DESCRIPTION OF SCHLUMBERGER SOUNDINGS, HEAD-ON PROFILING AND SOME EXAMPLES OF THEIR USE IN GEOTHERMAL EXPLORATION

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ABSTRACT

In the last few years, geophysical methods have become more important in geothermal exploration. Of these geophysical methods, Schlumberger soundings and head-on profiling are the most successful ones. Iceland is very rich in geothermal energy. As the main geophysical methods Schlumberger soundings and head-on profiling have been used with success in geothermal exploration. The report discribes mainly application of Schlumberger soundings and head-on profiling as well as one-dimensional and two-dimensional interpretation of them. The results of Schlumberger soundings and head-on profiling in Urridavatn and Glerardalur, Iceland are discussed. In geothermal fields of Tianjin, China the overburden is thick. In some areas the depth is more than 1000 m to the bedrock. On the other hand, there are saline sediments in the upper layers of the geothermal field. This report discusses how to use Schlumberger soundings and head-on profiling in exploration of geothermal fields in Tianjin, China.

TABLE OF CONTENTS

Page

ABSTRACT 3

1 INTRODUCTION
1.1 Scope of work 7
1.2 Introduction to Schlumberger soundings and head-on profiling 7

2 SCHLUMBERGER SOUNDINGS AND HEAD-ON PROFILING
2.1 Schlumberger soundings 9
2.1.1 Field procedures 9
2.1.2 One-dimensional interpretation 11
2.1.3 Two-dimensional interpretation modelling 12
2.2 Head-on profiling 14
2.2.1 Principles of head-on profiling 14
2.2.2 Field procedures 14
2.2.3 Interpretation of head-on profiling 15

3 APPLICATION OF SCHLUMBERGER SOUNDINGS AND HEAD-ON PROFILING IN GEOTHERMAL FIELDS OF ICELAND
3.1 The Urridavatn geothermal field 17
3.1.1 Geology of the geothermal field 17
3.1.2 Geophysical servey 17
3.1.3 Conclusions 18
3.2 The Glerardalur area 19
3.2.1 Geology of the study area..... 19
3.2.2 DC-resistivity servey 19
3.2.3 Conclusions 20

4 THE POSSIBLE FUTURE APPLICATION OF SCHLUMBERGER SOUNDINGS AND HEAD-ON PROFILING IN WANG-LAN-ZHUANG GEOTHERMAL FIELD, TIANJIN, CHINA
4.1 Geology of the area 21
4.2 The possible application of Schlumberger soundings and head-on profiling in the area 22

5 CONCLUSIONS AND RECOMMENDATIONS 23
ACKNOWLEDGEMENTS AND REFERENCES 24

LIST OF FIGURES

Fig. 1 The Schlumberger array 25

Fig. 2 One-dimensional interpretation 26

Fig. 3 Measured pseudosection and two-dimensional modelling of line 3 of Krafla 27

Fig. 4 Calculated pseudosections of line 3 of Krafla; a) By the author, b) By Arnason et al 28

Fig. 5 Head-on profiling field layout 29

Fig. 6 Head-on profiling over a vertical contact 30

Fig. 7 Head-on profiling over a buried dike 32

Fig. 8 Two-dimensional interpretation of head-on profiling 35

Fig. 9 Geological map of Urridavatn 36

Fig. 10 Results of resistivity profiling at Urridavatn 36

Fig. 11 Model of the Urridavatn geothermal area 37

Fig. 12 A geological map of Sulumyrar and neihbourhood 37

Fig. 13 Akureyri, results of resistivity measurements at - 400 m depth 38

Fig. 14 Interpretation of resistivity measurements from Glerardalur 39

Fig. 15 Location of Tianjin 39

Fig. 16 Map of geological structures and top of basement in the Tianjin geothermal field 40

Fig. 17 Stratum in Wang-Lan-Zhuang geothermal field 40

1 INTRODUCTION

1.1 Scope of work

The Geothermal Training Program is sponsored by the United Nations University (UNU) and the National Energy Authority of Iceland (ORKUSTOFNUN). In this year the training course began at 15th of April and lasted about six months. During the first five weeks we were given general lecture course by the geothermal training program. This course involved the geothermal exploration and utilization such as Geological exploration, Hydrology, Geophysics, Geochemistry, Borehole geology, Borehole geophysics, Reservoir engineering, Drilling technology, Geothermal utilization, etc. After these the program gave the author a training in Schlumberger soundings and head-on profiling and magnetic survey. The fellows took an excursion (10 days) to visit high and low temperature geothermal fields and several factories that benefited from geothermal energy. The author went on a 5 days excursion to Urridavatn and Glerardalur areas to study low temperature exploration. The rest of the time the author learned Schlumberger soundings and head-on profiling interpretation that include one-dimensional and two-dimensional interpretation. As a summary the last month was used to write the final report.

1.2 Introduction to Schlumberger soundings and head-on profiling

Recently Schlumberger soundings and head-on profiling have been used extensively, in mapping fault zones, fracture zones and contacts of different geological units. In geothermal fields the resistivity of thermal water decrease with increasing salinity and temperature up to 300°C. According to the principle that the resistivity decreases with increasing temperature up to 300°C, we can find geothermal anomalies.

In geothermal fields, there are some active faults, fractures and permeable dikes. Because the resistivity of geothermal water is much lower than of the country rock, the resistivities of permeable faults, fractures and dikes

are low. Therefore using Schlumberger soundings and head-on profiling one can investigate permeable faults, fractures and dikes.

In the early days of Schlumberger soundings interpretation master curves were used. The last few years one-dimensional interpretation and two-dimensional interpretation have been developed. Comparing the two interpretation methods shows that the numerical methods are much better than the classical ones in interpretation speed and accuracy.

2 SCHLUMBERGER SOUNDINGS AND HEAD-ON PROFILING

2.1 Schlumberger soundings

2.1.1 Field procedures

A) The equipment: The instruments in use in Iceland are designed and made in Iceland. The VN 110 and VN 111 are a portable DC resistivity equipments, based on twenty years of experience in both measuring methods and electronic design.

The Power Unit is a adjustible current controlled source with swith-selectable maximum output current and voltage, capable of handling 0.5 Kw output power at a maximum of 1000 volt. Obviously this can be dangerous so the operator must be well aware of that fact. The Power Unit is protected against such as reverse power polarity, overvoltage and overheating. It is run by a 24 V DC source.

The Measuring Unit consists of 3 Input Amplifier Modules, a Computer Module and a Hand Held Display Terminal. The input modules have combination of interference voltage. The input range is 100 V FSD to 0.1 mV FSD and the resolution is 14 bits, resulting in maximum sensitivity below 1 µV. The Measuring Unit is a state of the art and in a class all by it self, it consist of a Digital Microcomputer with Hand Held Disply Terminal and three Digitally Controlled, high precision, Differential Input Amplifiers. By using 3 inputs simultaneously higher efficiency is achived and also more precise results.

These two units, the Power Unit VN 110 and Measuring Unit VN 111 are separated galvanically but are coupled together by means of optical cable for signal transmission (see Technical Data at the end of this chapter).

A car battery is used for power. The material of the current electrodes is aluminimum. So the current electrodes are light. Non-polarizing small porous-pots are used as potential electrodes.

TECHNICAL DATA

POWER UNIT VN 110:

Dimension:	H * W * D	31 * 26 * 41 cm
Weigth:		12 kg
Input voltage:		24 V DC
Input current:		30 A max.
Output power:		500 W max.
Output voltage:	1000 V	500 V 250 V
Output current, max.:	0.5 A	1 A 2 A
Ground- and wiring control:		24 V DC
Measuring cycles:		2, 4, 8 sec.

MEASURING UNIT VN 111:

Dimension:	H * W * D	52 * 51 * 22 cm
Weigth:		18 Kg
Power requierments:		
Input voltage:		8 - 15 V DC
Input current:		0.4 - 0.2 A
Input modules:		
Voltage range, FSD:		0.1 mV to 100 V, in 7 steps
Measuring sensitivity:		± 0.1 µV
Dynamic range (auto. surpressing range):		16 times FSD
Accuracy:		0.5 %

When the measuring lines intersect the object of interest perpendicularly the bigest anomaly will be observed. Then the fissures, faults, dikes as well as the geothermal water can be found.

D) Selecing a proper separation of AB and MN: The separation of AB depends on the object of prospect. If it lies deep then the separation must be large. If the object of the prospect lies shallow the separation can be smaller. Selecting a proper MN is important too. If the separation of MN is too large the resolution and depth of investigation is poor. If the separation is too small the resolution is good but the potential difference is too small and difficult to measure.

E) Effects of topography: A valley can produce a large spurious resistivity low which could easily be misinterpreted as an evidence of a buried conducter. Similarly a hill can produce an apparent resistivity high. If it is possible the measuring line should be parallel to the contour lines to overcome the effect of the topography.

F) Methods to guaranty the accuracy: It is important to keep a good insulation of the wires for preventing current leakage. The direction and distance of AB/2 and MN/2 must be accurate.

A regulated steady-current square wave with pulse length 2, 4, or 8 seconds is transmitted to the earth. Several readings are taken in the reciver and stacked into a processor in order to sum. Then the average and the standard deviation of the measurements are calculated. Telluric noise can be prevented with this procedure. Usually there are filters in the receiver to prevent the culture noise.

2.1.2 One-dimensional interpretation

The last few years one-dimensional interpretation has been carried out by the ELLIPSE method in Iceland. The program was written and developed by Ragnar Sigurdsson in 1983. The ELLIPSE method is based on the following equation:

$$\rho a(C,P) = 2\rho 1 \frac{C2-P2}{4CP} \int_{o}^{\infty} K(\lambda)(J_o(\lambda C-\lambda P)-J_o(\lambda C+\lambda P))d\lambda \quad (1)$$

Where $K(\lambda)$ is a kernel fuction J_o is Bessel function of order 0; C is the current electrode distance; P is the potential electrode distance.

The equation is considered in the case that the configuration is symmetrical.

If P<<C then

$$\rho_a = \frac{2\pi C2\Delta V}{IP} \quad (2)$$

Where ρ_a is the Schlumberger apparent resistivity. The ELLIPSE is a inversion method for Schlumberger soundings. This method compares the theoretical values which are obtained by a numerical computation with the field data. The theoretical values are fitted to the field data by inversion. The starting model should at least be a rough approximation of the reality whereas the interpretation tends to converge slowly or even fails to converge.

As training and preparation for two-dimensional interpretation, the author did one-dimensional interpretation. The result are illustrated in Fig. 2.

2.1.3 The modelling for two-dimensional interpretation

Dey and Morrison (1976) have developed a numerical method to solve three-dimensional potential distribution. The distribution is from a point source that is located in or on the surface of a half space containing arbitrary two-dimensional conductivity distribution.

An apparent resistivity curve is calculated by dividing the earth into certain two dimensional blocks, through an arbitrary cross section with an infinit extent along the strike. The potential equation is written in three dimen-

sions X, Y, and Z, but the Y variable is Fourier transformed to simplify all calculations. This creates a varible k_y. If a constant is put for k_y, a two-dimensional equation is formed which can be solved numerically to get transformed potential. This is done for a few values of k_y, so the k is called a filter. The transformed potentials are then inversely Fourier transformed to get the real potential values. Then they can be integrated to calculate the apparent resistivity for certain domains.

The two-dimensional interpretation of Schlumberger soundings is named DIM2. The rectangular grid consists of some nodes, for example, there are 113 nodes in the X direction and 16 in the Z direction. At the center of the soundings the grids are denser and equally spaced. As the distance increases from the center the spacing of the grids increase. The situation of the vertical resolution of the nodes distribution is similar. Near the surface it is fine and become coarse further to the infinite depth. The unit lengths can be chosen by the user.

