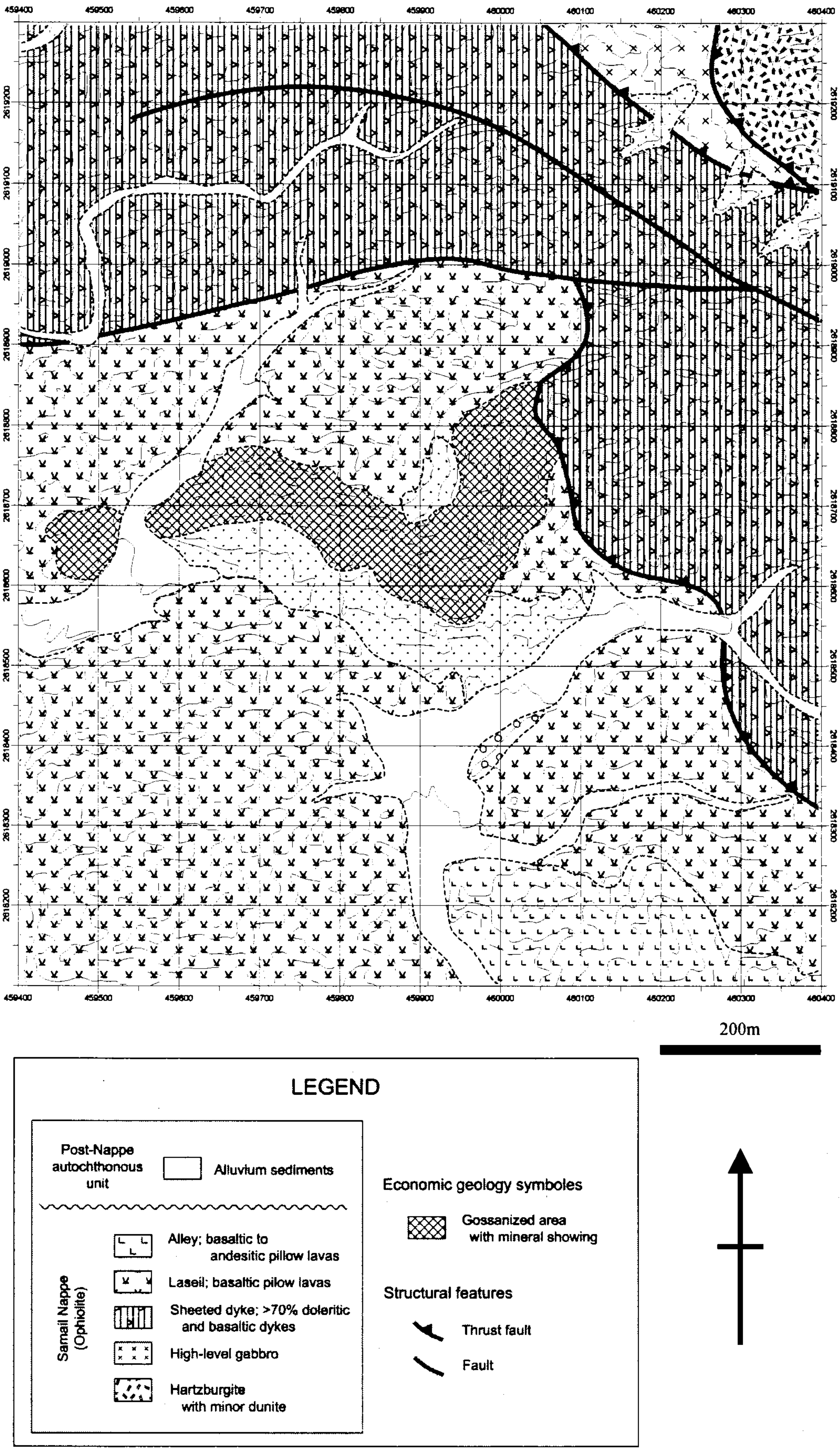

Fig. II-1-12 Geological map of Quron Al-Akhbab area

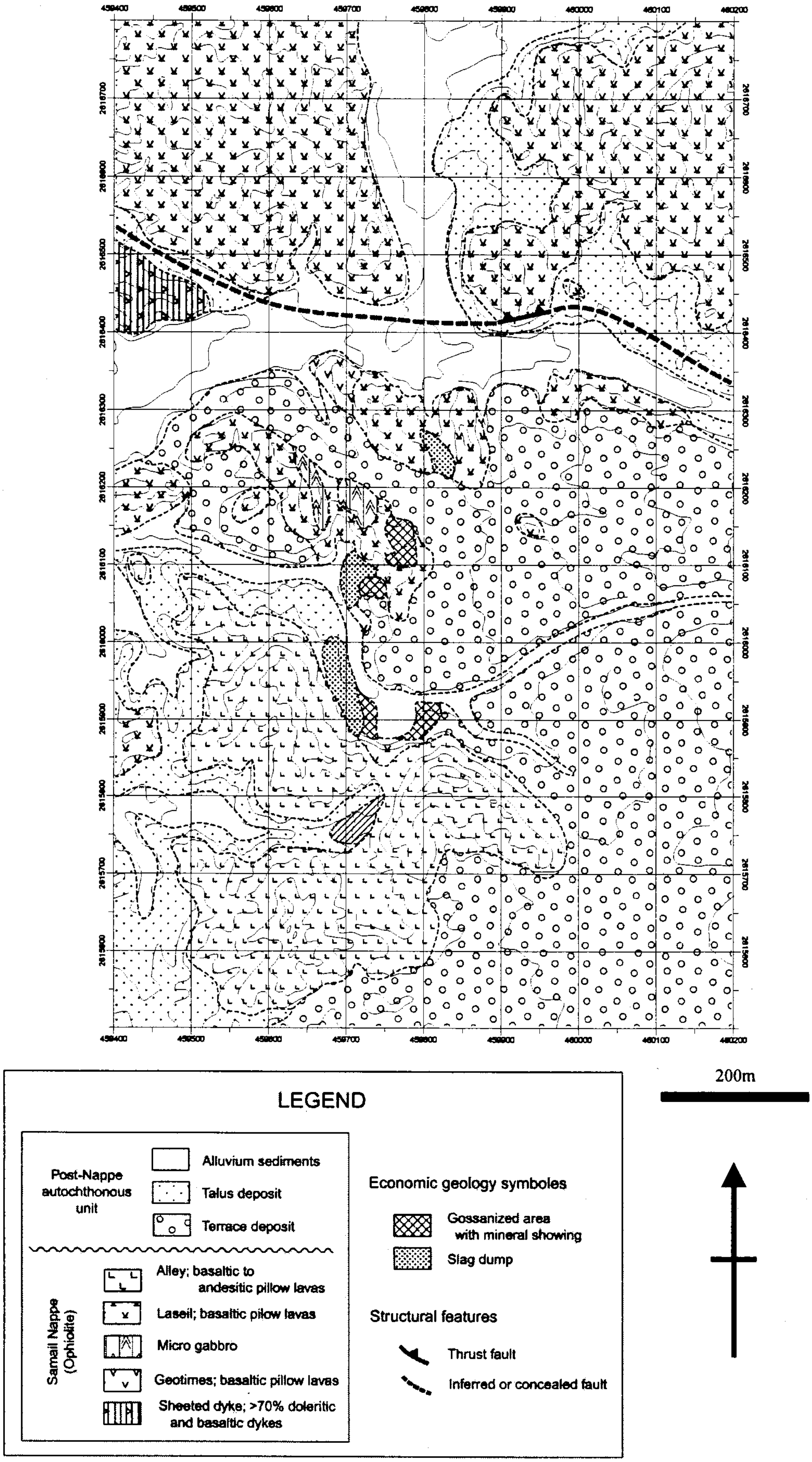

Fig. Ⅱ-1-13 Geological map of Tawi Rakah area

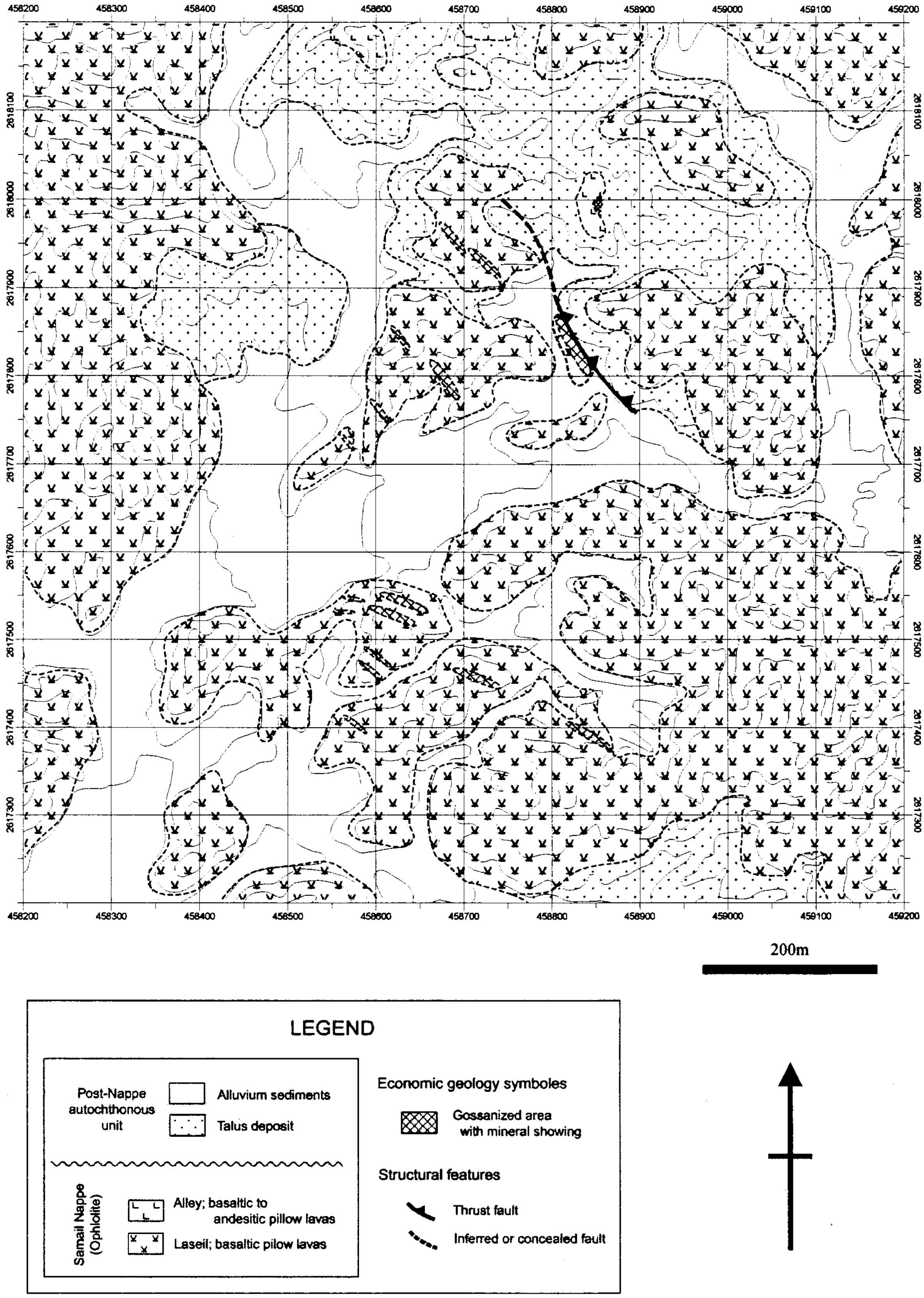

Fig. II-1-14 Geological map of Najaid area

CHAPTER 2 TDIP SURVEY

2-1 Objectives

The TDIP (Time Domain Induced Polarization) survey was carried out during this project in order to extract mineralized zones related to the existence of massive sulphide deposits in the Yanqul region on the basis of the results of the geoscientifical surveys previously carried out.

2-2 Survey Locations and Specifications

During the Phase I of this project, the Yanqul region was selected for exploration work. This area, with its center around the Rakah Gold Mine, extends about 9km along E-W direction and 5km along N-S direction covering an area of about $20km^2$. The geophysical investigations conducted within this area included also the Rakah Gold Mine, the Hayl as Safil deposit as well as Tawi Rakah area.

The TDIP survey carried out during Phase I consisted of 44 lines with a total length of 95.9 km and 3220 measurment points. The IP data were taken along lines spaced every 200m by keeping a potential dipole of 100m with a separation factor from 1 to 4.

During Phase II, the TDIP survey was carried out at the 5 areas where IP anomalies were detected in Phase I. Five areas are Tawi Rakah, Najaid, Quron Al-Akhbab, Rakah and Hayl as Safil. The survey consisted of 40 lines with a total length of 33.1km that corresponds to 2510 measurement points. The IP data were taken along lines spaced every 100m by keeping a potential dipole of 50m with a separation factor from 1 to 5.

