



823

YE.RA 89

---

Yemen Arab Republic / Kingdom of the Netherlands

# Rada' Integrated Rural Development Project

---

823-YERA89-7789

Yemen Arab Republic  
Ministry of Agriculture  
and Fisheries

Kingdom of the Netherlands  
Ministry of Foreign Affairs  
Development Cooperation  
(Asia) Department

RADA' INTEGRATED RURAL DEVELOPMENT PROJECT

Technical Note 33

GROUNDWATER INVESTIGATIONS  
SEVENTH PHASE

Geophysical survey in the Al Bayda Province  
January 1987 - November 1988

May 1989

code 4.08.046

LITERARY, INT	REFERENCE
COPIES AVAILABLE	BY TELETYPE
DATE	INITIALS (DAG)
POSTAL CODE 93100, 2609 AD The Hague	
Tel. (070) 814911 ext. 141/142	
ISN 7789	
823 YEAA89	

H.S. Nieuwenhuis

Ilaco  
Arnhem, The Netherlands

## CONTENTS

	Page
1 INTRODUCTION	1
2 SITE SELECTION FOR SHALLOW WELLS AND BOREHOLES	5
2.1 Abbas	7
2.2 Al 'Abil	9
2.3 'Arad (At Taffah)	11
2.4 Dar Khalaban	13
2.5 Ad Dray'a (Dhi Na'im)	15
2.6 Ghawl Bashir (Radman)	17
2.7 Hajarrah as Salal (Sha'aban)	19
2.8 Hamak	21
2.9 Al Hujlah (Dhi Na'im)	23
2.10 Jabil Ishaq (Dhamar Province)	25
2.11 Jubayr	27
2.12 Junubah	29
2.13 Khanaq	31
2.14 Al Khuf (Haikal)	33
2.15 Maswarah (Sabah)	35
2.16 Na'wah (Juban)	37
2.17 An Nazim	39
2.18 Al Qaharah (Ar Riashiyah)	41
2.19 Qa'qa	43
2.20 Qarn al 'Asad	45
2.21 Qaru'al (Ar Riashiyah)	46
2.22 Al Qum'ala (Haikal)	47
2.23 Ruba'atayn	48
2.24 Sabah (Dhi Na'im)	49
2.25 Ash Sharaf (Sabah)	50
2.26 Tayyab (Dhi Na'im)	51
References	53
Annexes	
Annex A Geo-electrical soundings	55
Annex B Geo-electrical profile Qa'qa	78
Annex C Electromagnetic profiles	79
Annex D Legend to the Maps	101

## 1 INTRODUCTION

The seventh phase of ground water investigations, concerning well sitings for boreholes and shallow wells in Al Bayda Province, was carried out at the request of the RIRDP, LCCD's and private persons. The measurements compiled in this report were carried out from January 1987 until November 1988.

The well sitings in Dar Khalaban, Hamak, Jubayr, Na'wah, An Nazim, Qa'qa, Qaru'al and Ar Rub'atayn were carried out to select sites for the water supply scheme programme of the engineering section of RIRDP. The LCCD in Dhi Na'im requested for the site selections in Ad Dray'a, Al Hujlah, Al Khuf, Al Qum'ala, Sabah and Tayab. The measurements in Maswarah, Ash Sharaf and Khanaq were performed on request of the representative for the Sabah area. Other requests through various LCCD's were honoured for Al Qaharah, Qarn al 'Asad, Hajarah as Salal, Ghawl Bashir, 'Arad. A well siting for the Dhamar Rural Health Project was carried out in Jabil Ishaq. Private site selections were carried out for farmers in Al 'Abil, Junubah, Abbas.

During this seventh phase ground water investigations private site selections were performed as less as possible, since during this period there was a lack of staff to carry out more work. From November 1988 onward the subsection geohydrology was strengthened with an associate expert geophysicist.

The geo-electrical method was used to locate aquifers and assess their thickness and depth. The half-electrode distance usually reached upto about 350 m. Further measuring is often not possible because of the topography or the limited homogeneity in horizontal extent (especially in the Tertiary volcanic areas).

Electromagnetic profiles were made to locate faults. The best results are obtained in the Precambrian basement rocks; the small fault areas are the only suitable aquifers in these regions. Electromagnetic methods are the most commonly used methods to locate faults (Geophysical prospecting, Vol. 29). Also areas of deeper weathering can be located with this method. However, the EM-34 equipment could not be used until August 1988, since it was to be sent to Canada for repair after it had broken down earlier in 1986.

From May-July 1988 the site selection equipment was in use with the Rada' Water Supply and Sanitation Project for a well siting survey for the drinking-water of Rada'.

For both methods applied it should be noted that with the ever dropping water levels in the province and the subsequently deeper drilling depths, the reliability of the results decreases. The interpretation depth of the EM-34 is only 60 m at the maximum, whereas in many areas water yielding faults are tapped at depths below 150 m. This problem is faced more and more and asks for a solution in the near future, if the project is to maintain the service that has been rendered for so long in the field of well siting.

In this report the geo-electrical soundings are indicated with VES --/-- (sequence number/year), whereas the electromagnetic profiles are named EM --/--. The measuring spots are indicated on the aerial photographs available at the RIRD, or shown on the maps presented in this report.

In cases where sites were found on faults it is important to drill exactly on the selected site. Drilling more than a few metres away may already result in a failure. In these cases the site is clearly indicated in the field with an iron bar or paint, in some cases with a heap of big stones. The sites are usually known to the representatives of the village or the owner of the land.

Table 1 indicates for each site the topographic map sheet and the soundings or profiles made during the seventh phase groundwater survey. Measurements performed in an earlier phase are mentioned in the heading of each site selection description in chapter 2. The villages are presented throughout the report in alphabetical order.

To facilitate a quick reference to the location of each village all site selections are shown on a map of Al Bayda province in Figure 1. In addition, the coordinates of the villages according to the 1:50 000 topographical map of the Yemen Arab Republic are mentioned in the heading of each site selection description. Also the topographical map number is indicated there.

The elevations indicated in the heading of each site selection description refer to the wadi bedding where the measurements were carried out. These elevations are derived from the 1:50 000 topographical maps of the Yemen Arab Republic.

The spelling of Arabic names is according to the topographical map of the Yemen Arab Republic, as far as the printed versions are available for Al Bayda Province. For other villages transcriptions according to the BGN/PCGN 1956 system are used.

Computer print-outs of the geo-electrical soundings and electro-magnetic profiles are presented in Annex A, B, and C. A legend to the maps prepared for each site selection can be found in Annex D.

All surveys have been carried out by the geohydrology subsection of the Rada' Integrated Rural Development Project, coordinated by the geohydrologist. Thanks are due to Mr. Saleh Johaysh and Mr. Jamil Raweh, both hydrogeological engineers who joined the subsection in the course of the seventh phase. They assisted in the field work. Before their assignment the fieldwork was assisted by Mr. 'Adil Oshaysh, assistant to the subsection. Mr. L.J. Dijkhuis, student from Wageningen University, carried out part of the measurements in Qa'qa and Junubah.

Figure 1 Site selections carried out in the groundwater investigations seventh phase

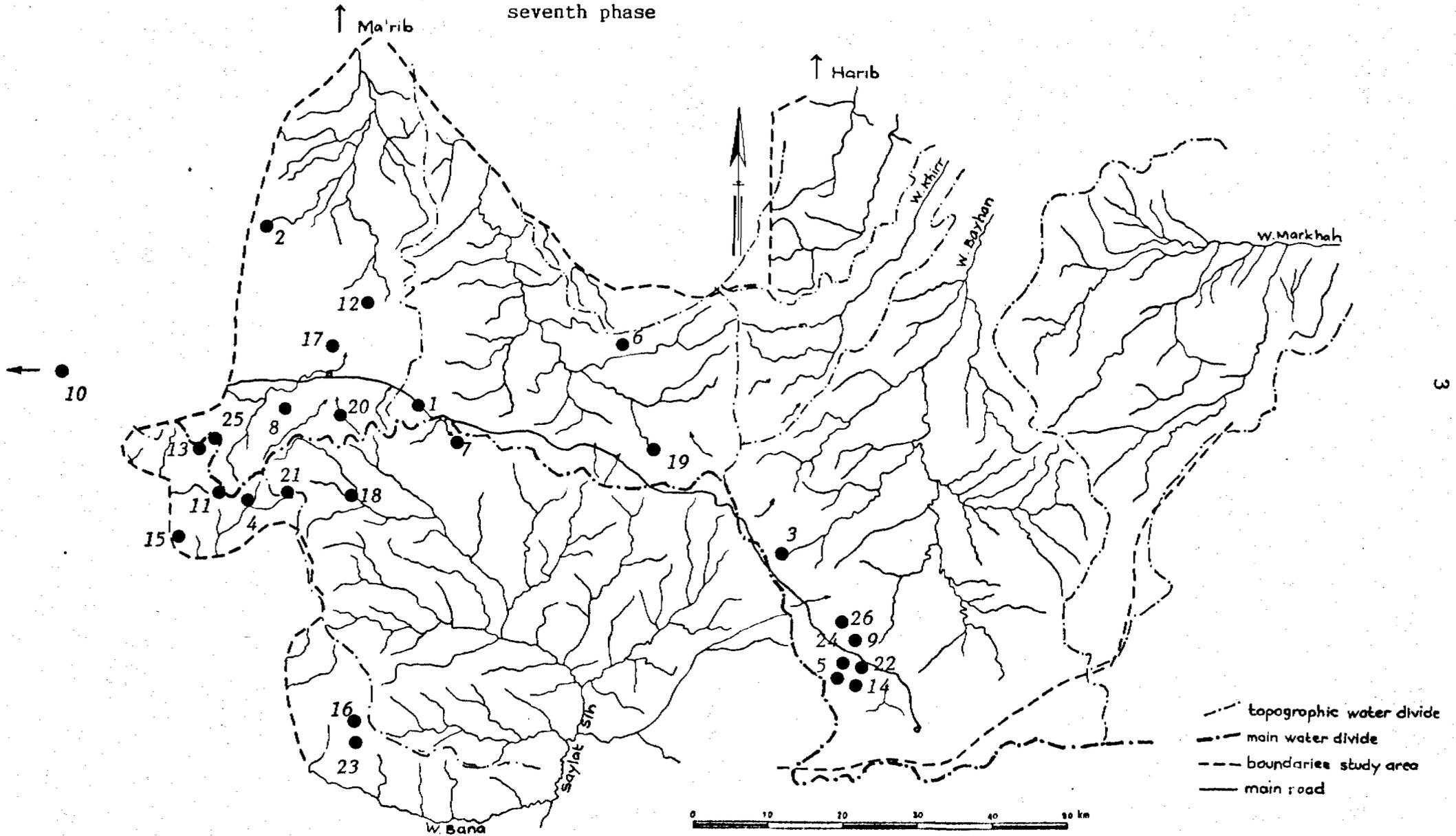


Table 1 List of maps, geo-electrical soundings and EM-profiles

Village	Map number	Sounding or profile number
1 Abbas	1	EM 21,22,23/88
2 Al 'Abil	2	VES 4/87 EM 19,20,21,22/87
3 'Arad	3	VES 6,7,8,9/87
4 Dar Khalaban	4	VES 1,2,3/87
5 Ad Dray'a	5	EM 6,7,8,9,10/87
6 Ghawl Bashir	6	EM 4,5,6,7/88
7 Hajarah as Salal	7	EM 11,12,13,14,15/87
8 Hamak	8	VES 28,29,30,31/87
9 Al Hujlah	9	EM 15,16/88
10 Jabil Ishaq	-	VES 11,12/87
11 Jubayr	10	EM 1,2,3/88
12 Junubah	11	VES 35,36,37,38,39/87
13 Khanaq	12	VES 27/87
14 Al Khuf	13	VES 40/41; EM 14/88
15 Maswarah	14	VES 17,18,19,20,21/87
16 Na'wah	15	EM 17,18,19,20/88
17 An Nazim	16	VES 5/87
18 Al Qaharah	17	VES 1/88; EM 24,25/88
19 Qa'qa	18	VES 13,14,15,16,32,33,34/88; GEP 1/87
20 Qarn al 'Asad	19	EM 1a,1b,2,3,4,5/87
21 Qaru'al	4	EM 26/88
22 Al Qum'ala	13	EM 16,17,18/87
23 Rub'atayn	15	VES 10/87
24 Sabah	5	EM 23,24,25,26/87
25 Ash Sharaf	12	VES 22,23,24,25,26/87
26 Tayyab	20	EM 8,9,10,11,12,13/88

VES = Vertical Electrical sounding (geo-electrical measurement)

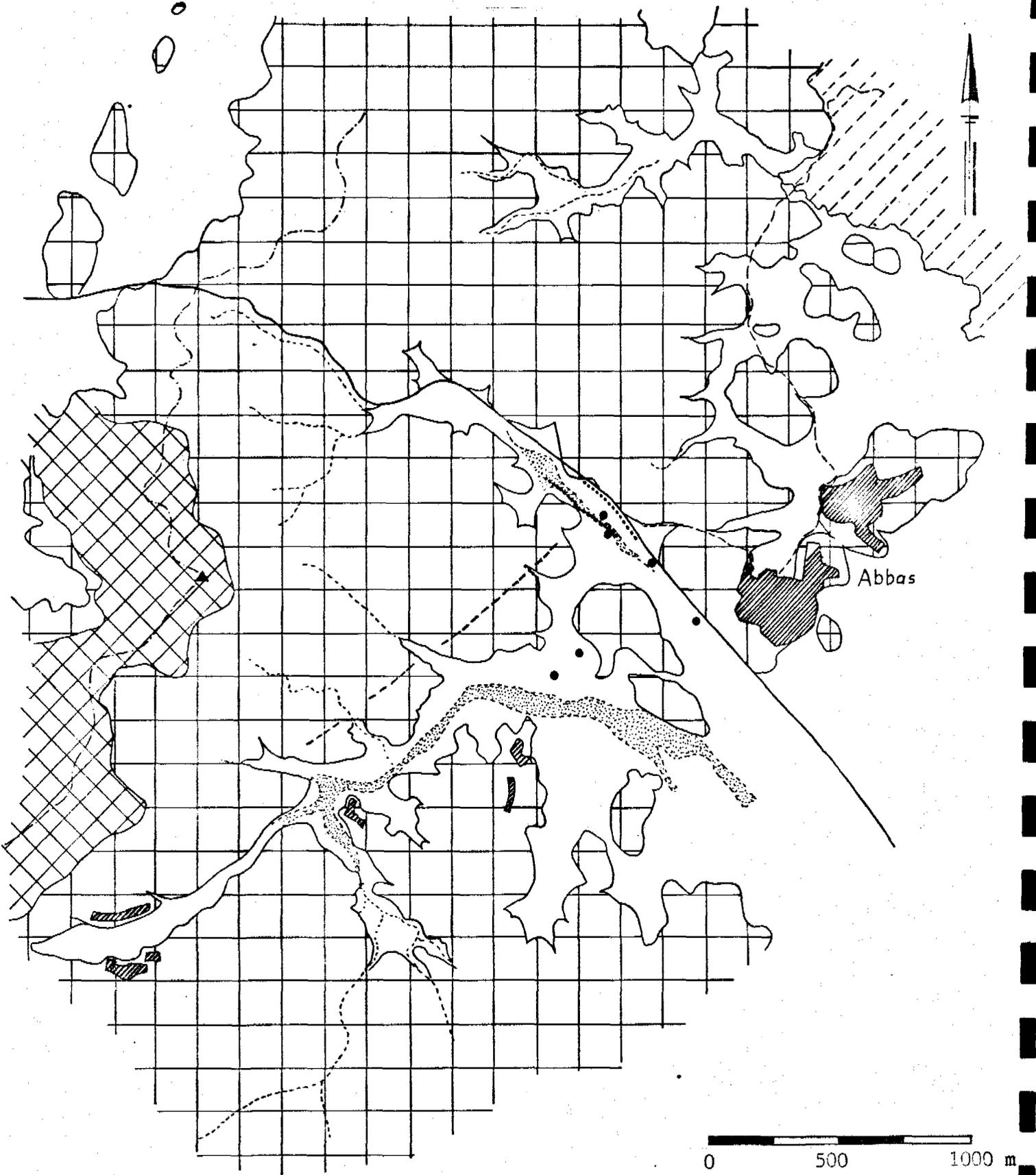
EM = Electro-magnetic profile

GEP = Geo-electrical profile

The numbers of villages refer to Figure 1 and the respective paragraphs. Only measurements carried out during the seventh phase groundwater investigations are mentioned; soundings carried out in the past are mentioned in the headings of each paragraph.

2

SITE SELECTION FOR SHALLOW WELLS AND DEEP BOREHOLES



approximate scale  
1:20 000

Map 1

## 2.1 Abbas

coordinates: X: 494 km; Y: 1591 km; elevation: 2060 m  
 top. mapsheet 1444 D2  
 soundings: EM 21,22,23/88  
 aerial photograph: 863/101  
 well numbers: 8620-8626, 8641-8642, 8649

On 12 September 1988 a site selection was carried out for a farmer in the village of Abbas. The well is to be used for agriculture. The village is located along the tarred road Rada' - Al Bayda, 12 km east of Rada'.

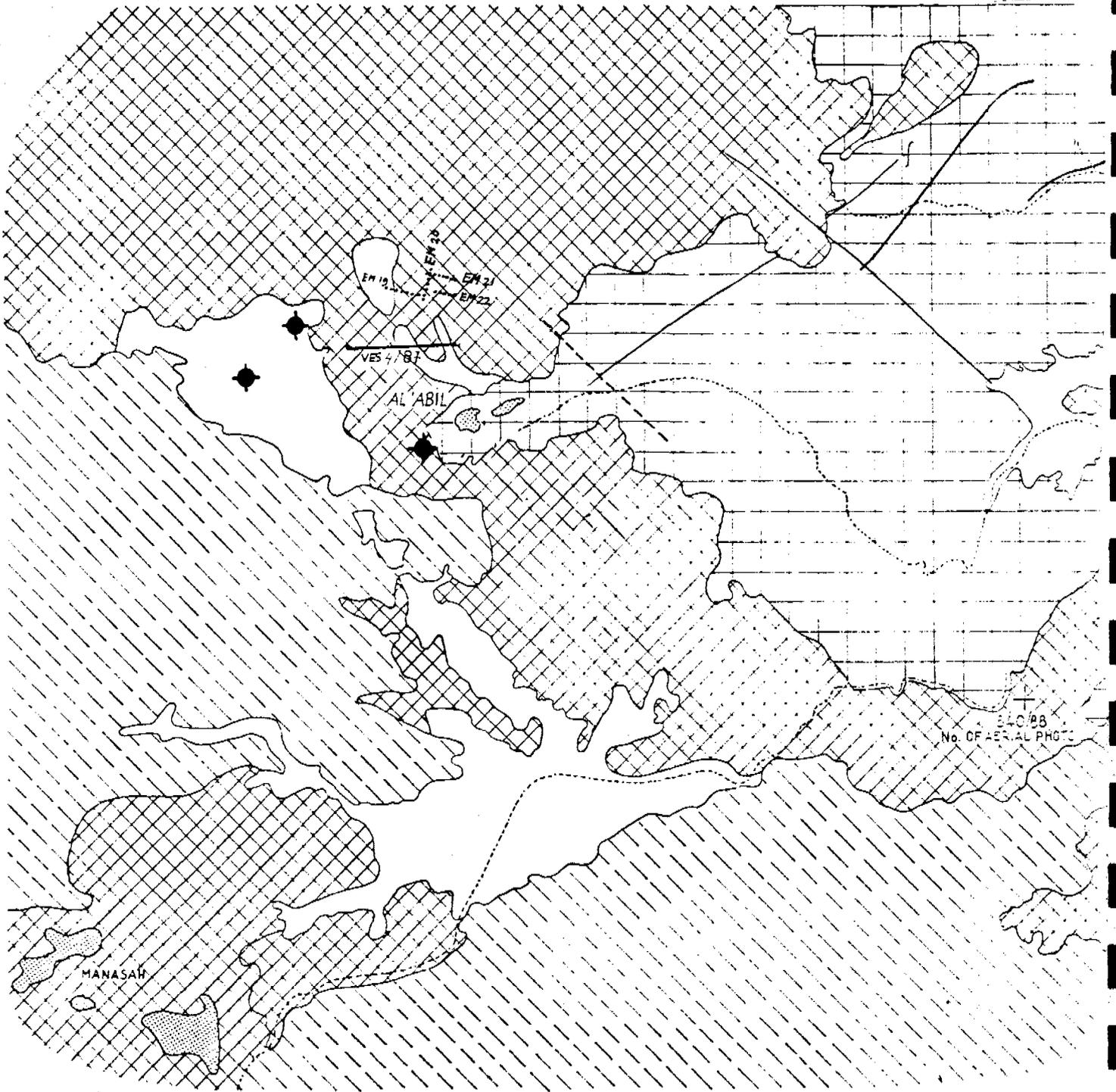
The area consists of migmatites and gneisses of the Precambrian basement, at some places intersected by dykes. Some faults cross the area. In the southwest Tawilah sandstone overlies the mountains that form the watershed of the area. Many shallow wells have been dug in the alluvial plains, but the water level is in most cases very deep (below 30 m), so that wells had to be dug far into the basement rocks. Pumping can take place for a short time only in most of the wells, a quarter of an hour per day.

Three electromagnetic profiles were made on the land of the farmer, about 1 km west of the village, just southwest of the asphalt road. A coil spacing of 40 m was used. The first line, along the asphalt road, did not reveal any point of interest, conductivities being around 5 to 10 mmho/m. Another line was made somewhat more to the south, in the wadi bed. Here a point of interest was found where the bed runs along the outcropping basement. Near a volcanic intrusion horizontal coil conductivities rise to 15 mmho/m. However, the farmer later stated that this area is not his property, so another profile had to be made.

More to the west a large dyke is present, running west-southwest / north-northeast. A profile was made over this dyke, showing a distinct dip in conductivities, especially in the horizontal coil position (vertical dipole mode). The dyke has an inclination of 55% to the west, so a site was pointed out 28 m west of the point where the dyke virtually crosses the EM-profile. When drilling takes place on the indicated spot, a fractured zone may be struck between 40 and 60 m, since the thickness of the dyke is approximately 10-12 m. Drilling should not continue if no water is struck before a depth of 100 m is reached. The site is marked with blue paint and known to the farmer.

Since the water availability in the shallow wells is low, and overpumping in the area already takes place, the yield of the well will not be very high, and may even decrease in future. The upstream catchment area is small, a few square kilometers only.

The quality of the groundwater on this site is expected to be good, the EC probably between 600 and 800 microSiemens.



0 500 1000 m

approximate scale  
1:30 000

Map 2

## 2.2 Al 'Abil

coordinates: X: 475 km, Y: 1615 km; elevation 2260 m  
 mapsheet: 1444 B4  
 aerial photograph: 840/88  
 soundings: EM 19,20,21,22/87, 11/785 VES 39/86 4/87  
 well numbers: not surveyed

On 1 November 1987 a private site selection was carried out for a farmer in Al 'Abil. This village is located approximately 25 km north-northwest of Rada'. Several surveys have been carried out in this area before (Ilaco, 1984, 1986, 1987), but until now no drilling on the indicated sites has taken place. Two good productive boreholes exist northwest of the village.

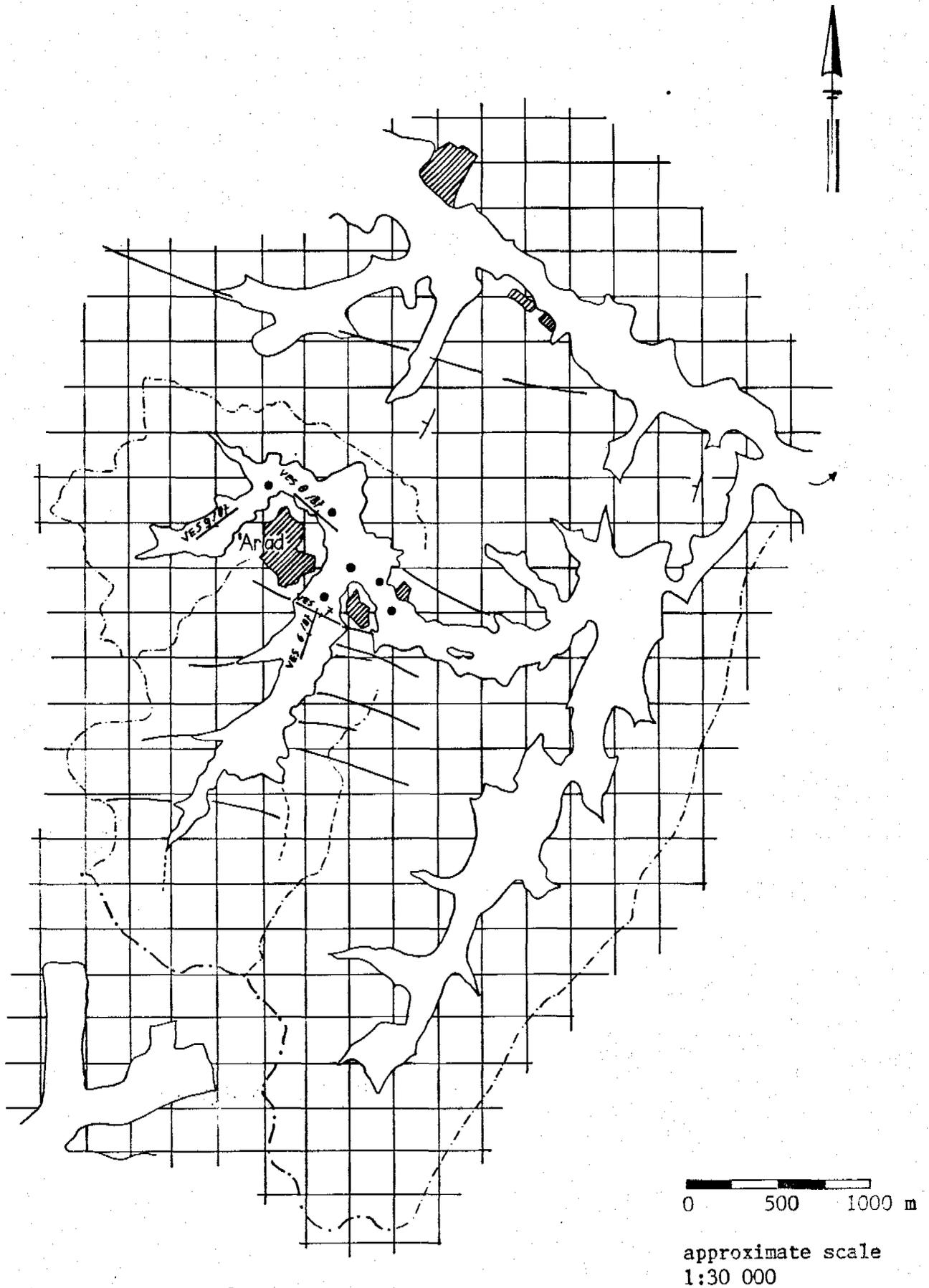
The land of the farmer is situated about 2 km north-northwest of the village. The area is located on the eastern border of the Holocene Jabil Isbil complex, on a plateau of older (Pleistocene?) volcanic formations. The Precambrian basement, outcropping in the east, is underlying these volcanic formations. Wadis have developed in the numerous faults present in the basement.

Electromagnetic measurements were performed in order to investigate the chances for borehole drilling in the area. In general the measurements with the coils in vertical position (depth penetration 30 m), show lower conductivities than those taken with the coils in horizontal position (depth penetration 60m). This suggests that there are chances to encounter water at greater depth. In one area the conductivities were found to be around 20 mmho/m, which seems promising for drilling a borehole.

It is advised to drill a borehole on this site. Water may be found at a depth below 40 m. It is expected that the basement will be found at greater depth, maybe from 100 m onward. When no water is found before the basement rock is encountered, it is dissuaded from drilling further when the formation is unweathered. When the Precambrian is not too compact however, drilling can continue upto a depth of about 200m. There is a fair chance that one of the west-east running fault zones is hit.

The catchment area upstream of the well, about 10 km<sup>2</sup>, consists of Holocene formations of the Jabil Isbil. The infiltration rate is high, and since only few wells are present in the area, chances for a sustained yield in future are good.

Water quality is expected to be good, EC around 800 microSiemens/cm. The site is indicated in the field with an iron bar. Drilling should preferably take place within 10 m of the selected site.



Map 3

## 2.3 'Arad (at Taffah)

coordinates: X: 543 km; Y: 1571 km; elevation: 1950 m  
 mapsheet: 1445 C4  
 aerial photograph: 863/120  
 soundings: VES 6,7,8,9/87  
 well numbers: not surveyed

On 10 February 1987 a site selection was carried out for a well for drinking water of the village 'Arad in the sub-district of At Taffah. The village is located about 65 km east-southeast of Rada', 3 km north of the asphalt road. At present water is available from the shallow wells around the village only. The availability of water varies with the rainfall.

The area consists of Precambrian basement, the wadis are filled with alluvium to a depth of 10 m at the maximum. At the time of the survey, water was abstracted only from the hardrock, which seems to be rather dense. Some minor faults can be seen on the aerial photographs running in west / east direction. Unfortunately the electromagnetic equipment was out of order at that moment.

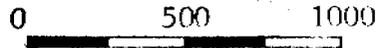
Therefore soundings were made with the geo-electrical equipment, in total 4 around the village. Half electrode spacing varied between 60 and 100 m. Thereafter apparent resistivities rise sharply, which means that the hardrock is very dense indeed. An upper layer with low resistivities is found varying between 4 and 18.5 m. This last value was found in VES 6/87, that was made at a place where the width of the wadi is somewhat bigger due to a joining tributary that developed in a small fault. This seems the best place for digging a well.

The catchment area upstream of the well will be about 2 km<sup>2</sup>. This is not much of course, but since the well will be situated upstream of the other wells, constant water supply for drinking could be guaranteed. The yield will be lower however in dry years.

The quality of the water is expected to be fair, around 800 - 1000 microSiemens/cm. It is strongly advised not to drill boreholes in this area. There is no indication that important aquifers are present at greater depth.



approximate scale  
1: 25 000



DAR KHALABAN

AS SUWRAYMIH

AN NUWAYRAH

QARU'AL

146

EM 26

VES 1/84

VES 2/83

AL HASSAN

## 2.4 Dar Khalaban

coordinates: X: 470 km; Y: 1576 km; elevation: 2600 m  
mapsheet: 1444 D1  
aerial photograph: YE 8/13  
soundings: VES 1,2,3/87  
well numbers: 1340

On 11 and 13 January 1987 a site selection was carried out to locate a source for a water supply scheme to be constructed in Dar Khalaban. The village is located some 6 km west-southwest of Aqabat Riashiyah, on the edge of an escarpment.

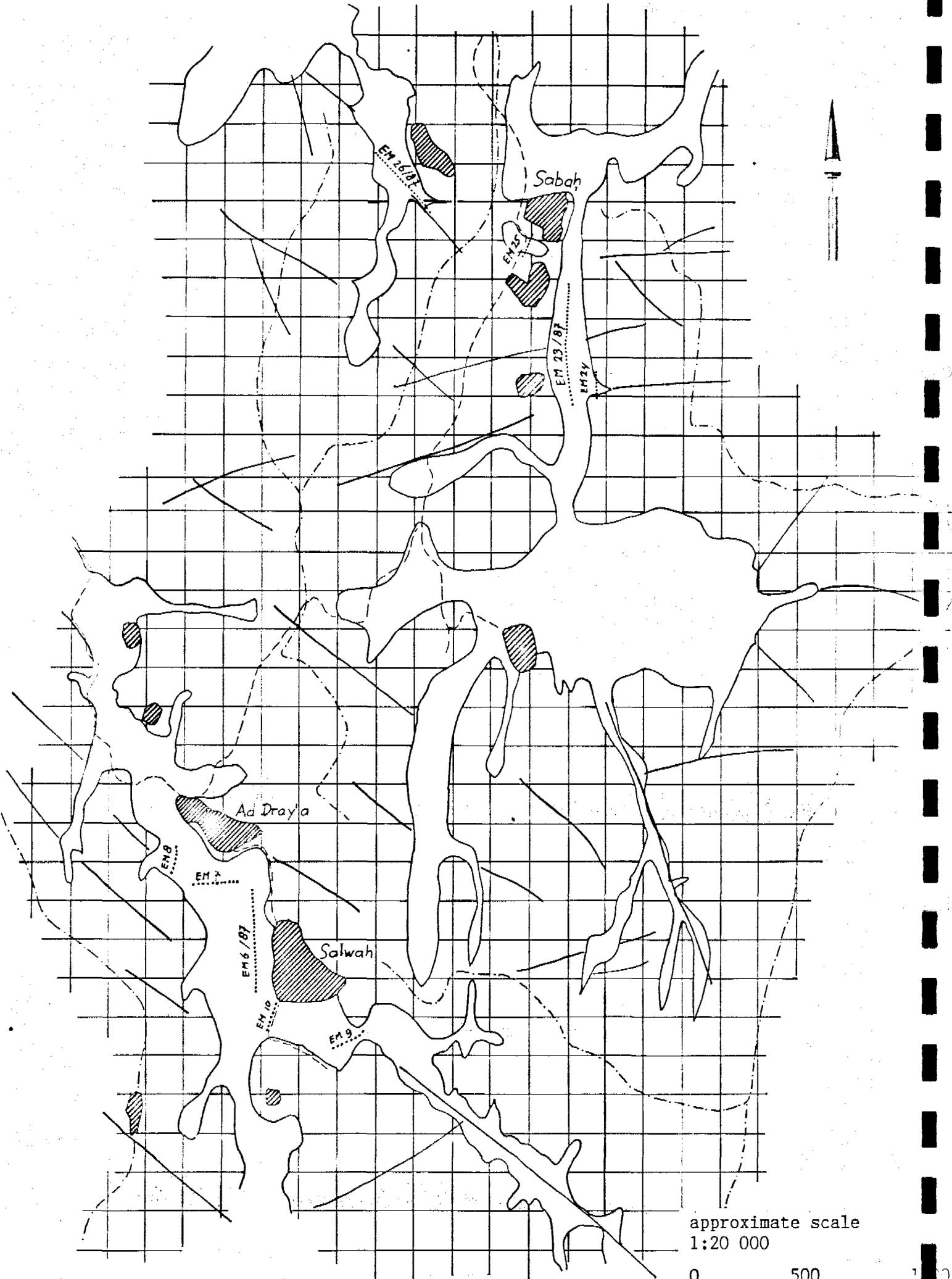
The catchment area above the village, a plateau surrounded by Tertiary volcanic cones, has an area of about 3 km<sup>2</sup>. In this area one shallow well was dug, with a depth of about 12 m. Somewhat more downstream, in the wadi bed, a spring yields water 4 months per year. Another spring is found down the escarpment. The area mainly consists of basalts and tuff layers. Until now, no attempts have been made in the vicinity of the village to drill boreholes.

Two geoelectrical soundings were carried out upstream of the village. One in the stream bed of the wadi that drains the water from the catchment in the north down the escarpment, one on a higher level closer to the village. The measurement in the streambed (VES 2/87) shows a promising layer between 3 and 11 meters. More down, resistivities drop to a low level, probably indicating tuffs. The sounding closer to the village (VES 1/87) shows no layers of interest.

Down the village another measurement was performed. This one shows very low resistivities, even below 10 Ohmm. Interpretation depth is 100 m at the maximum. Tuffs and shales were observed in similar layers downstream the main wadi. This site is not promising.

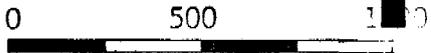
Since there is no evidence for promising layers at greater depth, it is advised to dig a shallow well downstream the existing one, near the wadi bed, just upstream of the spring area. The estimated depth is 12 m. The water quality is expected to be very good. (EC around 500 microSiemens/cm).

Drilling boreholes in the upstream area should be avoided as the chance of finding water is low, and if any water is encountered, the chance to lose it to lower layers is big.



Map 5

approximate scale  
1:20 000



## 2.5 Ad Dray'a (Dhi Na'im)

coordinates: X: 547 km, Y: 1553 km; elevation: 2000 m  
 mapsheet: 1445 C4  
 aerial photograph: YE 3/73  
 soundings: EM 6,7,8,9,10/87  
 well numbers: 6100,6101 (not completely surveyed)

On 20 October 1987 a site selection was carried out at the request of the LCCD of Dhi Na'im for the village Ad Dray'a, 6 km south of Al Minqatha. At present there is very little water in the village, the shallow well used for drinking water can be operated only one hour per day.

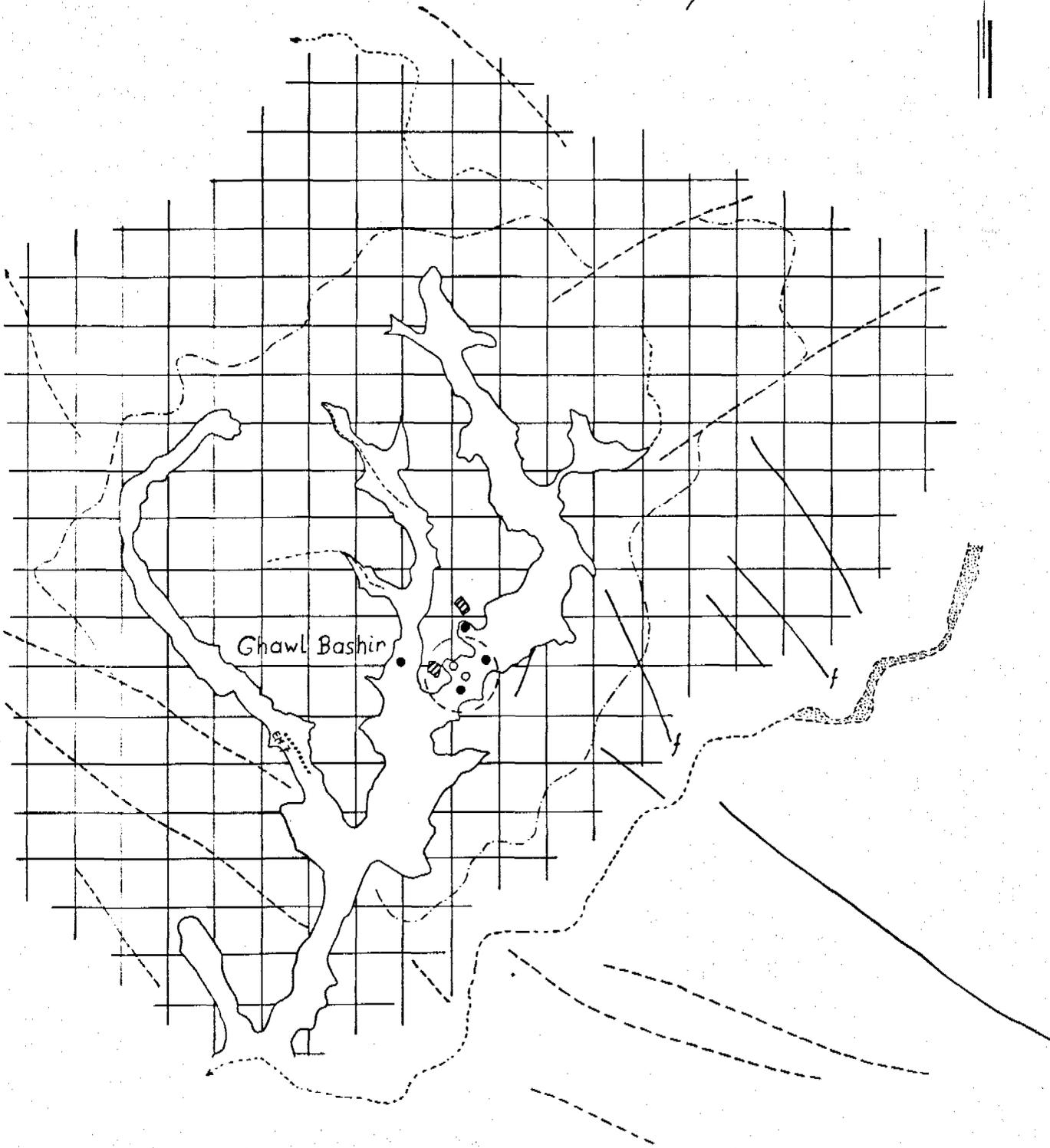
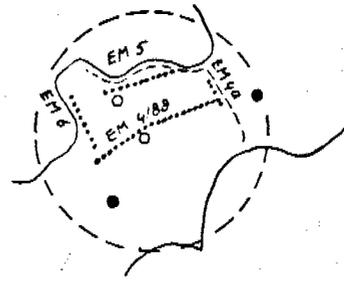
The village is located close to the main watershed of the province, which means that there is only a small catchment area that provides the area with water. The wadis are oriented northwest/southeast, developed in faults running in this direction. Unfortunately, on the land of the village no clear fault structures could be detected on the aerial photographs. The basement consists of unweathered metavolcanic rock. From rock samples of recently deepened wells it could be concluded that the rock is not weathered, and that secondary porosity is extremely low.