As an exercise the author did two-dimensional interpretation for line 3 of the Krafla-Hvitholar area. The result is shown on Fig 3. In the beginning the depth and the resistivity of every layer of each block is chosen by refering to the one-dimensional interpretation result and in the model soundings the center is in the middle of the grids. The mesh for every sounding were chosen such that the symbol of distance of left side is negative and right one is positive. In the exercise the unit length is 50 m. Consideration of the areal situation and adjusted resistivity and depth of each layer and boundary to fit both the distorted and the other parts of the soundings. Repeating this procedure to change the parameters of each block and calculations were done using DIM2, until a resonable fit was found.

From Fig. 3 and Fig. 4 we can see that around the sounding KR-106, there may be a vertical zone of low resistivity. It is inferred that there is a faultzone by drilling.

2.2 Head-on profiling

2.2.1 Principle of head-on profiling

The head-on profiling arrangement is shown on Fig. 5. Like Schlumberger soundings, A and B are current electrodes and M and N are potential electrodes. In addition, the third current electrode C is put at "infinity". The distance from O to electrode C has to be more than four times of AO (AO = BO = AB/2). The array AMNB is moved gradualy along the profile to get the apparent resistivity of the measuring points. The apparent resistivity is plotted as a function of the location of the arrangement O.

In Iceland ρ_{AC}, ρ_{BC} and ρ_{AB} are measured and $\rho_{AC} - \rho_{AB}$, $\rho_{BC} - \rho_{AB}$ and ρ_{AB} are plotted.

Theoretical model for a profile crossing a conductive dike is illustrated on Fig. 7a. The electric current always tends to flow in a conductive medium. So when the array is approaching the dike from the left, the values of ρ_{AC} are increasing ($\rho_{AC} - \rho_{AB}$ are positive). When the electrode A is on the left hand side of the dike and MN on the right hand side, the current density j beneath MN will be reduced. According to the following equation: $\rho_a = (j/j_o)\rho$ the ρ_{AC} will decreace.After O crosses the dike the value of ρ_{AC} is lower and $\rho_{AC} - \rho_{AB}$ is negative. When both A and MN lie to the right hand side of the dike ρ_{AC} will increase ($\rho_{AC} - \rho_{AB}$ is still negative). The situation of ρ_{BC} is reversed and $\rho_{BC} - \rho_{AB}$ is also reversed. Just above the dike ρ_{AC} and ρ_{BC} will be equal. So we get a cross of $\rho_{AC} - \rho_{AB}$ and $\rho_{BC} - \rho_{AB}$.

2.2.2 Field procedures

The instruments and equipment used for head-on profiling are same as that the author described in CHAPTER 2.1.1.

In the field ρAB, ρAC and ρBC are measured and $\rho AC - \rho AB$ and $\rho BC - \rho AB$ are calculated by microprocessor. Usually AB/2 is between 100-750 m long and MN/2 is 25 m long. A head-on profile must be near perpendicular to the major tectonic zones of interest.

2.2.3 Interpretation of head-on profiling

In Iceland head-on profiling modelling can be done by a finite difference program, based on Dey (1976).

A) Vertical contact: The vertical contact modelling are illustrated on Fig. 6. Left hand side of these models are low resistivity and the right hand side are high resistivity. Positive maximum anomalies of $\rho BC - \rho AB$ of these curves are got on the right of the vertical contact and negative minimum anomalies are got on the same side also. Then the anomalies decrease. So we see that there are no cross overs of $\rho AC - \rho AB$ and $\rho BC - \rho AB$.

B) Buried conductive dikes: Some low resistive buried dikes are shown on Fig. 7. The depth of buried dike on the a of Fig. 7 is 50 m and it is 75 m on the b of Fig. 7. Above these dikes a cross over of the head-on profil is got. The depth of the buried dike is 100 m on the c of Fig. 7 and it is 150 m on the d of Fig. 7. Above these buried dikes we get cross overs of $\rho AC - \rho AB$ and $\rho BC - \rho AB$ but maximum anomalies of Schlumberger arrangement are got at the same position. So sometimes Schlumberger arrengement can easily be misinterprated. If the depth of the buried dikes increase the resolution reduce. It is shown on Fig. 7.

C) Complicated case: Like for two-dimensional interpretation of Schlumberger soundings method complicated modelling can be made. The model response is calculated by the program DIM2K. It is then visually compared to the original data. The modelling is then adjust until a satisfactory fit is obtained. But in some cases the result of the modelling is not an unique solution.

The modelling of head-on profiling of Urridavatn is shown on Fig. 8.

The wires are lightweight ones. They are made of copper and have a good insulation of plastic. The diameter of wire is about 0.9 mm and the resistance is about 20 ohm/km.

All of the equipment is put in a van. So it is convenient to move this equipment from one measuring point to another.

B) The Schlumberger configuration: The Schlumberger array is illustrated on Fig. 1. In this configration the four electrodes are positioned symmetrically along a straight line, the current electrodes on the outside and the potential electrodes on the inside. In order to change the depth range of the measurements the current electrodes are displaced outword while the potential electrodes, in general, are left at the same position.

However, when the ratio of the distance between the current electrodes to that between the potential electrodes becomes too large, the potential electrodes must also be displaced outward, otherwise the potential diffrence becomes too small to be measured with sufficient accuracy. At the beginning of a sounding the ratio of the potential electrode spacing to the current electrode spacing may be taken as 1/5. Outward displacement of the potential electrodes is usually necessary when the above ratio has decreased to 1/20-1/30. When the potential electrodes are displaced outward it is necessary to carry out measurements at a few values of the potential electrode spacing, combined with the same value at the current spacing.

C) The rule of measuring net: The distance from one line to the next line and from point to point must be reasonable. The distance is related to the object of prospect. If the geothermal reservoir is large and deep the distance between each line of measurements should be large but in the case of a small one the distance should be shorter. So the scale of the measuring net depends on the object of prospect.

The direction of the measuring line must be near perpendicular to the major tectonic trend and the possible direction of the stream of geothermal water (or to the major trend of fissures, fractures and dikes).

3 APPLICATION OF SCHLUMBERGER SOUNDINGS AND HEAD-ON PROFLING IN GEOTHERMAL AREAS OF ICELAND

3.1 The Urridavatn geothermal field

3.1.1 Geology of the geothermal field

The thermal activity is all confined to the bottom of the lake. The only surface manifestations are gas bubbles and holes in the winter ice. The landscape near the lake is characterized by low hills elongated in N-S direction. In the "grabens" between the hills, bogs or lakes occur. Faults with less movement than 5-10 m are hardly seen. Geological map is shown on Fig. 9.

The strike at lake Urridavatn is about 6° to SSW. The dikes and the faults trend generally NNE-SSW, formed mainly by the fissure swarm of a extinct central volcano lying 30 km to the south. The dip of the dikes is about 6° to the east measured from the vertical. The lava can be divided into four groups:

Unit A: Microporphyritic and aphyric tholiitic basalt; Unit B: Tholeiitic basalt; Unit C: Porphyritic basalt; Unit D: Aphyric tholeiitic basalt (from Einarsson et al. 1983).

In this area there are many dikes. Most of them trend "N 10-20 E", but NW-SE direction is also common.

3.1.2 Geophysical survey

The aim of the head-on profiling and magnetic methods were to find out what controls the upwelling of the thermal water. In this chapter the author focuses on the describtion of the head-on profiling. Head-on profiling was carried out in June and September 1982. The measuring net of the head-on profiling is shown on Fig. 10. The main direction of measuring lines is perpendicular to the major tectonic direction. Part of the measuring lines was on the lake. So the field work used was adapted for working on the surface of the water. A rope held the porous pots and the

current electrodes and they were pulled for changing stations. Buoys were used to keep the electrodes and the porous pots floating.

At lake Urridavatn, like many other areas in Iceland, it is thought that the geothermal water is associated with low resistivity which is often connected to dikes, faults or fissures. The result of resistivity profiling method is illustrated on Fig. 10.

A low resistivity area (<100 ohmm) occur at the bottom of the lake. A straight low resistivity wall passes though the area. The position of the low resistivity wall transformed in the area where the holes in the winter ice occur. Around the lake the resistivity is high. There are many high resistivity walls in this area. It is thought that high resistivity walls are caused by impermeable dikes or faults.

3.1.3 Conclusions

A) The resistivity of the country rock, impermeable dikes and faults around the lake are high, so it is thought that the low resistivity wall is caused by a fracture. The fracture controls the geothemal water upflow.

B) The low resistivity wall is located slightly to the east of the area where the holes in the winter ice form (see Fig. 11). So it is thought that the fracture is dipped to the east.

C) Because there is a big difference in resistivity of the area, using head-on profiling to find fractures is extremly successful.

3.2 The Glerardalur area

3.2.1 Geology of the study area

Most of the region is covered by thick gravel and morain from the last ice age, so the exposures are poor. Good exposures are only found down in the gully itself. A geological map of Sulumyrar and neighbhood is illustrated on Fig. 12.

The sequence is divided up into five units: A) The lowest are tholeiitic lavas with the average thickness of 10 m; B) A 60 m thick pile of porphyritic lavas; C) 7-8 tholeiitic lavas (total thickness are 70-80 m); D) Two olivine basalts; E) Most of them are tholeiitic but porphyritic lavas in between.

The strike of the lavas is N 45°E and dip around 6° to SE.

There are many faults with the direction 0°N - 10°E. About 4 faults can be found on the average per km. Most dikes have a strike 15°NE but a few strike have 45°N to 70°E (Flovenz et al. 1984).

3.2.2 DC-resistivity survey

Schlumberger soundings have been done in this area. The Schlumberger method describes the situation of this area. If we want a detailed resolution, we must use head-on profiling.

Fig. 13 shows the result of the Schlumberger soundings in the gully of Gleradalur done in 1981. It shows apparent resistivity at 400 m depth below sea level. A low resistivity anomaly, from 50-70 ohmm, appears in this area. That might show the highest temperature and water content position.

The interpretation from the measurements is illustrated on Fig. 14. The high resistivities seem to correlate to inpermeable dikes and faults. The low resistivity anomalies might represent dikes faults and fissures with some permeability.

3.2.3 Conclusions

A) Using Schlumberger soundings help to indicated higher temperature and permeable area; B) The strike of fractures with low resistivity is almost north-south with easterly trend over the Gleradalur region; C) There are low resistivity between high resistivity, so the systems are not connected; D) It is confirmed that Schlumberger soundings is powerful tool in the geothermal exploration.

4 THE POSSILE APPLICATION OF SCHLUMBERGER SOUNDINGS AND HEAD-ON PROFILING IN WANG-LAN-ZHUANG GEOTHERMAL FIELD, TIANJIN, CHINA

4.1 Geology of the area

A) Locality: Tianjin municipality is the third largest city of China. It is located in the eastern part of China near by the Bo-Hai gulf. The distance from Beijing to Tianjin is 137 km. Wang-Lan-Zhuang geothermal field is in the south urban and south-west suburb (Fig. 15).

B) Regional geological structure: The Tianjing area is the northern part of the Cang-Xian horst which is within the subsidence zones of the Hu-Bei plain. It belongs to the Neocathaysian strutural system. The south-east side is Huang-Hua and the north-west side is Ji-Zhong grabens.

In this area two directions of structures cross each other. So horsts, grabens and parallel fractures are formed in this area (Fig. 16).

C) Structural features of Wang-Lan-Zhuang geothermal field: The Wang-Lan-Zhuang geothermal area belongs to the Shuang-Yao horst. The boundaries are formed by the West-Of-Bai-Tang-Kou fault to the east, the Zen-Fu-Tai fault to the south, the North-Of-Tianjin fault to the west and the Chen-Lin-Zhuang fault to the north. The depth of the block is about 1000-2000 m.

The West of Bai-Tang-Kou fault have been activated resently with the rate that the upper wall rises more than 10 mm relative to the lower one.