Resistivity as well as chargeability values of rocks and core samples were also measured in the laboratory

2-3 Survey Method

2-3-1 Procedures

The Induced Polarization survey was carried out by using a time-domain method (TDIP) with a dipole-dipole electrode configuration. In the Phase I, the electrode configuration was arranged so that the survey lines were spaced 200m and the measurements were taken every 100m along the lines by using a separation factor from 1 to 4. To get more detailed information, in the Phase II the procedure was modified so that the lines were spaced 100m and data taken every 50 m by using separation factors from 1 to 5. In the survey area, the TDIP survey was carried out by injecting a current into the earth through current electrodes and the resulting voltage was measured across potential electrodes. Fig. II-2-1 shows the array utilized as well as the location of the plotting points.

In the TDIP surveys, the current is turned on for a certain length of time (on-time) then turned off (off-time). The transmitted waveform is then repeated with current flow in opposite direction. The pair of positive and negative on-off waveforms constitutes a cycle, which in this survey lasted 8 seconds, as indicated in Fig. II-2-2. According to Fig. II-2-3, the polarization of the target creates a transient decay voltage and its corresponding changing response is observed in the received waveform.

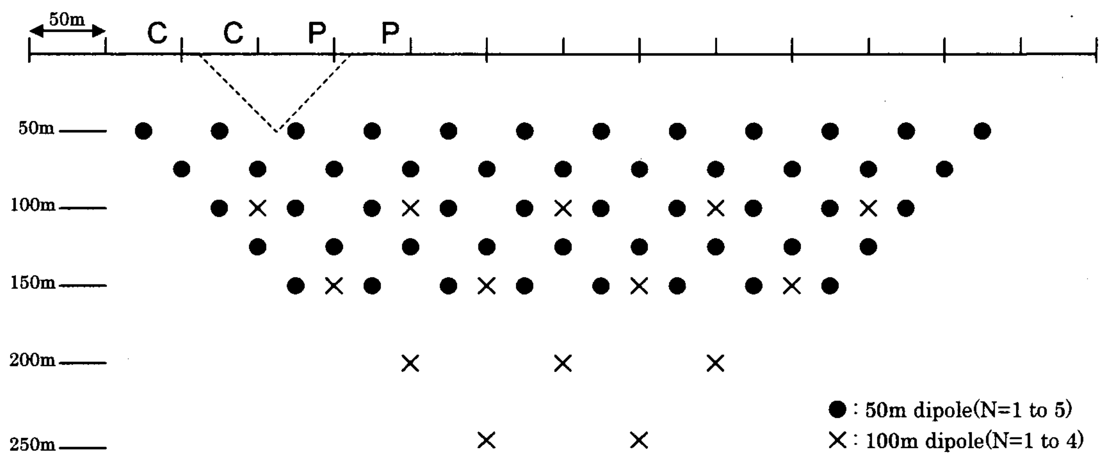

Fig. II-2-1 Dipole-dipole array and plotting procedure

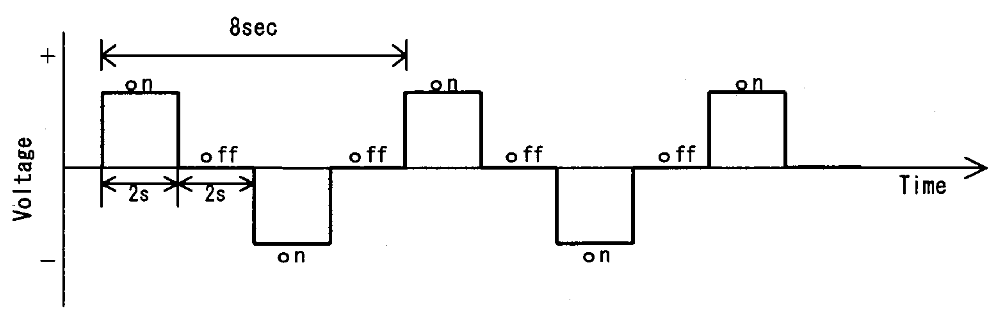

Fig. II-2-2 Waveform produced by the transmitter

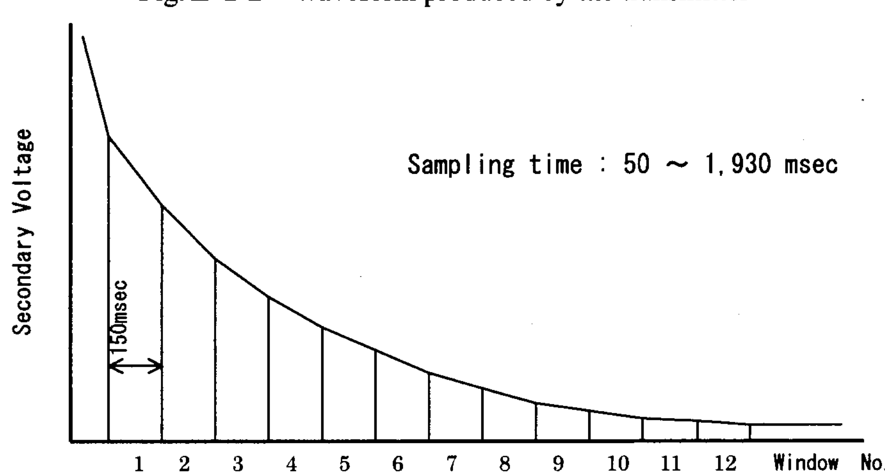

Fig. II-2-3 Sampling interval of the TDIP

2-3-2 Instrumentation

The instrumentation used for the conventional time-domain IP survey is described in the Table Ⅱ-2-1.

Table Ⅱ-2-1 Specifications of TDIP survey instruments

Receiver	**Zonge GDP-16**
Frequency range	DC to 8KHz
Number of Channels	8
Number of Stacking	8096
Detectable signal	1 μ V
A/D Conversion	16 bits
Number of Windows	13(from 50 to 1,930ms)
Transmitter	**CH-95A**
Output Power	2kw,800v,12A
Output Frequency	DC to 10KHz
Frequency control	Automatic
Generator	**Geonics GPU2000**
Maximum output	2Kw
Output Voltage	200V
Output Frequency	400Hz

2-4 Analysis Method

2-4-1 Data processing

The TDIP data processing involves the determination of 3 parameters, i.e., apparent resistivity, chargeability as well as metal factor. The first 2 parameters are calculated directly by the receiver unit during data acquisition. The third one is calculated as a simple relation between the first 2 parameters. These 3 parameters are calculated as follows:

a) Apparent resistivity (ρ)

$$\rho = K\frac{V_P}{I},$$

where $\boldsymbol{K} = \pi an(n + 1)(n + 2)$, $\boldsymbol{Vp}$ is the received voltage in volts, $\boldsymbol{a}$ is the A-spacing in meters, $\boldsymbol{n}$ is the separation factor and $\boldsymbol{I}$ is the transmitted current in amperes.