A number of electro-magnetic soundings were carried out in order to locate any faults or weathered zones. Without exception the conductivities found were very low. In fact, highest conductivities were found near the existing shallow well for drinking water.

In a wadi just southwest of Salwah apparently some good shallow wells were dug, but no geologic evidence for this higher yield could be found; conductivities here are very low as well. The hills show a somewhat higher degree of weathering however.

As no good site could be found in the main wadi, it is advised to dig a shallow well somewhere in the tributary southwest of Salwah, as this offers the best chances for digging a well with reasonable yield. It is very well possible however, that within a few years also the groundwater available in this wadi will be depleted, as is obviously the case in the main wadi. The catchment area of this tributary is smaller than that of the main wadi.

It must be dissuaded to drill boreholes in this area, as chances to find water at greater depth are very low. Water quality in the tributary wadi is good, EC about 700 microS/cm.



0 500 1000 m

Map 6

approximate scale  
1:30 000

## 2.6 Ghawl Bashir

coordinates: X: 530 km; Y: 1595 km; elevation: 1980 m  
 mapsheet: 1445 C2  
 aerial photograph: 850/105  
 soundings: EM 4,4a,5,6,7/88  
 well numbers: no well inventory carried out

On 29 June 1988 a site selection was carried out for the water supply of the village Ghawl Bashir. The village is located about 15-20 km north of the market of As Sawadiyah.

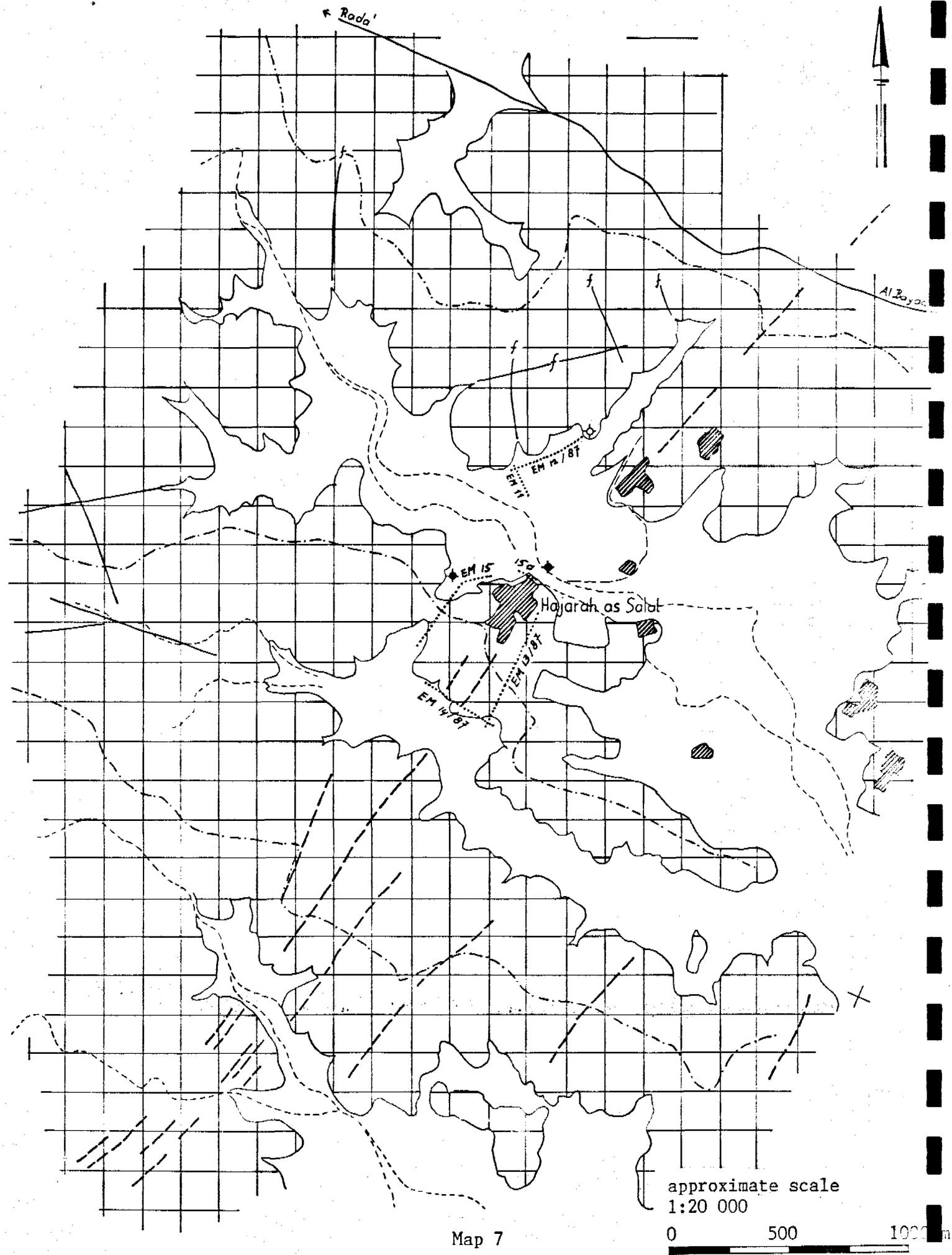
The area is locally marked by unweathered Precambrian formations. Valleys are filled with alluvium to a depth of about 10 m. The water levels in the vicinity of the village vary between 15 and 23 m, which means water is recharged by the hardrock only, which takes place very slowly. At present the village possesses only one well that can be pumped only half an hour or less every week. Other wells in the area reach a maximum capacity of maybe half an hour every day.

In an attempt to get more water 2 wells were dug by the villagers themselves, to a depth of about 15 m, both unsuccessful. It is probable however that the water table was not yet reached.

In order to select a site for a well, 5 electromagnetic profiles were made with a coil separation of 20 m, giving a maximum interpretation depth of 15 and 30 m. Four of these lines were measured close to the village, the other one in a valley farther away where the village possesses some land. In general the conductivities found are low, varying between 3 and 10 mmho/m for the measurements taken with horizontal coil position, and between 5 and 11 mmho/m for the vertical coil positions. The highest values were found in the middle of the main wadi upstream of the village next to the road, and in the upstream part of the tributary wadi northwest of the village. In the vicinity of the 2 dug wells conductivities are very low.

It must be concluded that there is little chance to find water in reasonable quantities in this area. However, the capacity of the existing well may be enhanced by deepening the well some 3 m. Digging a new well may also increase the water availability, but the yield cannot be expected to be much higher than the existing wells.

The best chances for finding some water may be found in the middle of the most upstream field measured in the tributary wadi. Water may be struck at a depth between 15 and 20 m. The quantity will be small however. The catchment area upstream of this site is about  $1\frac{1}{2}$  km<sup>2</sup>, which means that a yield in the order of 5 000 to 10 000 m<sup>3</sup> per year may be expected, which is just enough for the village of about 300 inhabitants. The water quality is expected to be good, EC between 700 and 1000 microSiemens/cm.



Map 7

approximate scale  
1:20 000

0 500 1000 m

## 2.7 Al Hajarrah as Salal (Sha'aban)

coordinates: X: 499 km; Y: 1586 km; elevation: 2000 m  
 mapsheet: 1444 D2  
 aerial photograph: 863/72  
 soundings: EM 11,12,13,14,15/87  
 well numbers: 8732-8745

On 25 October 1987 a site selection was carried out for a well for the drinking water supply of Hajarrah as Salal, 18 km east-southeast of Rada', some 2 km south of the asphalt road. The village is located at the upstream part of the Sha'aban area, where the wadi from Riam flows into the plain of Sha'aban.

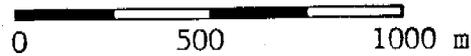
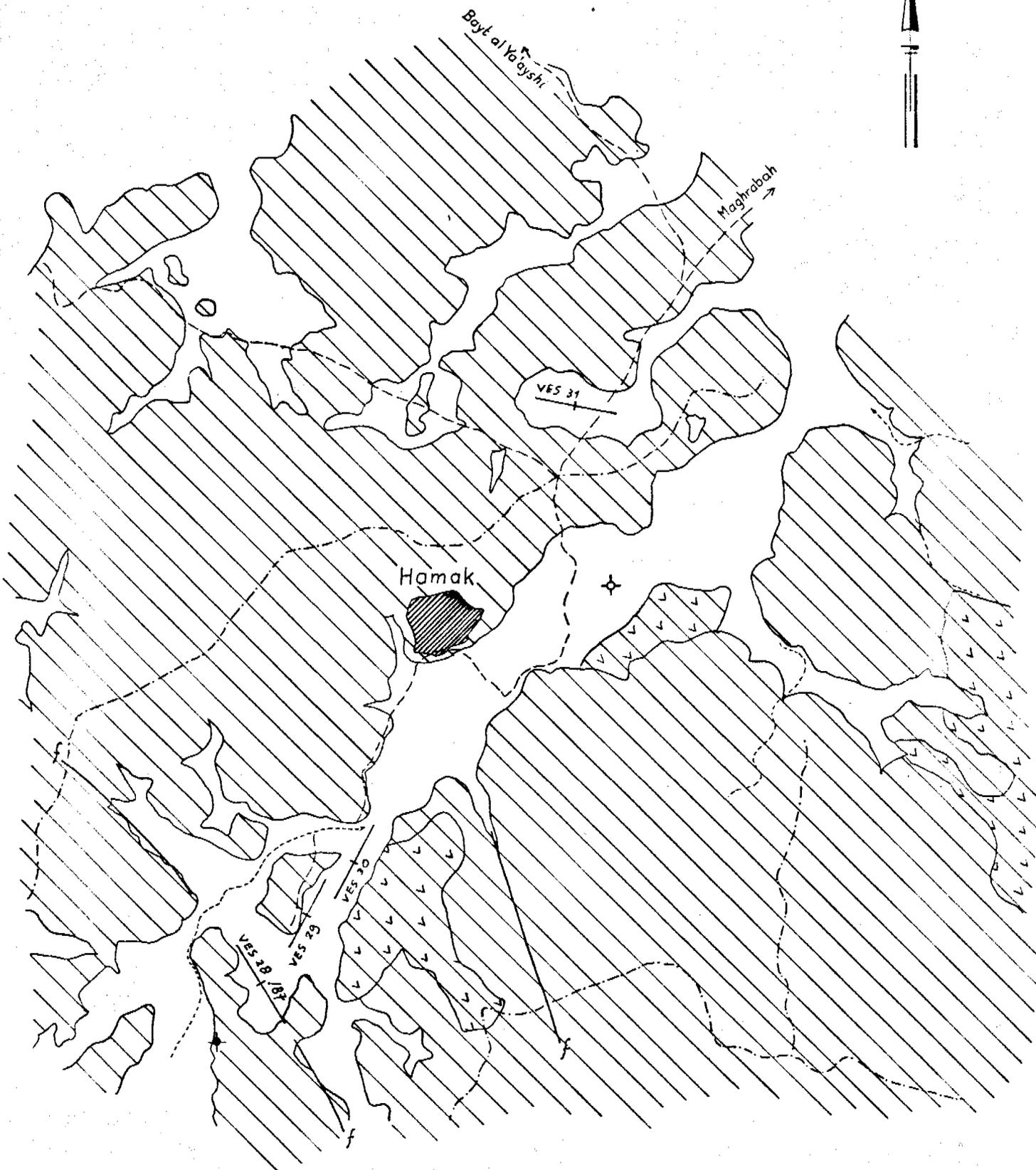
In 1980 and 1985 site selections have been carried out in this area (Ilaco, 1980, 1985). From these surveys it can be concluded that at the most sites chances to find deep groundwater are very small. This is also evidenced by a number of boreholes drilled in the area yielding only little water or no water at all. Deep groundwater, if any, can only be found in fissured zones.

The area is located in the Precambrian basement. The alluvial wadi fill reaches depths of 15 m at the maximum. The rock formations mainly consist of gneisses and migmatites, with some intrusions of more recent age.

On the aerial photographs a number of faults and dykes can be found. The village itself is located on an intrusion. Soundings EM 11 - 15/87 were carried out to locate any of these faults or dykes. In EM/12 a small fault shows up, which can also be seen on the photograph. Also in EM 13/85, south of the village, an anomaly shows up, but a fault or dyke can not be seen clearly on the photo. A more prominent anomaly shows up in EM 14/87, southwest of the village where the profile crosses the dyke on which the village is located. This is probably the best site to drill a borehole.

It must be understood however that, regarding experiences with other drilled wells in this area, chances for finding large quantities of water by drilling a well are low, and that in the best case the production of the well will be only moderate. Because the village of Hajarrah as Salal is the first to profit from the water coming from Riam, the chance of rapid depletion of the aquifer is not so big here as more downstream, where the recharge is lower.

It is dissuaded to continue drilling when no water is encountered before a depth of 100 m is reached. Water quality is expected to be moderate, EC around 1500 microSiemens/cm.



approximate scale  
1:20 000

Map 8

## 2.8 Hamak

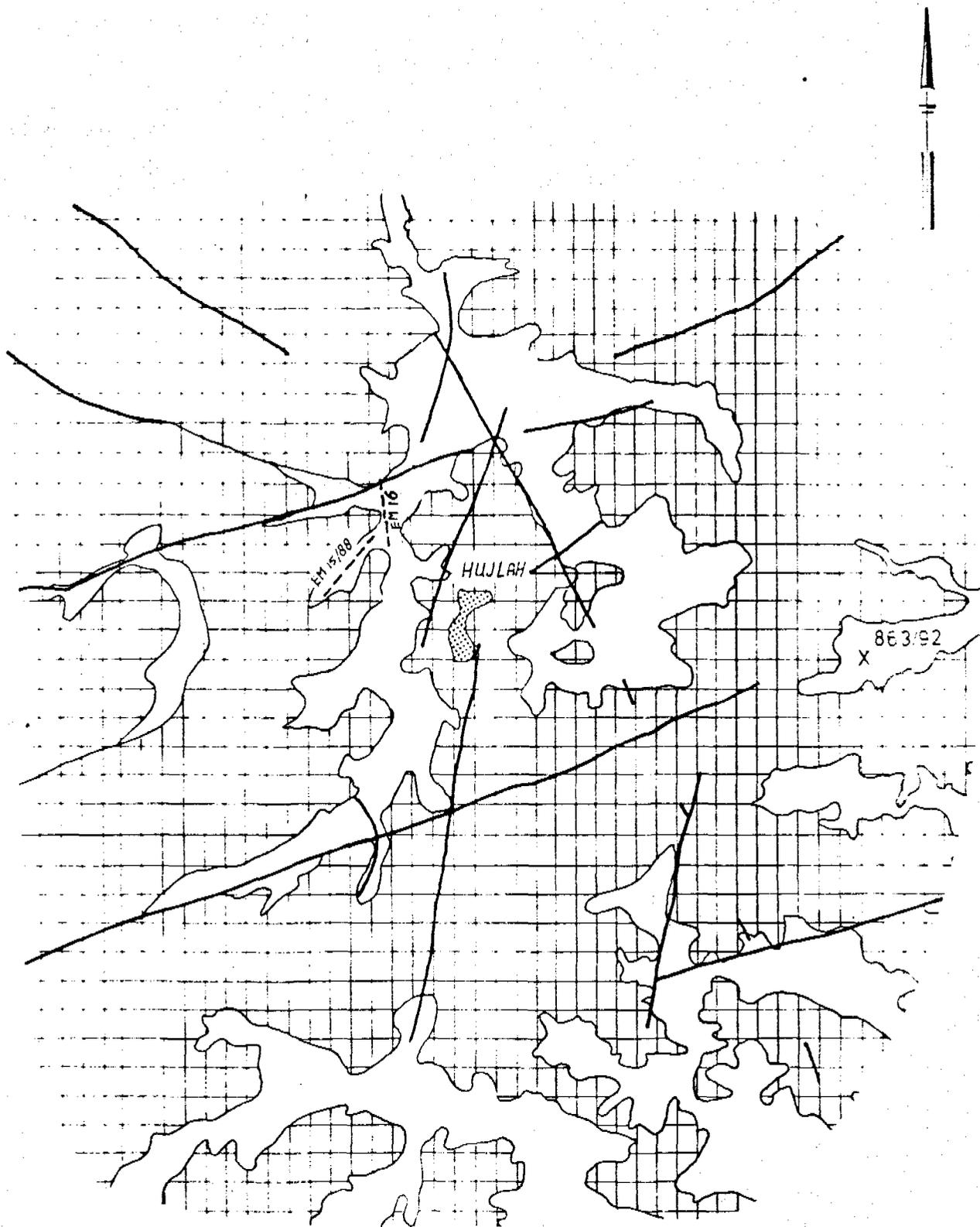
coordinates: X: 475 km; Y: 1590 km; elevation: 2220 m  
mapsheet: 1444 D2  
aerial photograph: 863/198  
soundings: VES 28,29,30,31/87, VES 48,49,50,51/86  
well numbers: 0158-0172

In November 1986 four geo-electrical soundings were carried out to determine a site for making a well for the drinking water supply of Hamak (Ilaco,1987). From these measurements it was concluded that only shallow groundwater was present at a depth between about 15 and 30 m. It was advised then, to dig a shallow well.

The villagers insisted on a site for a borehole, and four more measurements were carried out in April 1987 in areas farther from the village, not surveyed in November 1986. About 1.5 km southwest of the village a major fault is running southeast/northwest. This fault itself most probably contains no water, but south of the fault a productive borehole has been drilled. It is very well possible that at this side of the fault a good aquifer is present. However, the village has no land at this side of the fault. Nevertheless some measurements were carried out north of the fault, all showing low resistivities at greater depth, indicating formations which contain no water. One more measurement was carried out in a small valley north of the village, also not giving promising results.

Once more it must be concluded that the chances of drilling a productive borehole in this area are small. Especially at greater depth it is not likely to encounter water. It is advised again to dig a shallow well to a depth of 15 to 25 m, in the vicinity of the village, preferably upstream. The site of VES 30/87 seems most appropriate for this.

Water quality is expected to be good, EC around 700 - 900 microSiemens/cm.



0 500 1000 m

approximate scale  
1:20 000

Map 9

## 2.9 Al Hujlah (Dhi Na'im)

coordinates: X: 553 km; Y: 1560 km, elevation: 2000 m  
mapsheet: 1445 C1  
aerial photograph: 863/91  
soundings: EM 15,16/88 EM 21,22,23/85  
well numbers: not surveyed

At the request of the LCCD of Dhi Na'im a site selection was carried out for the village of Al Hujlah. The village is located northeast of the asphalt road, about 10 km east of Al Minqatah. A site selection carried out by the RIRD in 1985 revealed no promising sites for finding any water (Ilaco, 1986).

The water situation in this area is very bad. The few shallow wells in the area give water only some hours per week. Agriculture is mainly restricted to rainfed crops.

The area is located at the main watershed of Al Bayda province. The catchment area for recharge of the groundwater are therefore very small. Besides this, the primary porosity of the rocks is very low, and faults seem to be developed poorly. Most of the area constitutes a granitic plug.

Again some electromagnetic surveys were carried out in the vicinity of the village. Conductivities appear to be low in general. In one of the tributaries north of the village a clear dip in horizontal coil measurements was found (EM 16). This might well be an indication of a water bearing fault. On the aerial photo and in the field a fault structure could also be detected.

It is recommended to dig a shallow well at this site, to a depth of about 15 m. Nevertheless, it should be borne in mind that big quantities of water should not be expected in this area. The water quality at this site is expected to be fair, around 1000 microS/cm.

The site is marked with a heap of stones and known to the representative.

For the area around Jabil Ishaq no geological map is available.

## 2.10 Jabil Ishaq (Dhamar province)

coordinates:  
 mapsheet: 1444 A3 (?)  
 aerial photograph: not available  
 soundings: VES 11,12/87  
 well numbers: no wells

On 25 February 1987 two geo-electrical measurements were carried out for the Dhamar Rural Health Project, to advise on the continuation of digging a shallow well near Jabil Ishaq to provide the village with drinking water. The village is located between Dhamar and Madinat ash Sharq, on a high plateau-like mountain. This plateau is a remnant of the Dhamar plain, locally incised some hundreds of meters by wadis draining towards the Red Sea.

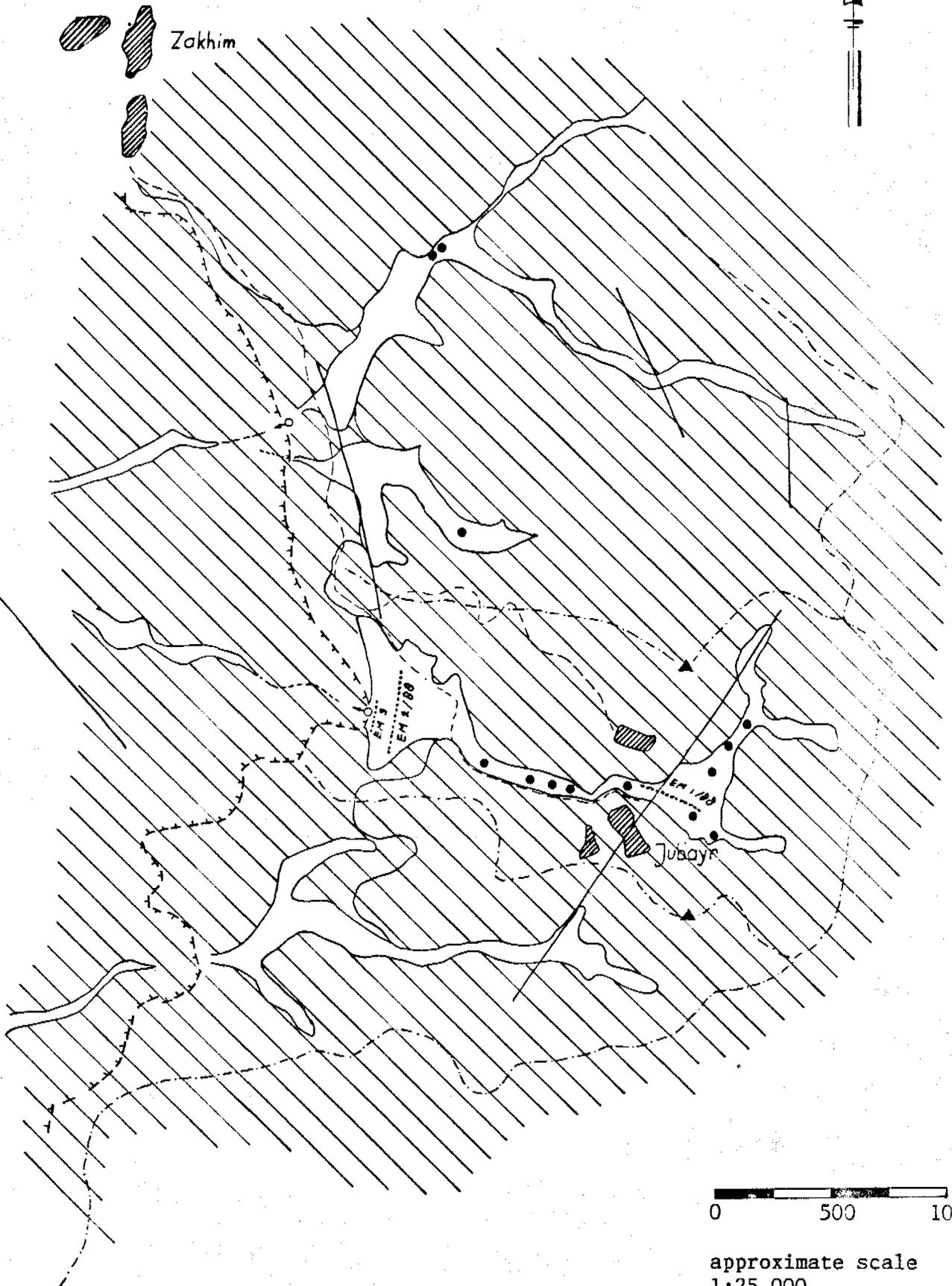
The whole area is built up of formations of the Tertiary volcanics (Trapp series), locally mainly consisting of tuffs, ignimbrite and basalt layers. In the wadis on the plateau some thin alluvial fill can be found. The topographic catchment on the plateau is small, probably less than one km<sup>2</sup>.

The well is dug at the end of the main wadi outlet of the plateau, draining towards the north. The thickness of alluvium in the well is about 5 m. At present the well has a depth of about 8 m. According to the villagers the well was dug twice as deep, but now partly filled up because of internal problems in the village. It seems reasonable to presume the well has been dug upto a depth of about 12 to 15 m. One geo-electrical sounding (VES 11/87) was performed along this well, the centre of the measuring line some 30 m upstream to obtain an electrode spacing of 100 m (L/2). This site was elevated some 2 m above the well. The sounding shows an alluvial toplayer of 7 m, under which layers of various resistivity are found, the last interpretable layer having a formation resistivity of 320 Ohmm. The interpretation depth of this measurement is about 30 m. Within this depth no water is expected to be present.

Another sounding (VES 12/87) was performed upstream, some 200 m southwest of the village. The measurement shows similar results, the alluvial toplayer having a thickness of only 2 metres.

From the results of the measurements it should be concluded that most probably no shallow water is present on top of this plateau. It is likely that infiltrating water quickly drains to deeper formations through faults and fissures in the rock.

It is therefore advised not to continue digging the shallow well. Drilling a borehole on the plateau might be the only solution, but the results will be unpredictable. On the small plateau it is impossible to carry out measurements that penetrate to a depth of 200 m with the equipment available; it is very well possible that the water table is even lower.



approximate scale  
1:25 000

Map 10

## 2.11 Jubayr

coordinates: X: 469 km; Y: 1578 km; elevation: 2800 m  
 mapsheet: 1444 D1  
 aerial photograph: 840/38  
 soundings: EM 1,2,3/88  
 well numbers: 1196-1198, 1213-1218, 1374

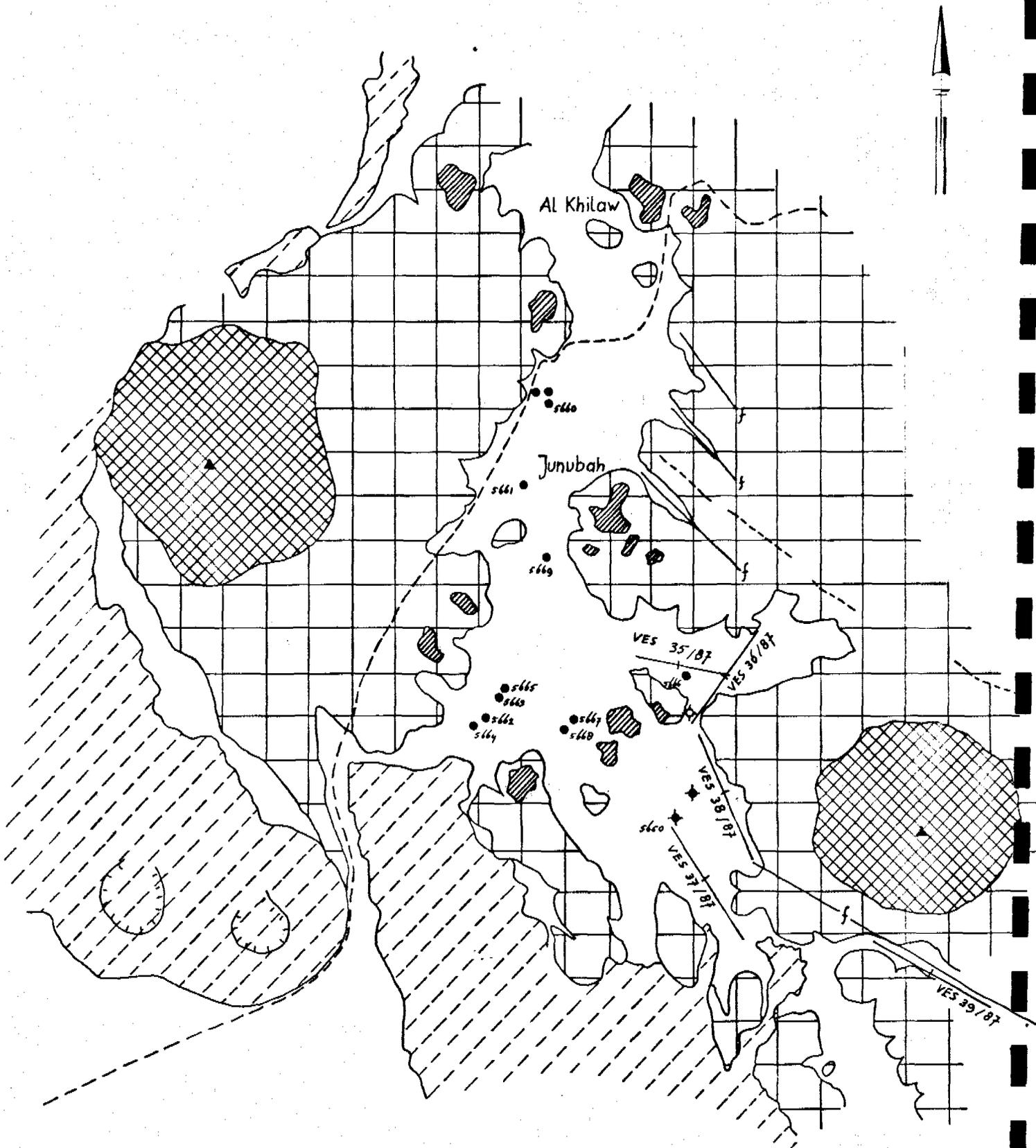
In the beginning of 1988 measurements were carried out for the village of Jubayr. The villagers complained that the well constructed by the RIRDP some years before did almost yield no water. From a simple well test it was concluded that the yield of the well was only 1 m<sup>3</sup> per day. It was decided then to make some electro-magnetic soundings in the area.

The village is located 21 km southwest of Rada', nearly on the top of one of the highest mountains in the area. The upper part of the mountain, near the villages, constitutes mostly black basalts, in the lower part a tuff formation is present. Near the village there is a small wadi in which some hand dug wells are present. The water levels varied between about 15 and 30 m at the time of the survey. More downstream a few more wells are found. Altogether these wells give only little water. A small spring on the escarpment down the village gives some water, but seems not to be used by the village.

First a profile was made in the wadi near the village, but this showed no sites of interest. Therefore electromagnetic profiles were made just upstream of the spring, in order to see if a good site for a shallow well could be found. Unfortunately a distinct site could not be assessed.

Nevertheless, of all places it seems most likely to have a fair chance in the area above the spring. A shallow well will certainly give some water, although chances to find water in large quantities are minimal. Drilling a borehole in this area seems to be very risky, since many failures in the area are known (Zakhim, Al 'Abi). Besides, the site is on an elevation of almost 2800 m, so even if water is present, it might be very deep.

If a shallow well is dug, the water quality is expected to be good, EC expected to be around 800 microS/cm



Map 11

approximate scale  
1:20 000

## 2.12 Al Junubah

coordinates: X: 490 km; Y: 1601 km; elevation: 2080 m  
 mapsheet: 1444 D2  
 aerial photograph: YE 8/75  
 soundings: VES 35,36,37,38,39/87, VES 1-9/1980  
 well numbers: 5666, 5654, 5651(new), 5650(new)

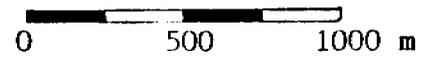
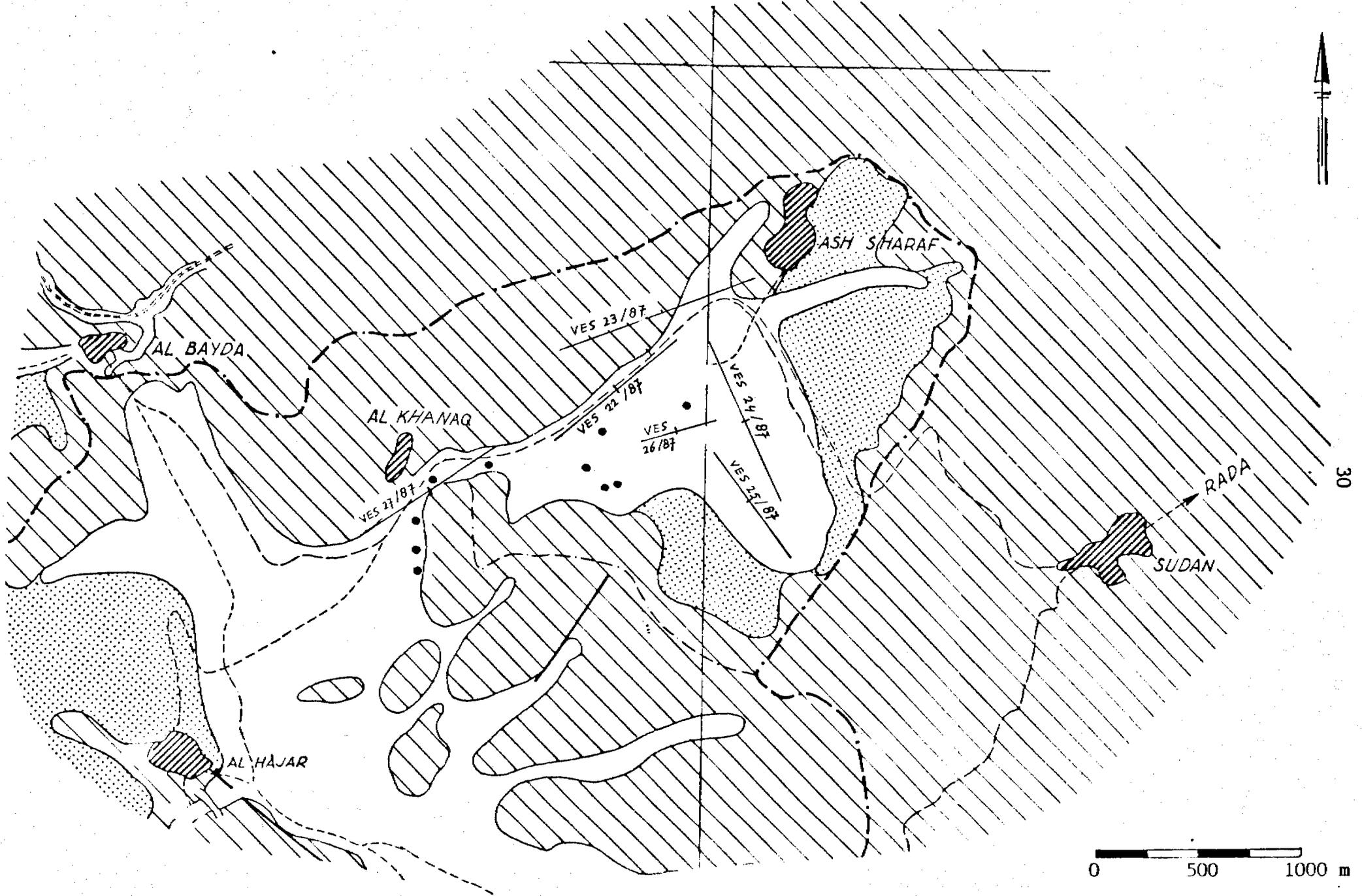
On 21 and 22 April 1987 a private site selection was carried out for a farmer of the village Al Junubah, in the southwestern corner of the Wadi Matar area, about 10 km northwest of Rada'.

Measurements for the location of a well for drinking water supply were conducted here at the end of 1980 (Ilaco,1980), which resulted in a successful drilling. Later a second successful borehole was drilled close to this one. The farmer applied to the project after a borehole drilled some hundreds of meters north of this borehole was unsuccessful.

The valley is situated at the southwestern edge of the Wadi Matar granite intrusion, surrounded by volcanos of Pleistocene and Holocene origin. Water quality in the main wadi, west of the area in question, is rather poor in view of EC's, between 1500 and 3000 microS/cm. The new drilled borehole, more upstream in the tributary wadi, has better water, the EC measured was 770 microSiemens/cm.

In total 5 geo-electrical soundings were carried out in the area. All results show high resistivities at greater depth. The first two measurements, north of the dry borehole, show no layers of lower resistivities. At the locations in the same valley as the productive boreholes (VES 37,38/87), a layer of lower resistivity is found between 17 and 78 m. This layer seems to be thickest in the middle of the wadi, as can be seen if it is compared with VES 37/87 and VES 4/80.