D) The strata of the Wang-lan-Zhuang geothermal area. The sequence from the overburden to the bedrock are with 550 m thickness uconsolidated sediments of Quaternary age, about 800m of fine grained sediments of Tertiary age and limestone formations of Ordovician, Cambrian and Sinian (pre-Cambrian) age.

The strata of Wang-Lan-Zhuang geothermal is illustrated on Fig. 17.

4.2 The possible future application of Schlumberger soundings and head-on profiling in the area

Some seismic methods and gravity method have been done in this area. Some result have been got by using these methods. It is thought that using Schlumberger soundings one can describe the regional case and using head-on profiling indicate the detailed situation. Most of the bedrock in this area are limestones, which usually have high resistivity. So the resistivity values of the regional background are high. Becase some of the active fauts, for example West of Bai-tang-kou fault, act as a path for the geothermal water, so it is thought that the resistivity of the permeable faults is low. Under these conditions it is thought that some resistivity methods can be useful.

In the suburbs of Tianjin there are many rivers, irrigation canals and roads, so in this area it is difficult to perform Schlumberger soundings or head-on profiling. Originally some AC-resistivity methods (artificial source), MT and AMT methods were considered. Comparing DC-resistivity methods to the above methods it is thought that the depth of investigation of some AC-resistivity methods (artificial source) is too shallow, and MT and AMT methods are too expensive and complex to interpret. In some cases very good result can be got by using some DC-resistivity methods.

It is thought that the aim of Schlumberger soundings and head-on profiling is to find the faults.

Because the bedrock lies deep the distance from one line to the next line and from point to point can be great in the Schlumberger soundings. It is thought the distance from line to line can be 4000 m and the distance from point to point can be 1000 m. The direction of measuring line should be near perpendicular to the west of Bai-tang-Kou fault. Because there are saline sediments in the upper layers the penetration of Schlumberger soundings is relative little in this area. It is recommended that the largest AB/2 should be more than 5000 m and largest MN/2 should be about 250 m and 500 m or more.

Head-on profiling can describe the detailed situation of the area, i.e. can indicate the faults location. Because the West of Bai-tang-kou fault is active, so the fault might be formed in Tertiary and even Quaternary. It is thought that the AO (AO = BO) of the head-on profiling should be 750 m, 1500 m, and 2500 m the MN should be 100 m. The larger AO can be used to indicated the fault in the deep layer and the smaller ones can be used to indicate the fault in the upper layers. Hence the dip of the fault can be indicated by head-on profiling.

One-dimensional and two-dimensional interpretation can be used to interpret the data of Schlumberger soundings and profiling.

5 CONCLUSIONS AND RECOMMENDATIONS

A) Geothermal anomaly, dikes, fractures and faults of geothermal fields can be found by Schlumberger soundings and head-on profiling. It is confirmed that Schlumberger soundings and head-on profiling are effective methods in geothermal fields in Iceland.

B) There is no doubt that numerical interpretation methods are much better than old interpretation methods of using master curves.

C) Schlumberger soundings and head-on profiling can be used in Wang-Lan-Zhuang and the other two geothermal area (Wan-Jia-Ma-Tou and Shan-Ling-Zi), but 10 kW trasmitter is needed and rubber rafts are needed for crossing rivers and canals.

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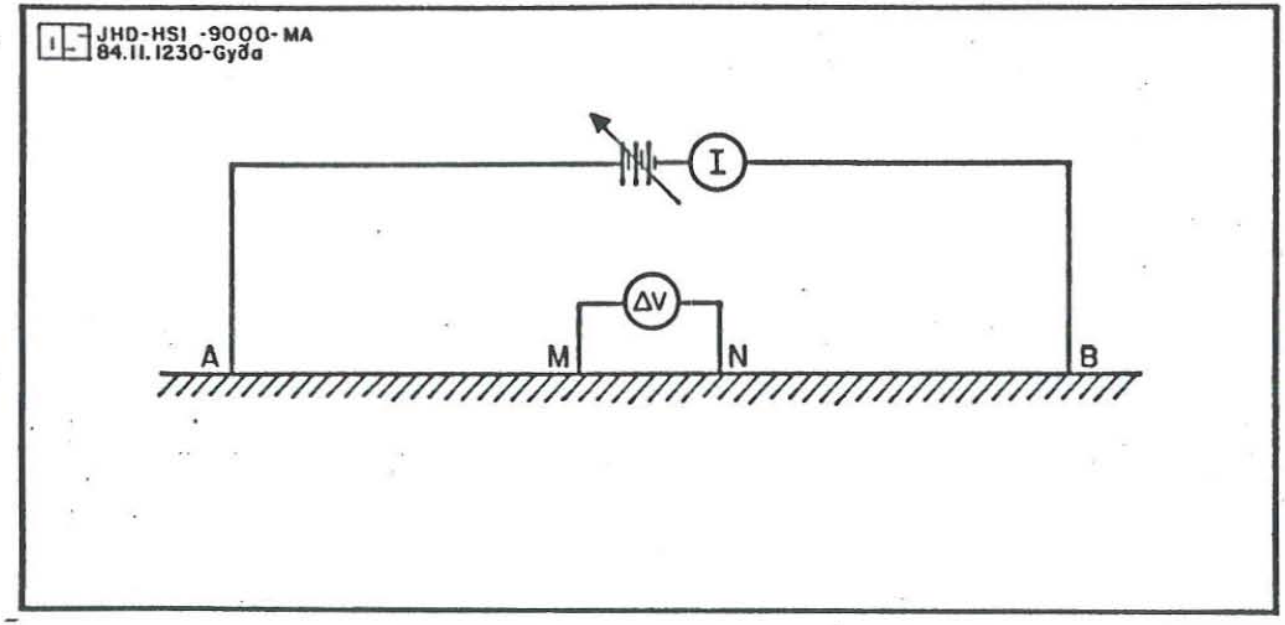


Fig. 1 The Schlumberger array.

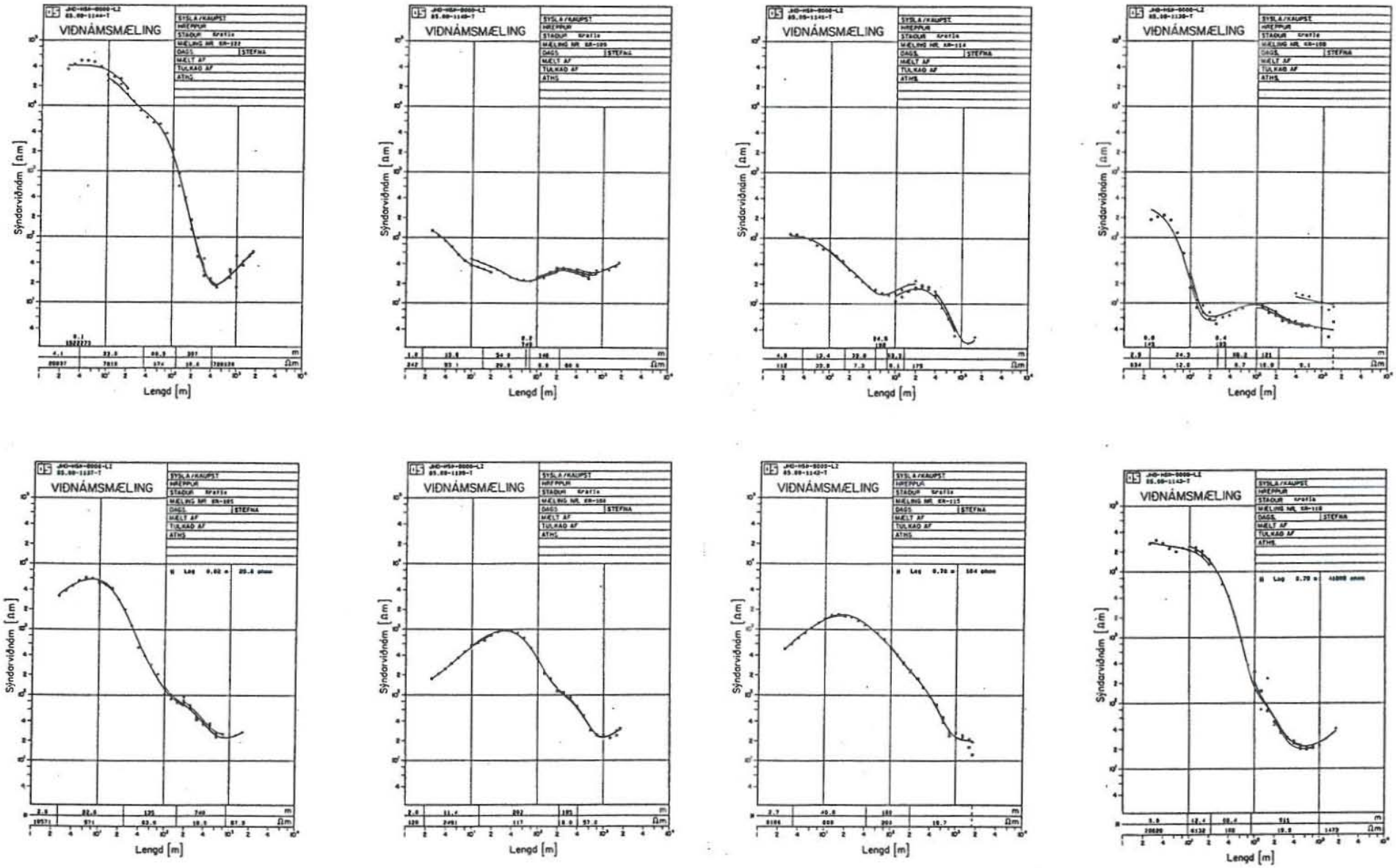
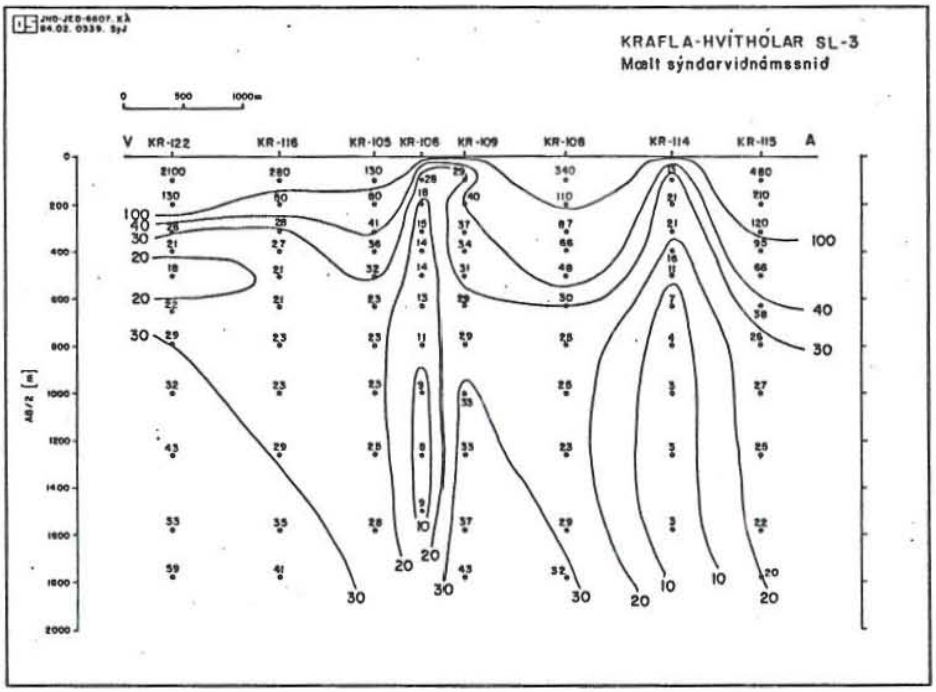


Fig. 2 One-dimensional interpretation..