b) Chargeability (M)

$$M = \frac{1.87}{V_P}\int_{t_1}^{t_2} V_t dt,$$

where $\boldsymbol{Vp}$ is the primary voltage in volts and $\boldsymbol{Vs}$ is the secondary voltage in millivolts.
Here, the secondary voltage is calculated from 450msec. to 1,100msec.

c) Metal factor (*MF*)

$$MF = \frac{M}{\rho} \times 100,$$

where ***M*** is the chargeability (mV/V) and ρ the apparent resistivity (Ωm)

2-4-2 Topographic corrections

Since the apparent resistivity is calculated here as a function of the location of the current and potential electrodes on a half-infinite plane, it is affected by topography depending on the location of the electrodes. For the case of a dipole-dipole configuration, the apparent resistivity appears to be high beneath a hill and low beneath a valley. On the other hand, the chargeability values are less affected by topography.

In order to make the appropriate corrections for the present survey, the topographic correction is calculated for each survey line by using 2D finite element method (FEM). The corrected apparent resistivity values are then used to construct the related sections and contour maps.

2-4-3 Pseudo-section and plane maps

After topographic corrections, apparent resistivity, chargeability and metal factor pseudo-sections are made for every line of the survey. Plane maps of the above mentioned 3 parameters are also made for every separation factor.

It is normal to plot the measured results as conventional pseudo-sections so that preliminary interpretations can be made. This is also important for assessing data quality. Anomalies having high chargeability are easily observed but caution should be taken to directly infer the location and depth by simple inspection of the pseudo-section.

2-4-4 Two-dimensional analysis

The pseudo-sections do not show the real image of subsurface structure. In order to estimate the subsurface structure from TDIP data, we applied a 2D quantitative analysis method to the measured data, consisting of forward calculations using FEM and inversion calculations using non-linear least square method.

In order to make the model calculations, the subsurface structure is divided into many small blocks, each of them having initially assigned their own chargeability and resistivity value. The size of the blocks are relatively small at the shallower part, but large at the deeper part.

Theoretical values are calculated from the block models using FEM, and the parameter of each block is made to change until the difference between the theoretical value and measured value is sufficiently small.

2-5 Survey Results

Fig. II-2-4 shows the location of all the IP lines surveyed.

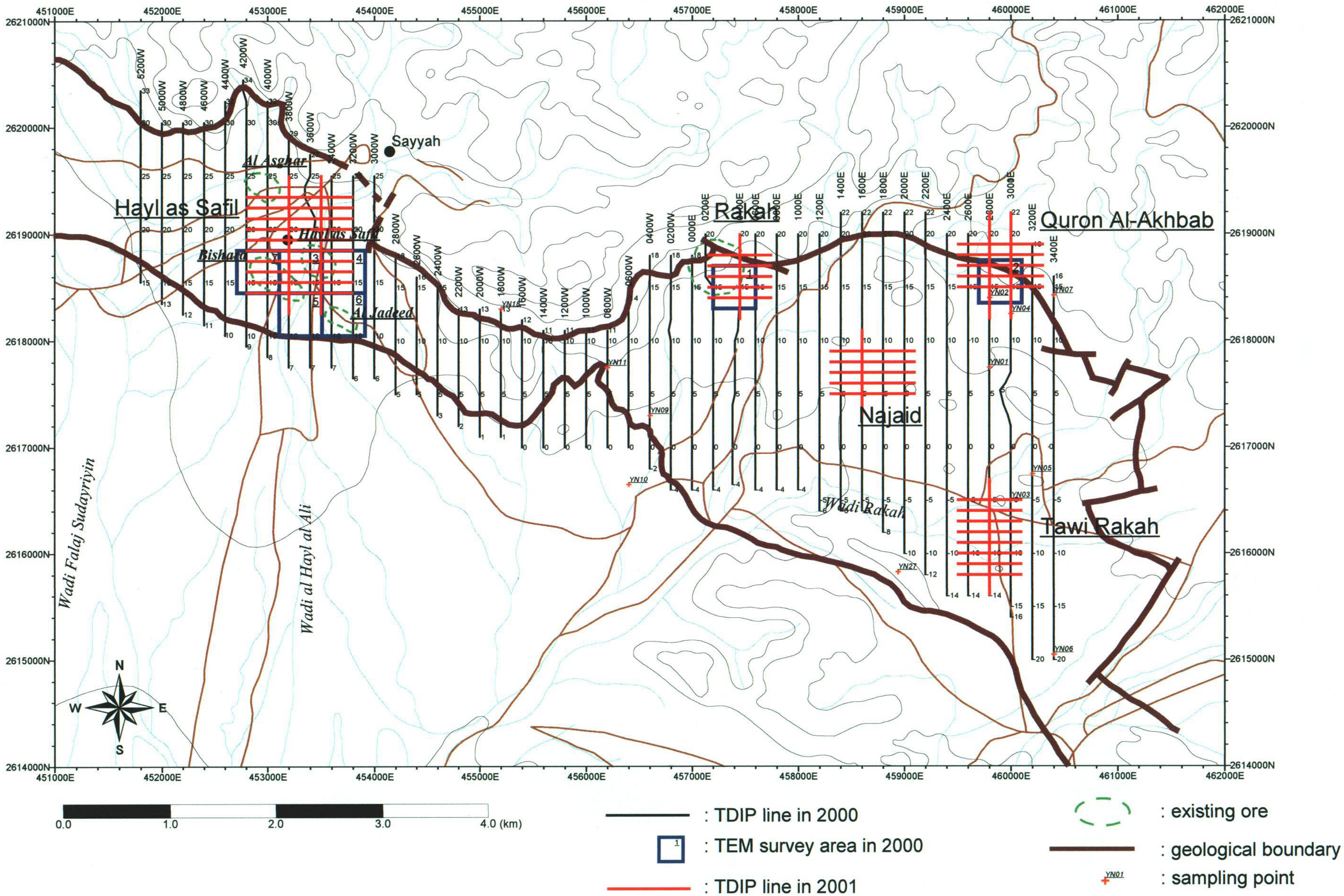

Fig. II-2-4 Geophysical survey location in Yanqul area

The results obtained during Phase I are presented as pseudo sections of apparent resistivity, chargeability and metal factor values from Fig.Ⅱ-2-5 to Fig.Ⅱ-2-11. Plane maps of apparent resistivity, chargeability and metal factor from N=1 to 4 are presented from Fig.Ⅱ-2-12 to Fig.Ⅱ-2-15.