The quantity of groundwater available in this wadi seems to be limited, as the sweet water can only originate from a relatively small catchment. To avoid interference with the present drinking water well it is advised to drill at least 250 m upstream, near the site of VES 37/87. Water can be expected between 40 and 80 m. The depth of the borehole should not exceed 100 m. Water quality is expected to be fair, EC around 1000 microS/cm. The site is made known to the farmer and indicated in the field with an iron bar.



approximate scale  
1:25 000

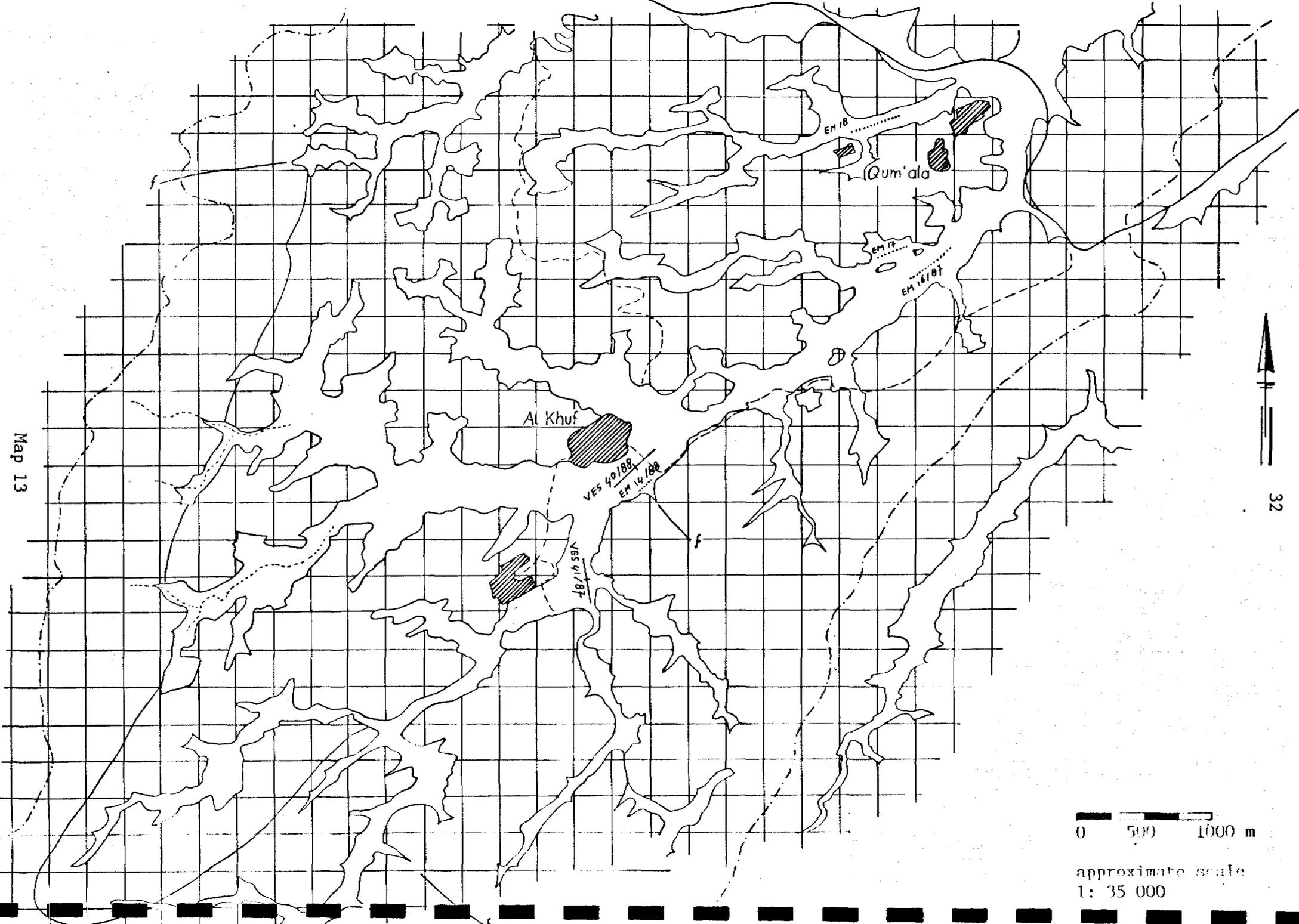
## 2.13 Al Khanaq (Sabah)

coordinates: X: 466 km; Y: 1584 km; elevation: 2600 m  
mapsheet: 1444 D1  
aerial photograph: YE 8/35  
soundings: VES 27/87  
well numbers: 1348-1352

At the request of the LCCD of Sabah a well siting was carried out for the village Al Khanaq. The village is located 19 km southwest of Rada', on the plateau of Tertiary volcanic formations southwest of As Sudan. At present the villagers get their water from one of the shallow wells that can be found in the wadi near the village. Boreholes have not yet been drilled in the village, but experiences in Al Hajar, 2 km to the southwest, were not good. A dry borehole was drilled near that village. A successful borehole was drilled more to the east.

Geologically the area consists mainly of basalts and tuffs. Dykes or faults could not be discerned on the aerial photographs. Therefore a geo-electrical measurement was made in the wadi along the village. The results of this sounding show alternating layers with high and low resistivities, indicating basalts and tuffs. The formations are probably the same as encountered near Ash Sharaf (see 2.25).

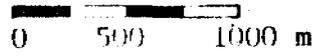
It is therefore advised not to drill a borehole in this area, but to dig a shallow well in the wadi instead, to a depth of about 20 m. The water quality is expected to be good, EC about 700 microSiemens/cm.



Map 13



32



approximate scale  
1: 35 000

## 2.14 Al Khuf (Al Haikal)

coordinates: X: 552 km; Y: 1554 km; elevation: 1950 m  
 mapsheet: 1445 C4  
 aerial photograph: YE 3/72  
 soundings: VES 40,41/87, EM 14 a,b,c/88  
 well numbers: not surveyed

On 26 April 1987 and 21 August 1988 geophysical measurements were carried out in order to locate a site for a well for the water supply of Al Khuf in the area of Al Haikal,  $7\frac{1}{4}$  km southeast of Al Minqatah (Dhi Na'im), approximately 3 km south of the asphalt road.

The village is located north of a wadi that drains in northeast direction to the Wadi Bayhan. The wadi has developed along a large NE/SW running sheerfault. Experience from other areas has learned that these faults mostly carry no water. The village is located at the southern edge of a circular granitic intrusion, as near Qum'ala. In the wadi a number of shallow wells have been dug.

Two geo-electrical soundings were made, one in the main wadi, and one in a smaller wadi south of the village. Half electrode spacing was 200 m. After 30 m resistivities start to rise sharply. Interpretation shows that unweathered hardrock starts at a depth of 8 m. This was evidenced by a nearby well. From these measurements not much could be concluded, since the presence of water depends on local fissured zones that can hardly be detected with geo-electrical soundings.

One year later new measurements were made with the EM-34, in order to detect any fissured zones. The survey was made next to the school, where a small fault zone runs through the gneissic formations opposite the village. The first profile, carried out with a coil interspacing of 40 m, shows a distinct anomaly in the vertical dipole mode (horizontal coil position). The two other soundings were carried out with a coil interspacing of 20 m. The results of these two measurements support the evidence of a fault being present here.

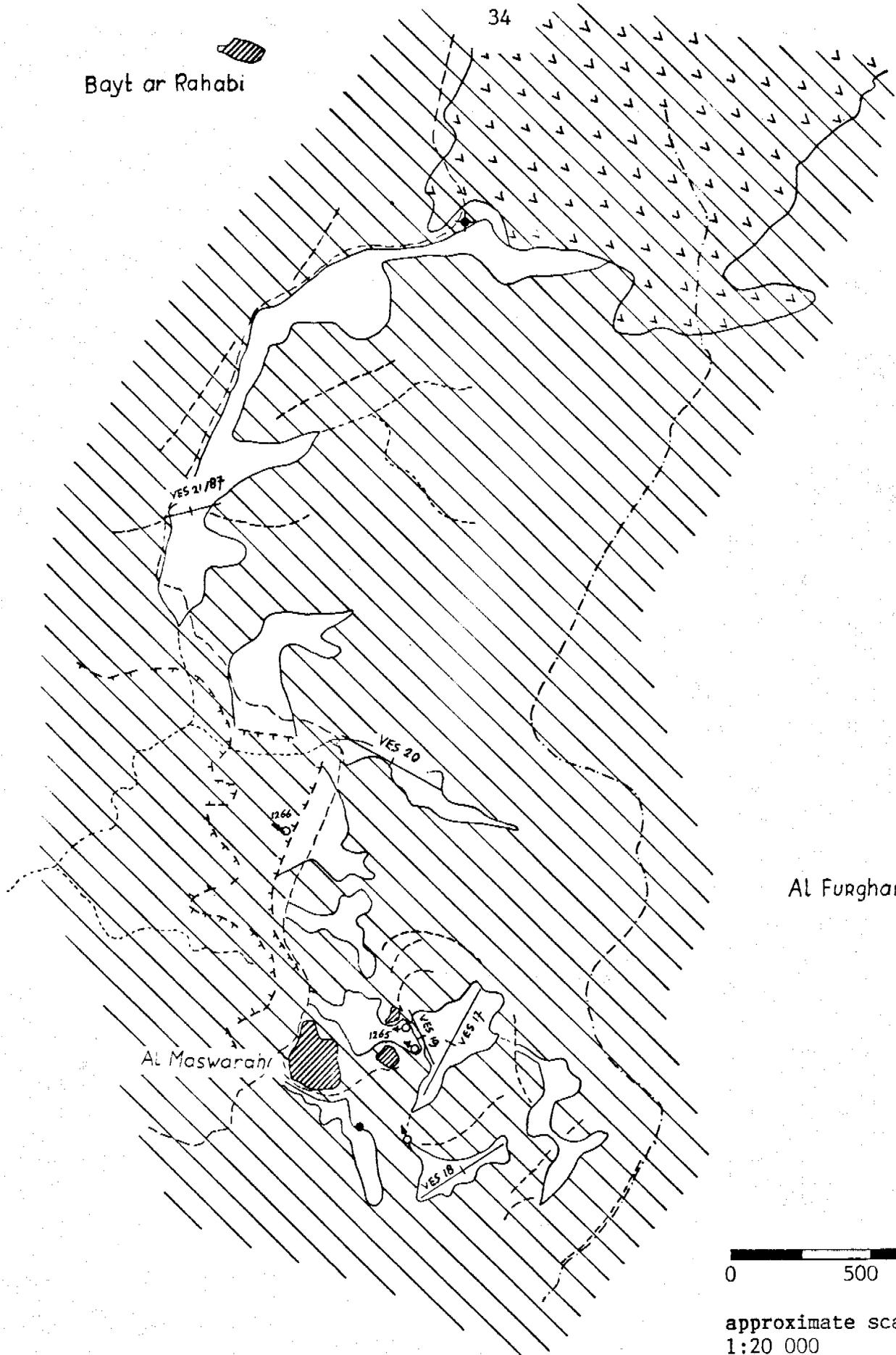
There is a fair chance that this fault indeed has good water bearing properties. A site was indicated on the anomaly of the second measurement, EM 14b/88. A shallow well can be dug on this spot. A depth of some 15 to 20 m will probably be sufficient. Water quality is expected to be fair, EC 1200-1500 microS, somewhat better than in the wells in the middle of the wadi. The quantity of the water will be moderate, since the catchment area lying behind is small.

The site was marked with stones, and made known to the representative of the village.

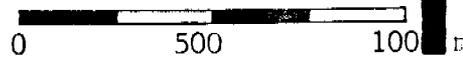
Bayt ar Rahabi



34



Al Furgham



approximate scale  
1:20 000

Map 14

## 2.15 Maswarah (Sabah)

coordinates: X: 463 km; Y: 1573 km; elevation: 2480 m  
 mapsheet: 1444 D3  
 aerial photograph: 840/36  
 soundings: VES 17,18,19,20,21/87  
 well numbers: 1265, 1266

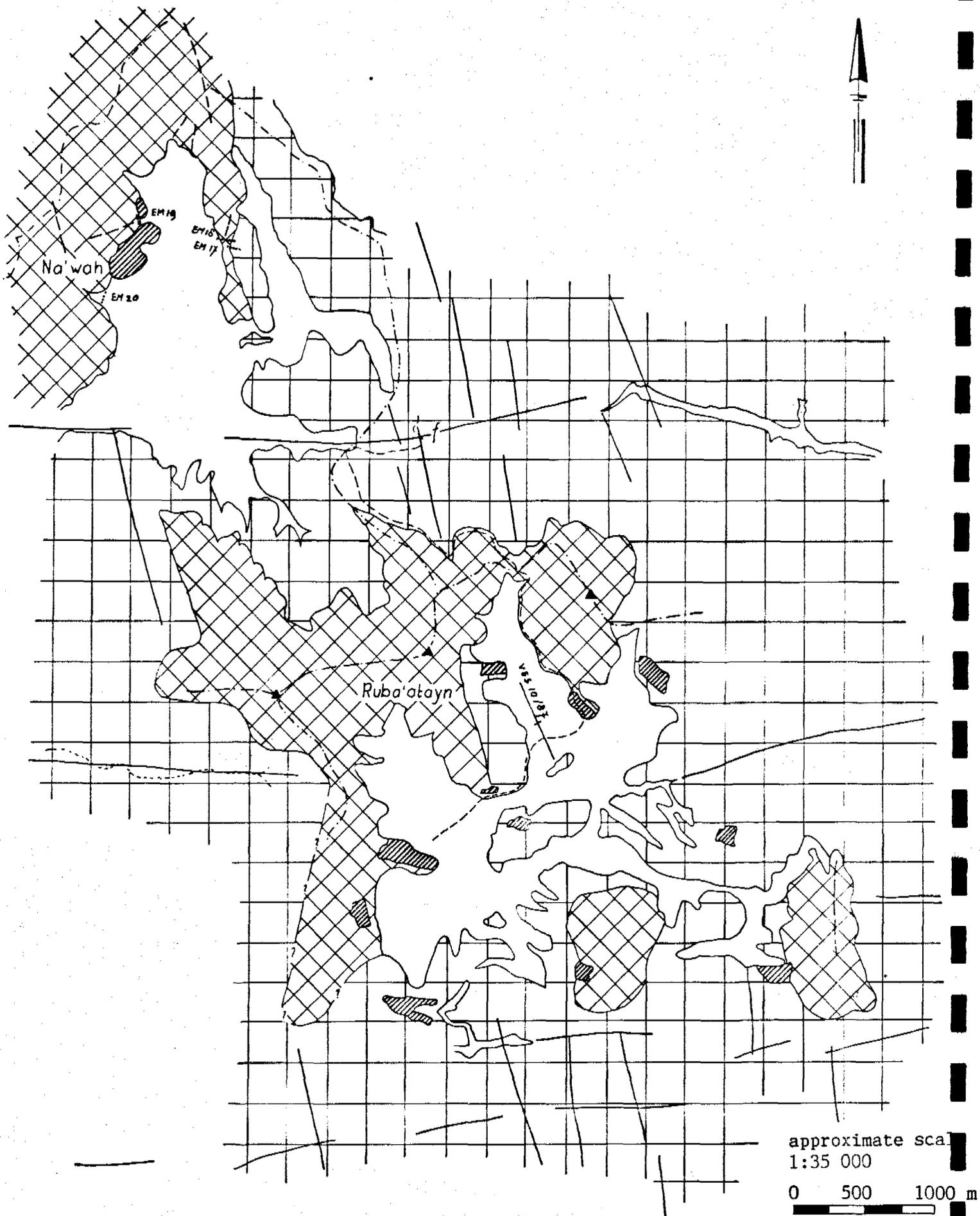
On 8 and 10 March 1987 a site selection was carried out for the village Maswarah, in the southwestern corner of the Sabah area, about 28 km southwest of Rada'. The village is situated on the edge of an escarpment sloping to a tributary of the Wadi Bana stream. The area consists of some small valleys draining westward from a north/south running mountain ridge.

At present the people drink from a number of springs, the main ones located just upstream of the village. These springs are associated with intrusive dikes, which have a predominant character in the area, that basically consists of Tertiary volcanic formations. The EC of the spring water is very low, 450 microSiemens/cm. The yield of the northern spring is about 8 m<sup>3</sup>/day, of the southern about 4 m<sup>3</sup> day.

The alluvial layer in the wadis is thin at most places. The basement is formed by impervious tuffs. About 3 km north, near Bayt ar Rahabi, a successful borehole has been drilled at the edge of a basaltic outcrop. This formation is not present on the land of Maswarah. South of Maswarah a shallow well has been dug a few years ago, yielding a daily amount of water that can be pumped out with a small pump in one hour. The water quality of the shallow water in the area is very good, having an EC of 450 microSiemens/cm.

Five geo-electrical measurements were carried out, VES 17,18 and 20 in order to assess the possibilities for borehole drilling. None of these measurements show any promising layers or anomalies; interpretation shows only layers indicating tuffs and hard basalts. Just upstream of the two springs VES 19 was performed, along a fractured zone in the basalt. This measurement shows a layer with resistivities that indicate the presence of water between 7 and 17 metres. The last measurement, VES 21, carried out along a dike shows a somewhat less developed dike, but the results are not so prominent; they may be disturbed by the surrounding tuffs of low resistivity.

The drilling of boreholes in this area will probably have little chance of success. Also the deeper groundwater may have a high content of Fluoride, as is the case in Furghan. On the other hand the water from the springs is of excellent quality. It is therefore advised to develop the two main springs near the village to a better captation, and prevent them from pollution. A reservoir should then be built downstream of the springs, in order to collect the spring water under gravity, so that no water will be lost during night time. If the quantity proves to be insufficient, a shallow well can be dug in the field upstream of the two springs, at the site of VES 19, in the fractured basalt. The expected depth required is 15 m.



Map 15

## 2.16 Na'wah

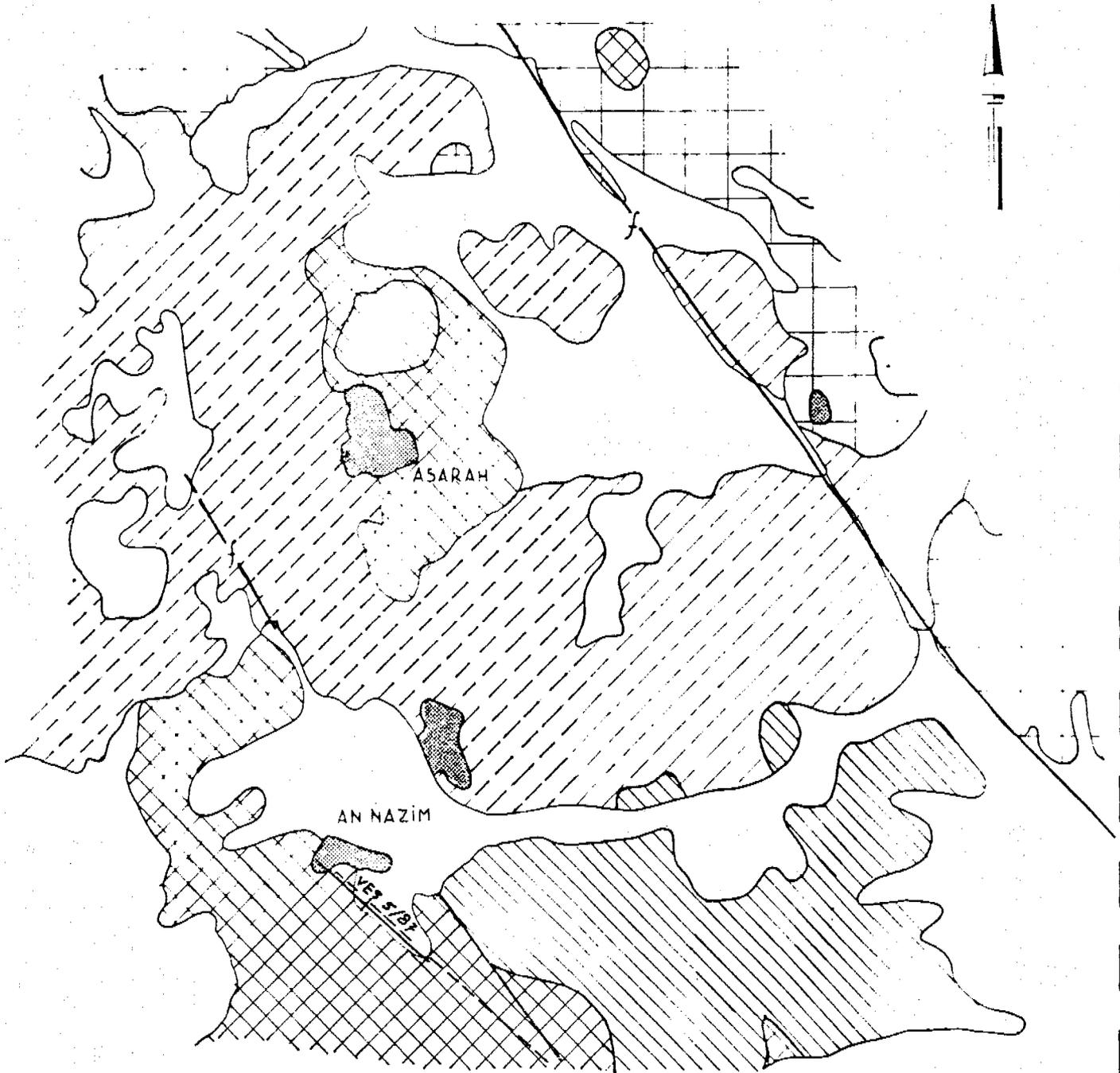
coordinates: X: 485 km; Y: 1546 km; elevation: 2050 m  
 mapsheet: 1344 B2  
 aerial photograph: 850/132  
 soundings: EM 17,18,19,20/88  
 well numbers: 2043, 2153-2174

In September 1988 a site selection for the water supply of Na'wah was carried out. The village is situated 3 km south-southwest of Juban.

A well drilled by the village was tested by the RIRD in the beginning of 1988. It proved to have a low yield, not enough to supply the whole village. According to the representative about 13 drilled wells exist in the area, most of which have a good yield. They tap water from fissures in the Precambrian underground, mostly at depths below 130 m. It is therefore almost impossible to point out a site with the equipment available.

Nevertheless some profiles were measured with the EM-34, on places where prominent faults or dykes were clearly visible in the field. EM 17/88 was made over a large NW/SE running fault, dividing surface outcrops in sandstone and cristalline basement. However no evidence for water was found by the measurement. Another measurement was made close to this one, over a virtually cracked zone (EM 18/88 ). Also this did not reveal any special site. There is a distinct change in horizontal coil measurements when the underground changes from granite to sandstone however. EM 19 and 20 were made perpendicular to dykes. EM 19 was made over a very prominent dike, that has an inclination of about 75-80 degrees. There is a very faint response in the profile, possibly because the water is so deep.

It is advised to drill a borehole some 20 m north of this dyke, so that it will be hit at a depth of about 100 m. Water quality is expected to be fair, EC around 1000-1200 microS. The area around the dyke should be protected from garbage however.



0 500 1000 m

approximate scale  
1:20 000

Map 16

## 2.17 An Nazim

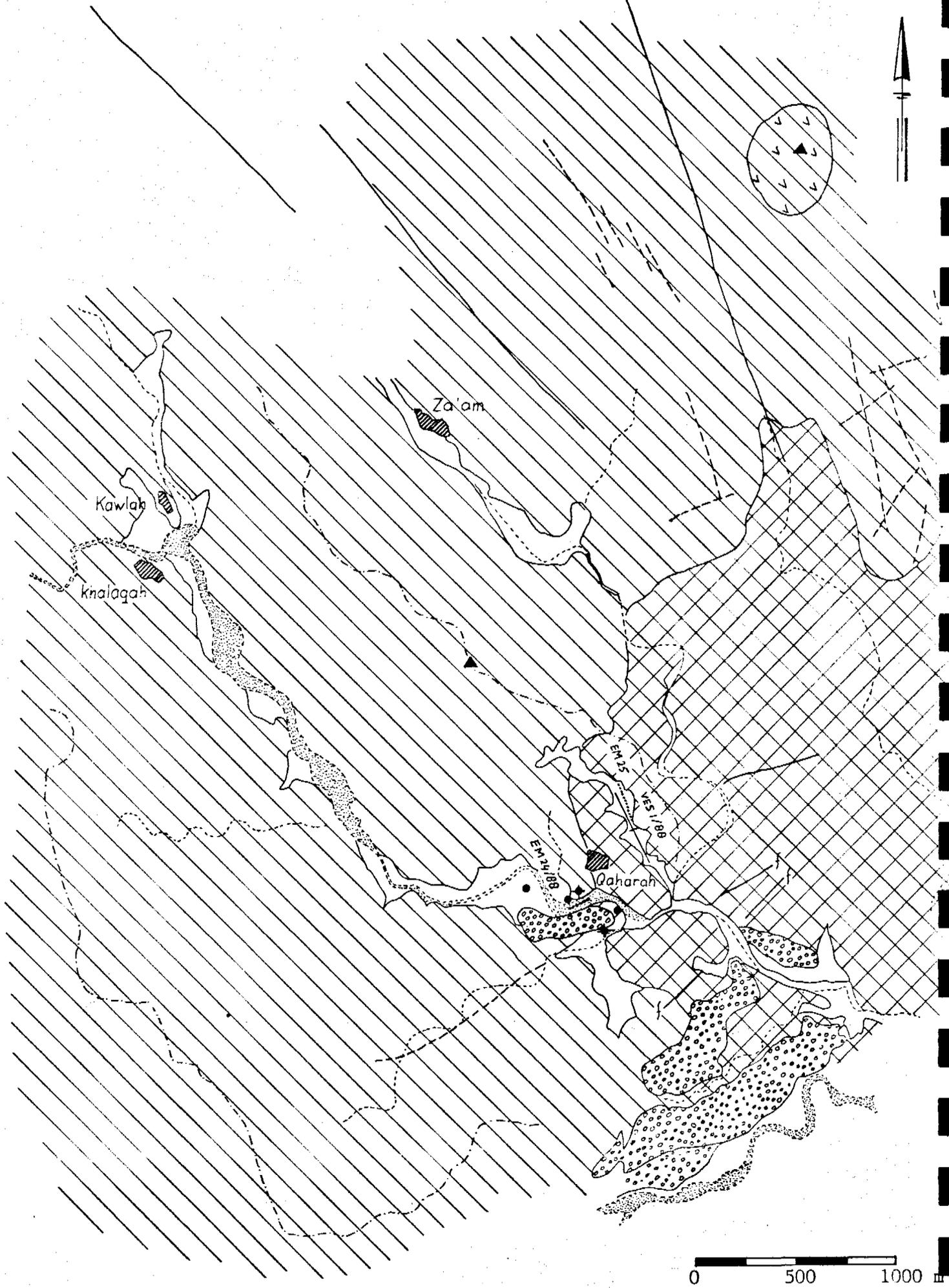
coordinates: X: 487 km; Y: 1594 km; elevation: 2140 m  
mapsheet: 1444 D2  
aerial photograph: 863/97  
soundings: VES 5/87  
well numbers: 379-388

On 20 January 1987 a site selection was carried out for a water source for the drinking water supply scheme of the village An Nazim. The village is situated 5 km north of Rada'.

The formations in the area mainly consist of Tawilah sandstone, at numerous places interbedded with sills of Tertiary age or younger. In the west and north the sandstone is buried with Holocene volcanic deposits. A major stepfault is present in the area, running northwest/southeast through the village. Just south of the village a dyke is running parallel to the fault. Along this dyke a geo-electrical sounding was made with a half-electrode spacing of 200 m. The results show a layer with a resistivity of 70-80 Ohmm starting at a depth of 25 m. This looks very promising for drilling a borehole. Upstream of the village some 5 boreholes were drilled, all of them successful.

It is advised to drill the borehole in the fractured zone somewhere along the dike, to a depth probably not deeper than 80 m. The quality of the water will be good, the electrical conductivity expected to be around 1000 microSiemens/cm. The inclination of the dyke could not be assessed, but probably it is almost vertical. The best is to drill the borehole within 1 meter of the dike, in order to hit the fractured zone.

The recharge of the water in this area is very good. Water is flowing from the recharge area of the Jabil Isbil complex into the direction of Nazim. Ample water will be available for many years. The quality is expected to be good, EC around 800 microSiemens/cm.



0 500 1000 m

Map 17

approximate scale  
1: 25 000

## 2.18 Al Qaharah

coordinates: X: 485 km; Y: 1578 km; elevation: 2000 m  
 mapsheet: 1444 D2  
 aerial photograph: 859/126  
 soundings: VES 1/88, EM 24,25/88  
 well numbers: 8058-8063

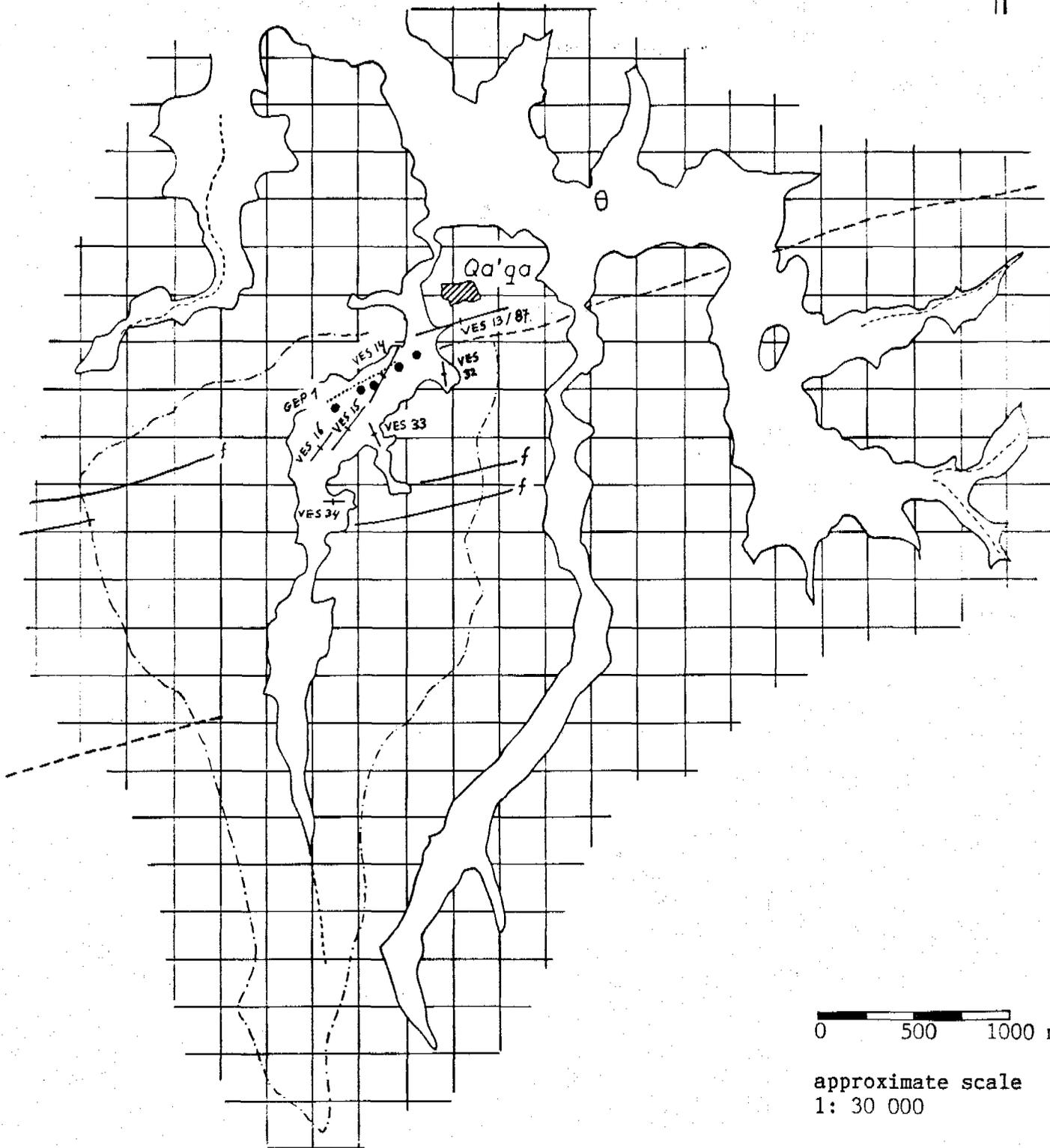
On 24 and 26 October 1988 measurements were carried out to determine a site for drilling a borehole for the water supply of the village Al Qaharah. The village is located in Wadi Hubabah, Ar Riashiyah, approximately 15 km south of Rada'. It has about 250 inhabitants. At present the water is carried by donkey or hand from nearby wells.

At present in and around the village there are some 6 wells, two of which are boreholes. Water was struck at 35 and 90 m respectively. The water quality of these sources is rather poor. Shallow water from the dug wells is better, which benefit from recharge of rainwater from the wadi.

The area is located just on the border of Tertiary volcanic and sandstone formations. Just west of the village the Tawilah sandstone is dipping under the volcanic formations under an angle of about 15°. The dips vary locally, obviously caused by volcanic activity. Numerous sills are found in the sandstone around the village. Dikes are not present in the immediate vicinity. Remnants of (Pleistocene?) alluvial fans overlie the outcropping sandstone west and south of the village.

An electromagnetic measurement was started in a wadi just east of the village, after a reference measurement was made near borehole 8060. This in order to see if a distinction could be found between saline and less saline areas. At some places vertical coil measurements reached high values, probably caused by sills. Finally a site was found with promising conductivities (12-14 Ohmm), that might indicate an area of fresh water. A geo-electrical measurement was carried out at this spot to get more information about the composition of the underground. From a depth of 18 m onward a layer shows up with a resistivity of about 115 Ohmm. This is an indication for a sandstone layer with fresh water and possibly moderate yield.

It is therefore advised to drill on this spot to a maximum depth of 150 m. Once water of good quality has been struck in a quantity that is enough for the village, about 2 l/s, drilling should stop within 5 m after the water has been struck, because a risk exists that water with higher salinity may be hit when drilling continues. Drilling should not continue after a depth of 150 m has been reached.



Map 18

## 2.19 Qa'qa

coordinates: X: 531 km; Y: 1582 km; elevation: 1980 m  
 mapsheet: 1445 C2  
 aerial photograph: 850/108  
 soundings: VES 13,14,15,16,32,33,34/87; GEP 1/87  
 well numbers: not surveyed

During March and April 1987 measurements were carried out in the village Qa'qa in order to select a site for a well for the drinking water supply of the village. The village is located some 50 km east of Rada', about 5 km north of the asphalt road near the market of As Sawadiyah. At present water is used from the 5 shallow wells southwest of the village.

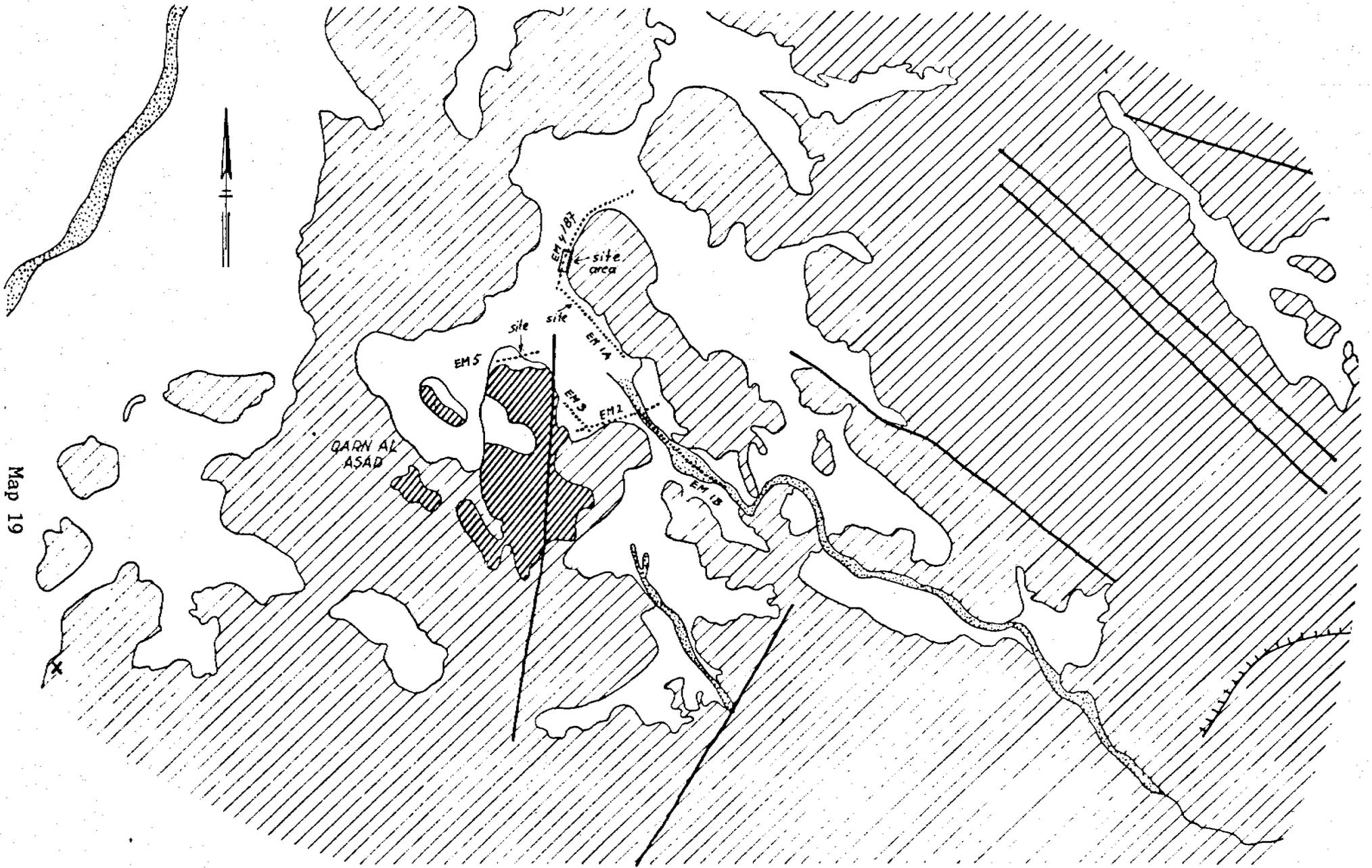
The wells have a low yield in dry periods. Near the village there is a narrow part in the wadi, probably the reason for higher salinities of the groundwater, due to direct evaporation from the risen groundwater table in wet periods. More upstream the water quality is good.

The area consists of gneissic Precambrian rocks, with little weathering. The alluvial wadi fill, usually not more than some 5 m, is rather coarse, especially upstream in the wadi. Some dikes and faults are present in the area.

Since the EM-34 was not available at the time of survey, geo-electrical measurements had to be done; a geo-electrical profile (GEP) was made with half-electrode spacings of 6, 20 and 60 m, in order to get insight in the degree of weathering of the upper part of the Precambrian basement. One measurement (VES 13) was carried out along the dike south of the village. Although a layer with relatively low resistivity shows up, the values are still too high to indicate the presence of water. Two soundings performed in the main wadi indicate unweathered basement starting at a depth of about 5 m. This corresponds with information gathered from the wells. The profile made in the area of the wells indicates an area with lower resistivities between the two wells that are located most to the southwest (see Annex C, stations 8,9,10). Resistivities in the north are low due to the saline water there.

Additional (short) soundings were carried out to the southeast of the wadi. VES 33 and 34 indicate areas of deeper weathering or thicker alluvium. One of these areas corresponds with the area of lower resistivities that shows up in the geo-electrical profile. It is therefore advised to dig a shallow well in that area. The expected depth is 15 m. Water quality is expected to be good, EC around 900 microSiemens/cm.

Since the well will be situated upstream of the other wells, water availability during dry periods is expected to be better than in the wells downstream.



Map 19

44

0 500 1000 m

approximate scale  
1:20,000

## 2.20 Qarn al 'Asad

coordinates: X: 481 km; Y: 1587 km; elevation: 2170 m  
 mapsheet: 1444 D2  
 aerial photograph: 863/200, YE 8/32  
 soundings: EM 1,2,3,4,5/87; EM 13,28-31/85  
 well numbers: 0488-0505

Qarn al 'Asad is situated 7 km south of Rada', along the road to Juban. The village requested a site selection for a second borehole for the village water supply. Although the present well has an excellent yield, the population increased considerably since the well was taken in production, and consequently the consumption will outrange the production of this one well.

All shallow wells in the area are dry or out of use since a few years. Boreholes have been drilled instead, especially in the north successful drillings were performed.

In 1985 four private site selections were carried out (Ilaco, 1986), mainly north of the village. It was already concluded then, that prospectives for borehole drilling in the south or southwest were not very hopeful. Moreover, some of the sites selected then, did not result in good wells. This proves that geophysical prospecting in this area must be carried out with great care.

The area is located at the southeastern border of the Rada' catchment, in fact very close to the main watershed of the Al Bayda province. The whole area comprises Tertiary volcanic formations, in the east some big volcanic cones and dykes mark the area. The village itself has been built on and around an eroded volcanic cone.

North of the village 5 electromagnetic profiles were made. EM 2, from the village to the wadi, does not show any site of interest. EM 1b, going to the east through the wadi, shows some anomalies, but not big enough to indicate favourable drilling conditions. EM 1a, 3, and 5 show some places of interest. Areas can be found with horizontal coil conductivities of around around 15 mmho/m, which corresponds with an apparent resistivity of about 65 Ohmm. These values are usually favourable for drilling, as can also be seen from a borehole drilled near such a spot shown on EM 28/85. In EM 4/87 a prominent anomaly occurs, that may also give good chances to find water.