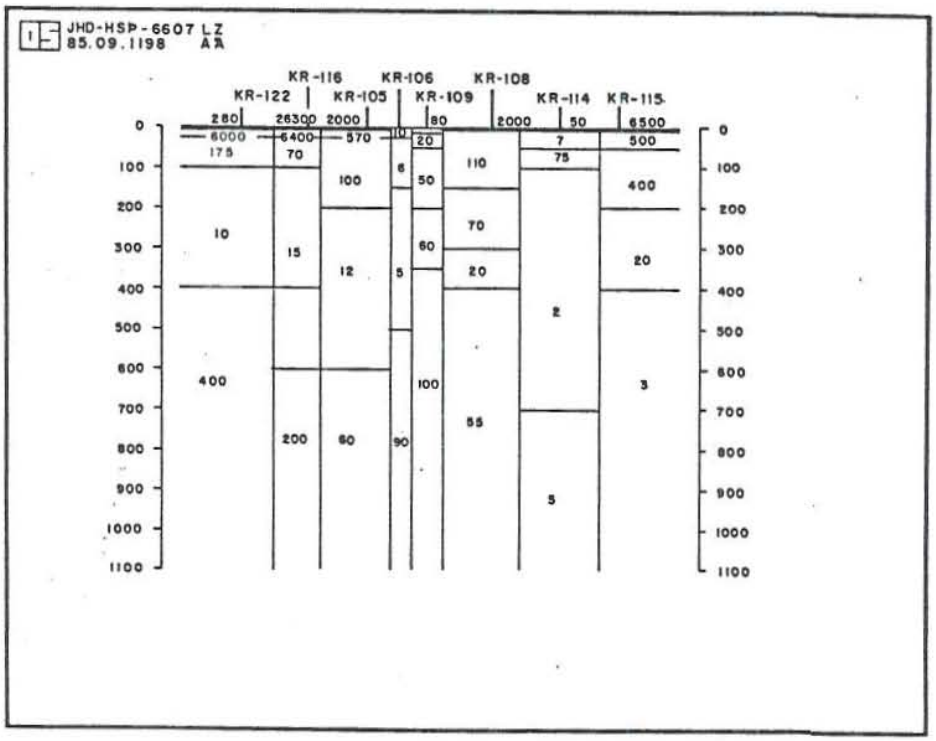
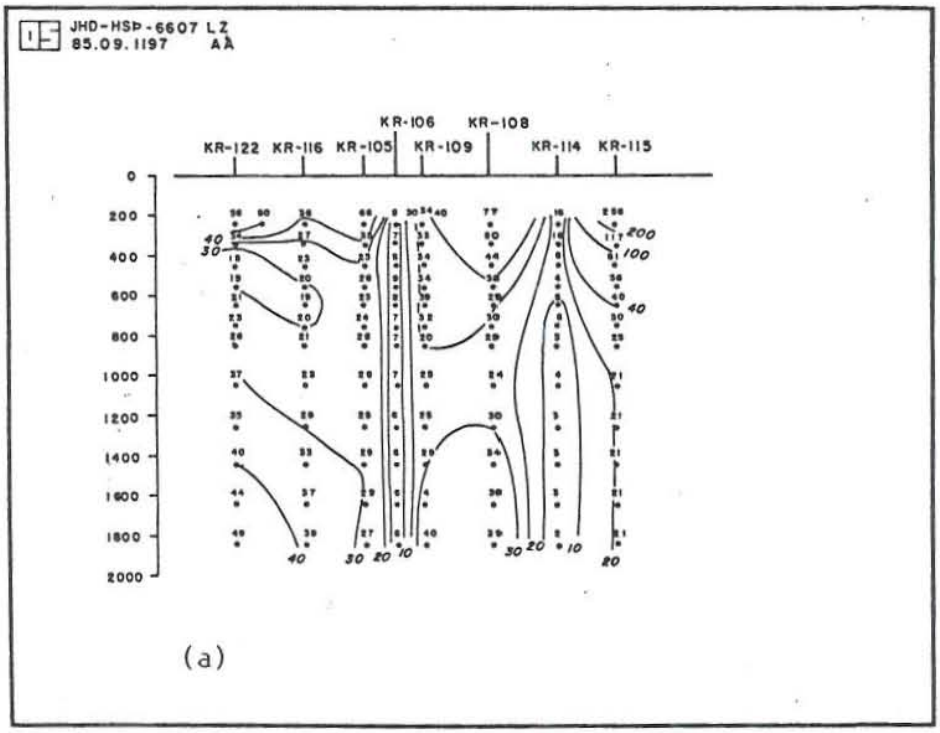


Fig. 3 Measured pseudosection and two-dimensional modelling of line 3 of Krafla.



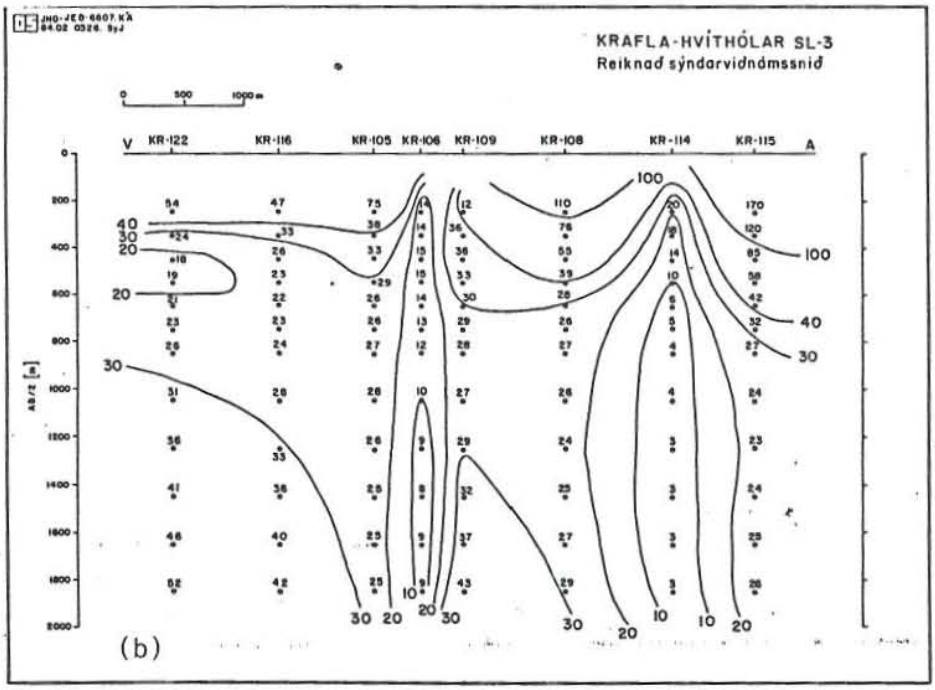


Fig. 4 Calculated pseudosections of line 3 of Krafla;

a) By the author, b) By Arnason et al .