Apparent resistivity values ranged from several Ωm to about 1,300Ωm with an average of about 160Ωm. To the east of line 200W, high resistivity values over 500Ωm are generally seen in places where sheeted dikes are distributed. To the west side of this line, low to medium resistivity values are seen distributed, representing the existence of sedimentary rocks. Chargeabilities from 0 to 45mV/V are distributed with an average value of about 7.5mV/V. Five places with high chargeability distributions were confirmed as follows:

- Rakah Gold Mine and surroundings
- Quron Al-Akhbab area (North East part of the survey area)
- Tawi Rakah prospect
- Hayl as Safil deposit and surroundings
- Najaid area (surroundings of line 1600E and station 700N)

In order to obtain more detailed information on the resistivity and chargeability distributions related to the IP anomalies above-mentioned, the survey carried out during Phase II was arranged to measure the points every 50m along lines spaced 100m. These results are described as follows.

2-5-1 Rakah Gold Mine and surroundings

The location of the lines in the Rakah Gold Mine is indicated in Fig.Ⅱ-2-16. In Phase II, 5 new lines of 600m length each were set along east-west direction, while one of 800m length was set along north-south direction passing through the center of the east-west lines.

The Figs.Ⅱ-2-17 (1) ~ (4) show the apparent resistivity pseudo-sections, while the Figs.Ⅱ-2-18 (1)~(2) indicate the plane maps from N=1 to 5. The Figs.Ⅱ-2-19(1)~(4) and Figs.Ⅱ-2-20(1)~(2) show the 2-D analysis sections and 2-D analysis plane maps for resistivity, chargeability and metal factor.

In this area, the apparent resistivity values ranged between 1.3~464Ωm with an average of about 100Ωm. The chargeability values ranged between 1.7~70mV/V with an average of about 12.4mV/V. When compared with other areas, the existing massive sulphide orebody presents relatively low resistivity values in general.

According to the TDIP plane maps, the central part of the open pit shows a zone of low resistivity–high chargeability distributed. This anomaly extend NE towards depth. According to the results of past drilling survey carried out around the Rakah deposit, stockwork ore had been intersected dipping NE. This anomaly is considered to reflect stockwork ore from this fact. On the SW side of the pit, around the station 2.5 of line 1600N, one anomaly of low resistivity-high chargeability was confirmed around the depth level of N=3.

On the other hand, 2D calculations confirmed low resistivity distribution at shallow levels in the

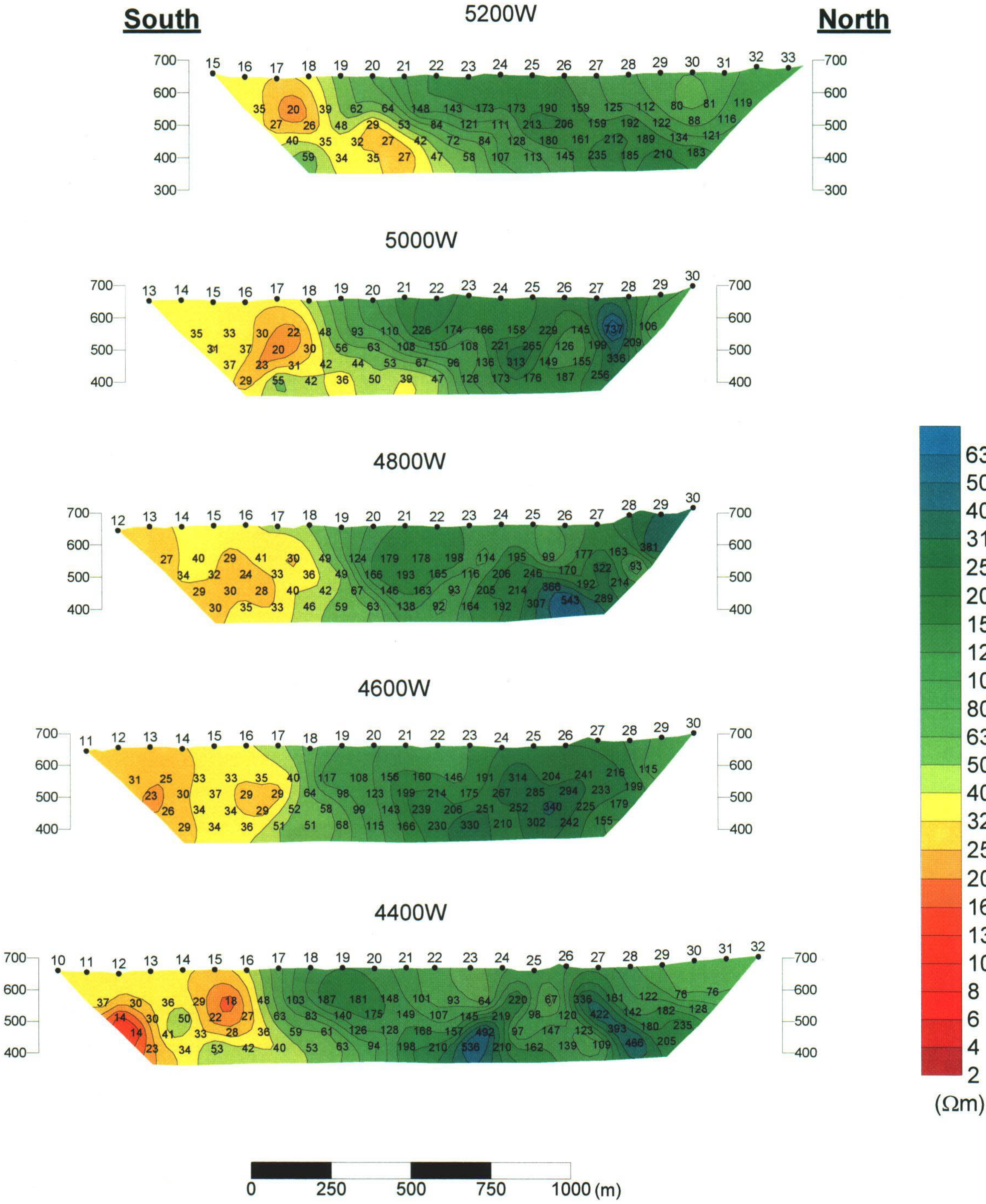

Fig. II -2-5(1) Apparent resistivity pseudo-sections(5200W-4400W)