It is advised to drill on one of the sites indicated on the map. The order of preference is EM 5, EM 1a, EM 4. The depth should not exceed 180 m. The water quality is expected to be good, EC around 600-700 microS/cm.

There is a danger of overpumping in this area, as is also seen in other Tertiary volcanic areas. The recharge area is not so large, and the fact that the area is situated close to the main watershed enlarges the danger of depletion of the aquifer.

2.21

## Qaru'al

coordinates: X: 474 km; Y: 1579 km; elevation: 2730 m  
 top. mapsheet: 1444 D2  
 aerial photograph: YE 8/14  
 measurements: EM 26/88, VES 30,31,32/86  
 well numbers: 1310, 1311, 1366, 1367

Qaru'al is situated approximately 16 km southwest of Rada', at the edge of the Ar Riashiyah escarpment, at an elevation of about 2700 m. For the geological map see Map 4 on page 12.

In 1986 three geo-electrical measurements were carried out, one of which seemed hopeful for drilling. Drilling took place in 1987 but did not result in a successful well. Another borehole was drilled near the village, almost on top of the escarpment. In both boreholes very little water was struck at shallow depth.

It must be concluded therefore, that the availability of sufficient quantities of groundwater in this area is at least questionable.

Nevertheless, upon request a new visit was paid to the village, and a site selection was carried out. Near the spring, at the northeast side of the escarpment, draining to the Wadi Hubaba, a fault could be seen on aerial photographs and in the field. The presence was evidenced by an electro-magnetic measurement over this fault. Here a possible site for drilling was indicated with an iron bar in the field.

It should be stated once more however, that chances to find water in large quantities here are very small. Drilling at this site should not continue to a depth deeper than 60 m. Whenever some water is struck before this depth, drilling should stop within two meters, since the water may be lost to deeper formations. This also happened to the second borehole drilled in 1987, where little water was struck between 20 and 40 m. The water level is now found at a depth of 97 m.

The catchment area for the indicated site is small; a well drilled here may tap the same water as the spring, so the yield of the spring might decrease, or the spring may even fall dry in future. If no water is found at the site resulting from the EM measurement, it could be tried to drill a borehole inbetween the two drilled in 1987. Better would be however, if the village could arrange to have a well drilled more in the direction of Bayt an Nuwayrah, since a lot of successful wells are drilled in that area.

## 2.22 Al Qum'ala (Al Haikal)

coordinates:	X: 554 km; Y: 1555 km; elevation: 1940 m
mapsheet:	1445 C4
aerial photograph:	363/92
soundings:	EM 16,17,18/87
well numbers:	not surveyed

On 27 October 1987 a site selection was carried out for the village Al Qum'ala. The village is located just south of the asphalt road, some  $7\frac{1}{4}$  km southeast of Minqatah (Dhi Na'im). For the geological map see Map 13 on page 32.

At present the people get their water from a shallow well east of the village. This well gives water for 1 hour per day; the water has to be shared by 3 villages.

The area is draining towards the northeast, into the Wadi Bayhan. The village and its surroundings are located on a circular granitic intrusion, separated from metavolcanic formations in the east by a large sheerfault. In this fault a wadi developed in which the present water supply well was dug. Experience in similar areas (Al Bayda town, Madhwaqayn, Az Zahir) has learned that secondary porosity in these faults is low. They offer no opportunities for borehole drilling.

The granite is very dense, porosity is very low, and fissures, if any, are hardly developed. This was evidenced by a shallow well dug by the villagers, that has to recover two weeks after 3 hours pumping (storage).

Three electro-magnetic profiles were made. The profile west of the village (EM 18/87) did not reveal any promising site. Indeed, conductivities are very low and the few wells in this wadi are dry or yield very little water. EM 17/87 was made to detect an observed zone of granite virtually weathered at the surface, but also here conductivities were very low. The first profile, EM 16/87, seems to offer the best chances. Although WNW/ESE running faults observed on the aerial photographs do not show up on this EM profile, a zone with higher conductivities was found between two shallow wells, upstream of the existing water supply well.

It is advised to dig a shallow well in this area to a depth of approximately 20 m. The yield will be in the same order as the existing shallow well, maybe somewhat higher. Water quality is expected to be fair, EC about 1600 microSiemens/cm.

## 2.23 Ar Ruba'atayn (Juban)

coordinates: X: 487 km; Y: 1542 km; elevation: 2120 m  
 mapsheet: 1344 B2  
 aerial photograph: 850/132  
 soundings: VES 10/87  
 well numbers: not surveyed

In February 1987 a site selection was performed for the area of Ar Ruba'atayn, consisting of a number of hamlets and small villages, to select a site for a well for their water supply scheme. Ruba'atayn is one of the most southerly situated villages in the Juban district, about 7 km from Juban town. For the geological map see Map 15 on page 36.

A number of boreholes have been drilled in the area, some of which have reasonable or good yields. Water is usually struck at depths below 130 m, sometimes even deeper than 180 m. This makes geophysical prospecting in this area a quite tricky business.

The area consists of a plateau that is elevated above the plains around Na'wah in the north. (see also 2.16). The mountains that form the watershed are formed by Tawilah sandstone formations, whereas the wadis and plains are eroded into the Precambrian basement, locally consisting of gneisses and migmatites. Several faults intersect the area. The main faults run almost west/east, smaller faults run perpendicular to those in an almost north/south direction. They can be seen clearly in the basement surrounding the area, in which wadis have sometimes deeply incised.

Only geo-electrical equipment was available at the time of the survey. A sounding was made somewhere in the wadi. The results show layers with a high resistivity, indicating the Precambrian basement. According to the interpretations at a depth of 106 m a layer with much lower resistivities is present, that looks very promising for drilling a borehole. However, part of this lower conductivity may also be caused by water of a higher salinity.

Nevertheless it seems that chances are good to drill a borehole somewhere in this wadi. The depth of the well should not exceed 200 m. It is difficult to predict the quality of the water. The EC will probably be higher than 1000 microSiemens/cm.

It is hard to come to a conclusion on the extent of the aquifer and the future availability of water, since the water is found at great depth. Usually the storage in faults or fissured zones is low. However, since geological information is lacking about the boreholes drilled in the area so far, it is not sure whether water is tapped from such structures or from weathered zones in the basement.

## 2.24 Sabah (Dhi Na'im)

coordinates: X: 548 km; Y: 1555 km; elevation: 2000 m  
 mapsheet: 1445 C4  
 aerial photograph: YE 3/73  
 soundings: EM 23,24,25,26/87  
 well numbers: 6103 (partly surveyed)

At the request of the LCCD in Dhi Na'im a site selection was carried out on 16 November 1987 for the village Sabah. The village is located 3 km south of Al Minqatah, and about 3 km from the asphalt road. The geological map of the area can be found on page 14, Map 5.

At present the village is supplied by water from a shallow well in the southern part of the wadi east of the village. This well can pump for 1 hour per day. The yield of other wells (about 10) in the wadi is more or less the same, pumping can take place between 1 and 2 hours per day. No attempts have been made so far to drill boreholes in this area.

The main wadi drains to the north into the wadi Bayhan. The upstream catchment area is about 4-5 km<sup>2</sup>. The wadi is embedded in rocks of metavolcanic origin. There is a distinct schistosity in a direction of about 15°. On the aerial photograph some distinct faults can be discerned, running in a west/east direction. It was decided to make a long electromagnetic profile in the main wadi to see if any promising sites could be found related to these faults.

Unfortunately no major anomalies were encountered. EM 24/87 was made in order to examine one of the faults more closely, but although some evidence for the fault was found, it is doubtful if it will be promising for drilling or digging a well. Another profile, EM 25/87, made in the village, also did not reveal any special site.

A last profile was made in a wadi west of the village, wadi Ath Thaybah. This wadi also runs from south to north, but drains to the west, directly into the plain of the Dhi Na'im area. This wadi developed in gneissic formations, that show a somewhat higher degree of weathering than the formations around the main wadi east of the village. The profile ended near two shallow wells, both yielding water about 5 hours per day.

Although no evidence from the measurements could be found for good water bearing properties of the formations in this wadi, it is advised to dig a shallow well in this area, since these wells seem to have a reasonable yield. Upstream of the two shallow wells, at the junction of the small wadi coming from the village and the Wadi Ath Thaybah would be the best place. The well should have a depth of about 20 m. Water quality is expected to be good, EC about 800 microS/m.

It is advised not to drill boreholes in this area. The results will most probably be disappointing.

## 2.25 Ash Sharaf (Sabah)

coordinates: X: 467 km; Y: 1585 km; elevation: 2620 m  
 mapsheet: 1444 D1  
 aerial photograph: YE 8/35  
 soundings: VES 22,23,24,25,26/87  
 well numbers: 1343-1437

At the request of the LCCD a site selection was carried out for a well for the drinking water supply of the village Ash Sharaf on 15 and 24 March 1987. The village is situated on the northern escarpment of the Sabah area, some 3 km west of Sudan. For the geological map see Map 12 on page 30.

South of the village a plain is sloping to the south, where finally a narrow wadi forms the outlet of the small catchment, draining to the next plain between Al Khanaq and Al Hajar.

At present people mainly drink from the nearest well, from which water is fetched with donkeys. In the lower part of the valley some 5 wells are present with low to moderate yields. No boreholes have been drilled yet in this area.

Five geo-electrical soundings were carried out with half electrode spacings varying between 150 and 600 m. The results of all soundings clearly show the presence of alternating tuff and basalt layers, with either very low or very high resistivities (10 Ohmm and above 1000 Ohmm respectively). No water can be expected in these layers. The maximum interpretation depth of the measurements with the longest electrode spacing is about 150-200 m. Experience with 3 dry boreholes north of Sudan has learned that tuffs being present below this depth yield no water. It must therefore be dissuaded to drill boreholes in the area of Ash Sharaf.

It is advised to dig a shallow well downstream of the well from which people drink at this moment, at the junction of two minor wadis. This is little downstream of VES 26/87. The expected depth is between 15 and 20 m, depending on the depth at which water is encountered. The water quality is expected to be good, EC about 600 microS/cm. The site is known to the representative of the village.

## 2.26 Tayyab

coordinates: X: 551 km; Y: 1564 km; elevation; 1910 m  
mapsheet: 1445 C1  
aerial photograph: 863/90  
soundings: EM 8,9,10,11,12,13/88  
well numbers: 6114-6131

At the request of the LCCD in Dhi Na'im a site selection was carried out for the village Tayyab. The village is located in the area of Dhi Na'im, some 5 km north of the asphalt road. For the map see Map 20 on the next page.

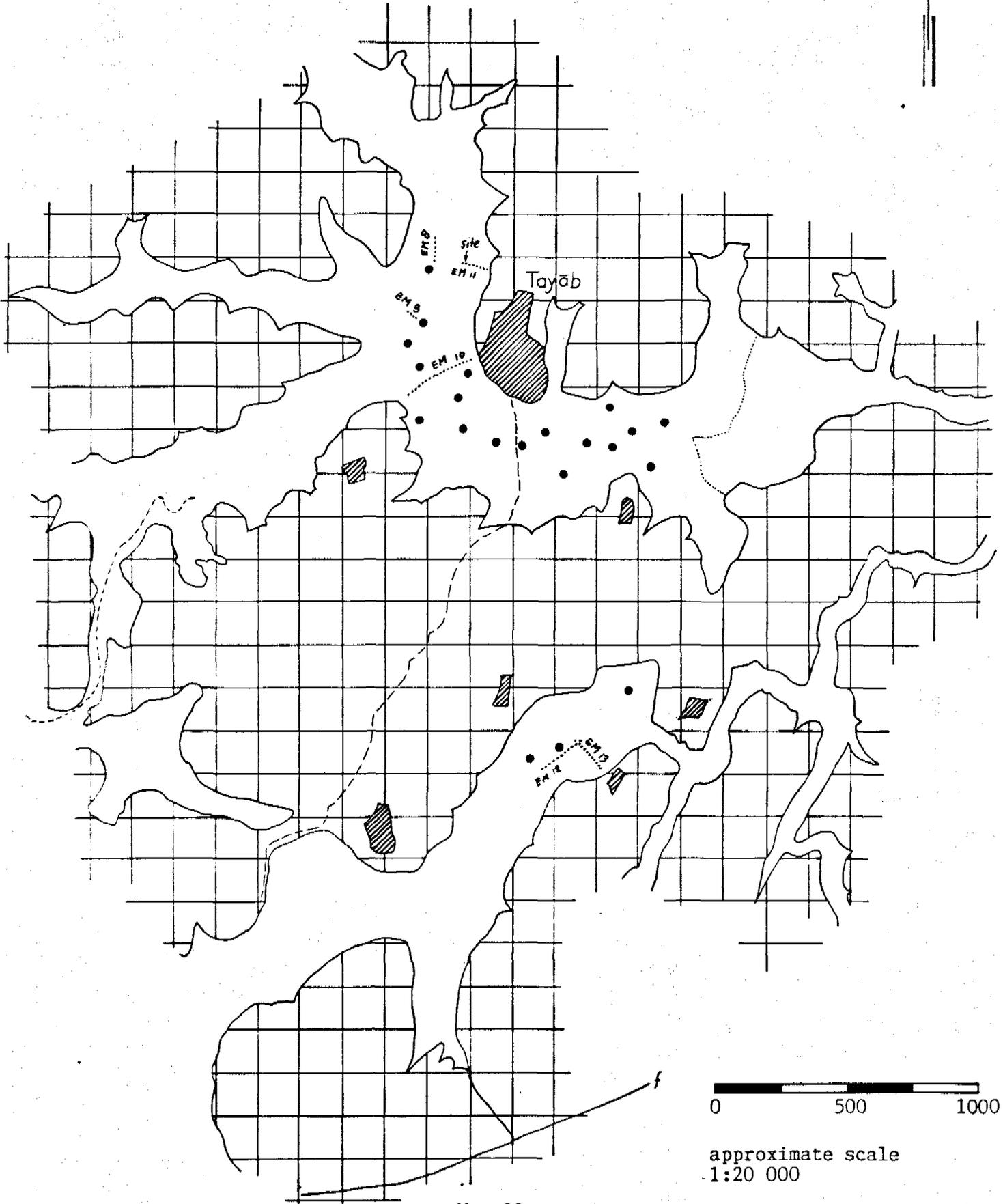
At present the village abstracts water from a well shared with private farmers; the water is pumped to a reservoir and distributed from there distributed over the village. A separate well is required to be able to meet the demand in future.

The area comprises gneissic and schistic Precambrian basement, the wadis are filled with deposits to a depth of 15 m at the maximum. It seems that ample water is available in the wadi. A well inventory carried during the well siting survey showed that the quality of the water decreases downstream, where EC's increase due to a large water logged area.

Three electromagnetic profiles were made in order to assess a suitable site for a new well. Anomalies caused by faults or dikes were not found, but some indications for promising places were found however. One suitable place found in profile EM 10,10a seemed not very accepted by the people. Later a site was found close to the existing water supply well EM 11, EM 11a. This site was indicated with an iron pole. Water quality is expected to be good at this site, around 800-900 microSiemens/cm.

When this site was selected, the representative asked to extend the survey to a small hamlet in the wadi southeast of the village. Another three soundings were carried out here.

The water availability seems to be much less than in the other area. Conductivities are higher here however, probably caused by a higher salt content. Two sites were indicated (EM 13/88). Water quality is expected to be moderate, around 1500 microSiemens.



Map 20

0 500 1000 m

approximate scale  
1:20 000

## References

BRGM, 1981

Al Bayda Ma'rib Project; evaluation of mineral resources potential  
1980 campaign YOMINCO

Geophysical Prospecting, Vol. 29 No. 6

Electromagnetic prospecting for groundwater in Precambrian terrains  
in the Republic Upper Volta, by Palacky, Ritsema and de Jong

Ilaco, 1984a

Rada' Integrated Rural Development Project, Study into water  
resources in Al Bayda Province. Vol. I, II, III, IV, Arnhem, The  
Netherlands

Ilaco, 1984b

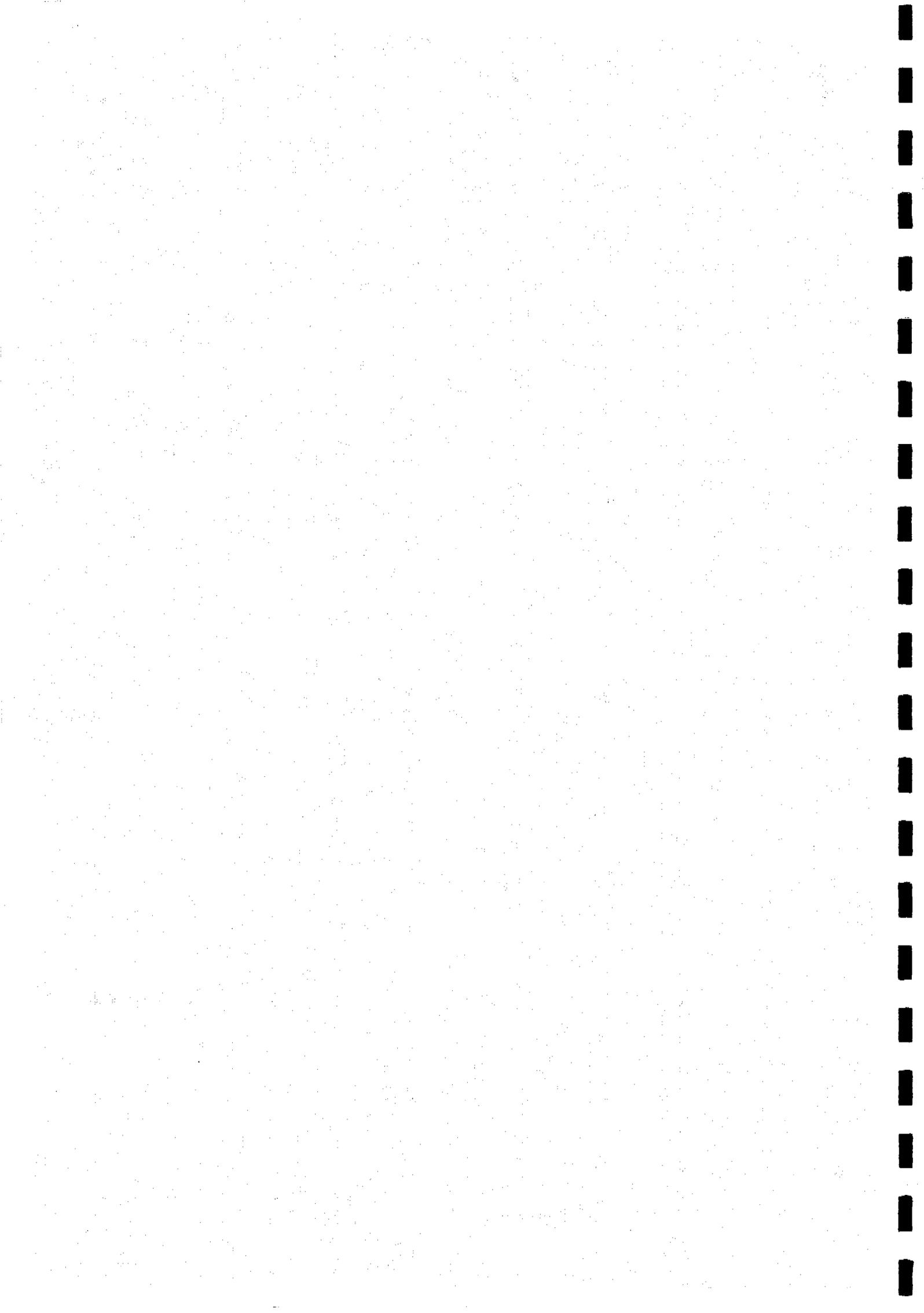
Rada' Integrated Rural Development Project, Study into water  
resources in Al Bayda Province. Addendum, Arnhem, The Netherlands

Ilaco, 1986

RIRD, Groundwater investigations fifth phase, Geophysical survey  
in the Dhamar and Al Bayda Province March 1984 - May 1986. Arnhem,  
The Netherlands

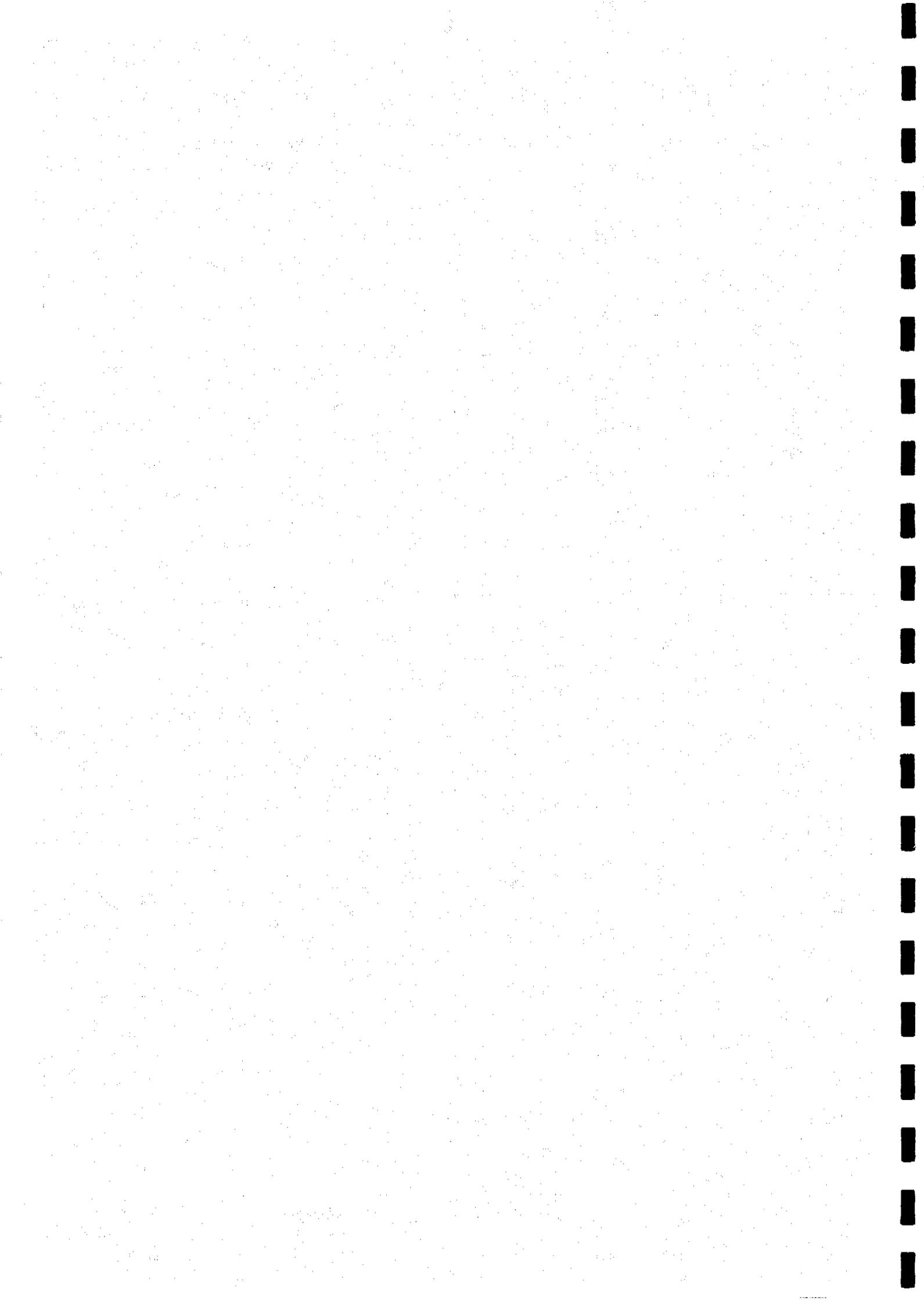
Ilaco, 1987

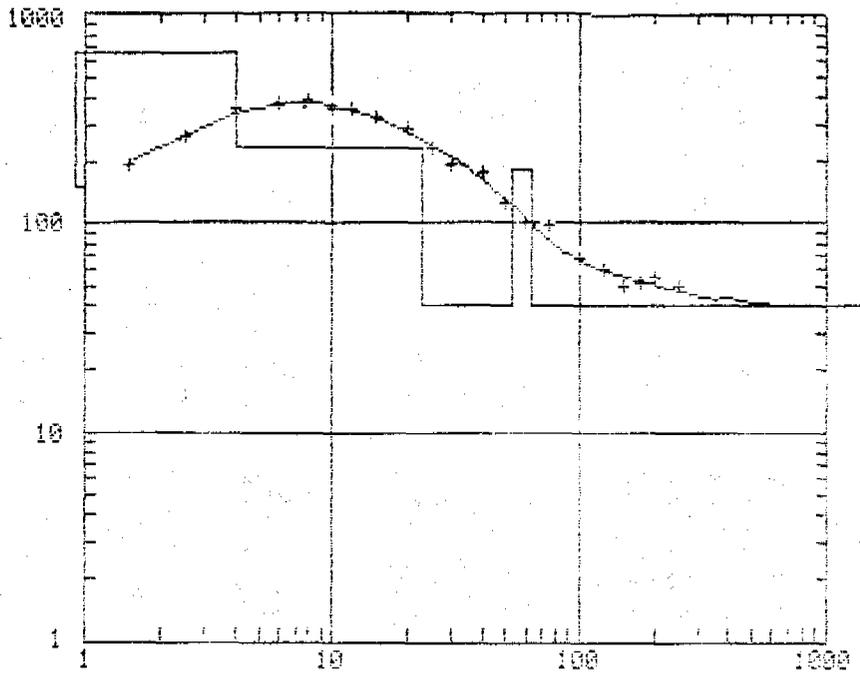
RIRD, Groundwater investigations sixth phase, Geophysical survey  
in the Al Bayda Province May 1986 - December 1986, Arnhem, The  
Netherlands



ANNEX A

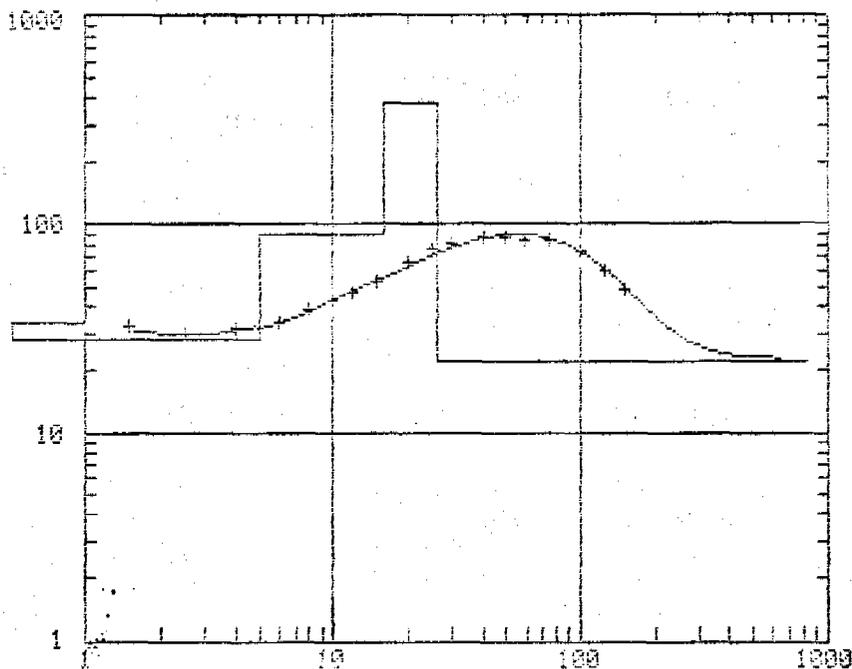
GEO-ELECTRICAL  
SOUNDINGS





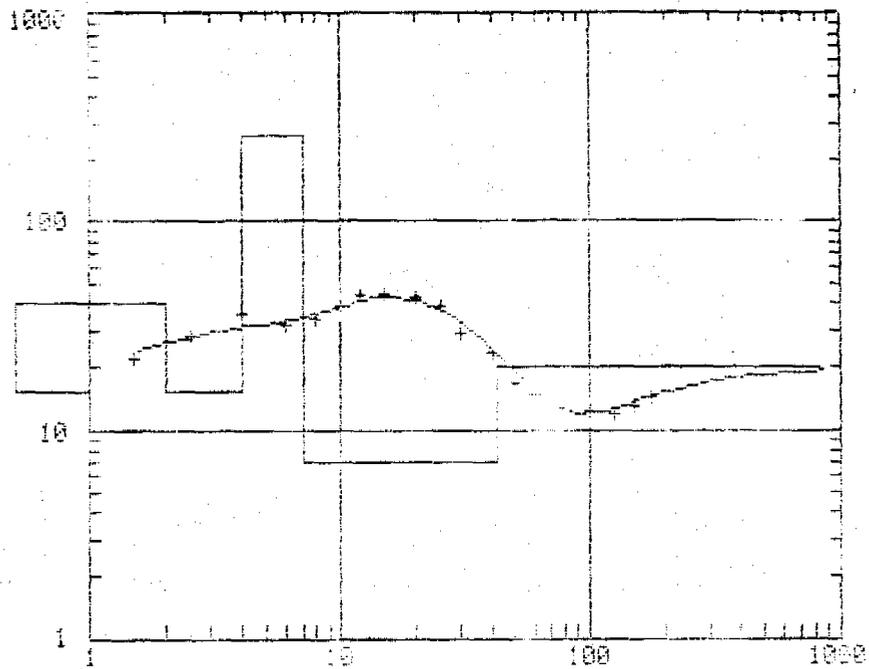
Dar Khalaban VES 1/87

layer	resistivity	thickness	depth
1	150	.9	.9
2	650	2.8	4
3	230	19	23
4	40	30	53
5	180	10	63
6	40	infinite	



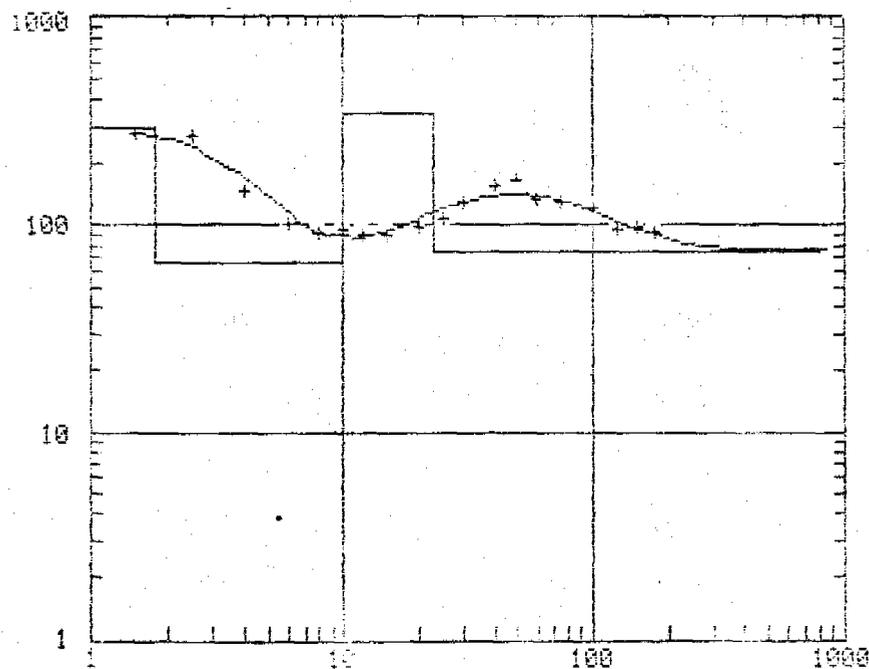
Dar Khalaban VES 2/87

layer	resistivity	thickness	depth
1	34	.5	.5
2	28	4	5
3	90	11	16
4	380	10	26
5	22	infinite	



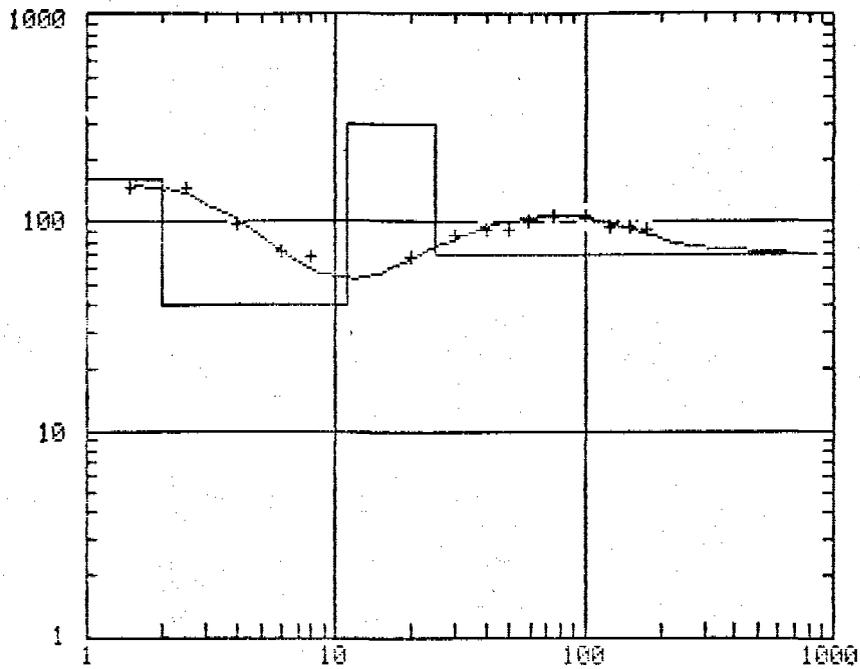
Dar Khalaban VES 3/87

layer	resistivity	thickness	depth
1	15	.5	.5
2	40	1.5	2
3	15	1.5	4
4	260	2.5	7
5	7	35	42
6	20	infinite	



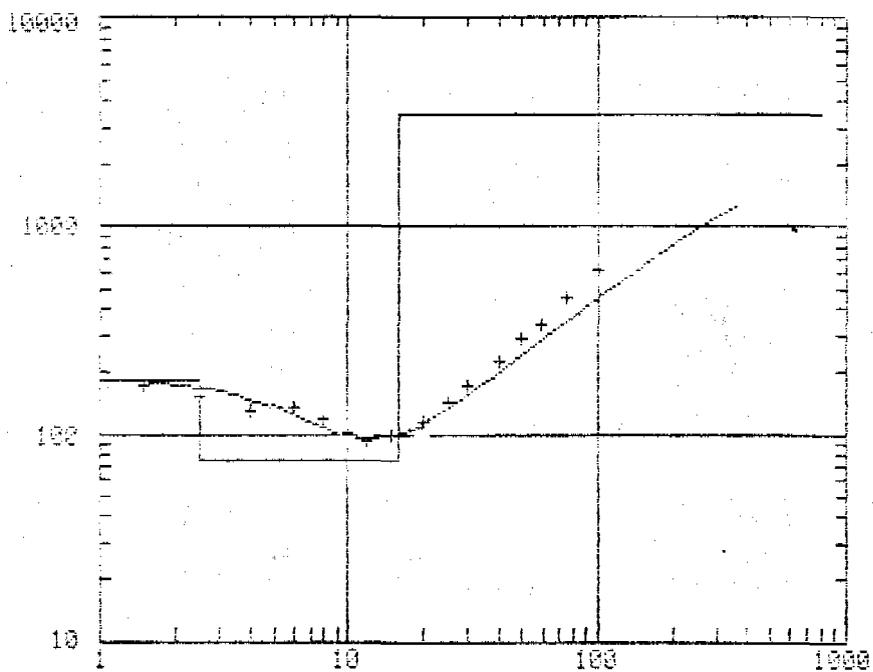
Al 'Abil VES 4/87

layer	resistivity	thickness	depth
1	300	1.8	1.8
2	65	8	10
3	350	13	23
4	75	infinite	



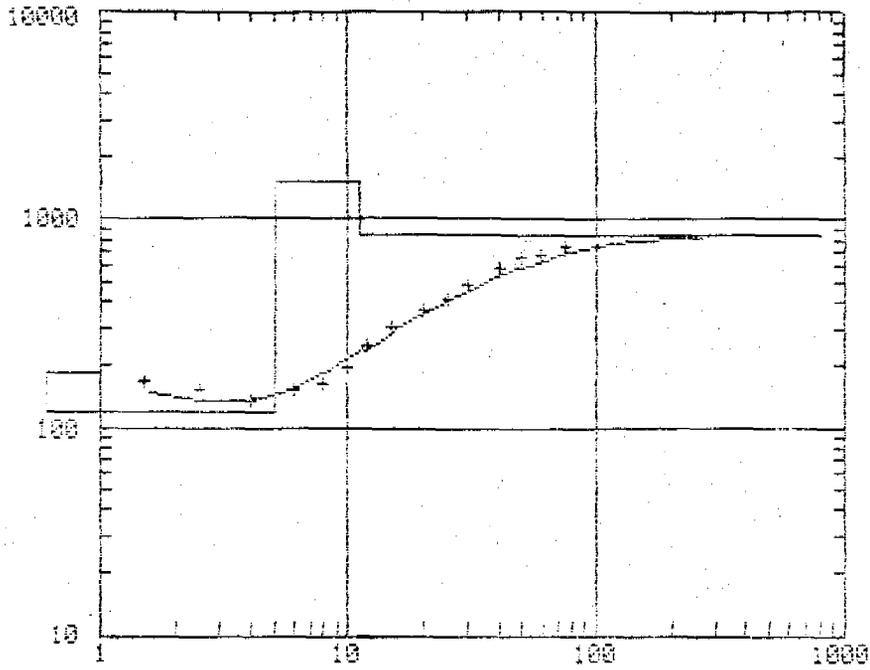
An Nazim VES 5/87

layer	resistivity	thickness	depth
1	160	2	2
2	40	9	11
3	300	14	25
4	70	infinite	



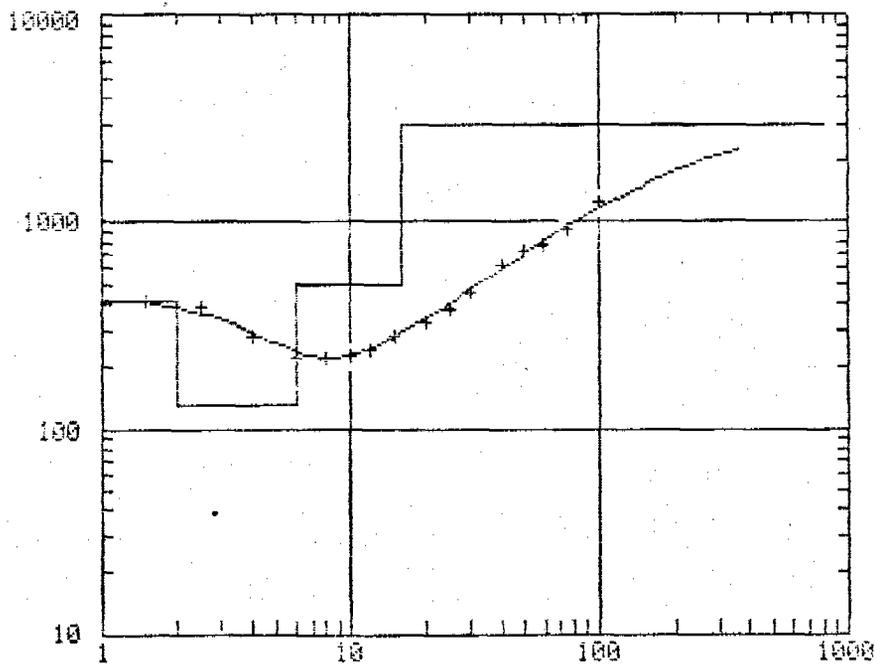
Al Arad VES 6/87

layer	resistivity	thickness	depth
1	180	2.5	2.5
2	75	13	16
3	3500	infinite	



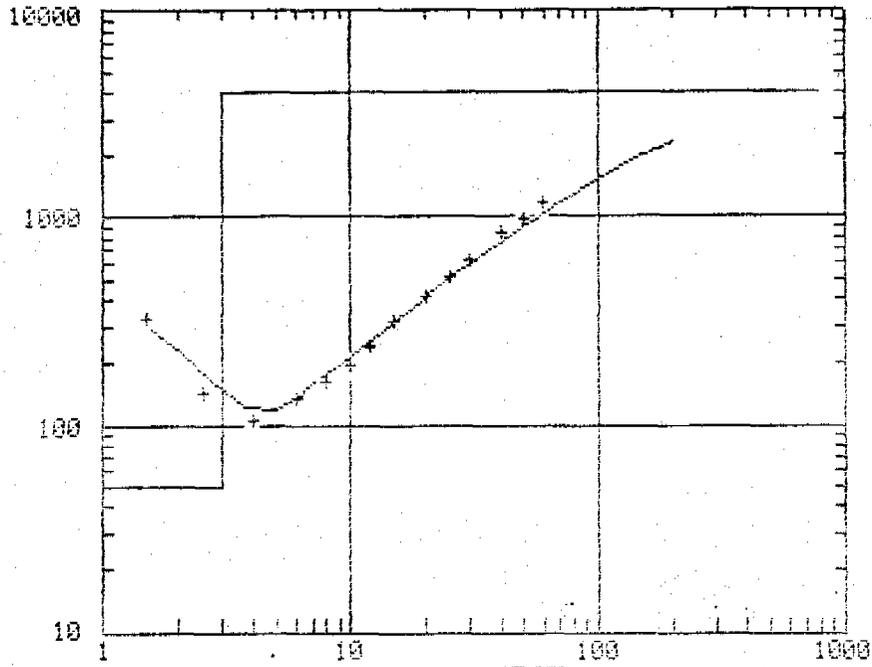
'Arad VES 7/87

layer	resistivity	thickness	depth
1	180	.6	.6
2	120	4.5	5
3	1500	6	11
4	850	infinite	