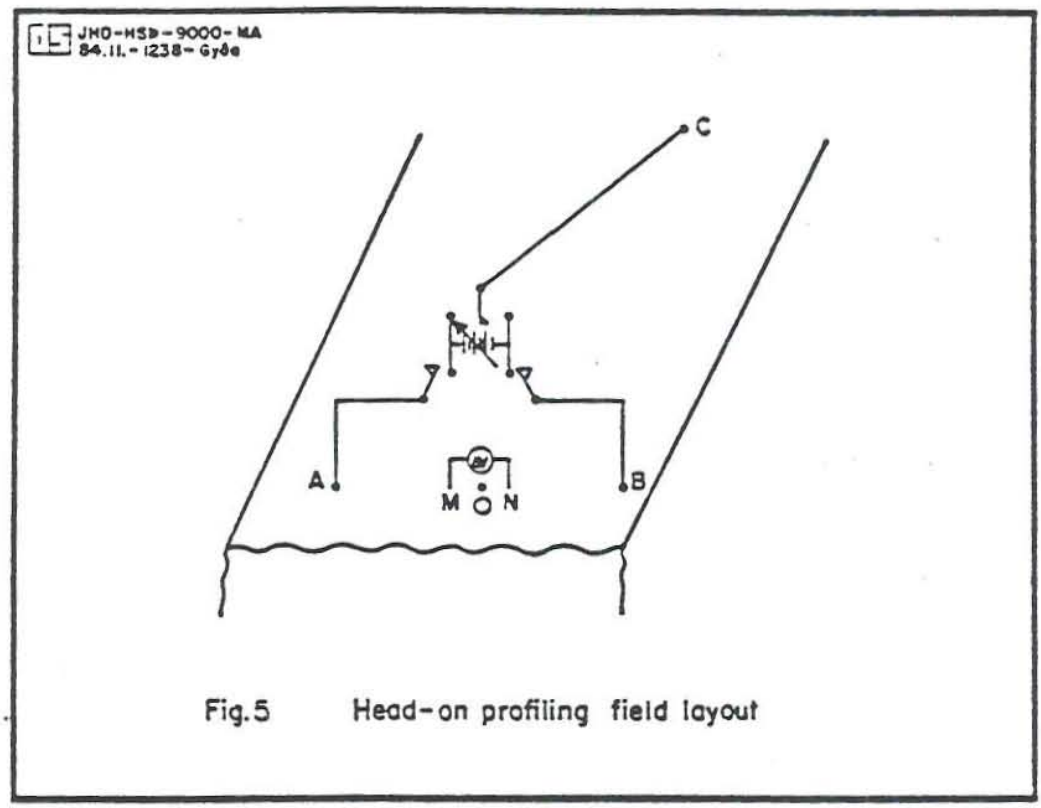


Fig.5 Head-on profiling field layout

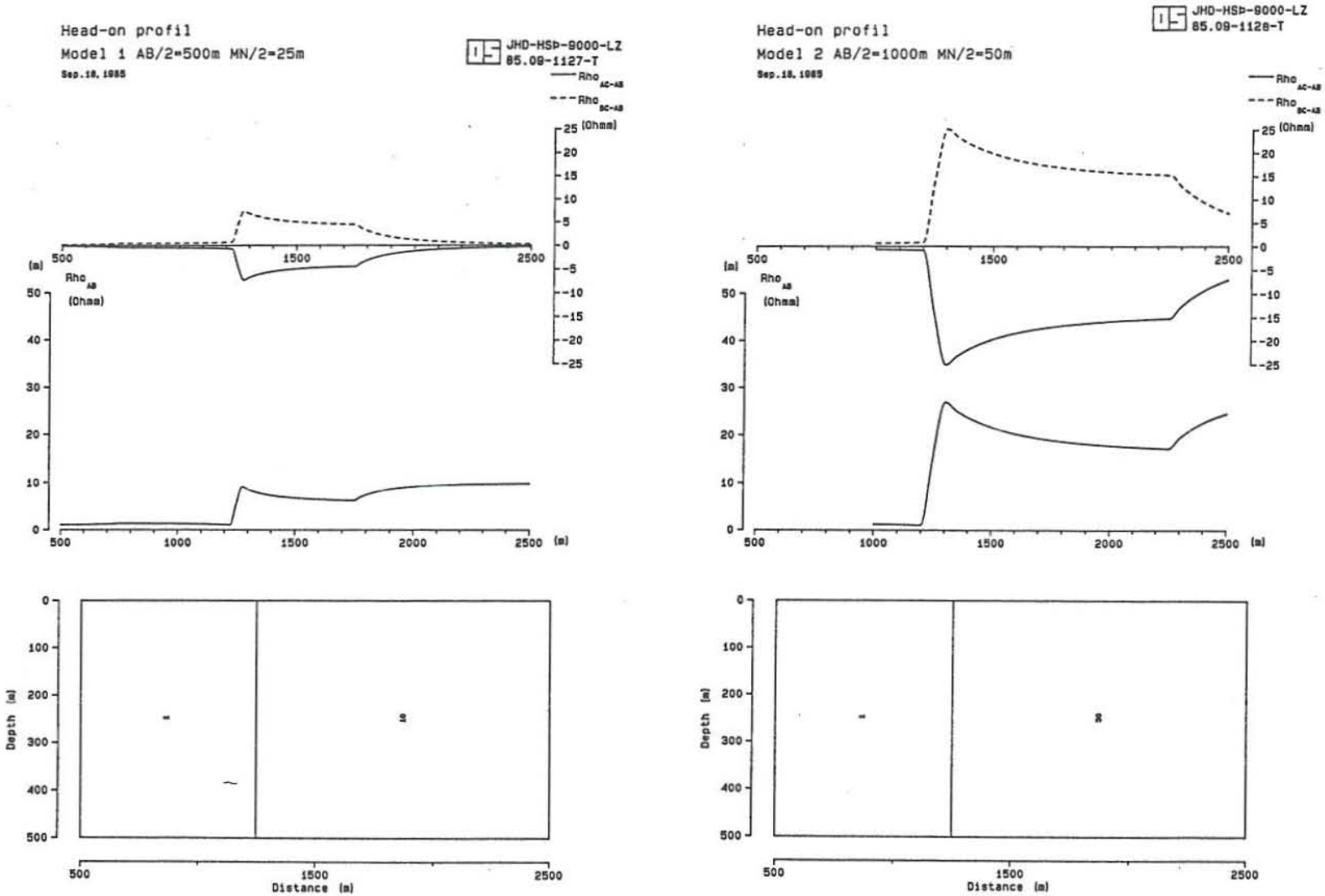
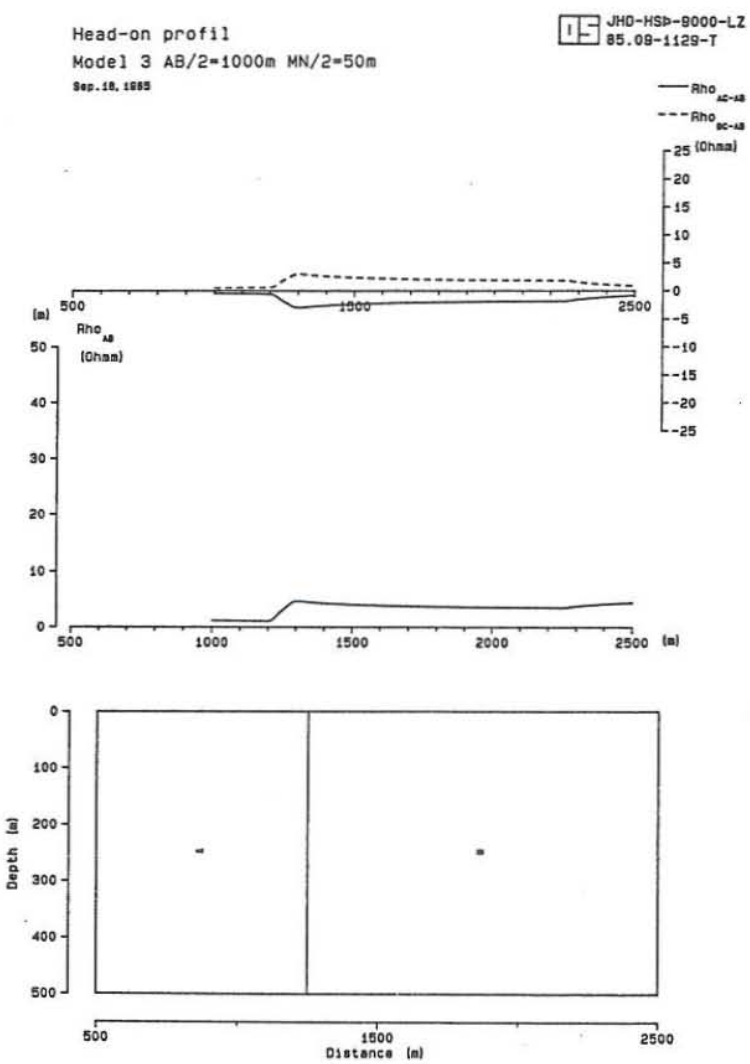


Fig. 6 Head-on profiling over a vertical contact.


Head-on profil
Model 3 AB/2=1000m MN/2=50m
Sep.18, 1985
JHD-HSÞ-9000-LZ
85.09-1129-T
Rho AC-AB
Rho BC-AB
(Ohmm)
Rho AB
(Ohmm)
(m)
Depth (m)
Distance (m)

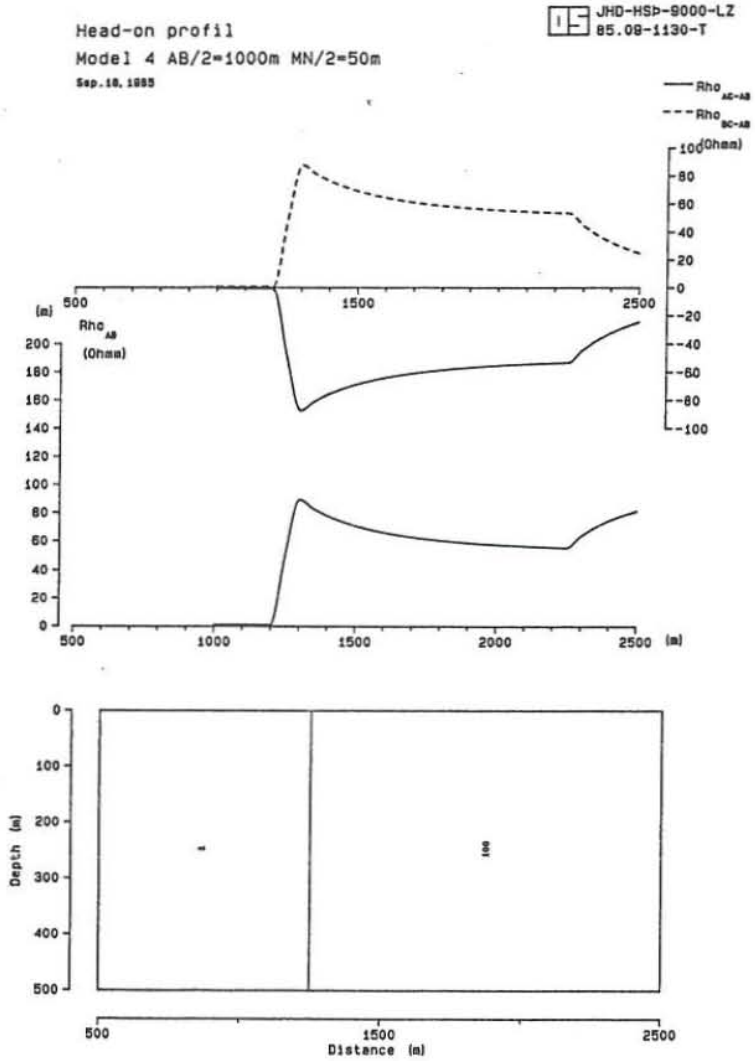

Head-on profil
Model 4 AB/2=1000m MN/2=50m
Sep.18, 1985
JHD-HSÞ-9000-LZ
85.09-1130-T
Rho AC-AB
Rho BC-AB
(Ohmm)
Rho AB
(Ohmm)
(m)
Depth (m)
Distance (m)

Fig. 6 cont.

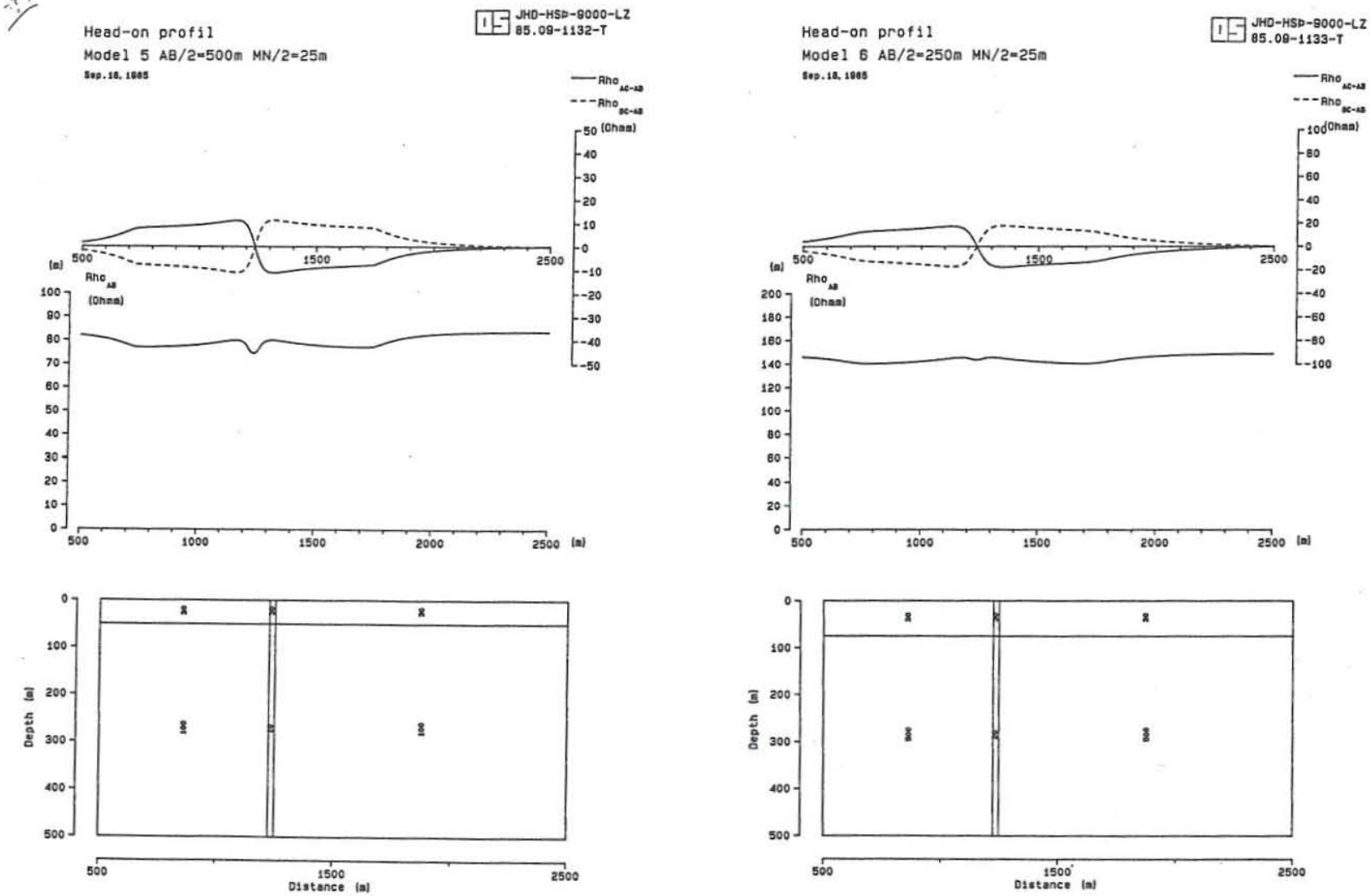
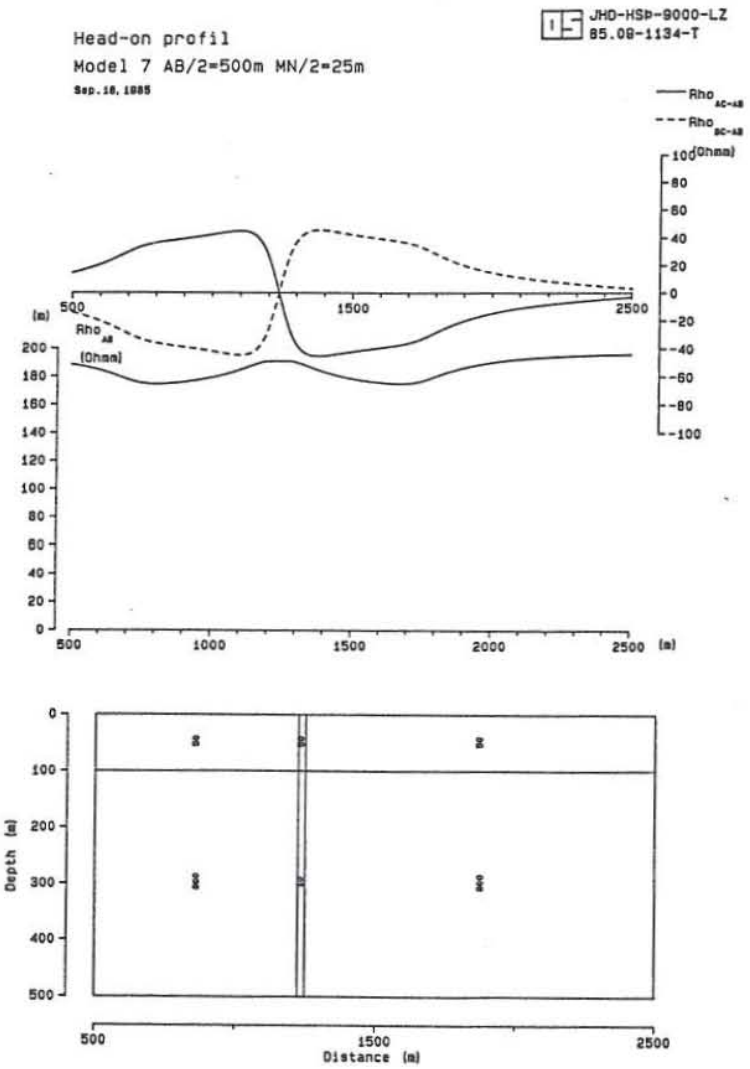