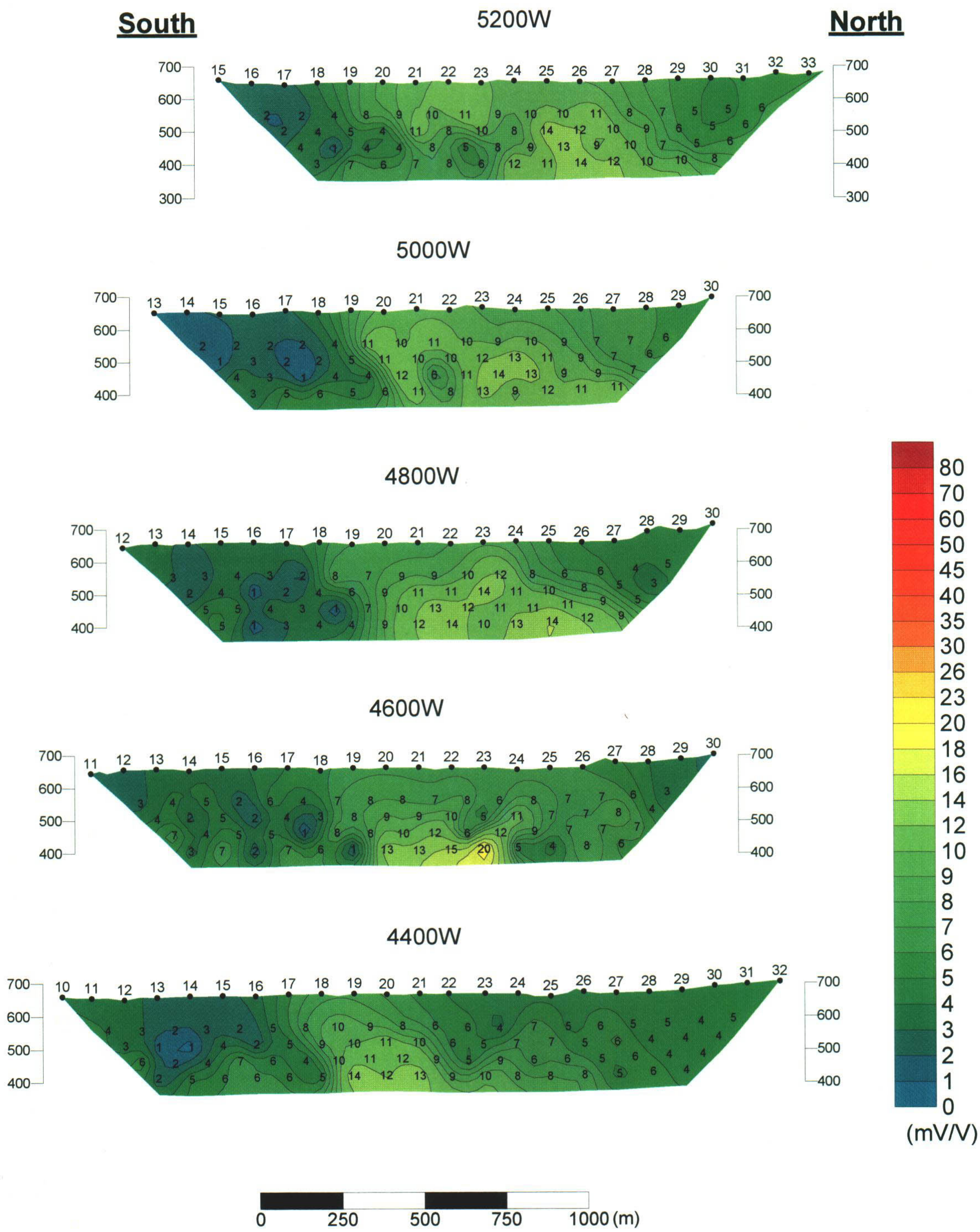

Fig. II-2-5(2) Chargeability pseudo-sections(5200W-4400W)