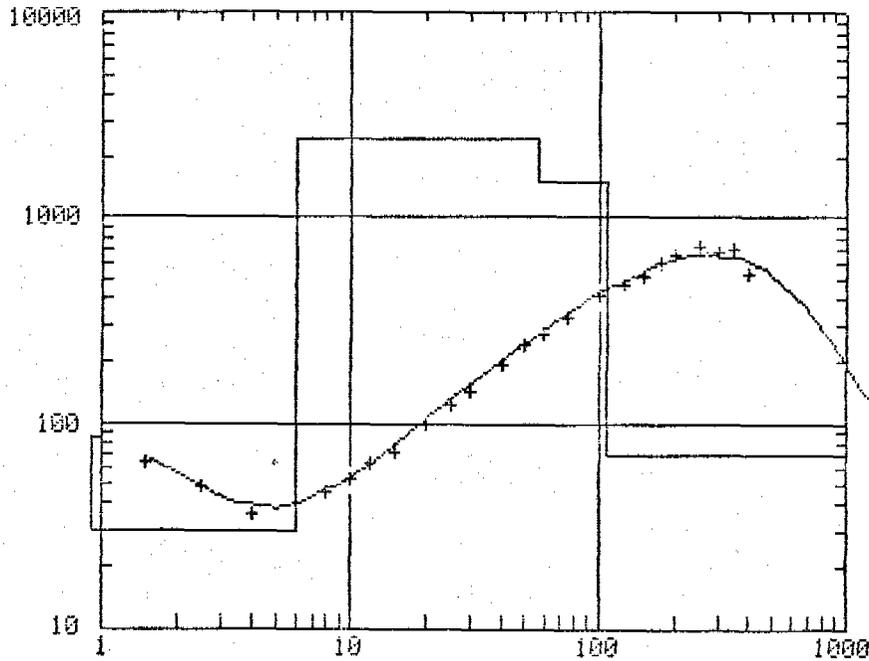
'Arad (At Taffah) VES 8/87

layer	resistivity	thickness	depth
1	420	2	2
2	130	4	6
3	500	10	16
4	3000	infinite	



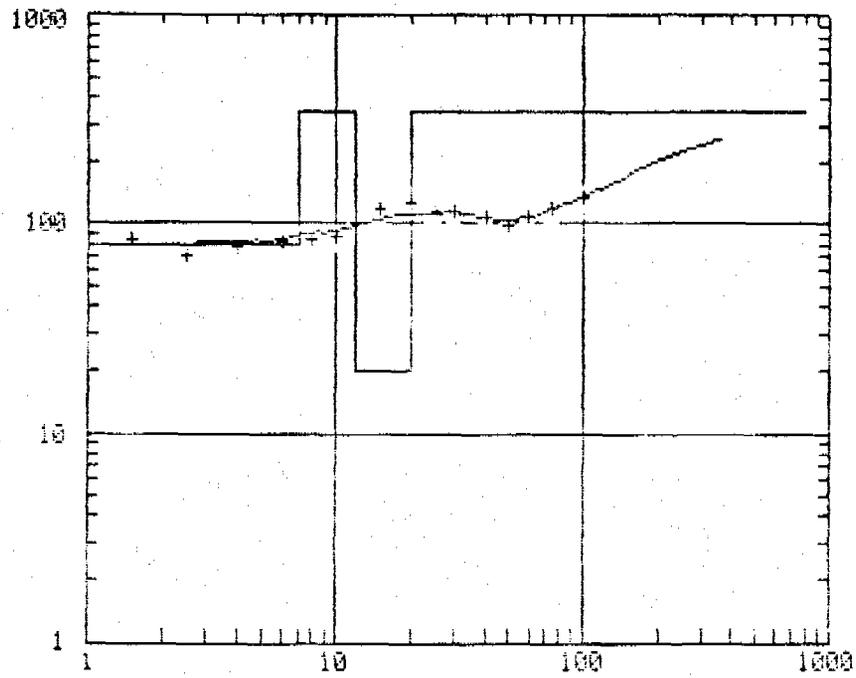
Al 'Arad VES 9/87

layer	resistivity	thickness	depth
1	400	1	1
2	50	2	3
3	4000	infinite	

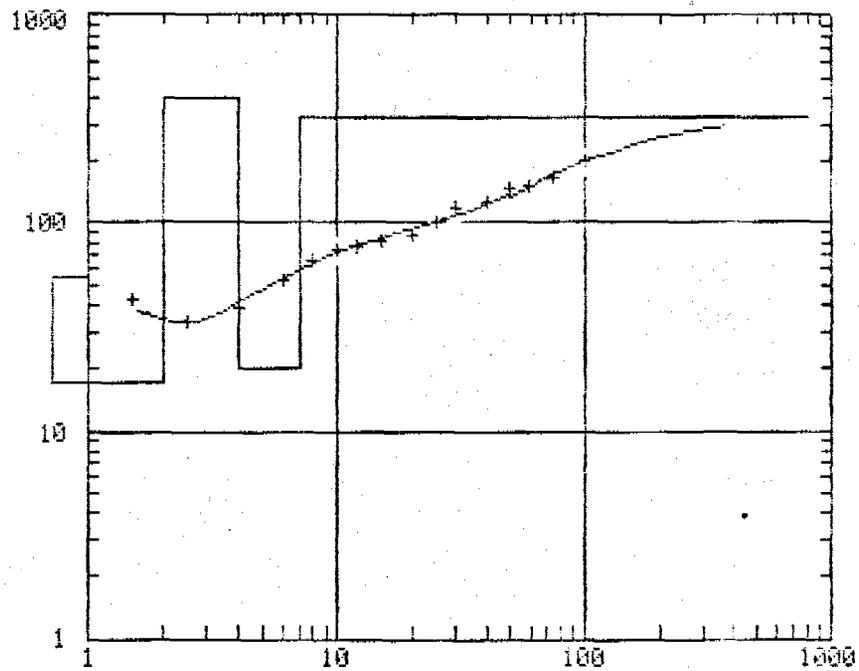


Ruba'atayn (Zuban) VES 10/87

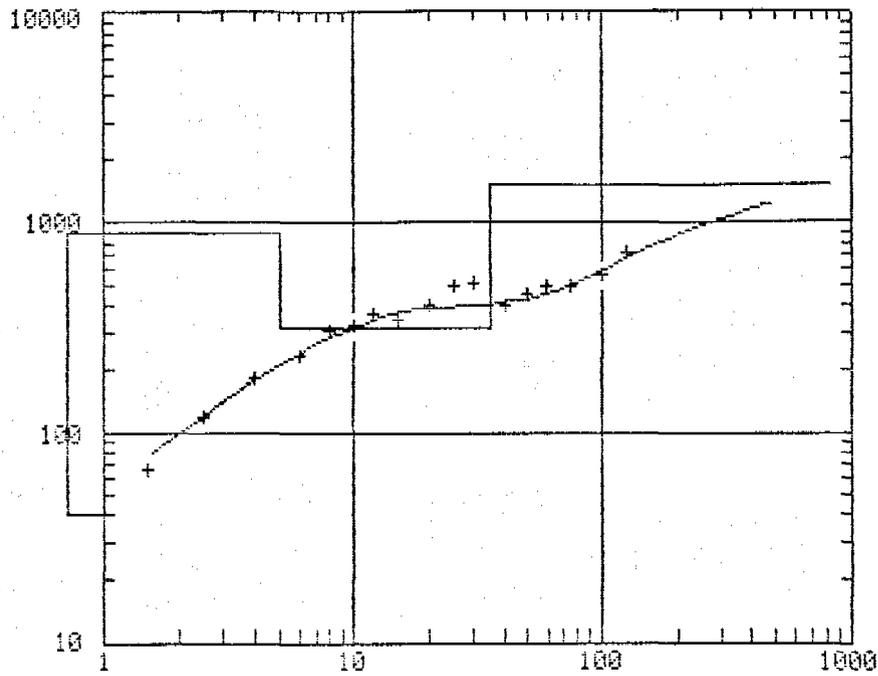
layer	resistivity	thickness	depth
1	85	.9	.9
2	30	5	6
3	2500	50	56
4	1500	50	106
5	70	infinite	



layer	resistivity	thickness	depth
1	80	7	7
2	350	5	12
3	20	8	20
4	350	infinite	

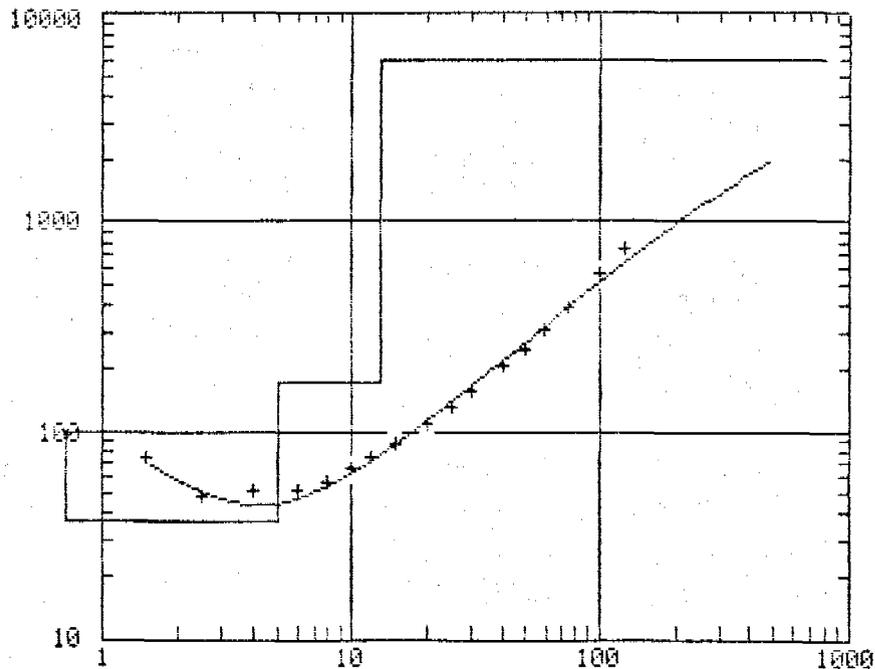


layer	resistivity	thickness	depth
1	55	.7	.7
2	17	1.2	2
3	400	2.2	4
4	20	3	7
5	320	infinite	



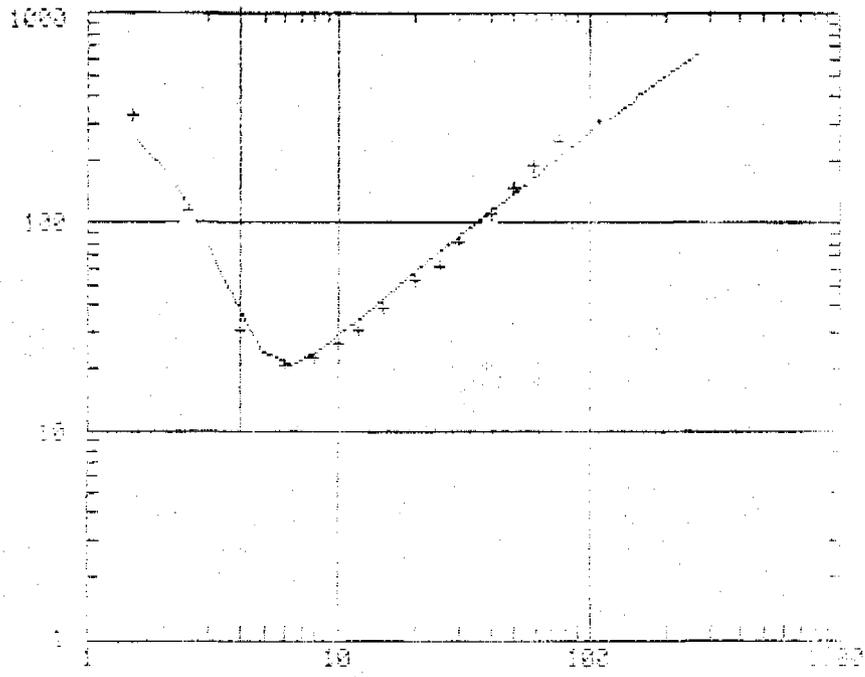
Qa'qa VES 13/87

layer	resistivity	thickness	depth
1	40	.7	.7
2	900	4	5
3	320	30	35
4	1500	infinite	



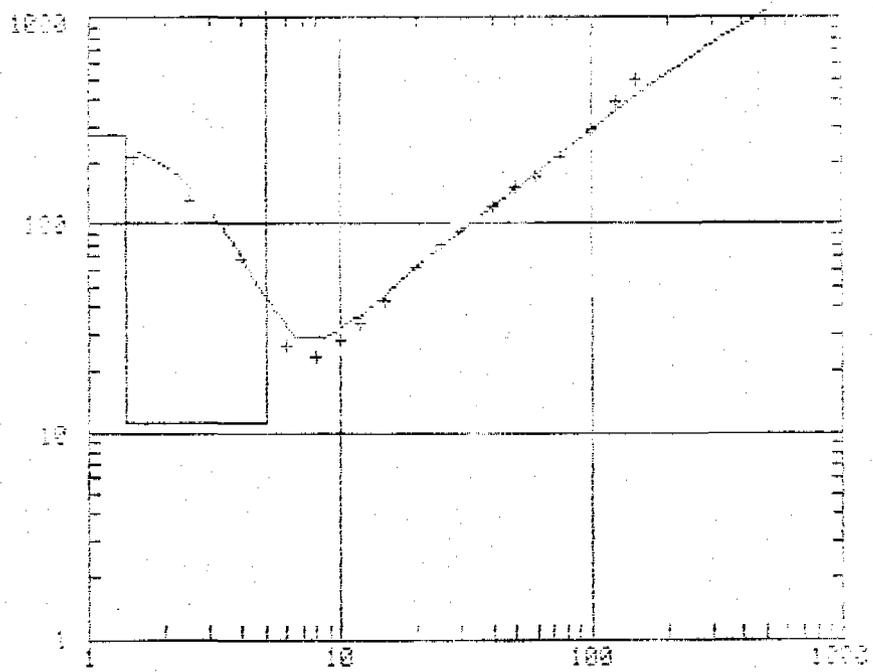
Qa'qa VES 14/87

layer	resistivity	thickness	depth
1	100	.7	.7
2	37	4.3	5
3	170	8	13
4	6000	infinite	



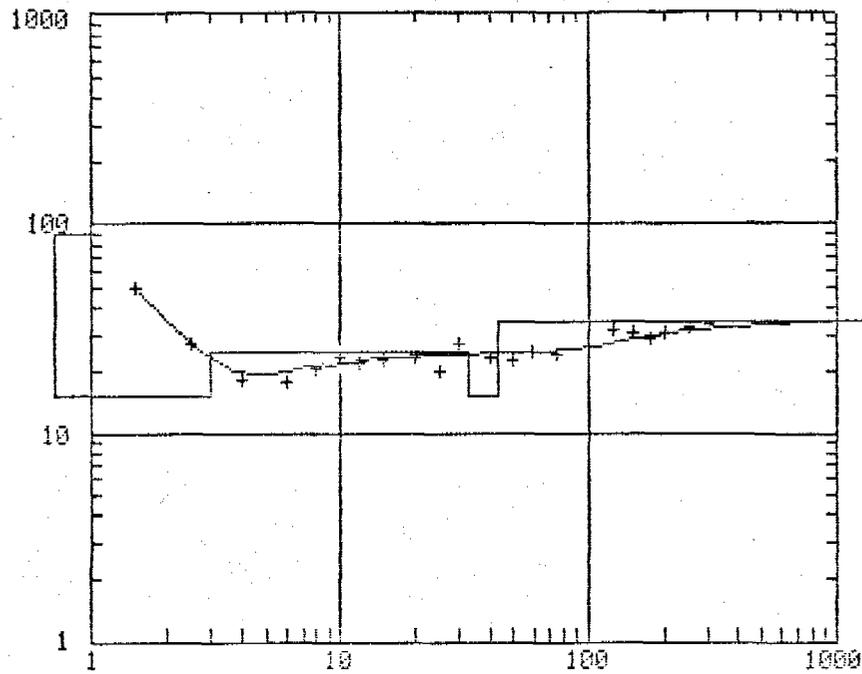
Qa'qa VES 15/87

layer	resistivity	thickness	depth
1	380	1	1
2	10	3.2	4
3	2500	infinite	



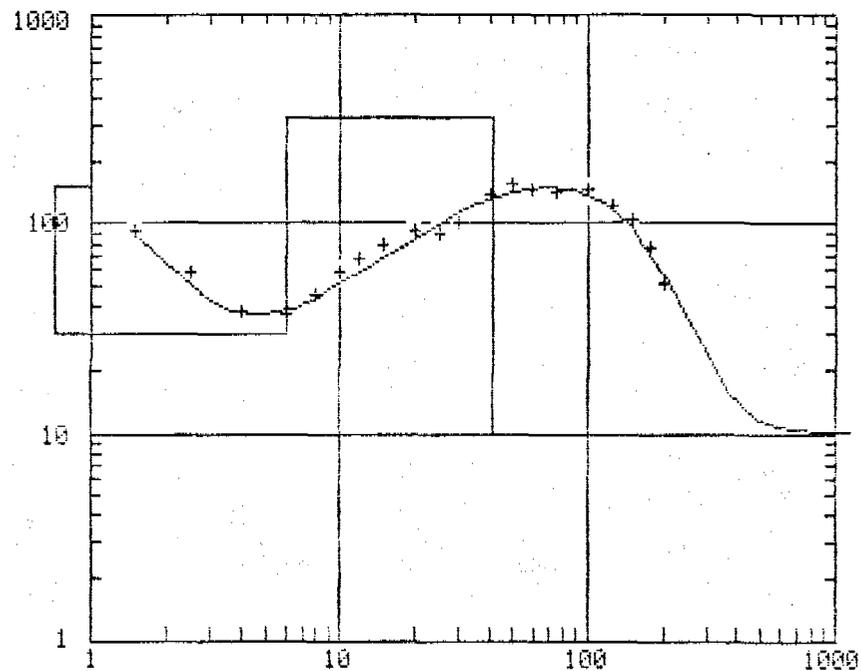
Qa'qa VES 16/97

layer	resistivity	thickness	depth
1	270	1.4	1.4
2	11	3.3	5
3	3000	infinite	



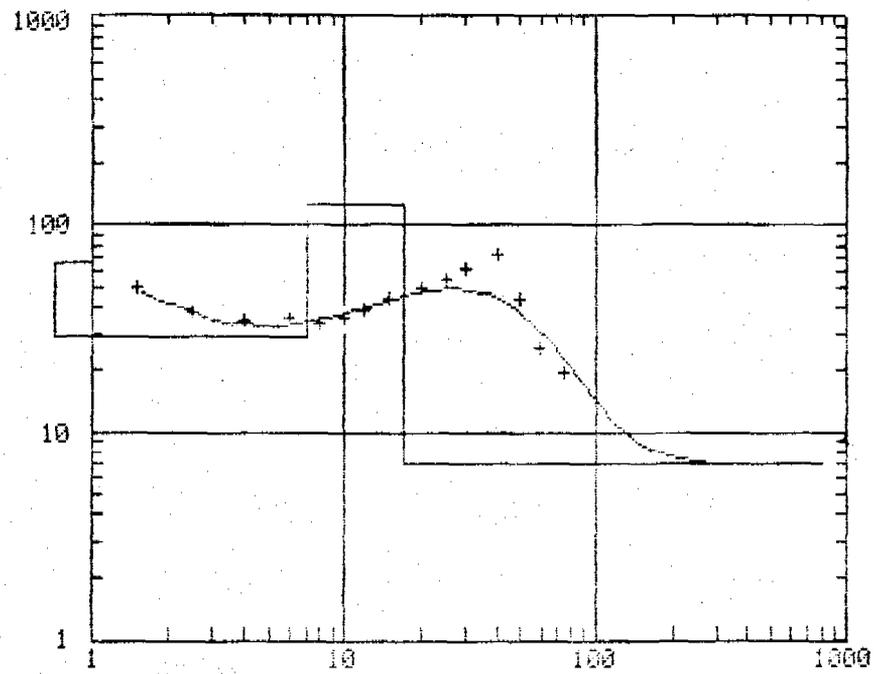
Maswarah (Sabah) VES 17/87

layer	resistivity	thickness	depth
1	90	.7	.7
2	15	2	3
3	25	30	33
4	15	10	43
5	35	infinite	



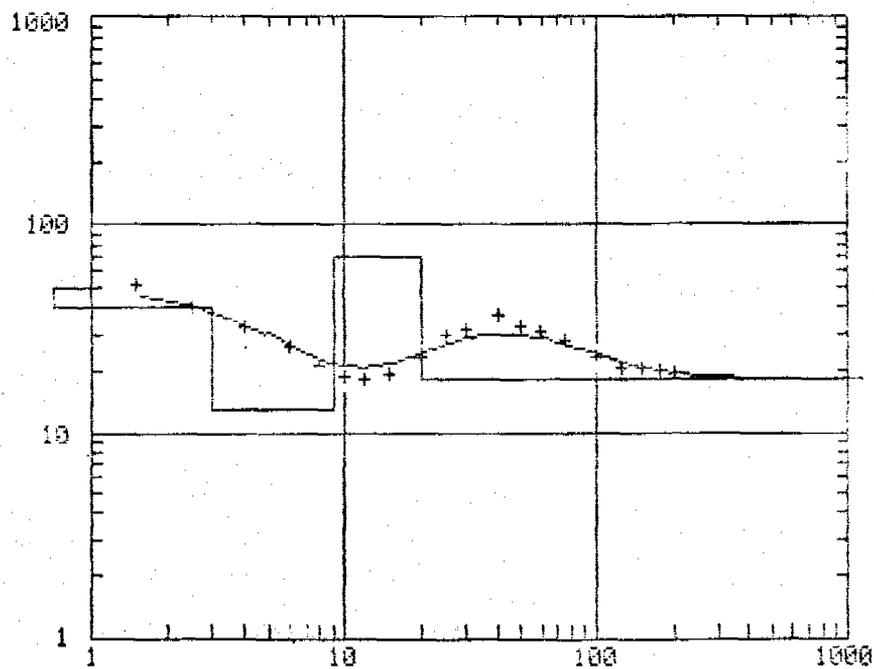
Maswarah (Sabah) VES 18/87

layer	resistivity	thickness	depth
1	150	.7	.7
2	30	5	6
3	325	35	41
4	10	infinite	



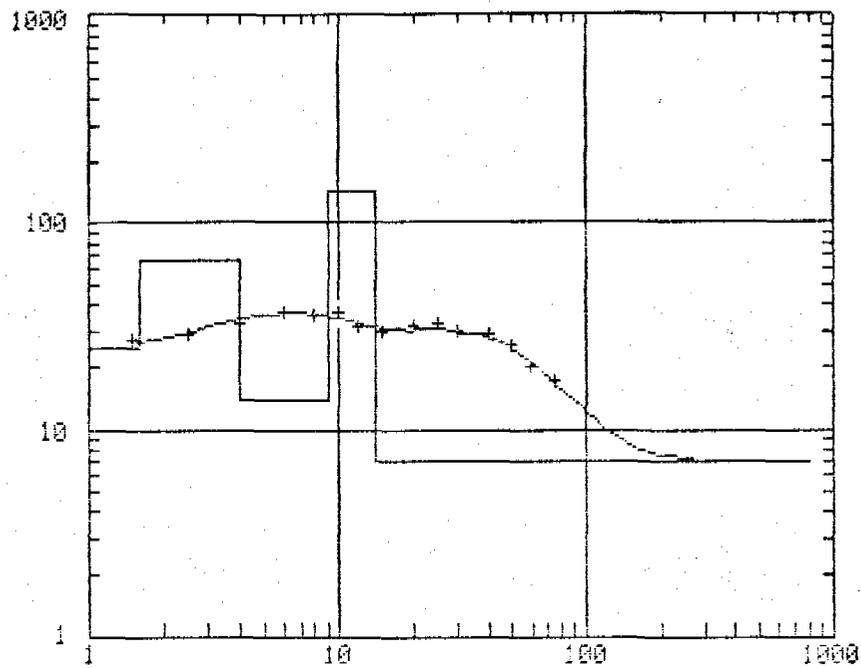
Maswarah (Sabah) VES 19/87

layer	resistivity	thickness	depth
1	65	.7	.7
2	29	6	7
3	125	10	17
4	7	infinite	



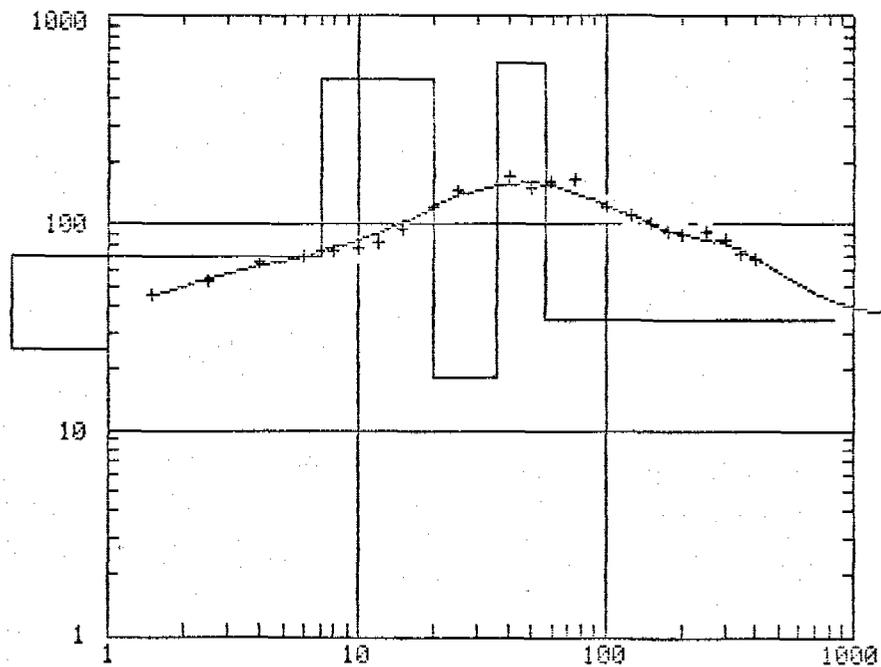
Maswarah (Sabah) VES 20/87

layer	resistivity	thickness	depth
1	50	.7	.7
2	40	2	3
3	13	6	9
4	70	11	20
5	18	infinite	



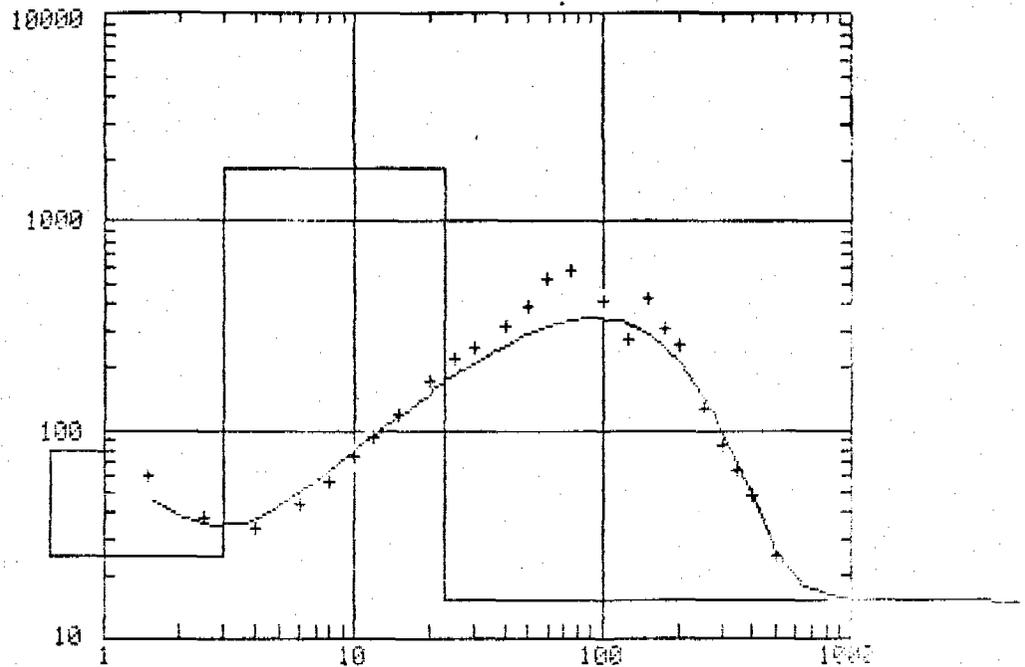
Maswarah (Sabah) VES 21/87

layer	resistivity	thickness	depth
1	25	1.6	1.6
2	65	2.4	4
3	14	5	9
4	140	5	14
5	7	infinite	



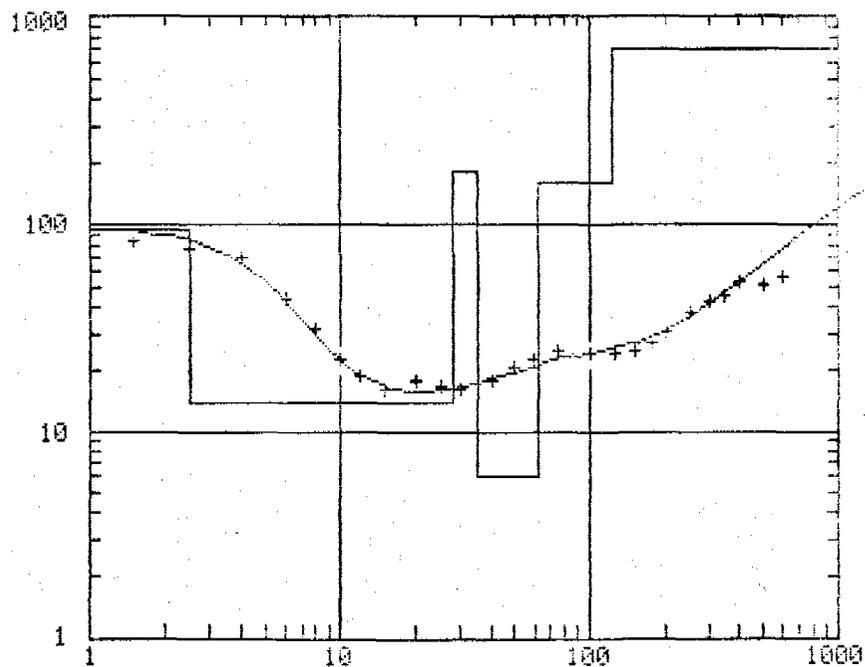
Ash Sharaf (Sabah) VES 22/87

layer	resistivity	thickness	depth
1	25	.4	.4
2	70	7	7
3	500	13	20
4	18	16	36
5	600	20	56
6	35	infinite	



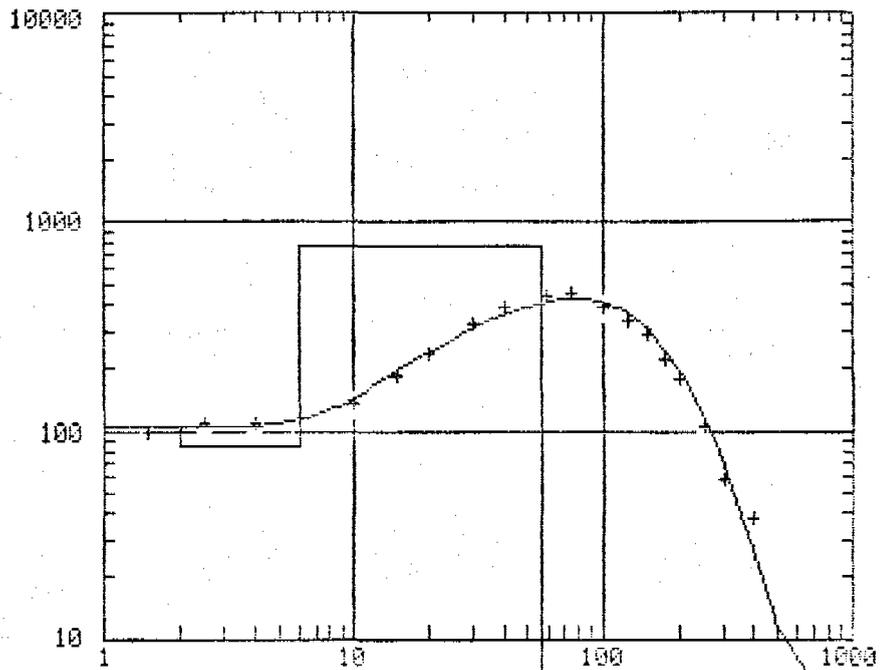
Ash Sharaf (Sabah) VES 23/87

layer	resistivity	thickness	depth
1	80	.6	.6
2	25	2.7	3
3	1800	20	23
4	15	infinite	



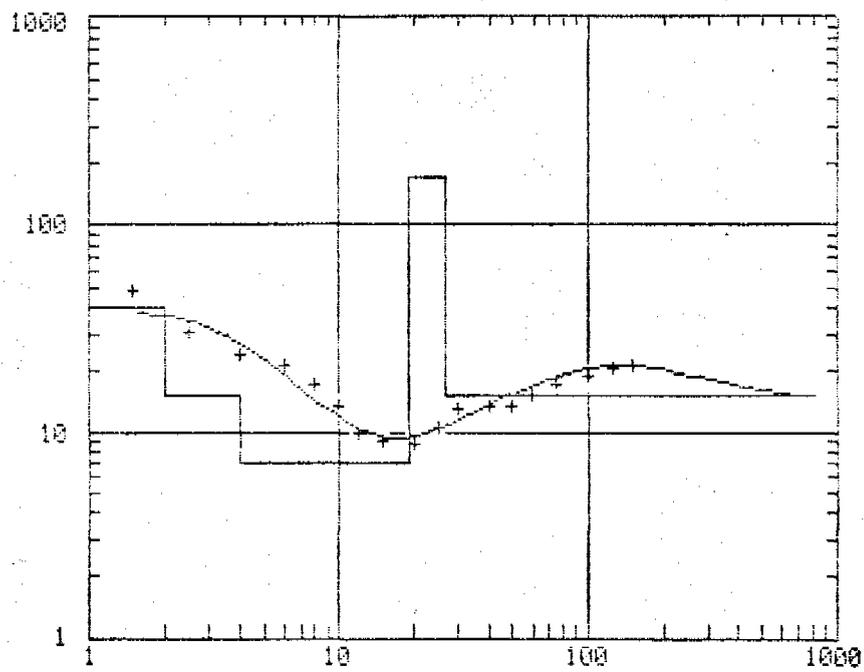
Ash Sharaf (Sabah) VES 24/87

layer	resistivity	thickness	depth
1	95	2.5	2.5
2	14	25	28
3	180	7	35
4	6	27	62
5	160	60	122
6	700	infinite	



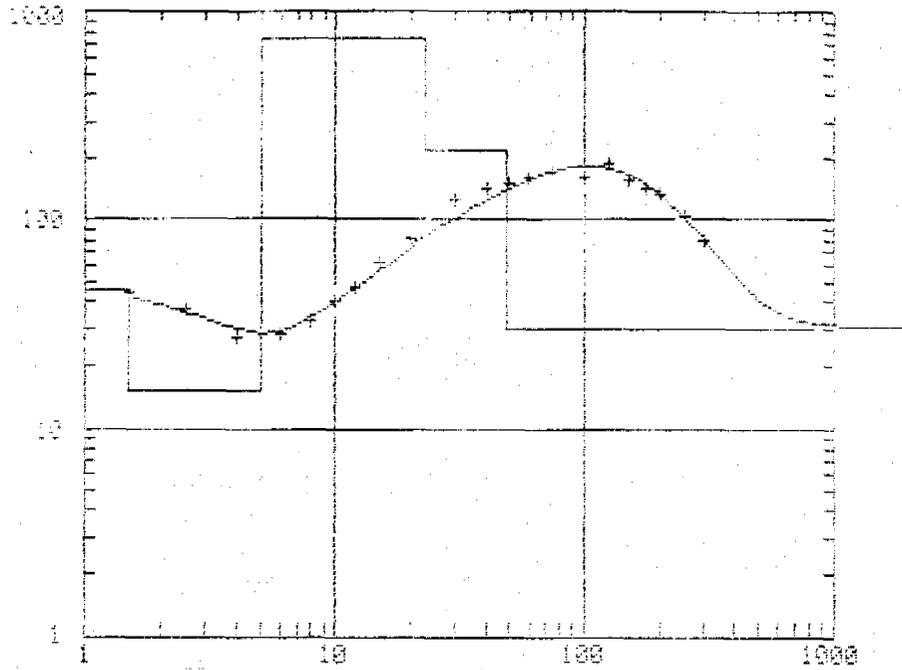
Ash Sharaf Ves 25/87

layer	resistivity	thickness	depth
1	105	2	2
2	85	3.5	6
3	780	50	56
4	6	infinite	



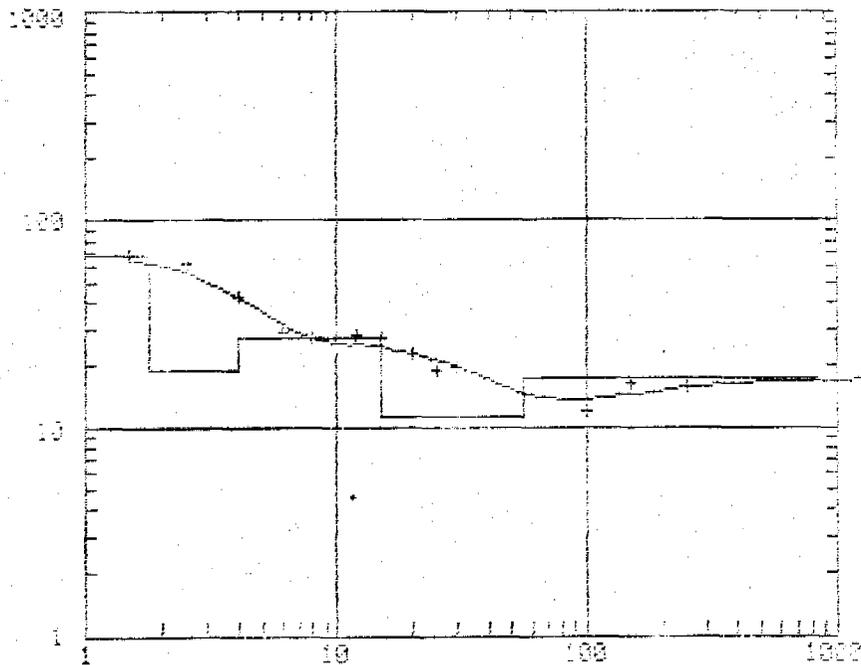
Ash Sharaf Ves 26/87

layer	resistivity	thickness	depth
1	40	2	2
2	15	2	4
3	7	15	19
4	170	8	27
5	15	infinite	