Fig. 7 Head-on profiling over a buried dike.


JHD-HSD-9000-LZ
85.09-1134-T
Head-on profil
Model 7 AB/2=500m MN/2=25m
Sep.18, 1985
Rho AC-AB
Rho BC-AB
(Ohmm)
Rho AB
(Ohmm)
(m)
Depth (m)
Distance (m)

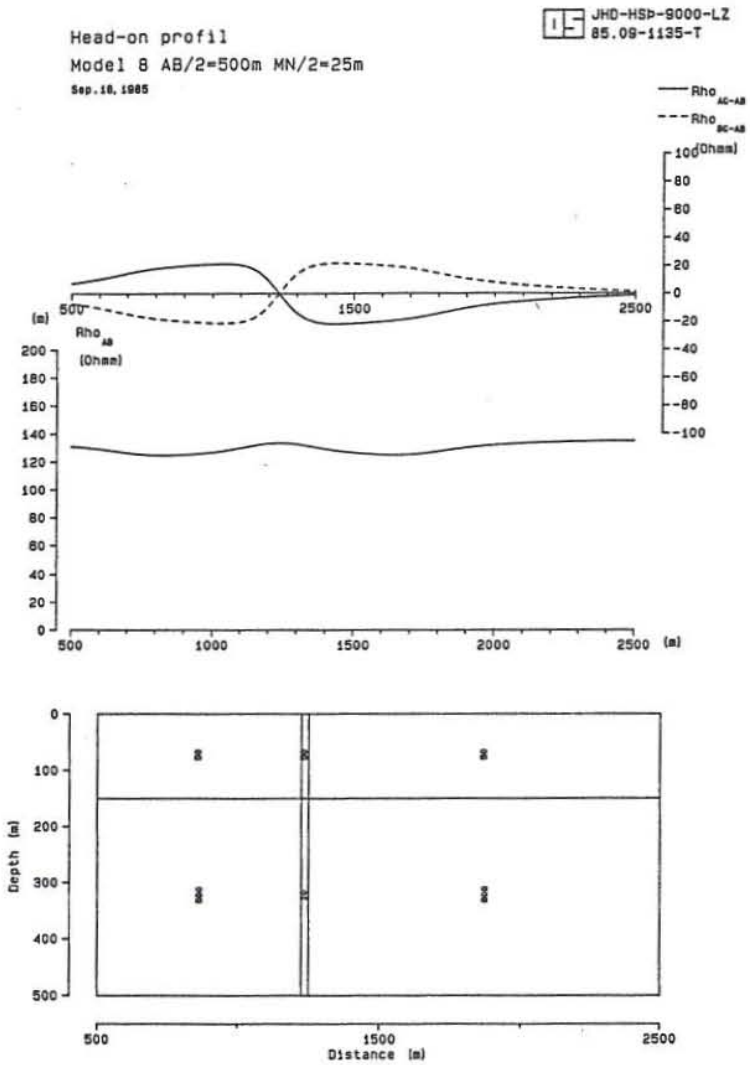
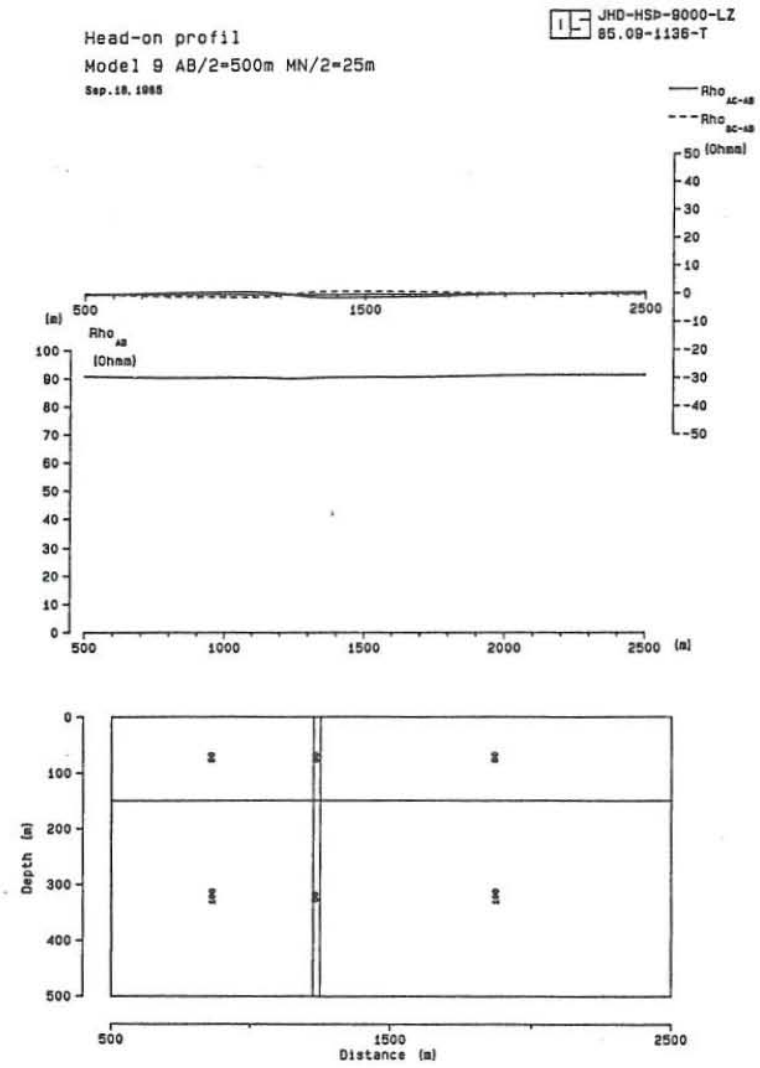

JHD-HSD-9000-LZ
85.09-1135-T
Head-on profil
Model 8 AB/2=500m MN/2=25m
Sep.18, 1985
Rho AC-AB
Rho BC-AB
(Ohmm)
Rho AB
(Ohmm)
(m)
Depth (m)
Distance (m)

Fig. 7 cont.


JHD-HSP-9000-LZ
85.09-1136-T
Head-on profil
Model 9 AB/2=500m MN/2=25m
Sep.18, 1985
Rho AC-AB
Rho BC-AB
(Ohmm)
Rho AB
(Ohmm)
(m)
Depth (m)
Distance (m)

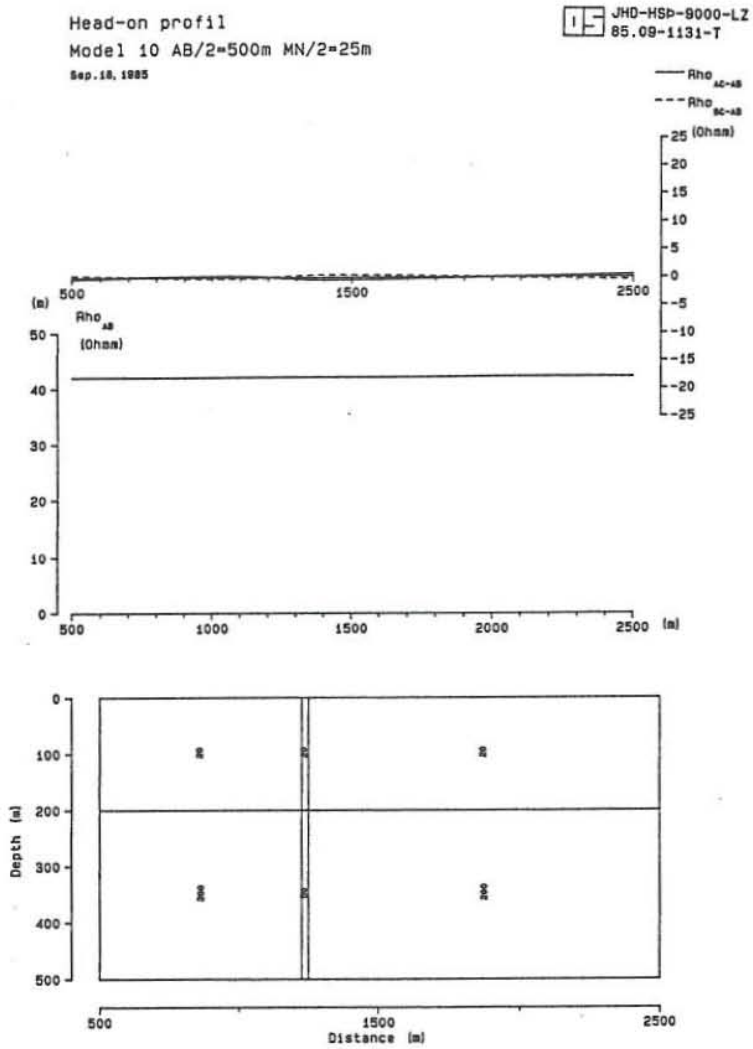

JHD-HSP-9000-LZ
85.09-1131-T
Head-on profil
Model 10 AB/2=500m MN/2=25m
Sep.18, 1985
Rho AC-AB
Rho BC-AB
(Ohmm)
Rho AB
(Ohmm)
(m)
Depth (m)
Distance (m)

Fig. 7 cont.