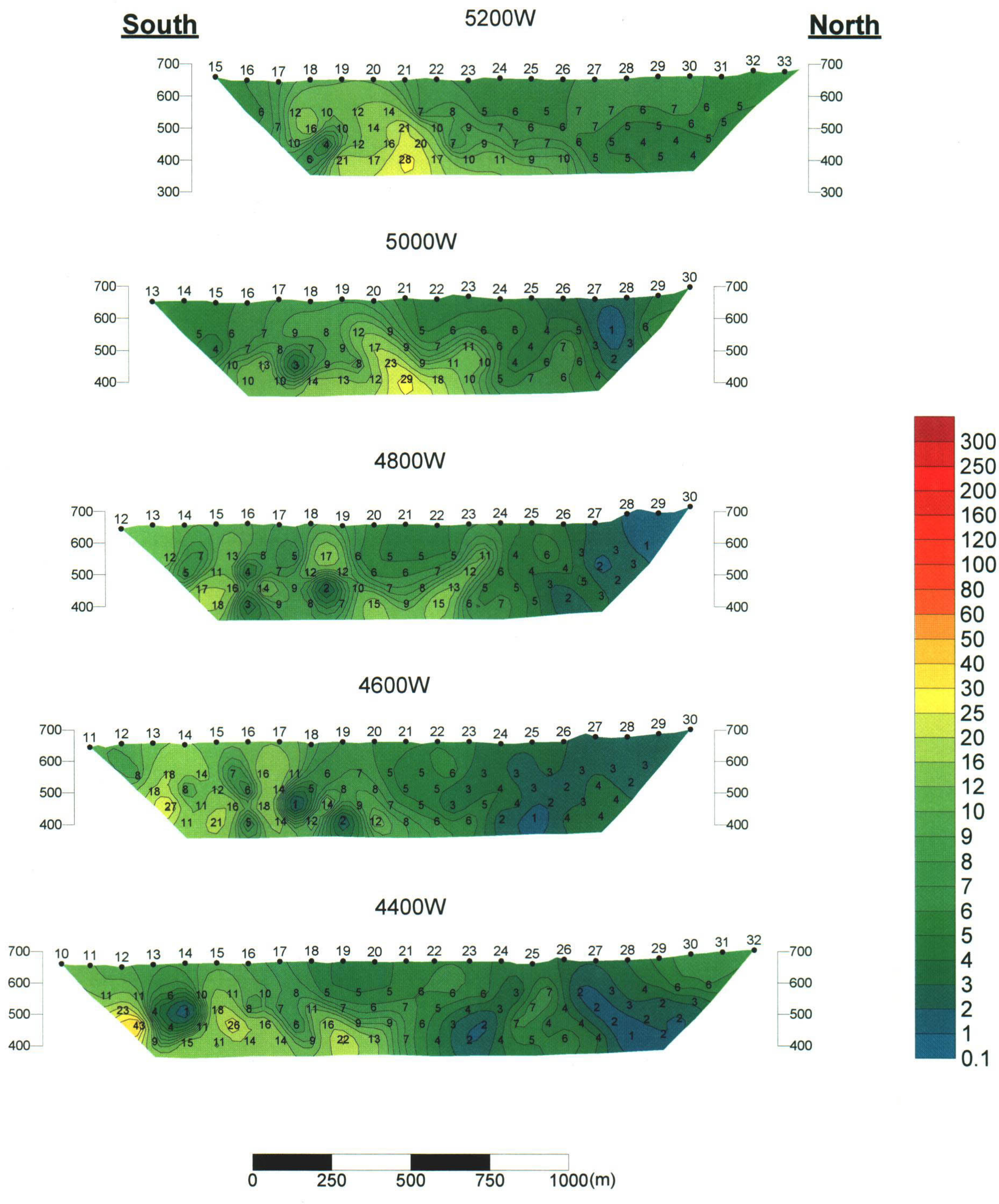

Fig. II-2-5(3) Metal factor pseudo-sections(5200W-4400W)

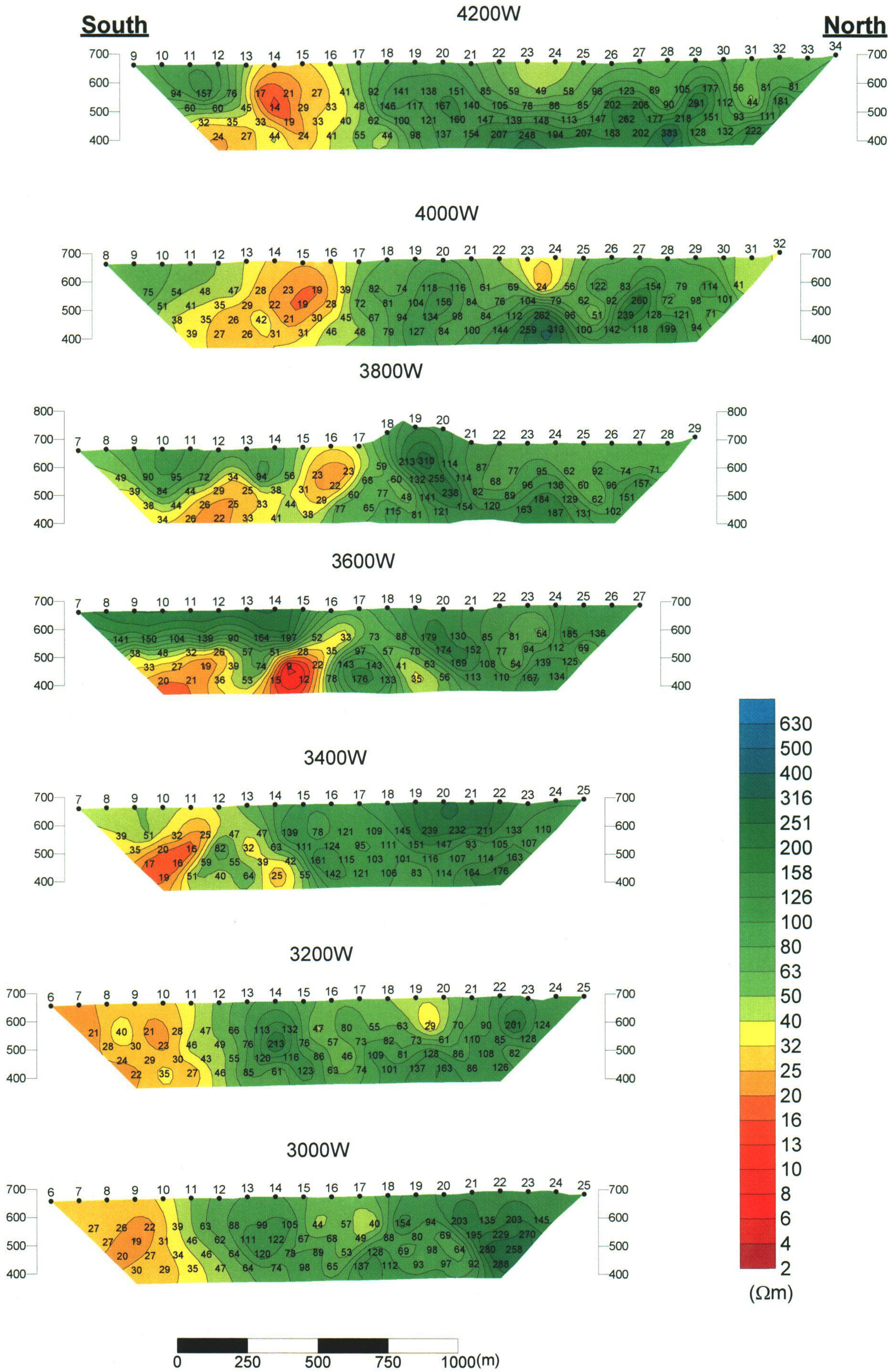

Fig. II -2-6(1) Apparent resistivity pseudo-sections(4200W-3000W)