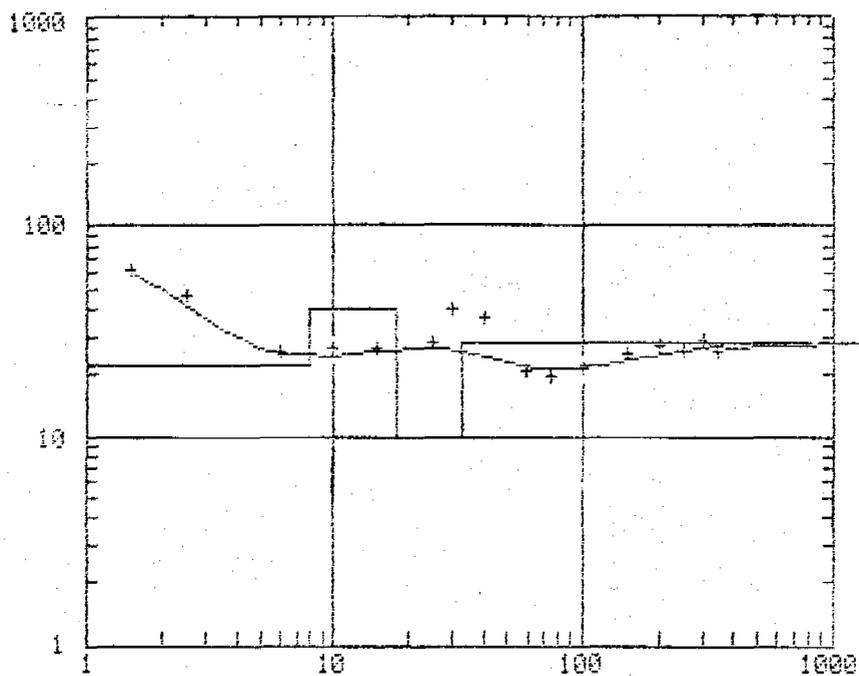
Al Khanaq VES 27/87

layer	resistivity	thickness	depth
1	45	1.5	1.5
2	15	3	5
3	750	18	23
4	220	25	48
5	30	infinite	



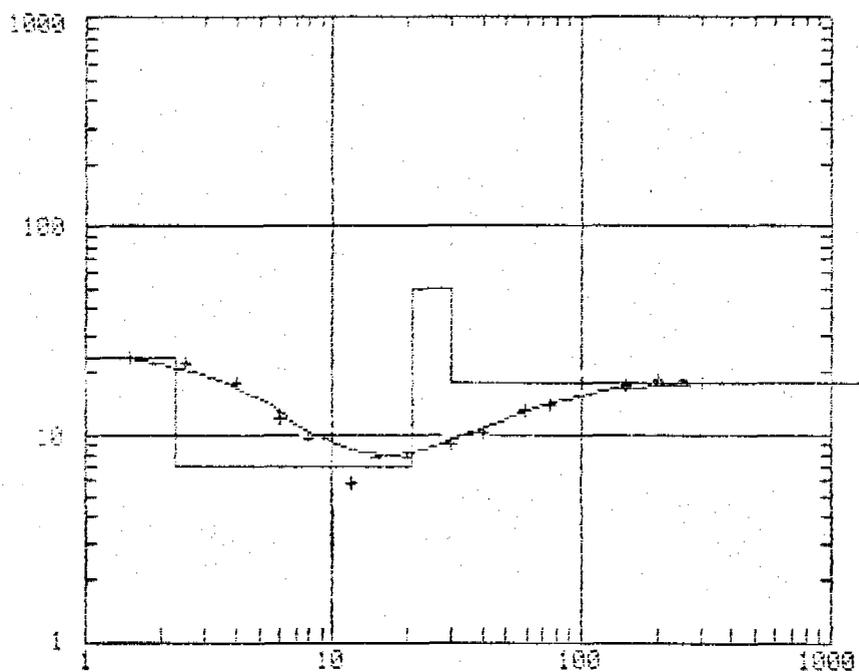
Hamak VES 28/87

layer	resistivity	thickness	depth
1	68	1.8	1.8
2	19	2.1	4
3	27	11	15
4	11	20	35
5	11	20	55
6	17	infinite	



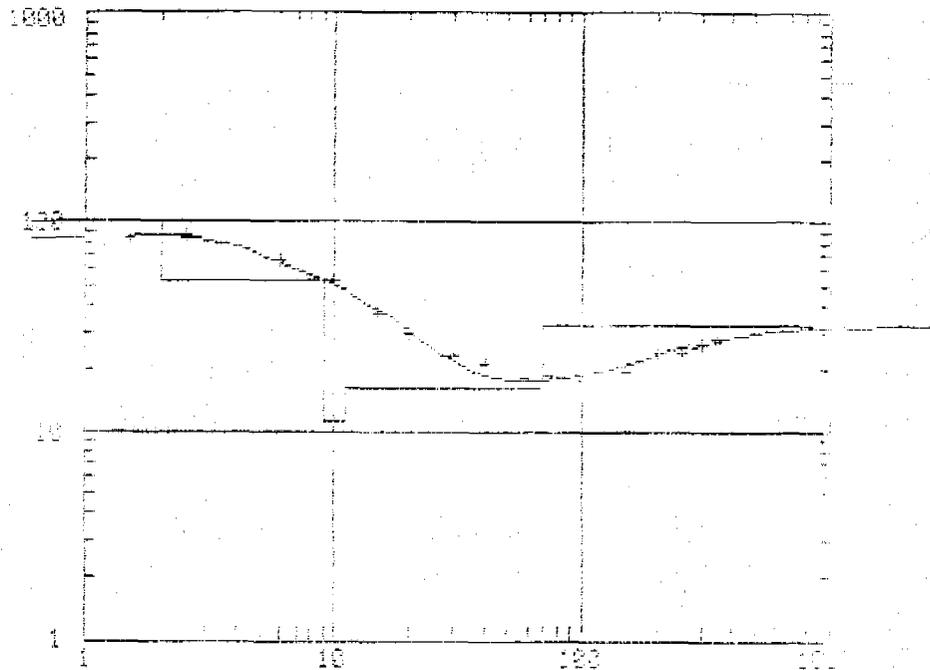
Hamak VES 29/87

layer	resistivity	thickness	depth
1	74	1	1
2	22	7	8
3	40	10	18
4	10	15	33
5	28	infinite	



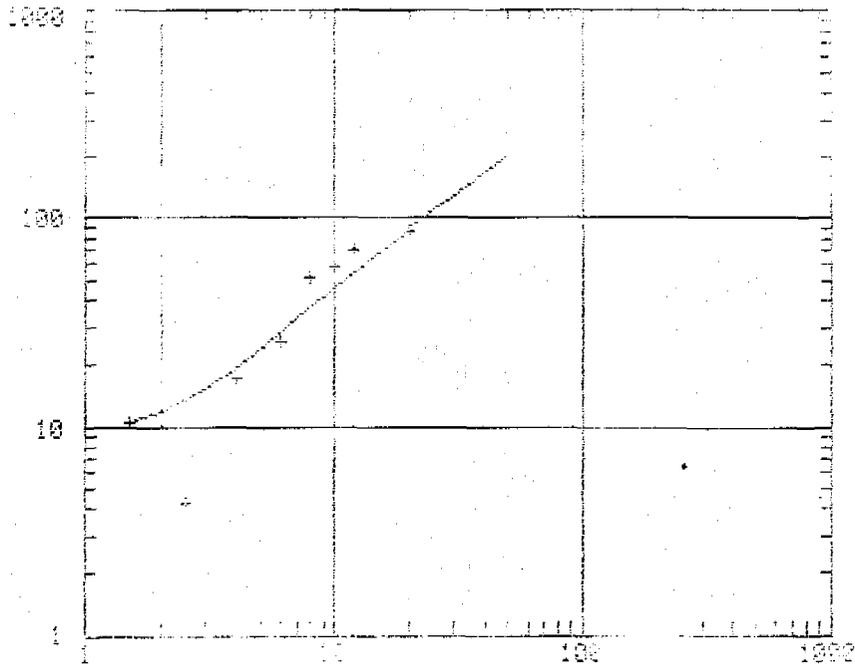
Hamak VES 30/87

layer	resistivity	thickness	depth
1	23	2.3	2.3
2	7	19	21
3	50	9	30
4	17.5	infinite	



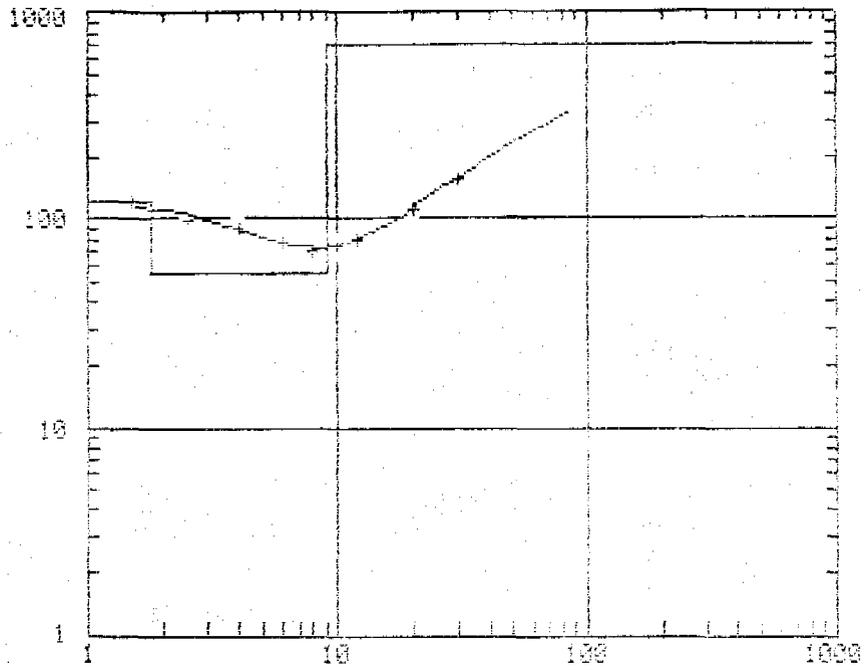
Hamak VES 31/87

layer	resistivity	thickness	depth
1	84	.6	.6
2	100	1.2	2
3	53	7	9
4	11	2	11
5	16	59	70
6	33	infinite	



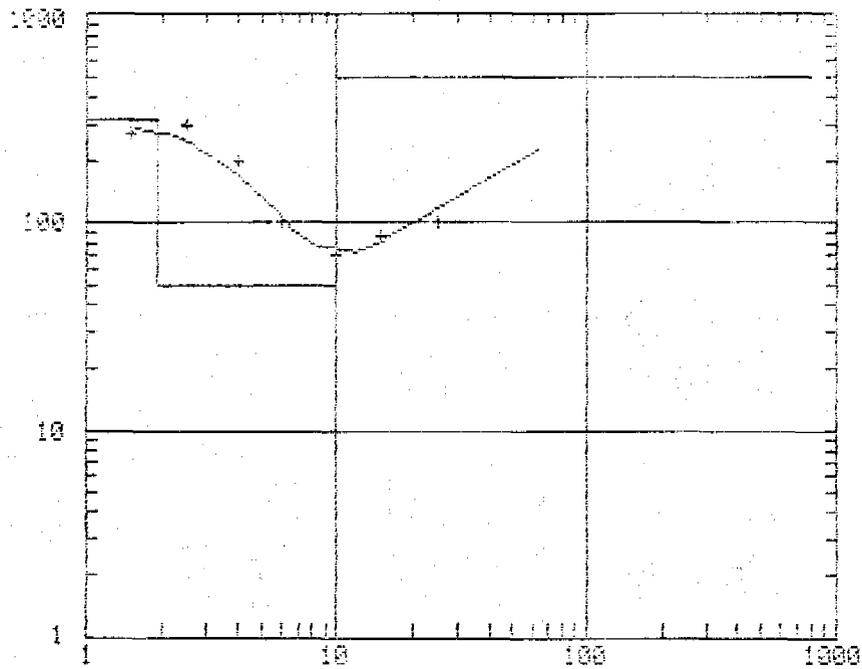
Qa'qa VES 32/87

layer	resistivity	thickness	depth
1	10	2	2
2	1000	infinite	



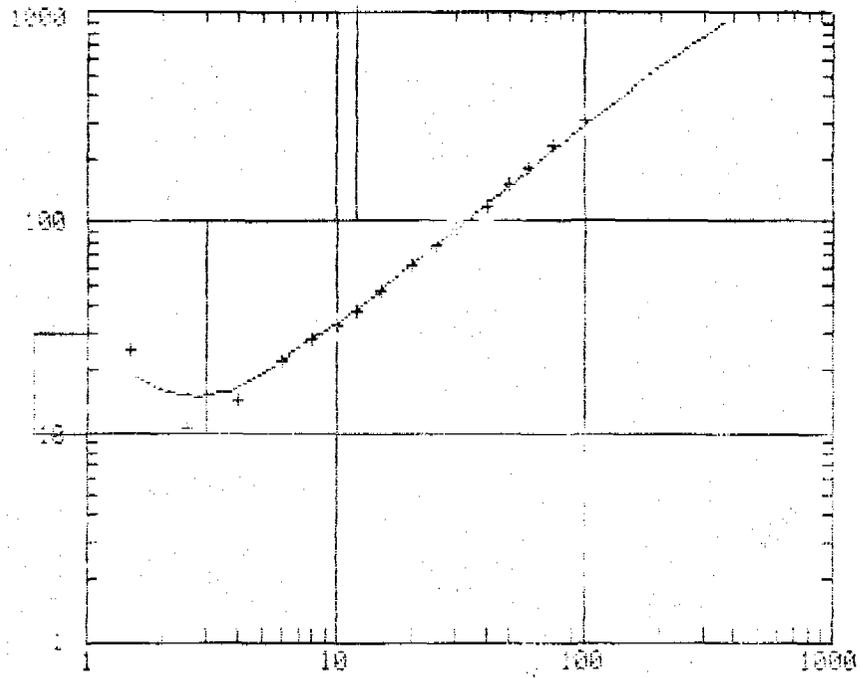
Qa'qa VES 33/87

layer	resistivity	thickness	depth
1	120	1.8	1.8
2	55	7.4	9
3	700	infinite	



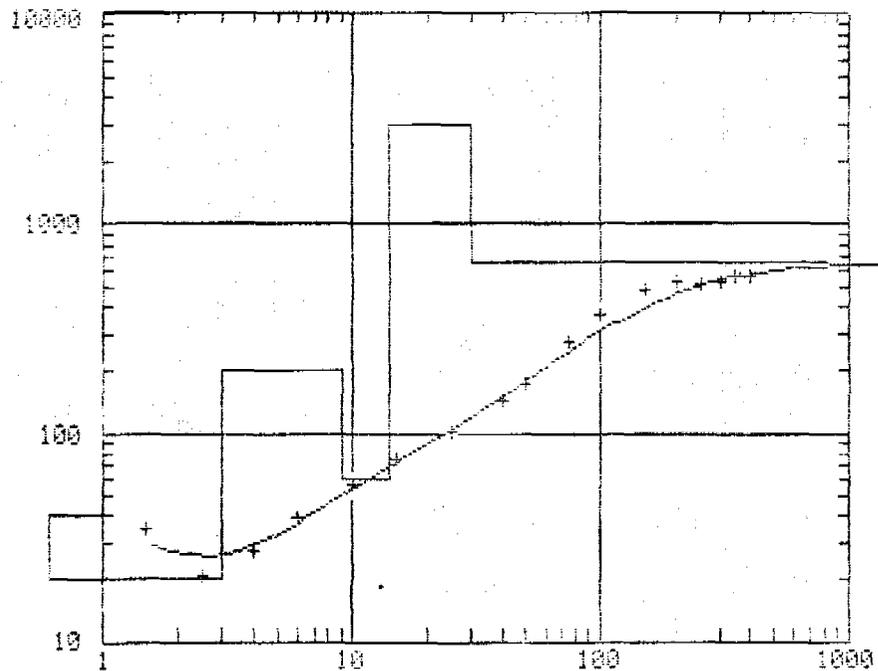
Qa'qa VES 34/87

layer	resistivity	thickness	depth
1	310	1.9	1.9
2	50	8	10
3	500	infinite	



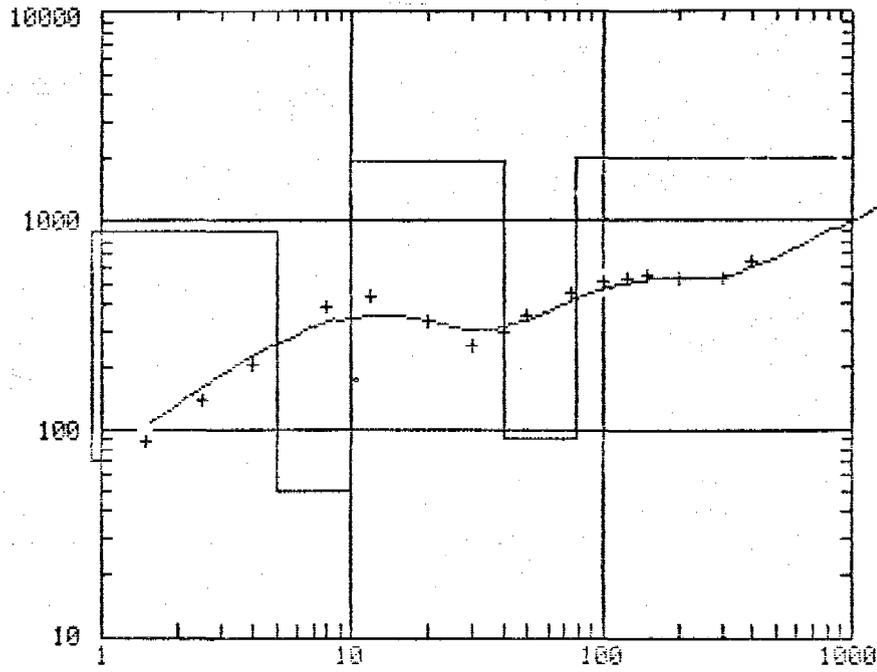
Junubah (Matar) VES 35/87

layer	resistivity	thickness	depth
1	30	.6	.6
2	10	2	3
3	100	9	12
4	4000	infinite	



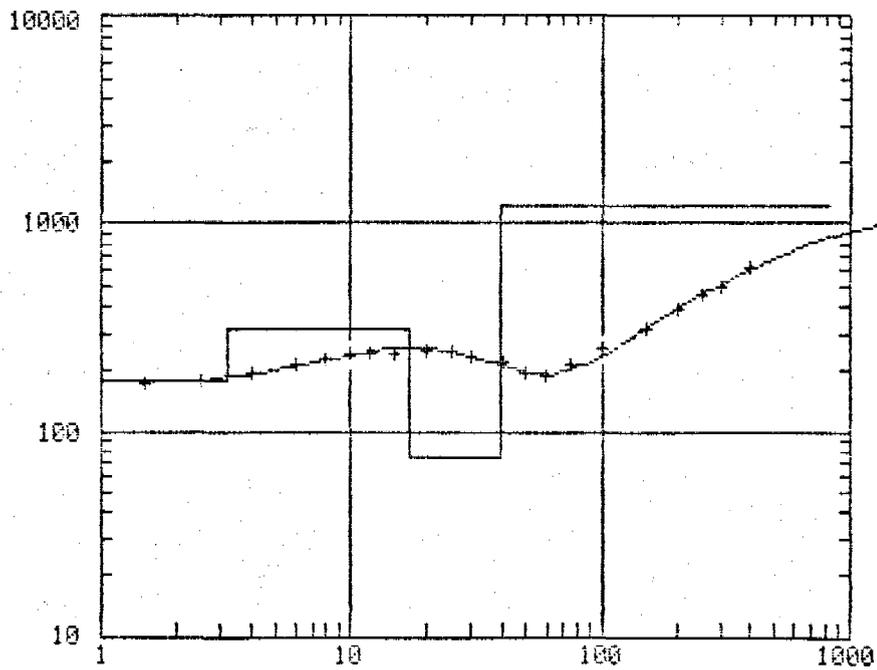
Junubah (Matar) VES 36/87

layer	resistivity	thickness	depth
1	40	.6	.6
2	20	2.4	3
3	200	6	9
4	60	5	14
5	3000	16	30
6	650	infinite	



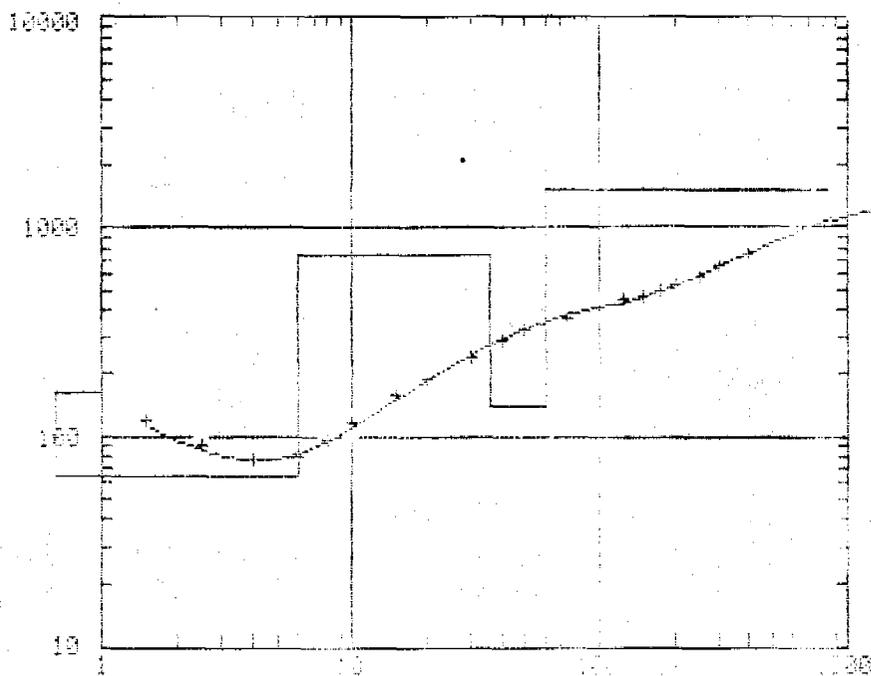
Junubah (Matar) VES 37/87

layer	resistivity	thickness	depth
1	70	.9	.9
2	900	4.4	5
3	50	4.8	10
4	1900	30	40
5	90	38	78
6	2000	infinite	



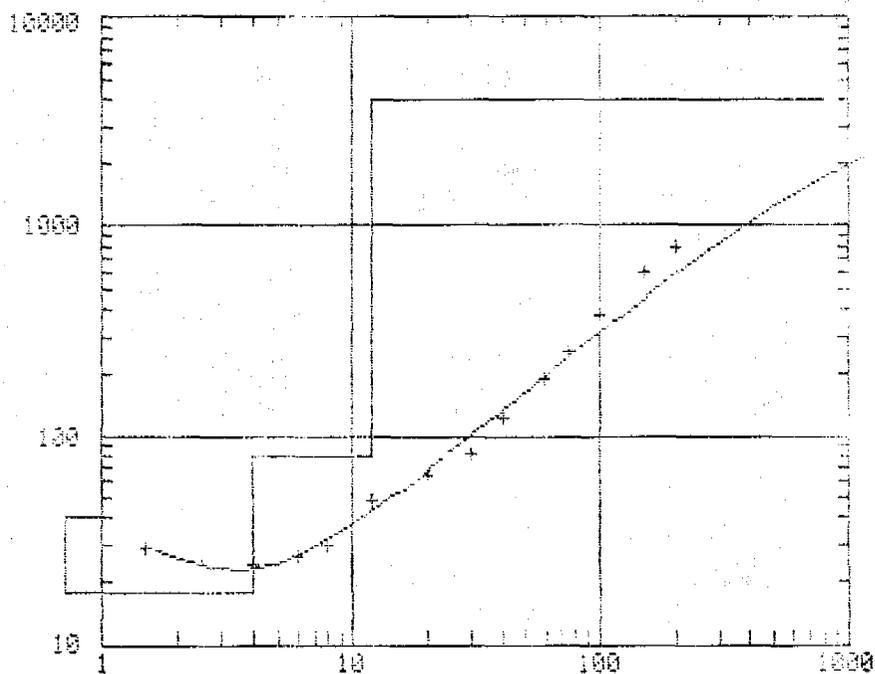
Junubah (Matar) VES 38/87

layer	resistivity	thickness	depth
1	175	3.2	3.2
2	320	14	17
3	75	22	39
4	1200	infinite	



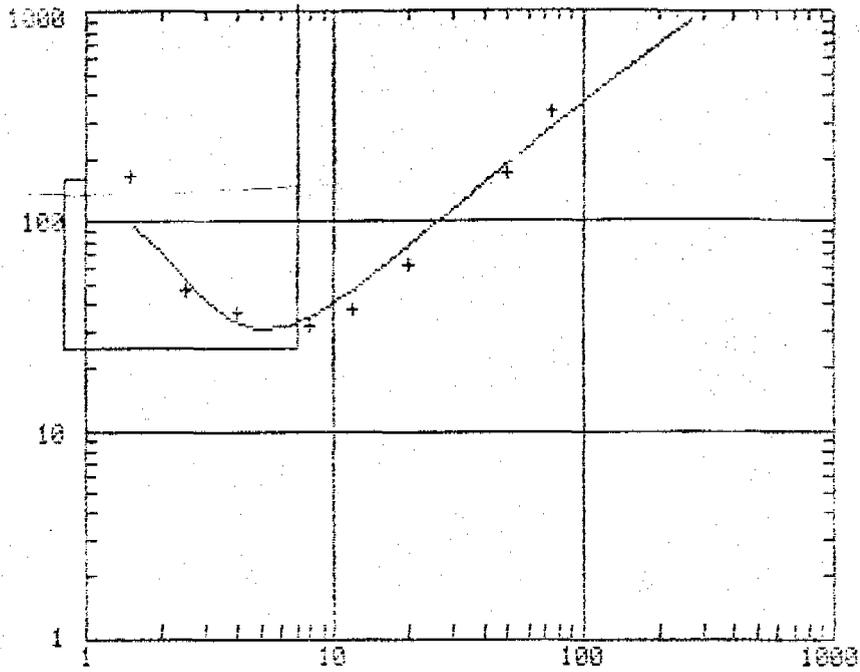
Junubah (Matar) VES 39/87

layer	resistivity	thickness	depth
1	160	.65	.68
2	65	5	6
3	750	30	36
4	140	25	61
5	1500	infinite	



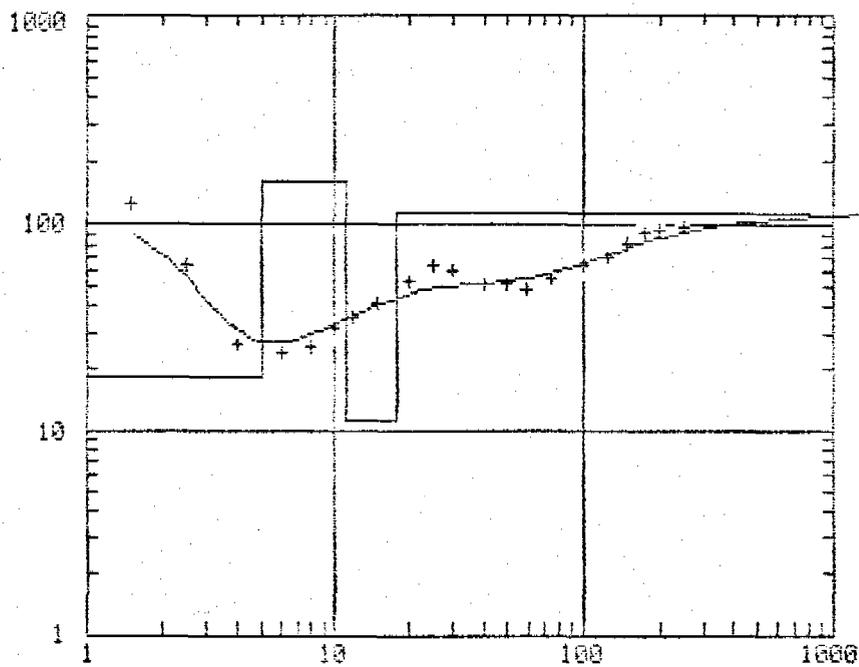
Al Khuf (Dhi Na'im) VES 40/87

layer	resistivity	thickness	depth
1	40	.7	.7
2	18	3	4
3	80	8	12
4	4000	infinite	



Al Khuf VES 41/87

layer	resistivity	thickness	depth
1	160	.8	.8
2	25	6	7
3	5000	infinite	



Al Qaharah VES 1/88

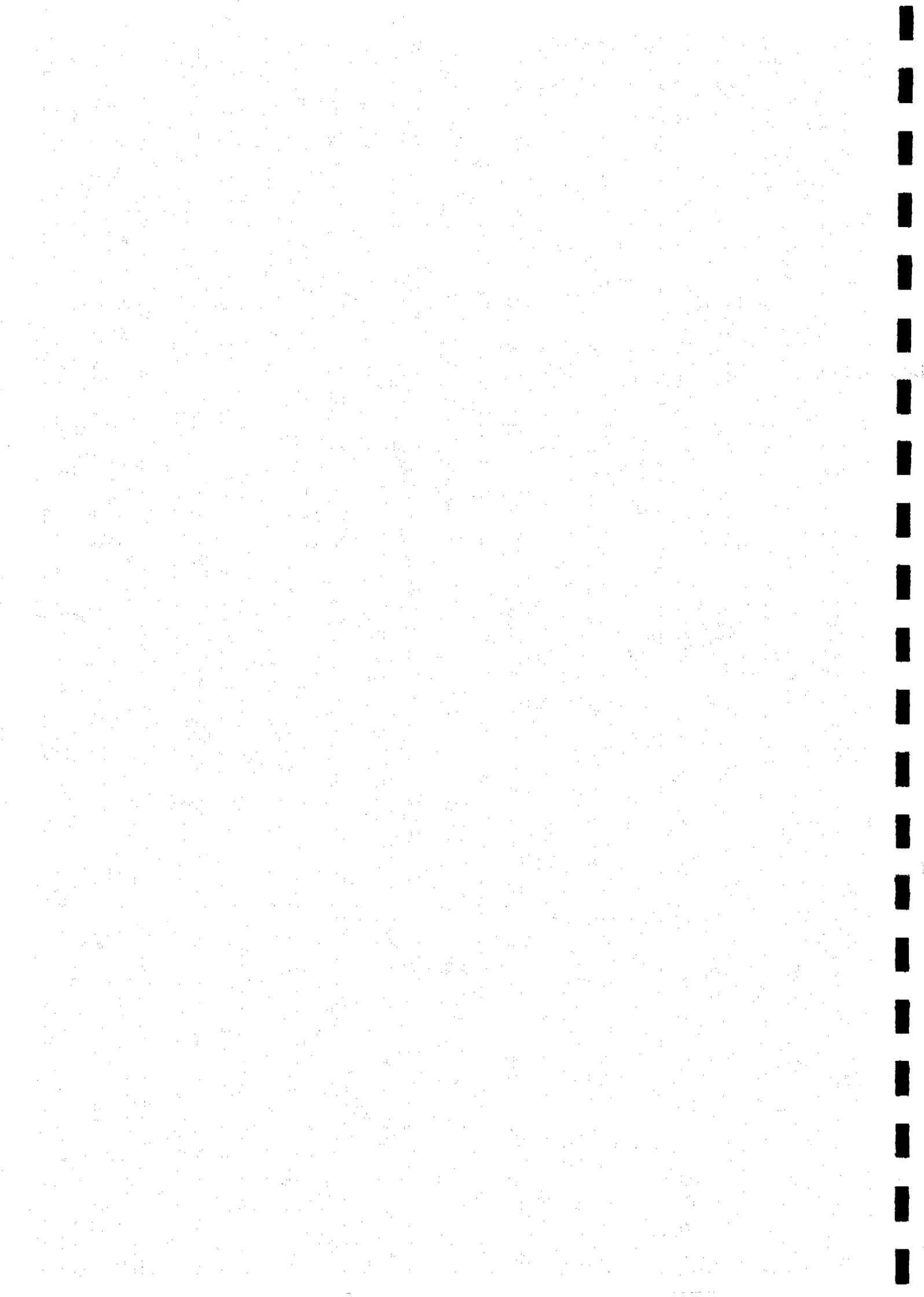
layer	resistivity	thickness	depth
1	125	1	1
2	18	4	5
3	160	6	11
4	11	6.5	18
5	115	infinite	

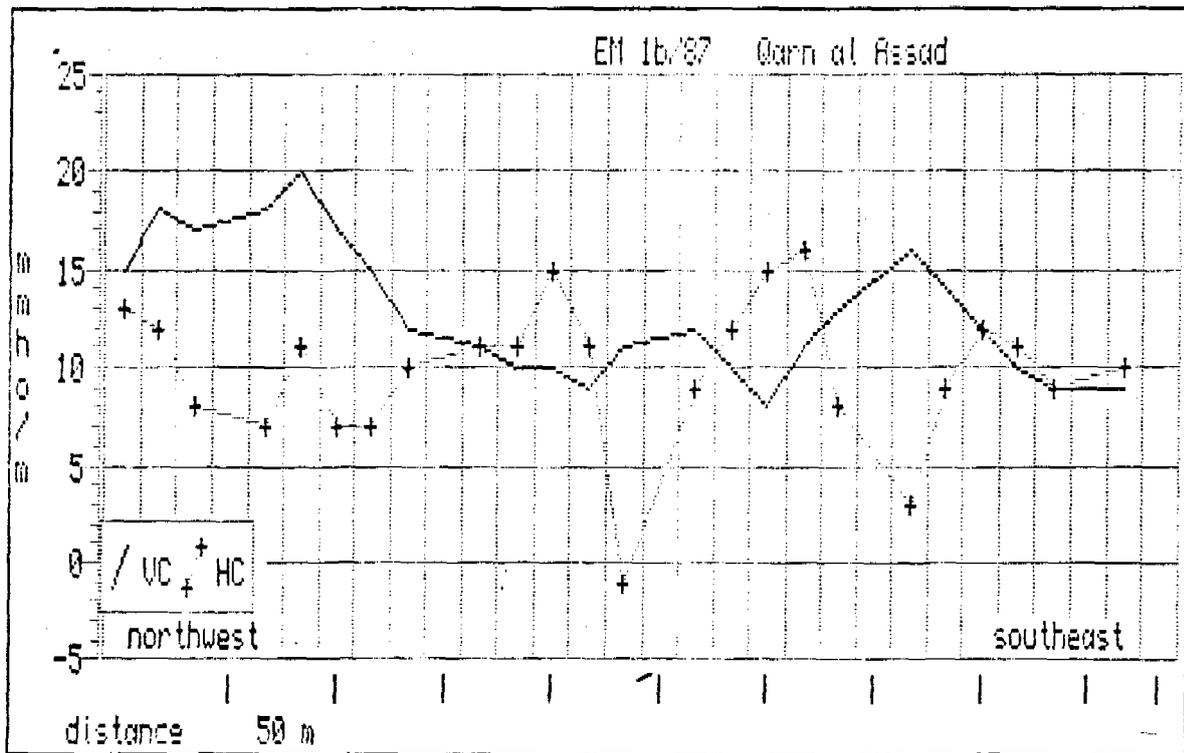
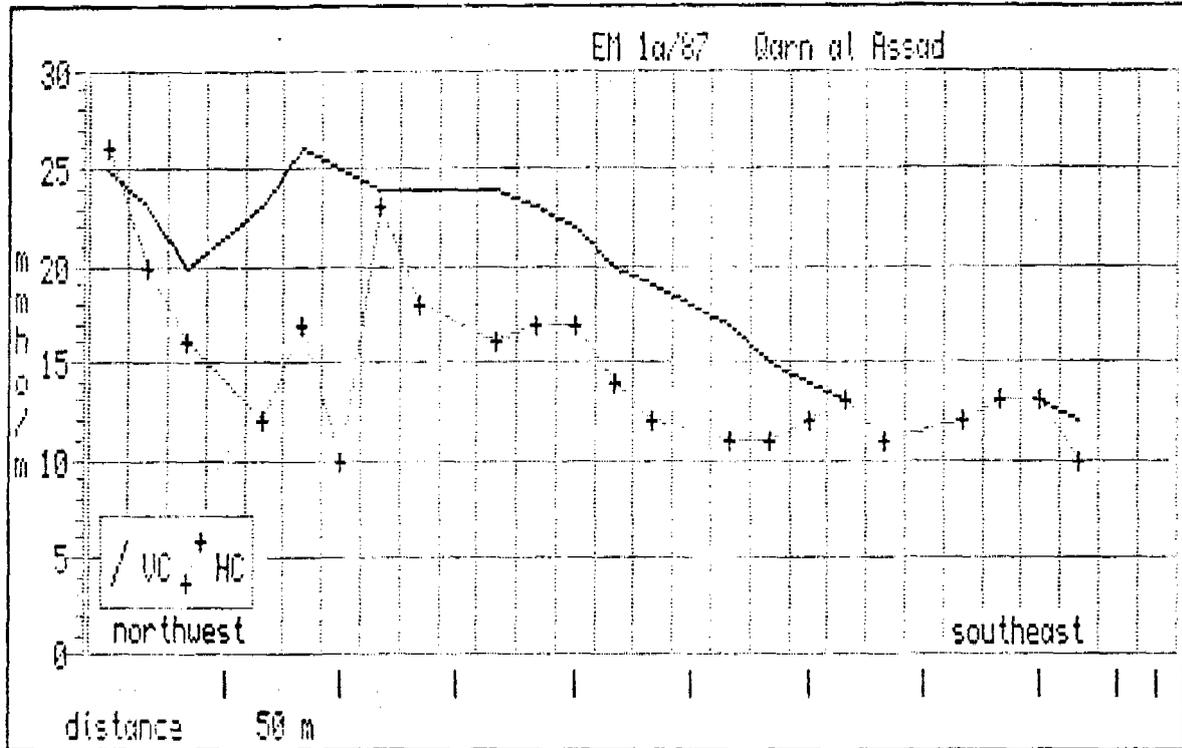
ANNEX B Geo-electrical profile Qa'qa