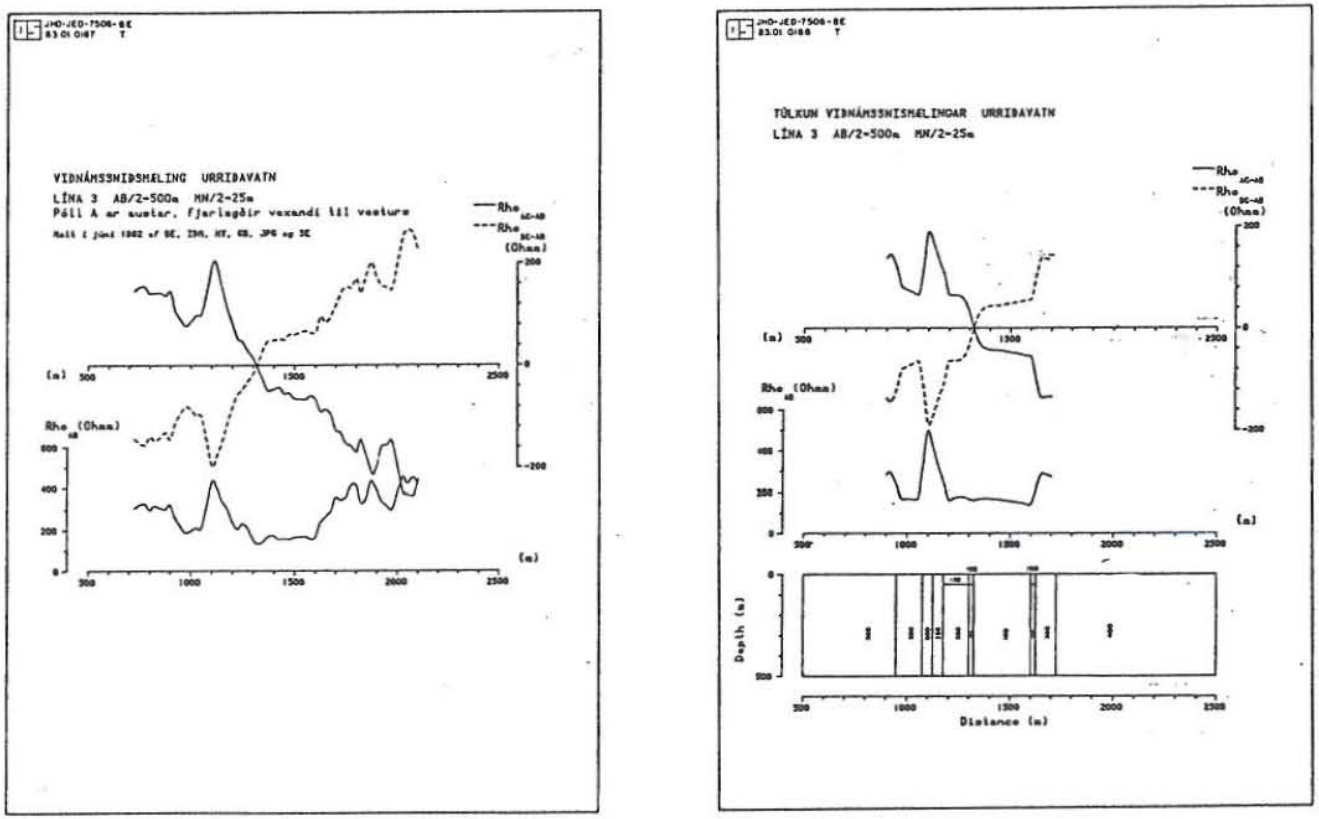


Fig. 8 Two-dimensional interpretation of head-on profiling.

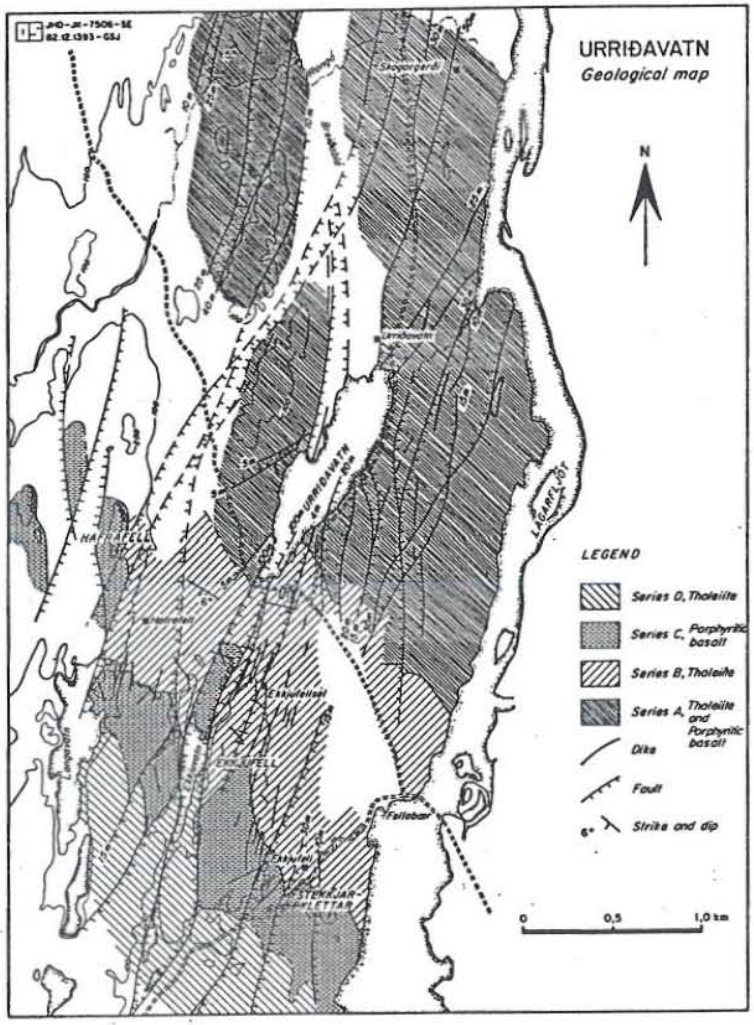


Fig. 9 Geological map of Urridavatn.

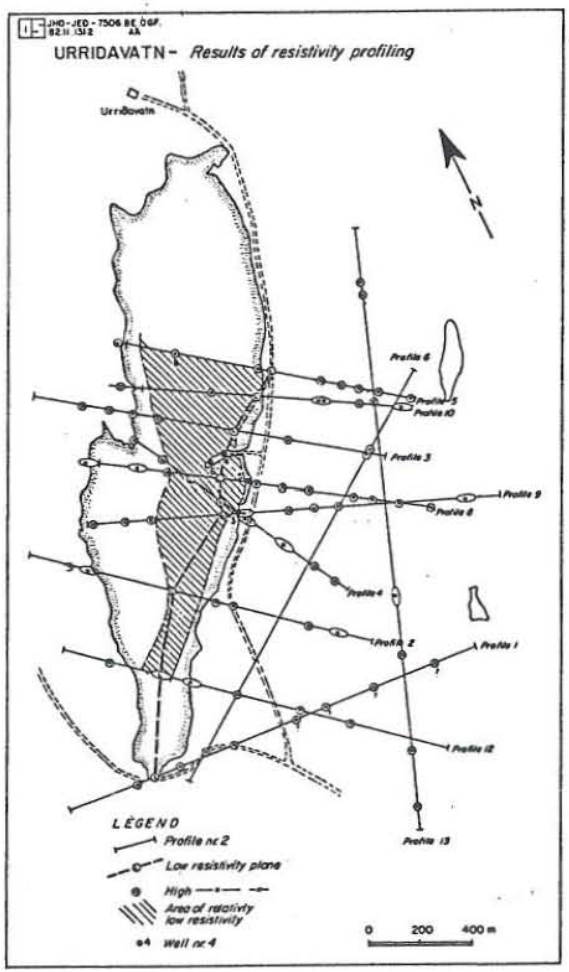


Fig. 10 Results of resistivity profiling at Urridavatn.

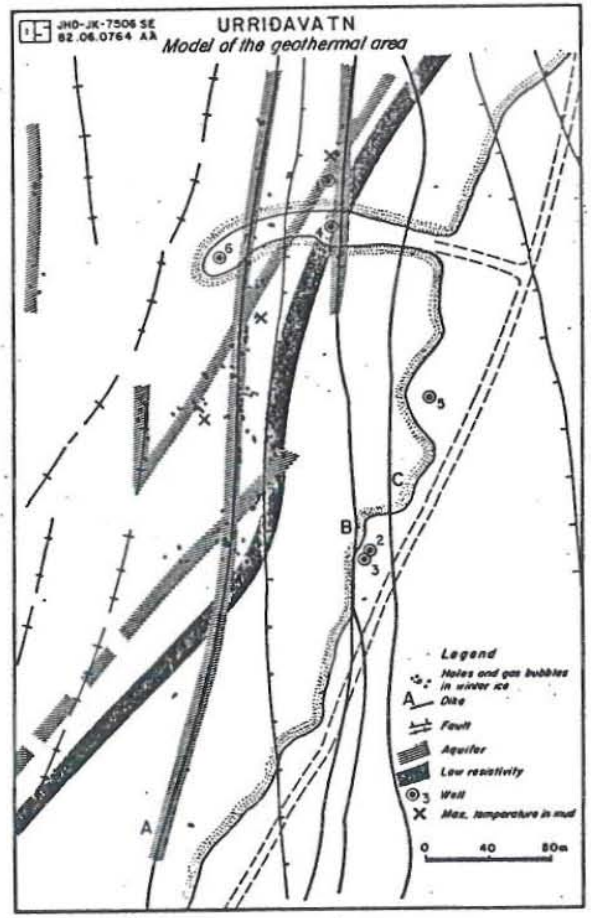


Fig. 11 Model of the Urridavatn geothermal area.

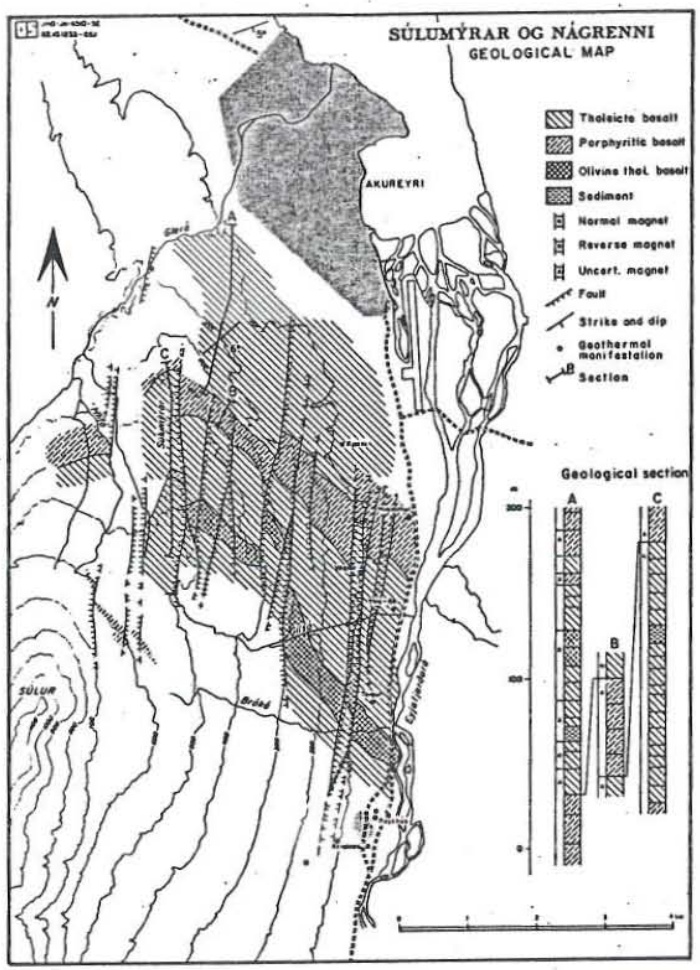


Fig. 12 A geological map of Sulumyrar and neihbourhood.