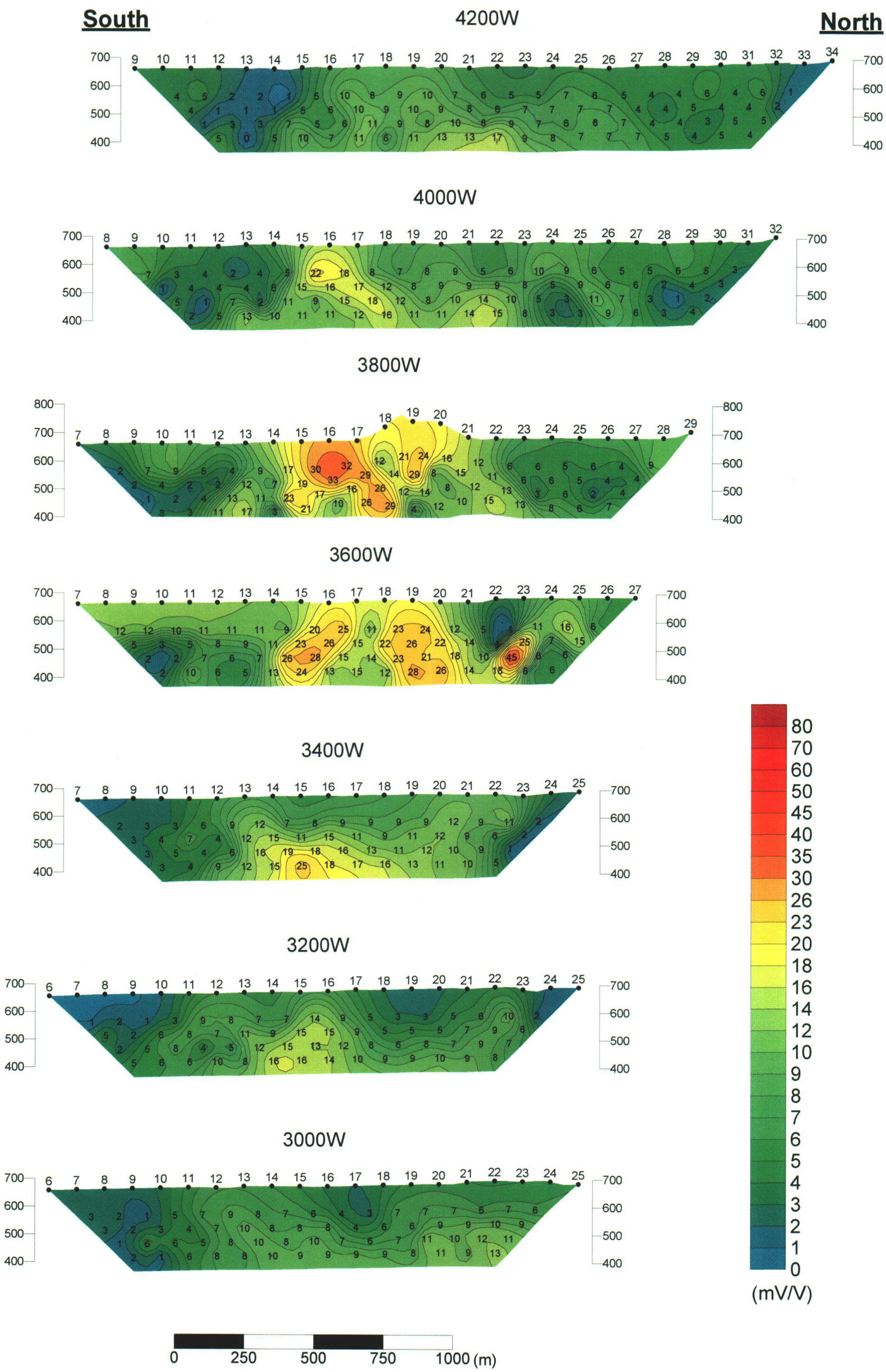

Fig. II -2-6(2) Chargeability pseudo-sections(4200W-3000W)

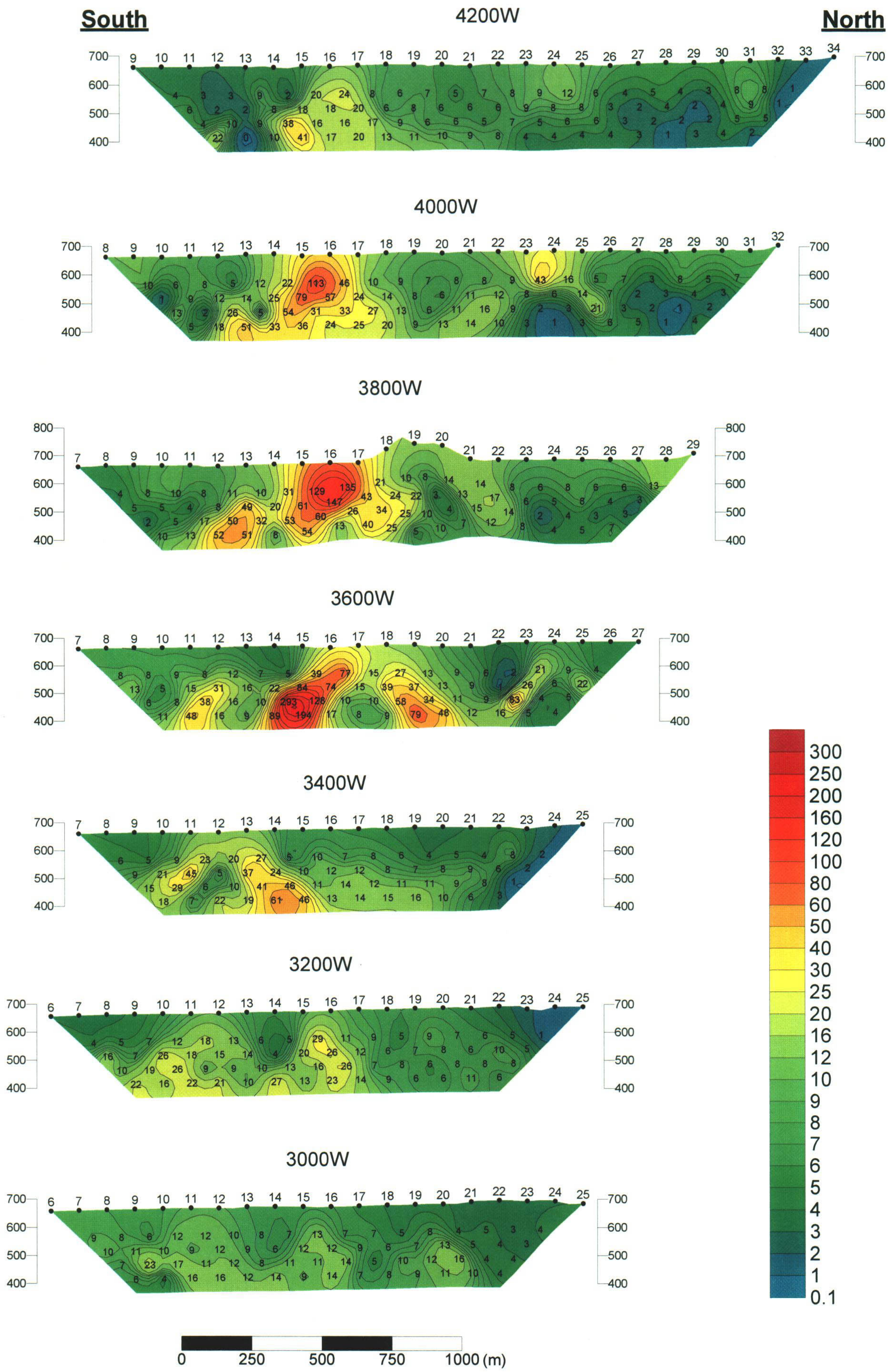

Fig. II-2-6(3)　Metal factor pseudo-sections(4200W-3000W)