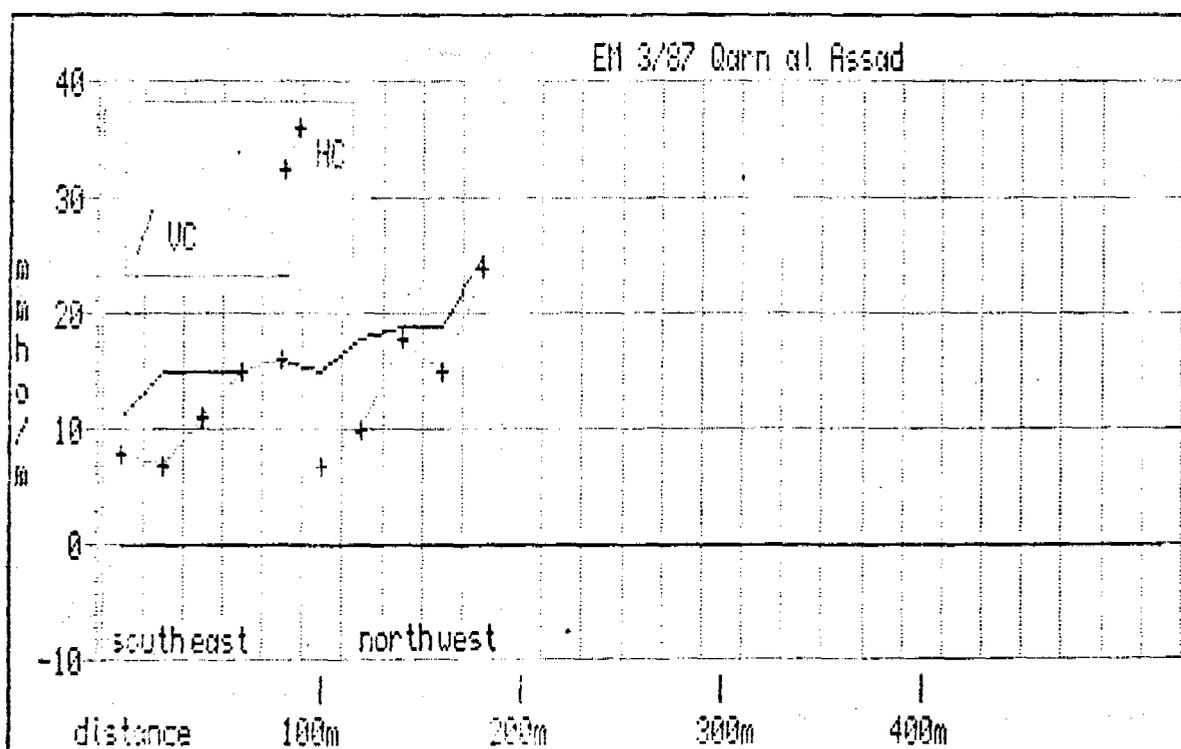
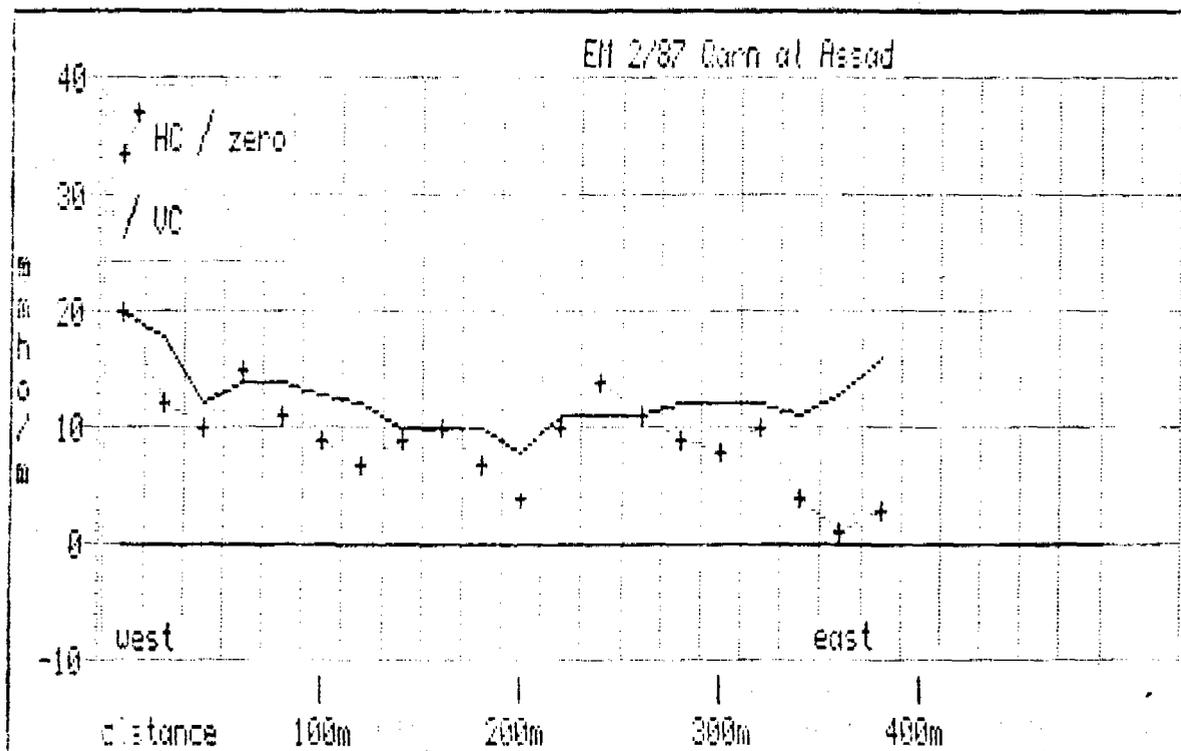


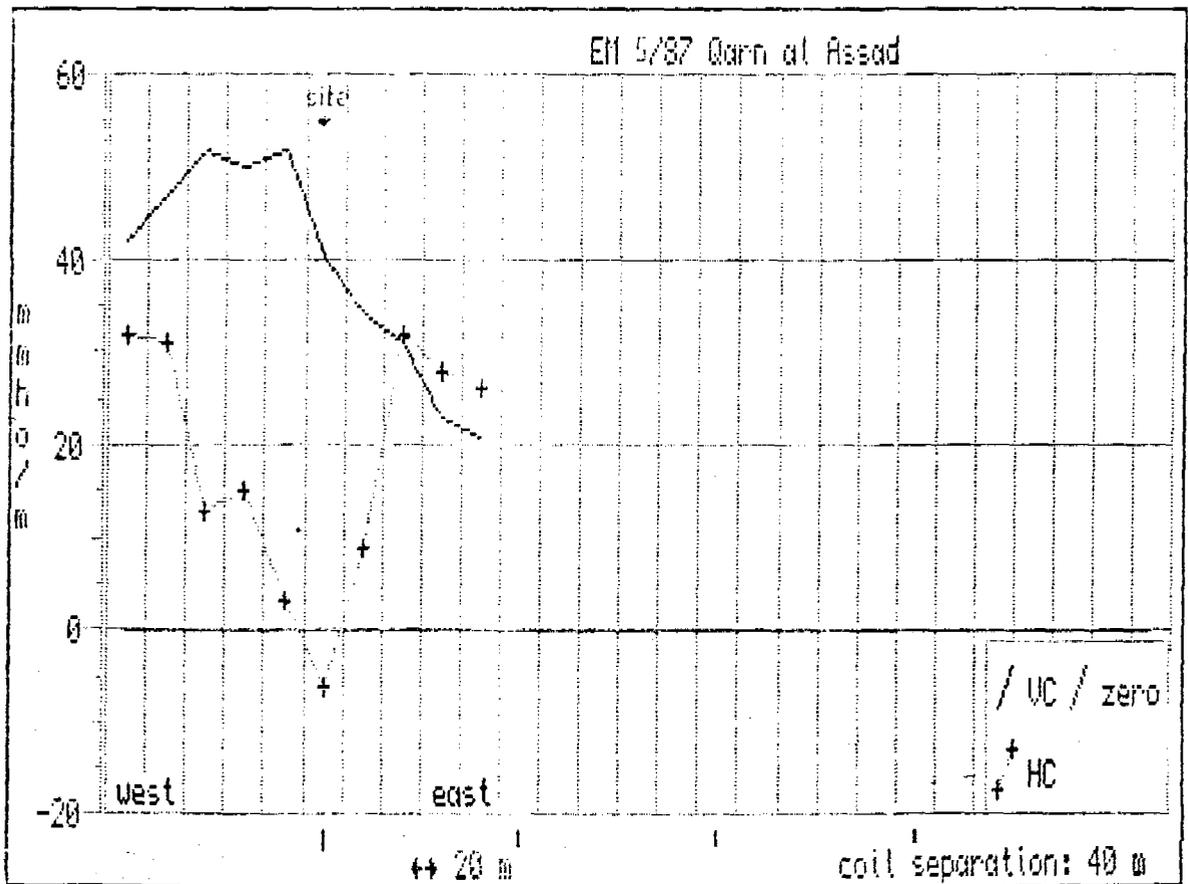
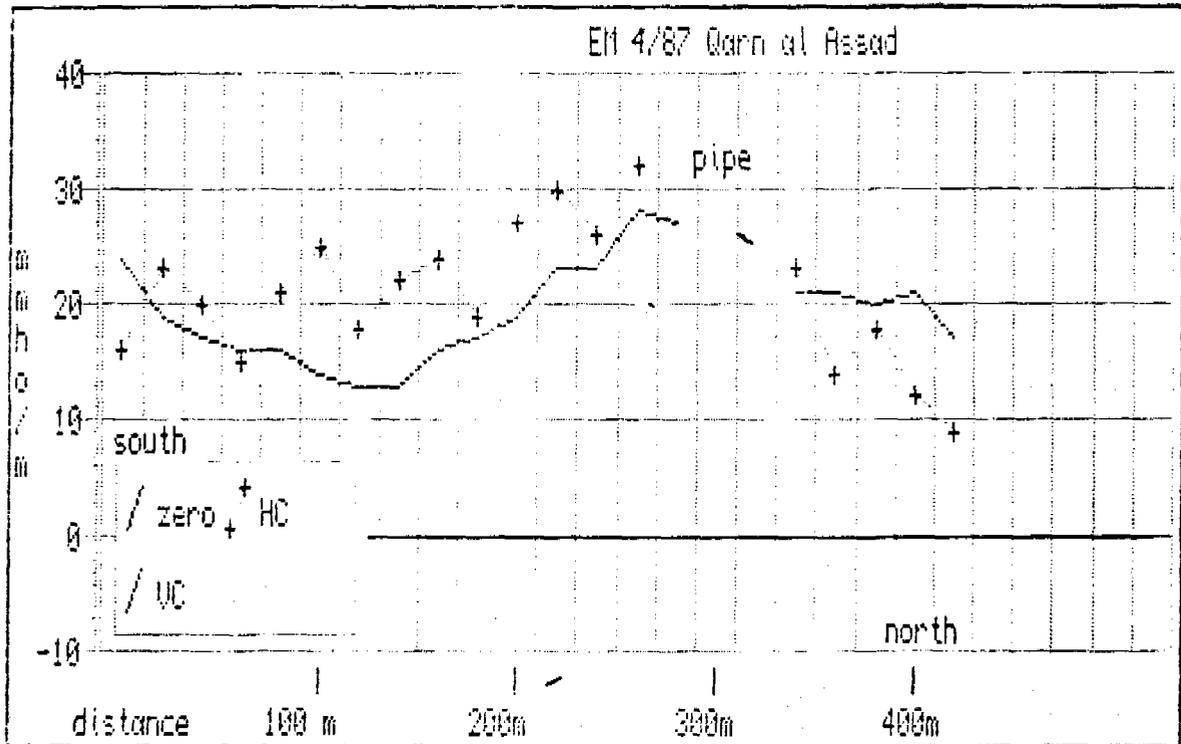
ANNEX C

ELECTROMAGNETIC  
PROFILES

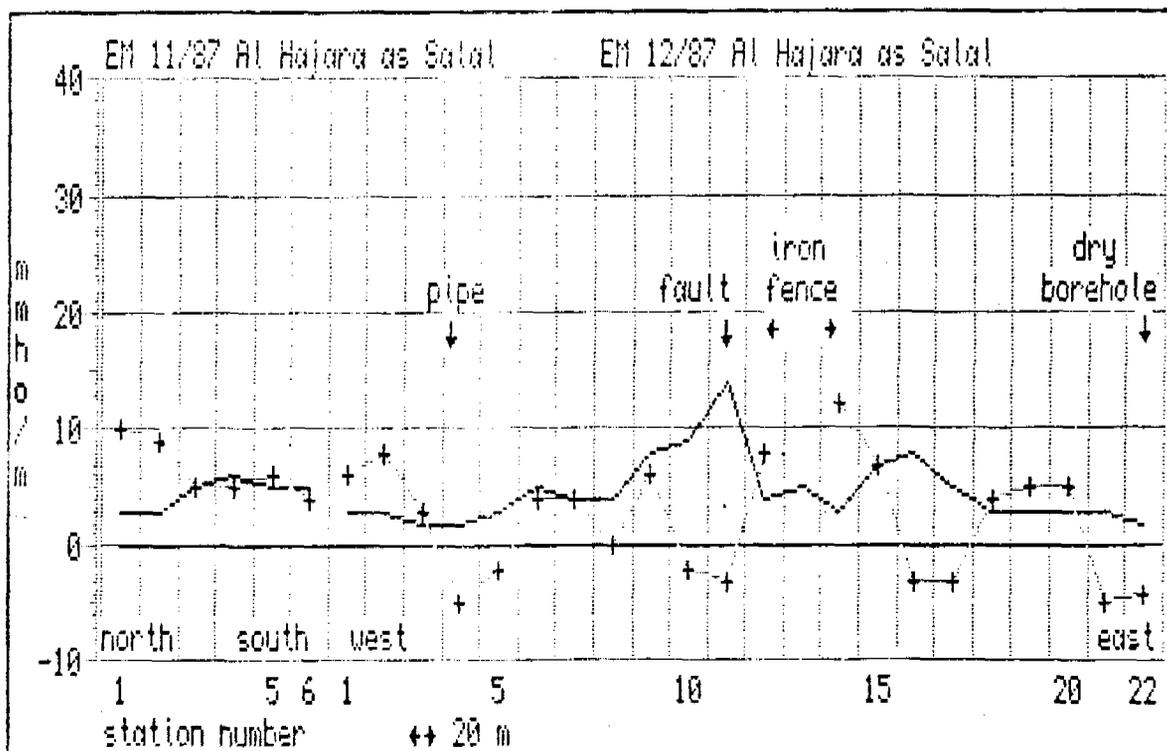
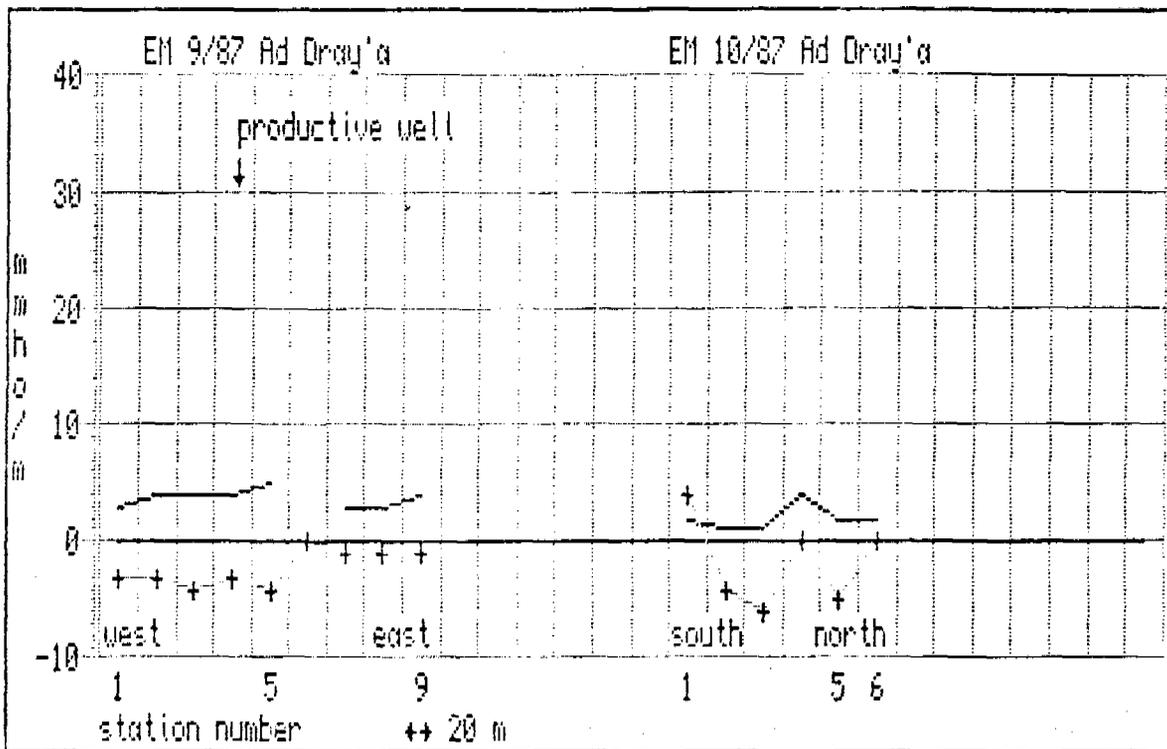


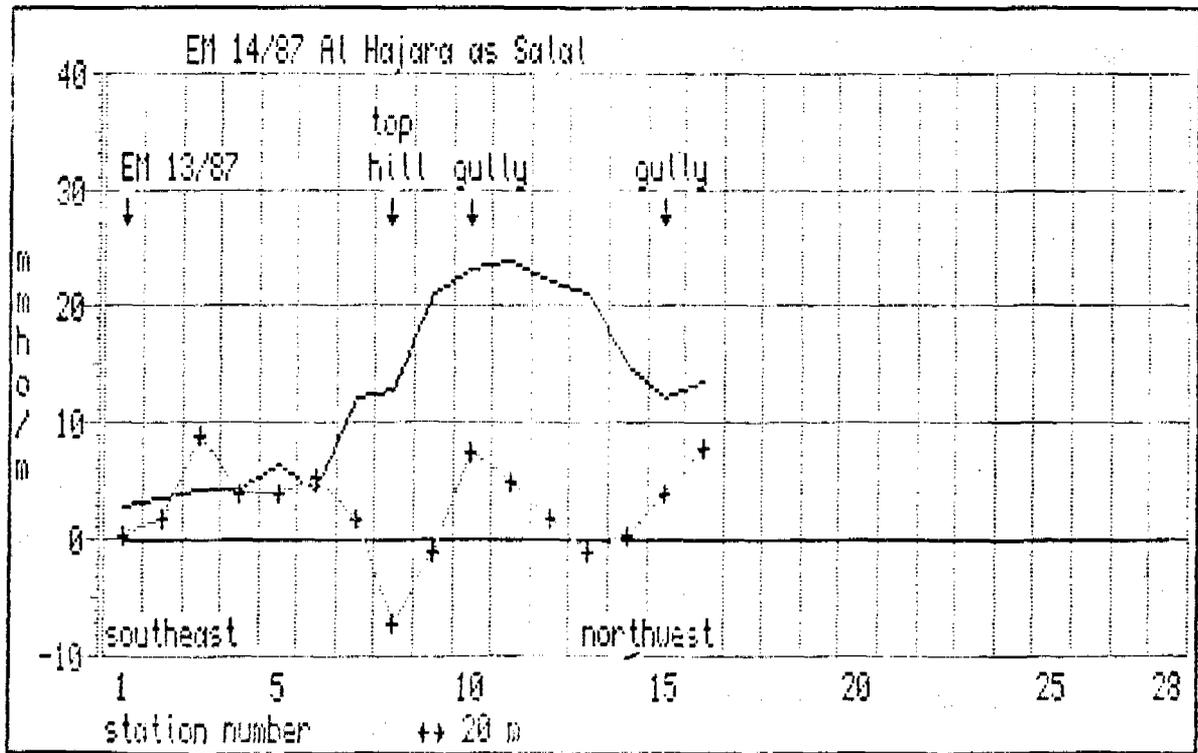
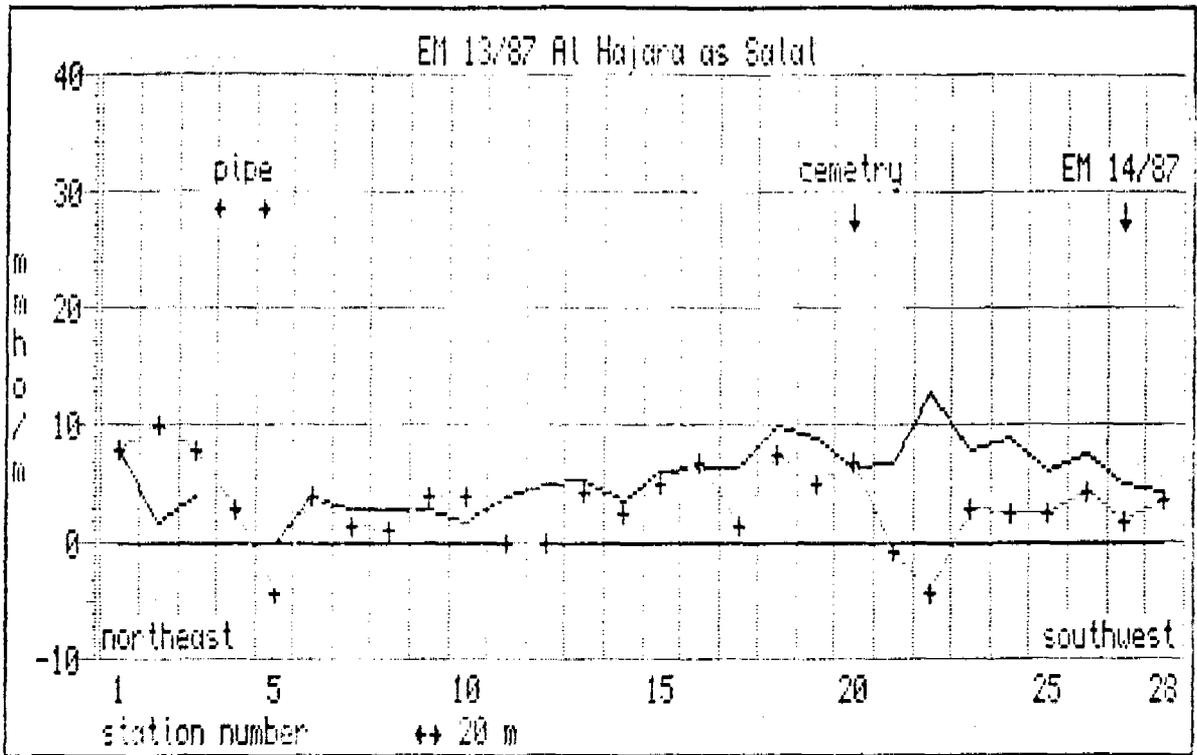


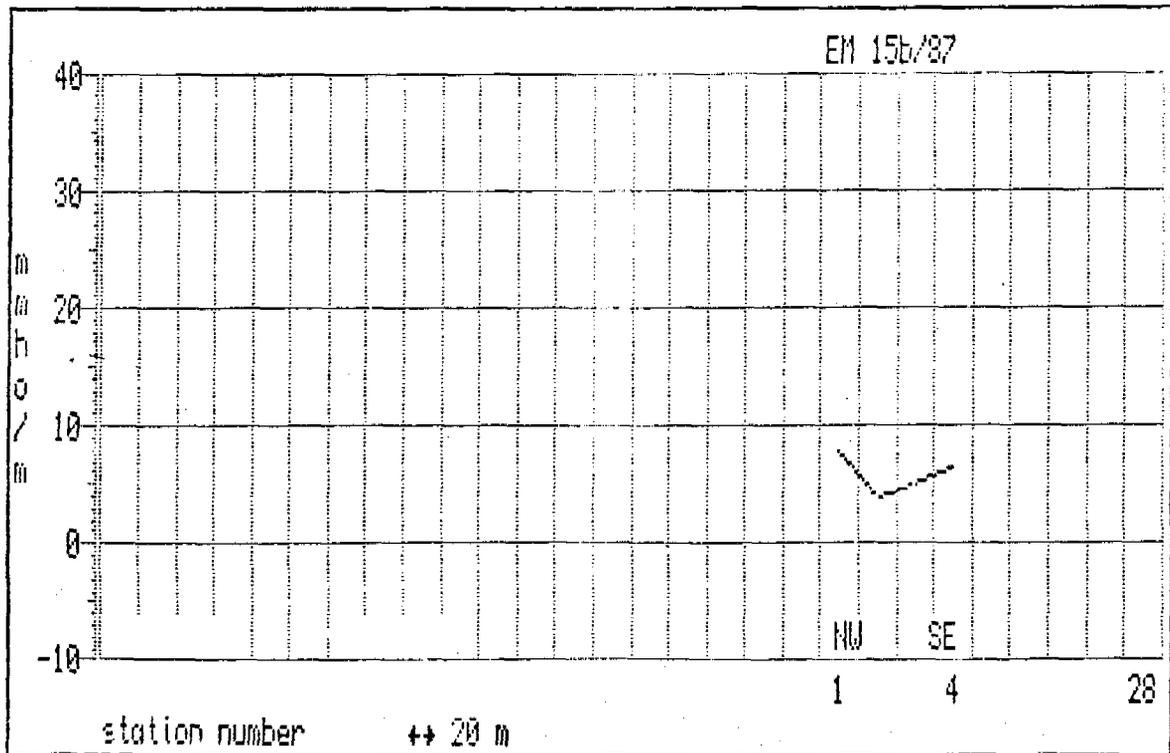
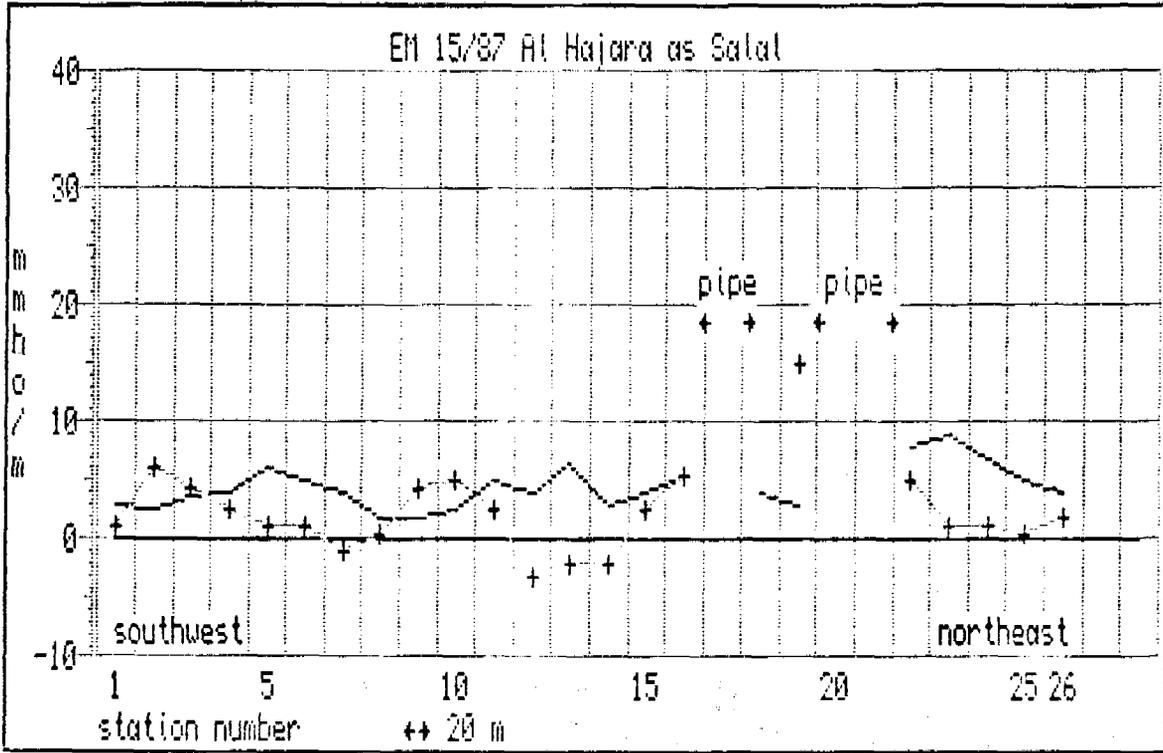


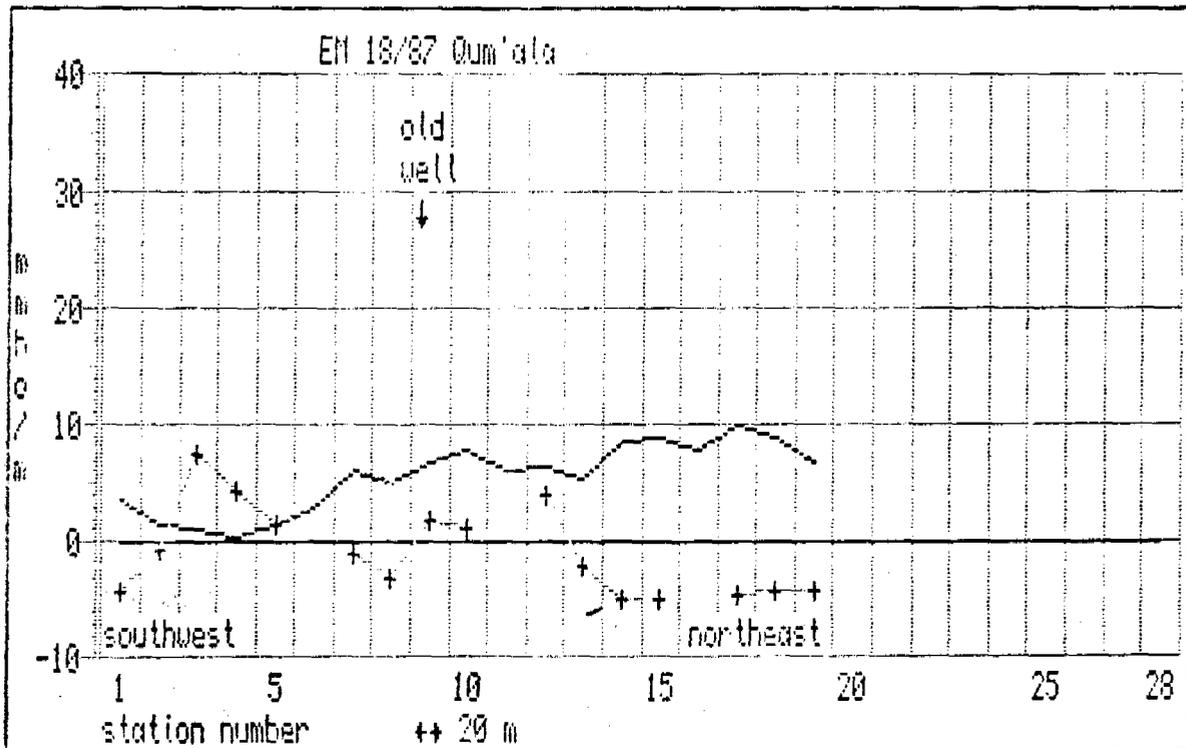
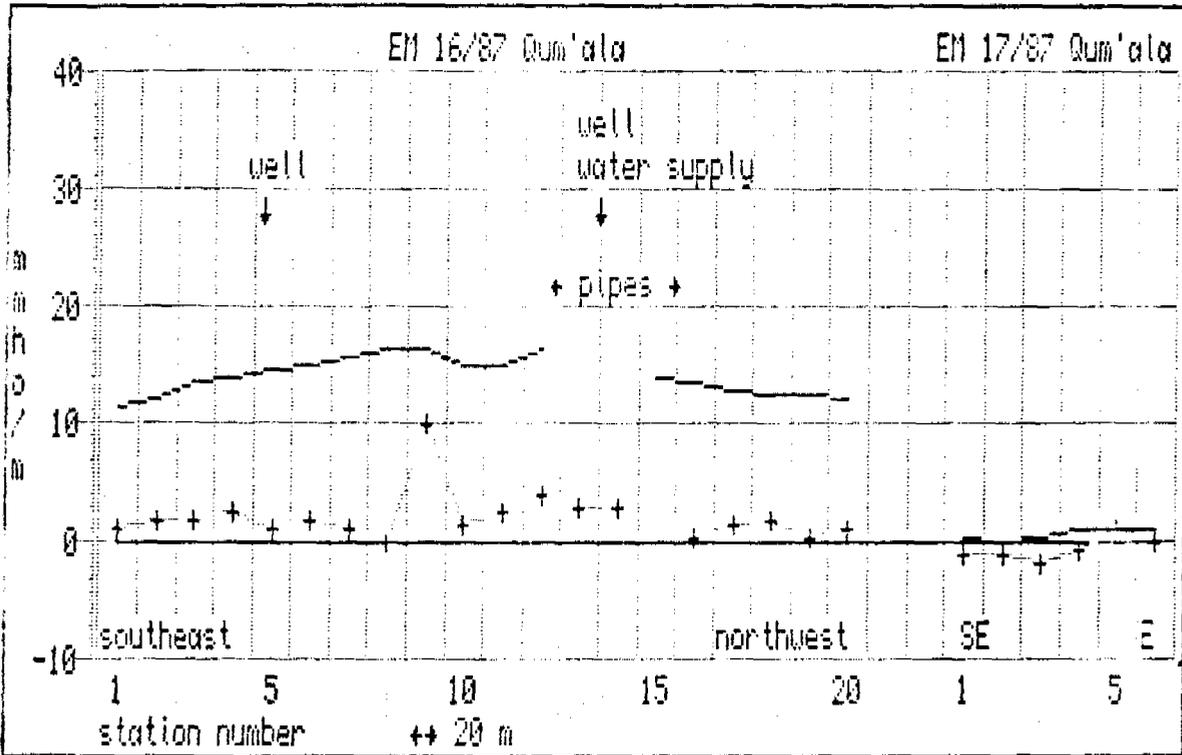


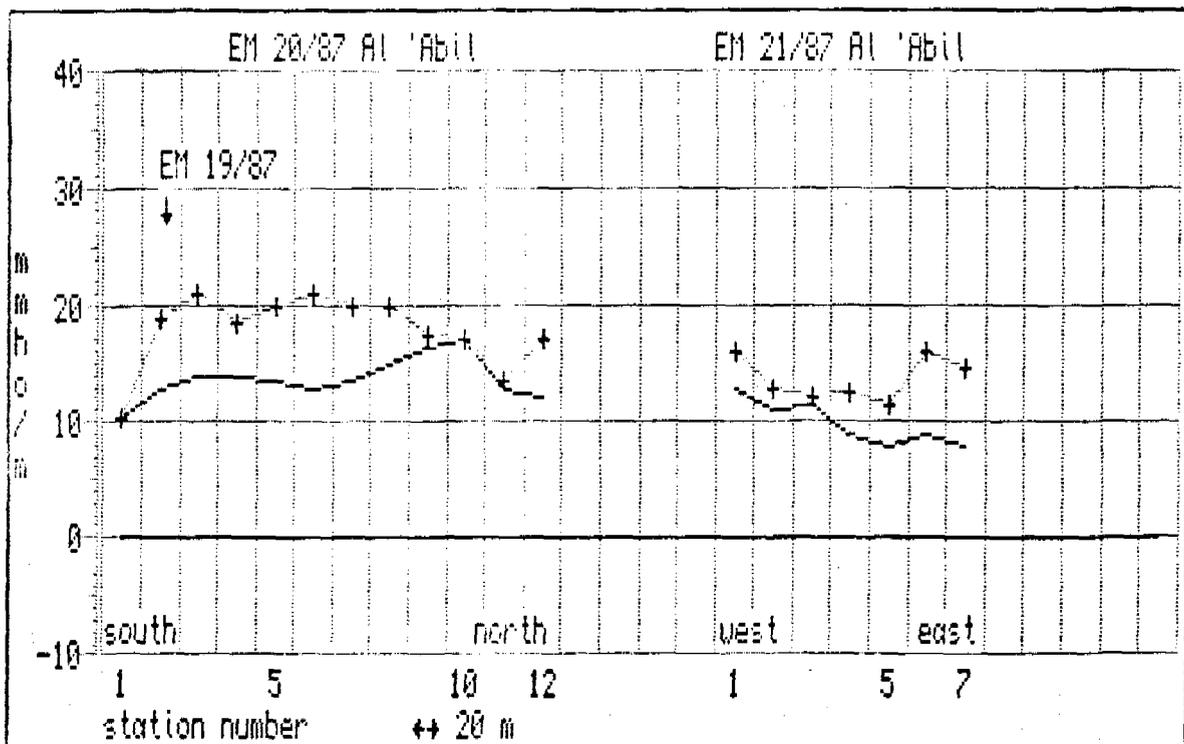
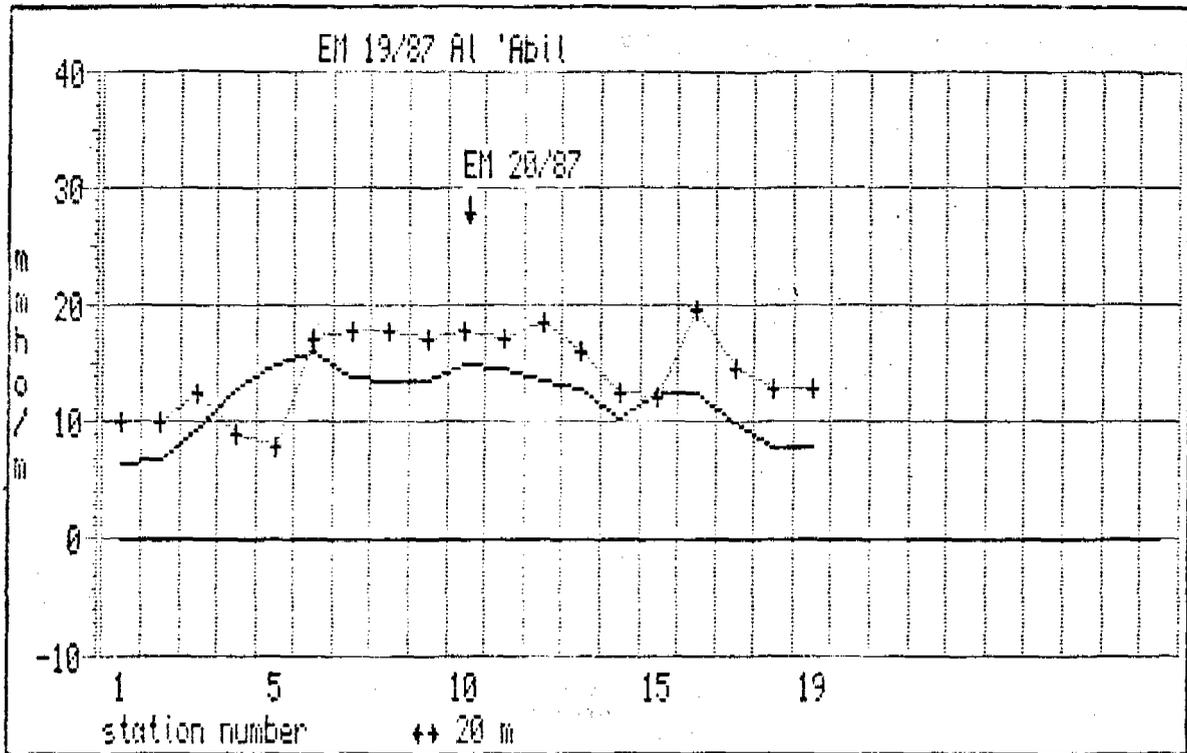