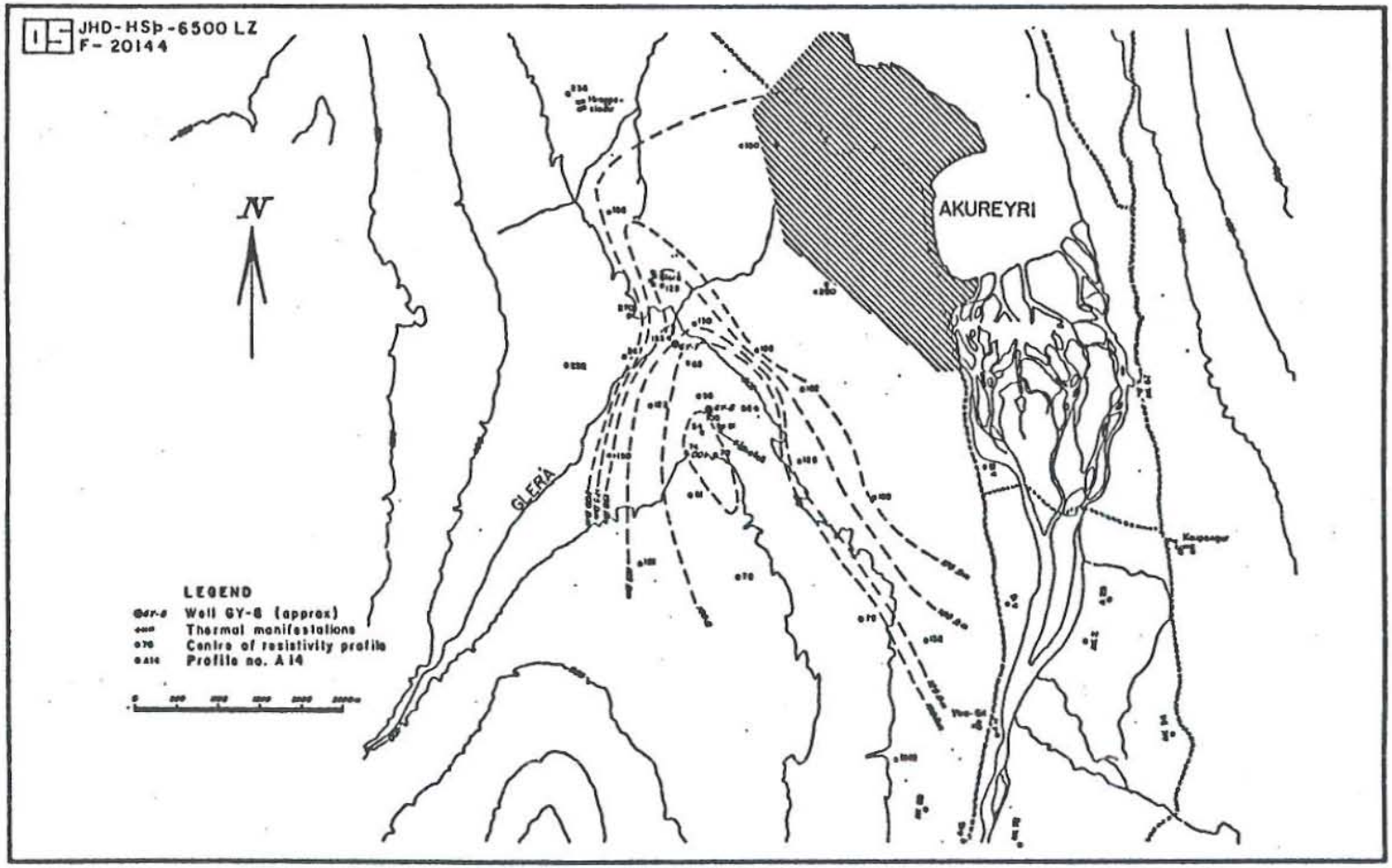


Fig. 13 Akureyri, results of resistivity measurements at - 400 m depth.

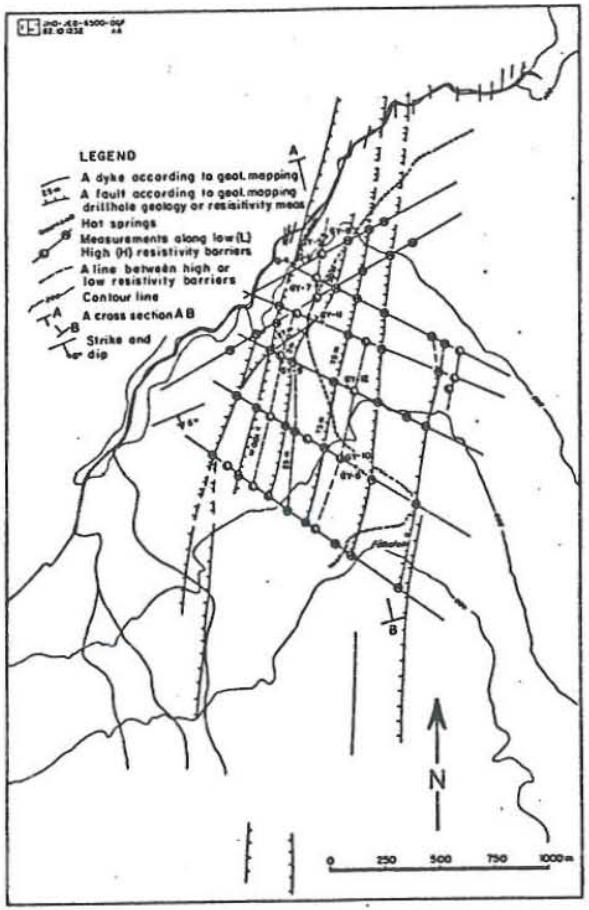


Fig. 14 Interpretation of resistivity measurements from Glerardalur.

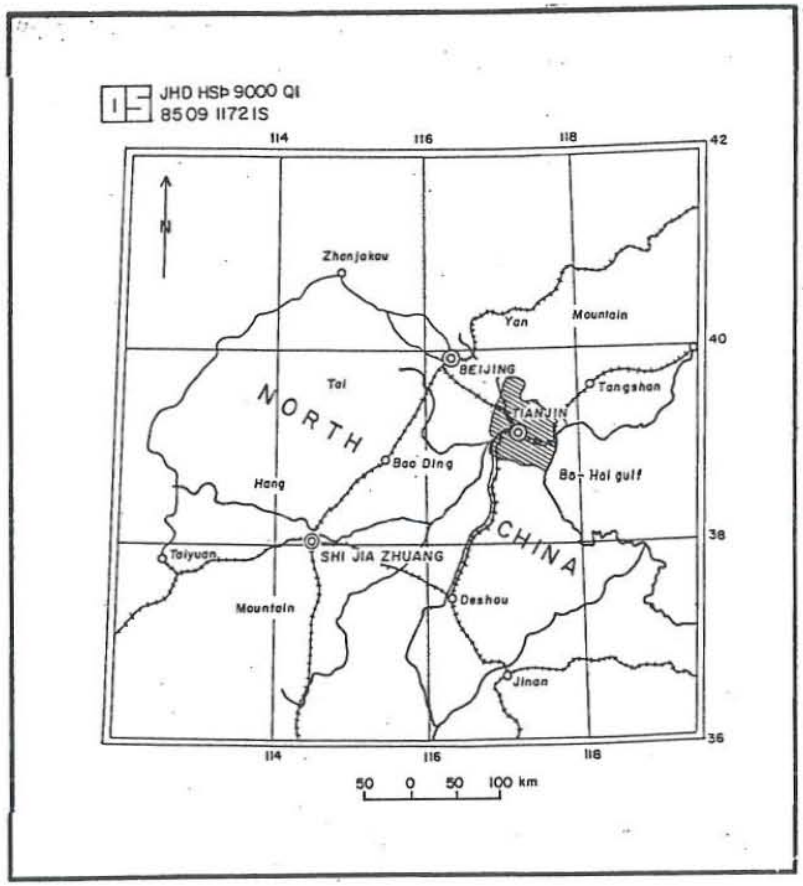


Fig. 15 Location of Tianjin.

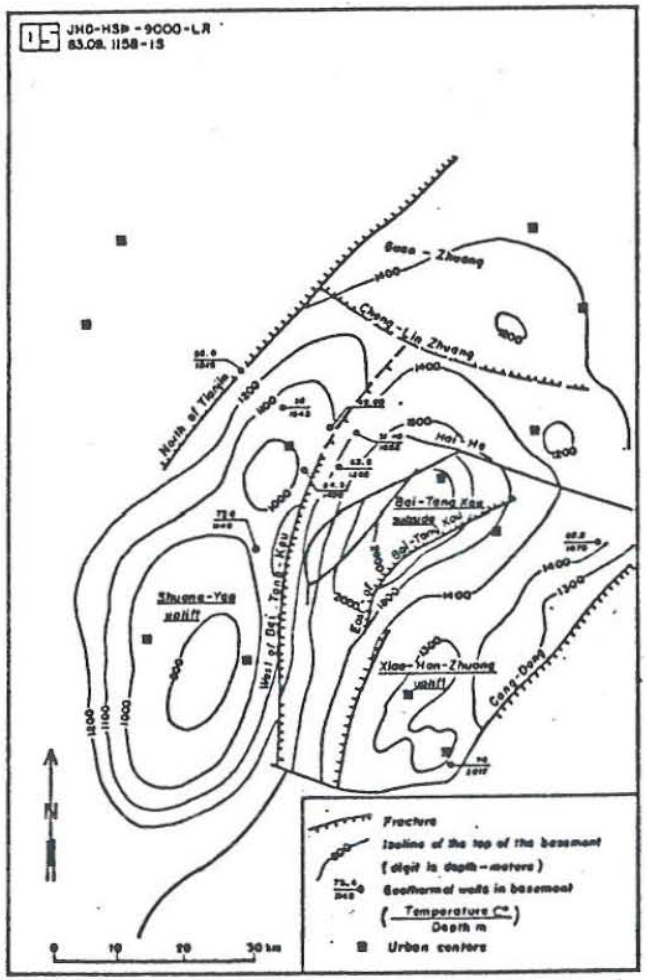


Fig. 16 Map of geological structures and top of basement in the Tianjin geothermal field.

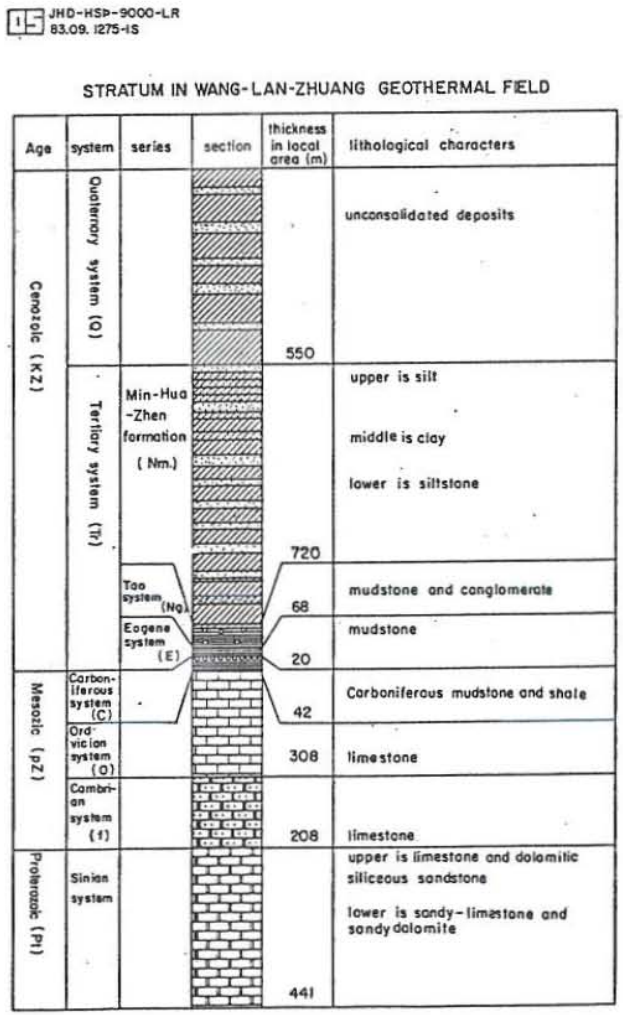


Fig. 17 Stratum in Wang-Lan-Zhuang geothermal field.