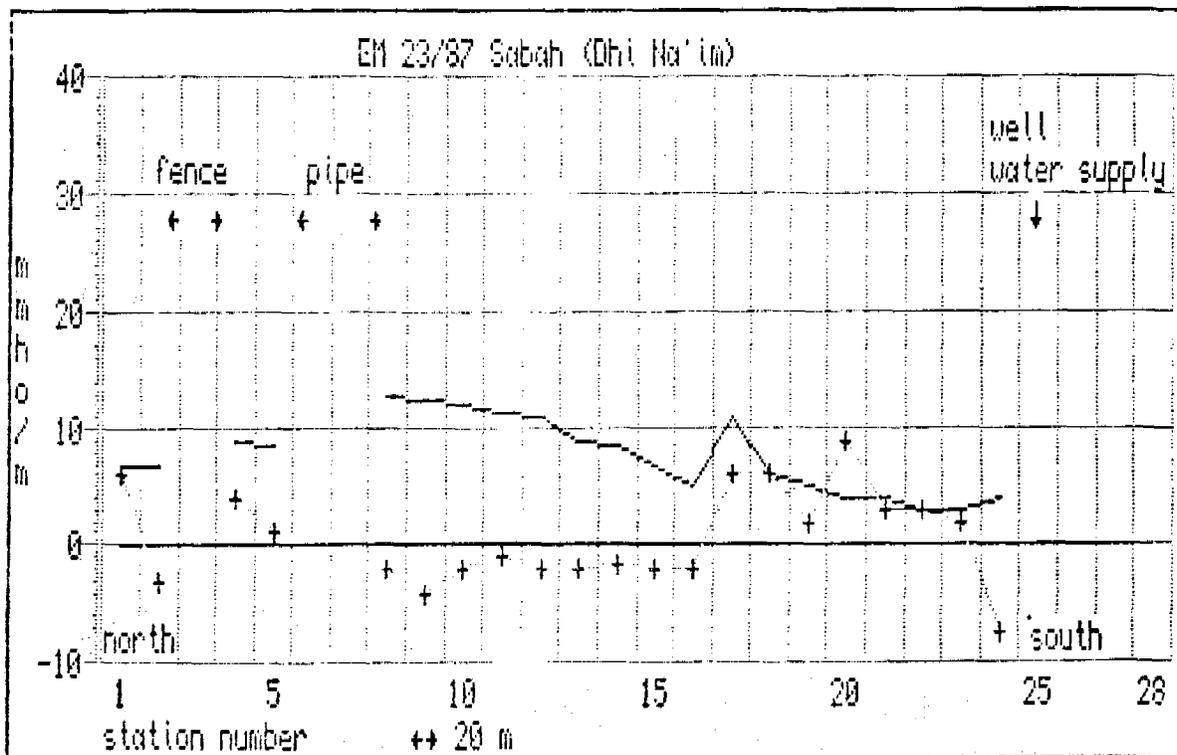
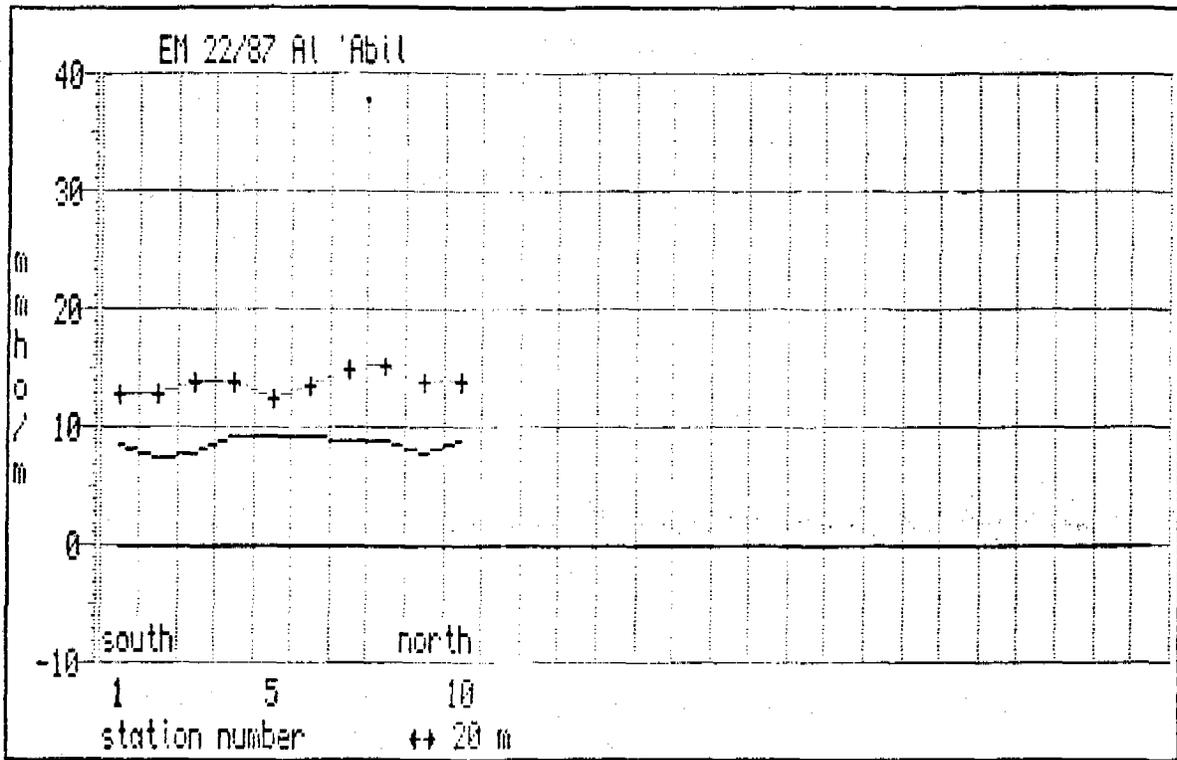


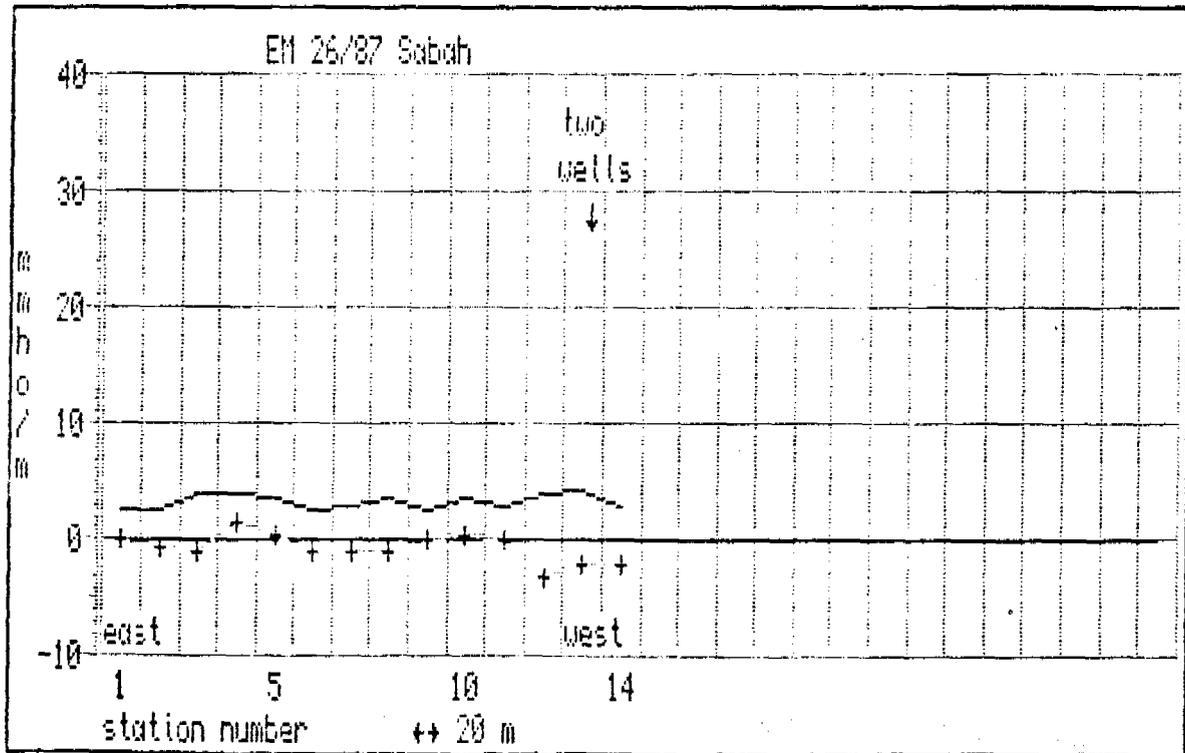
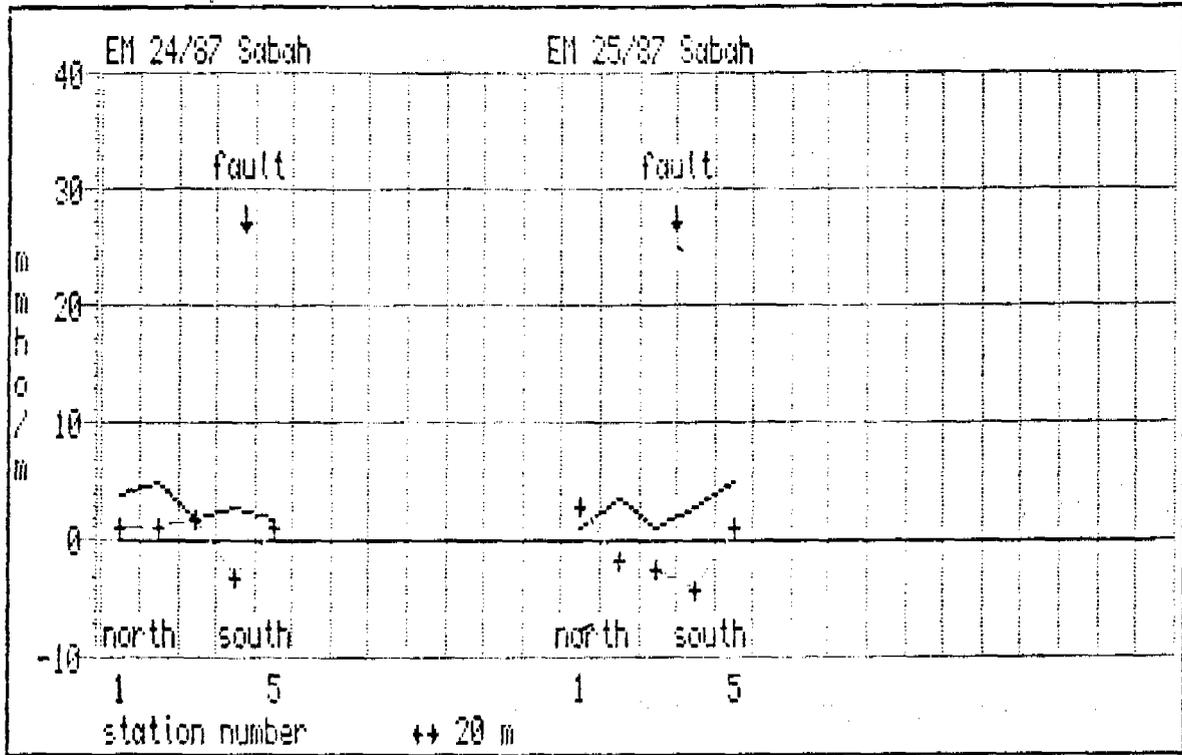


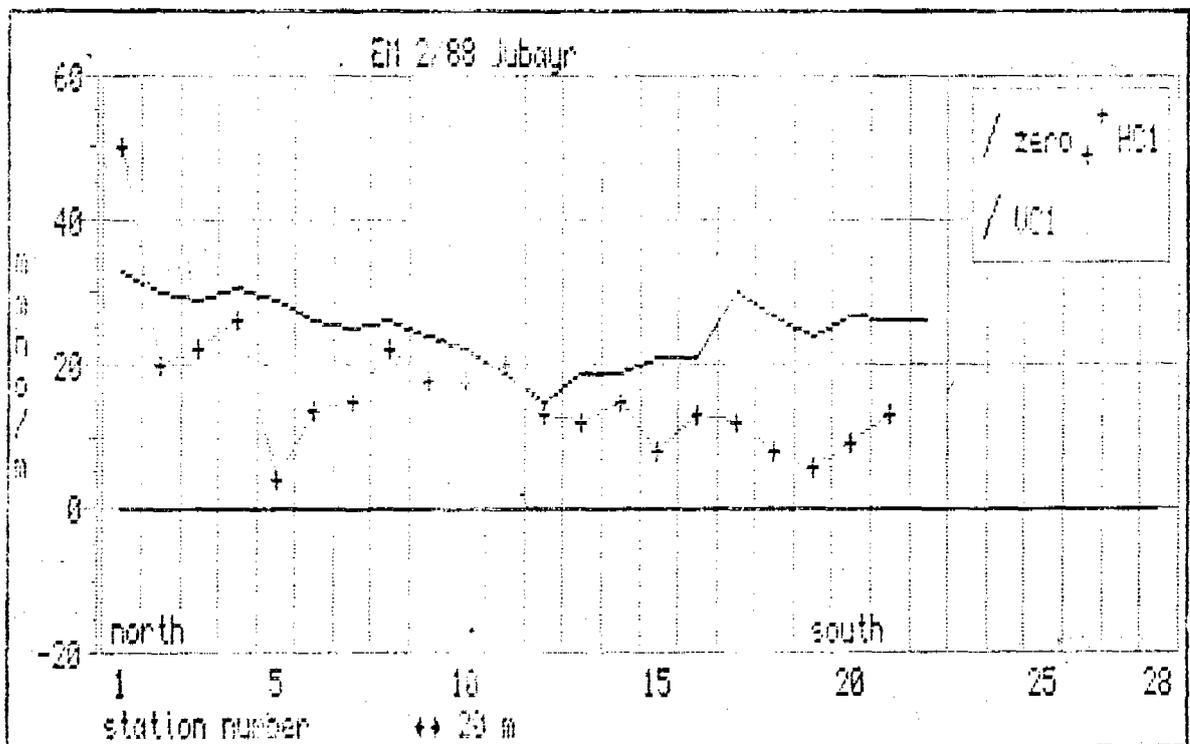
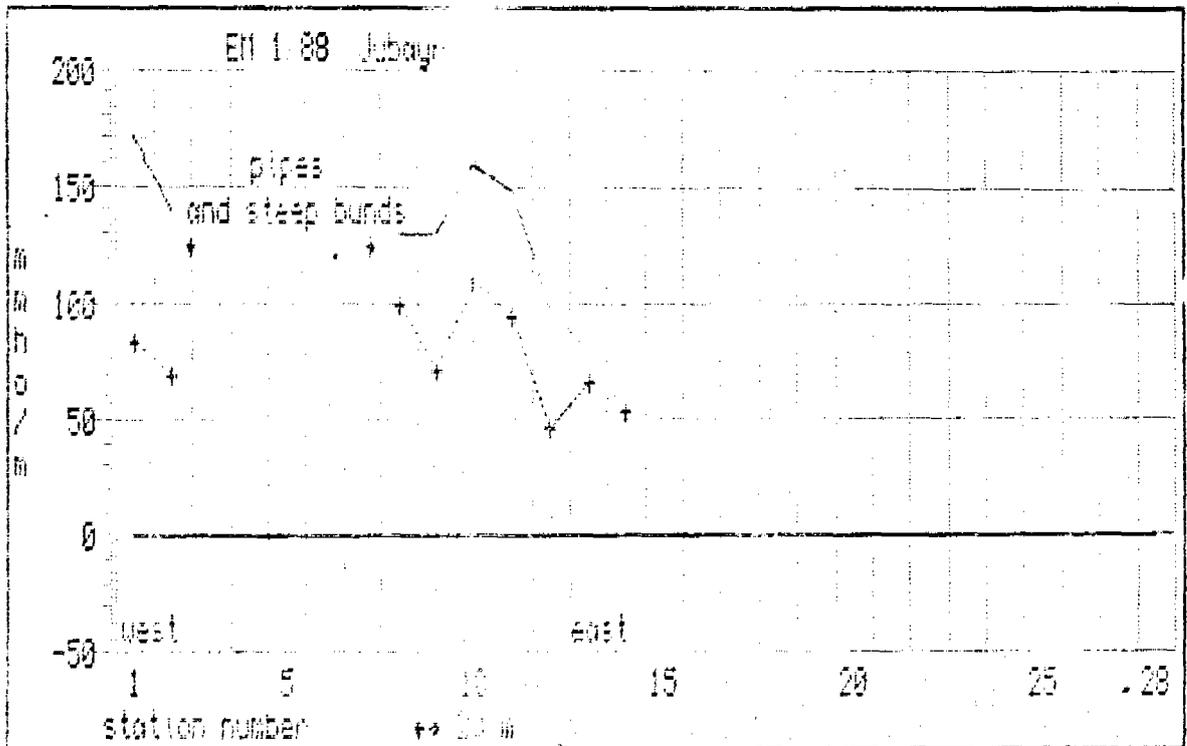


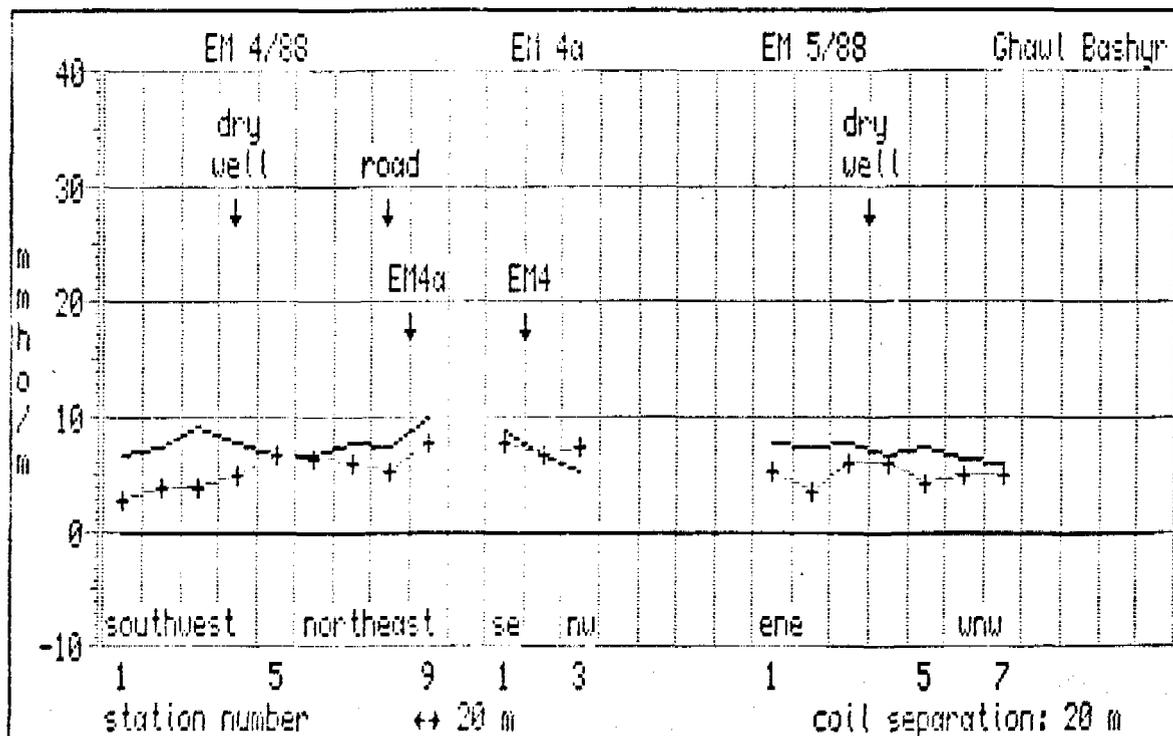
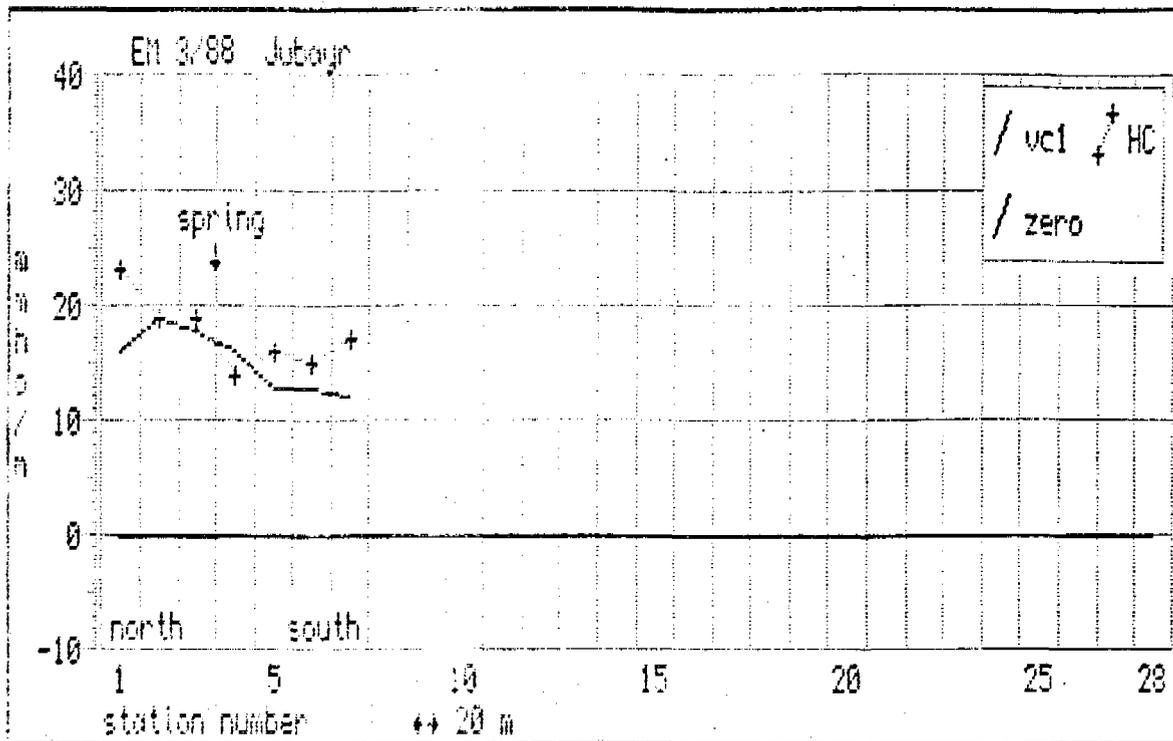


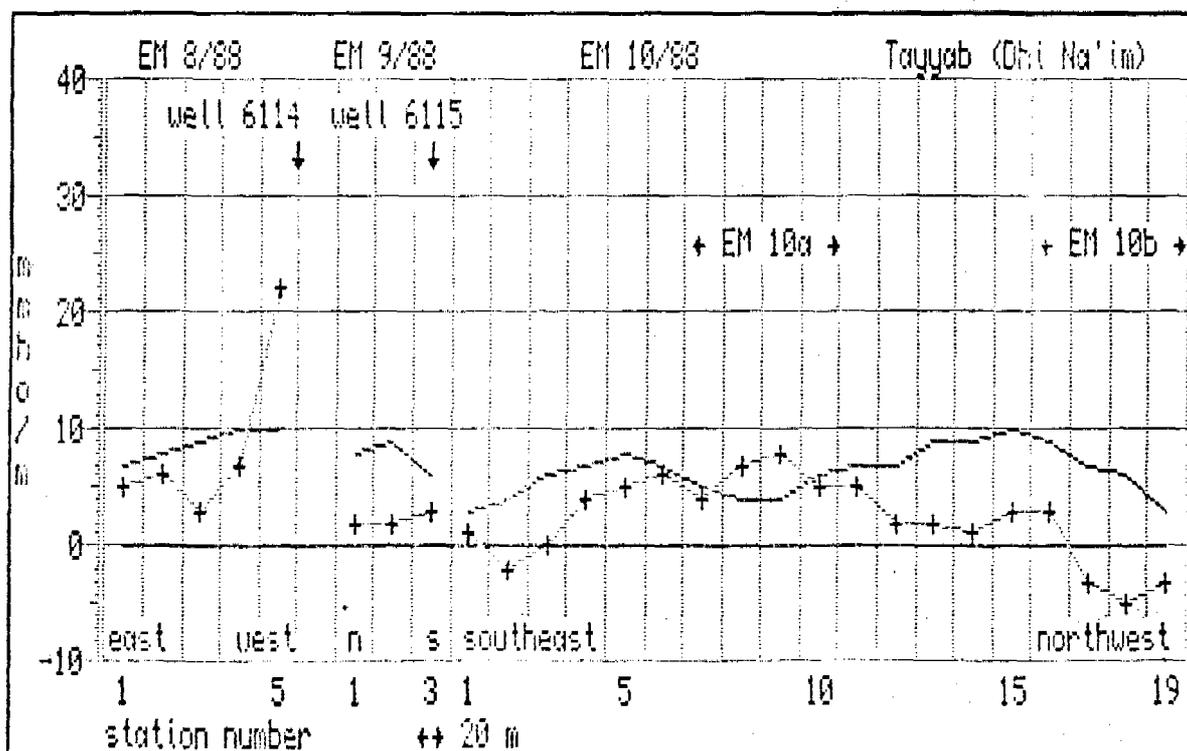
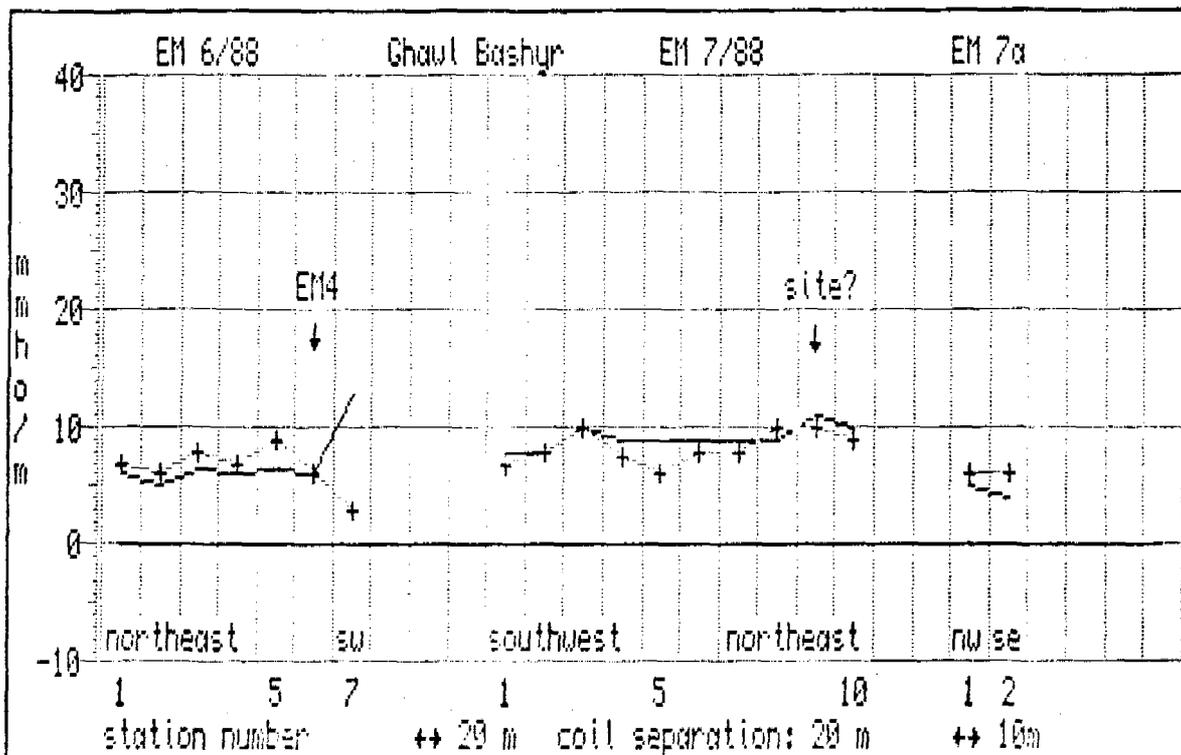


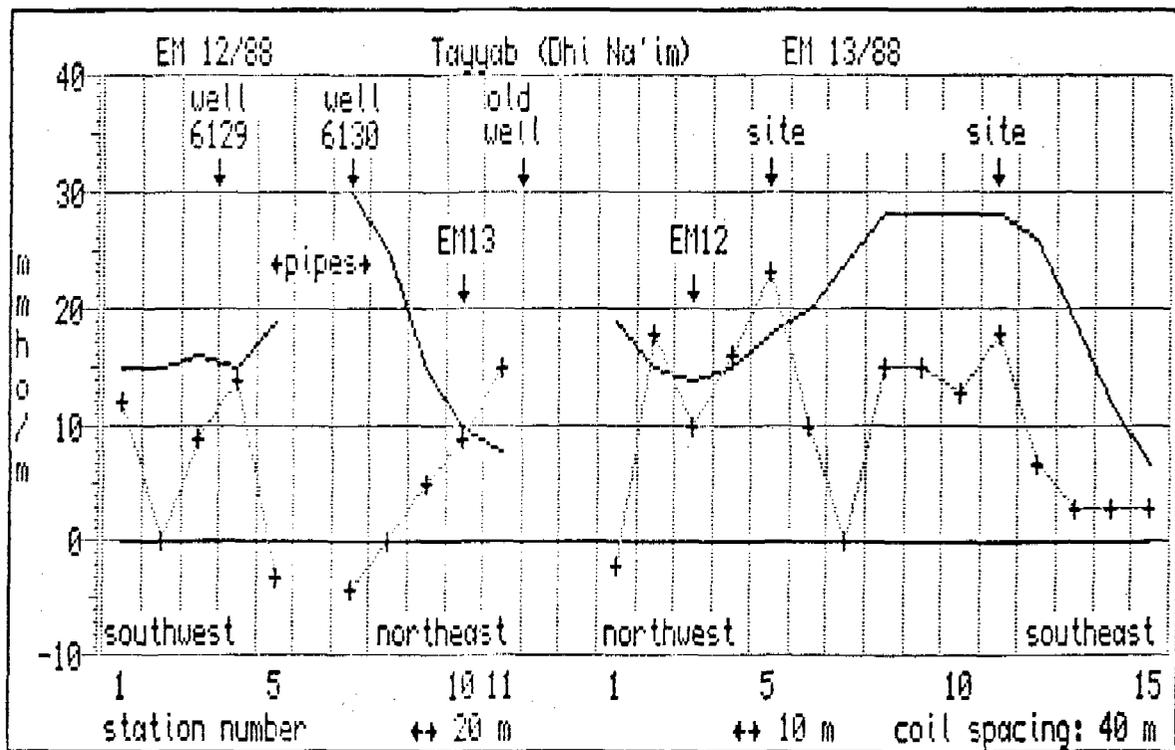
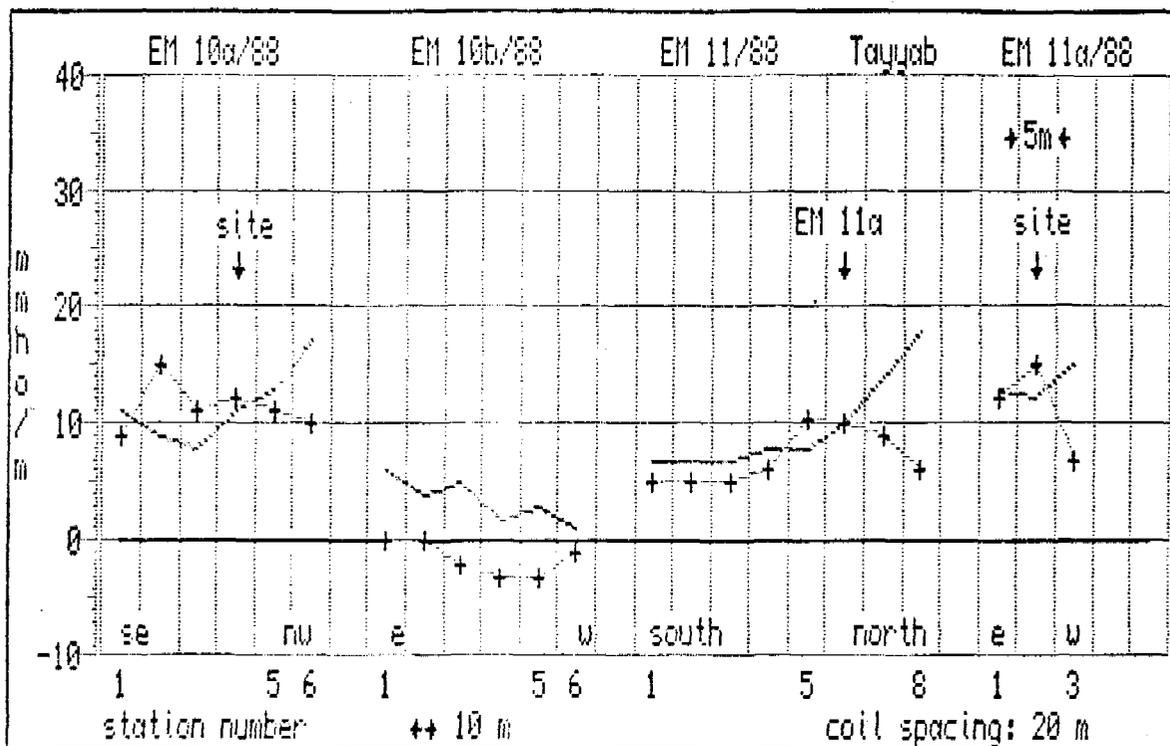


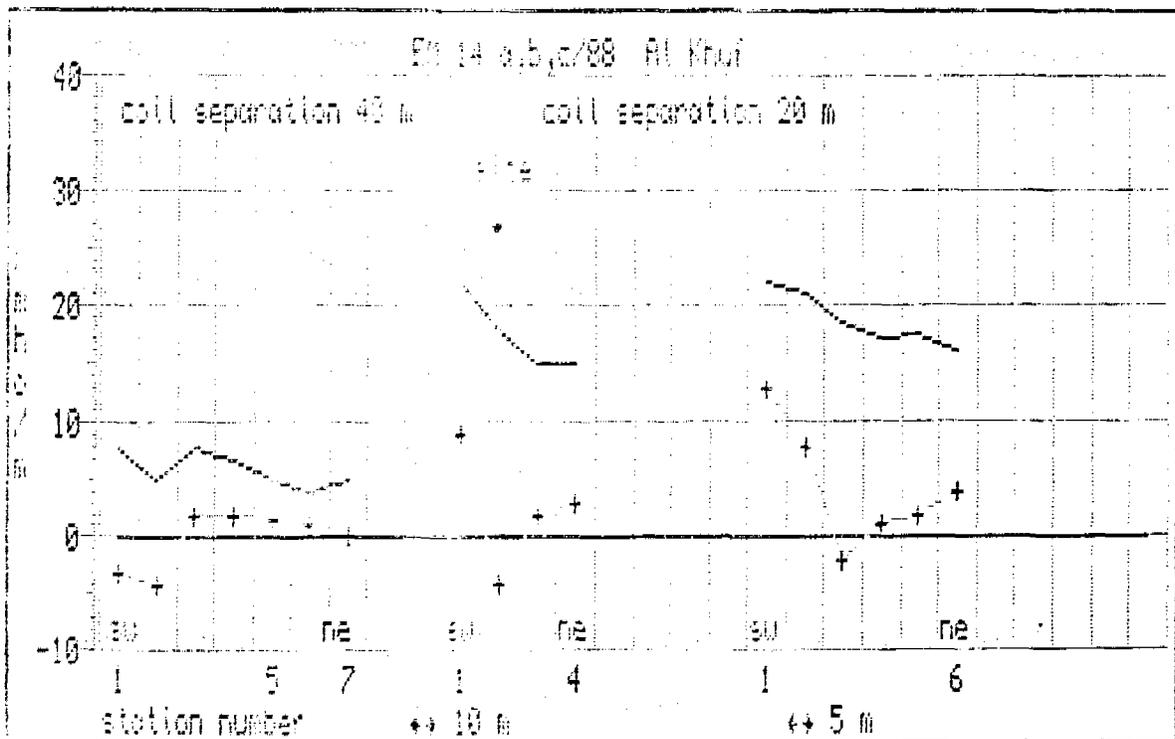
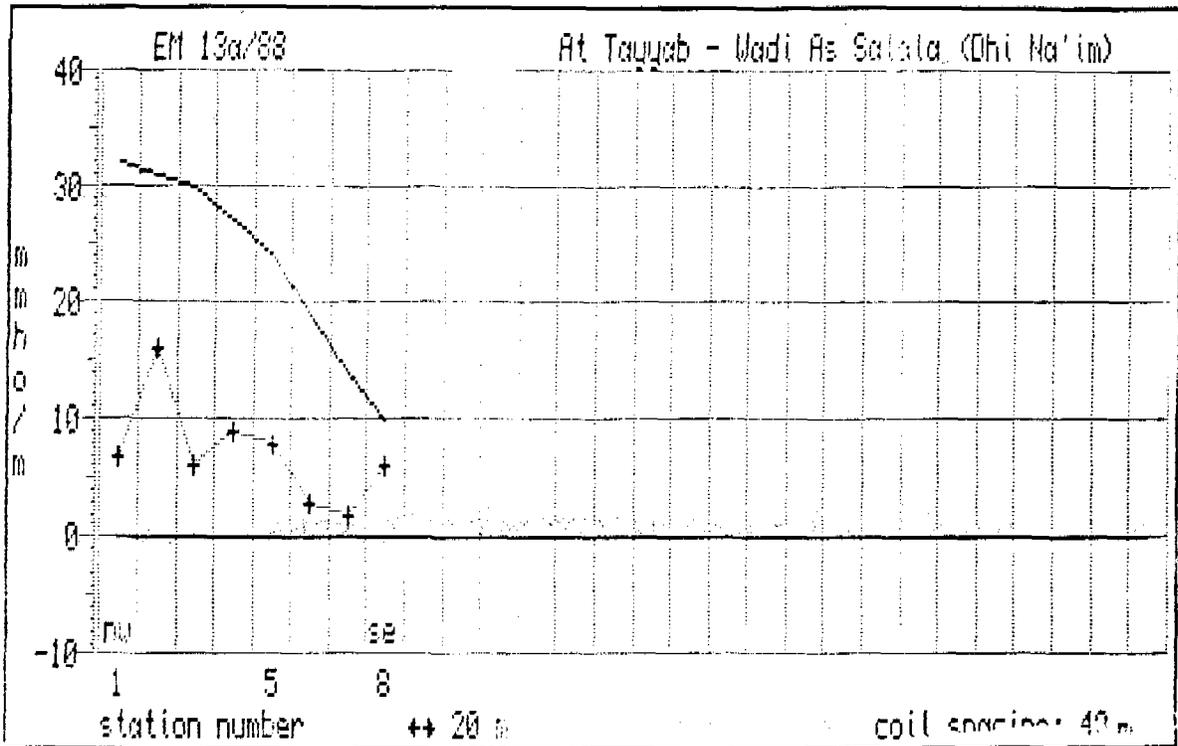


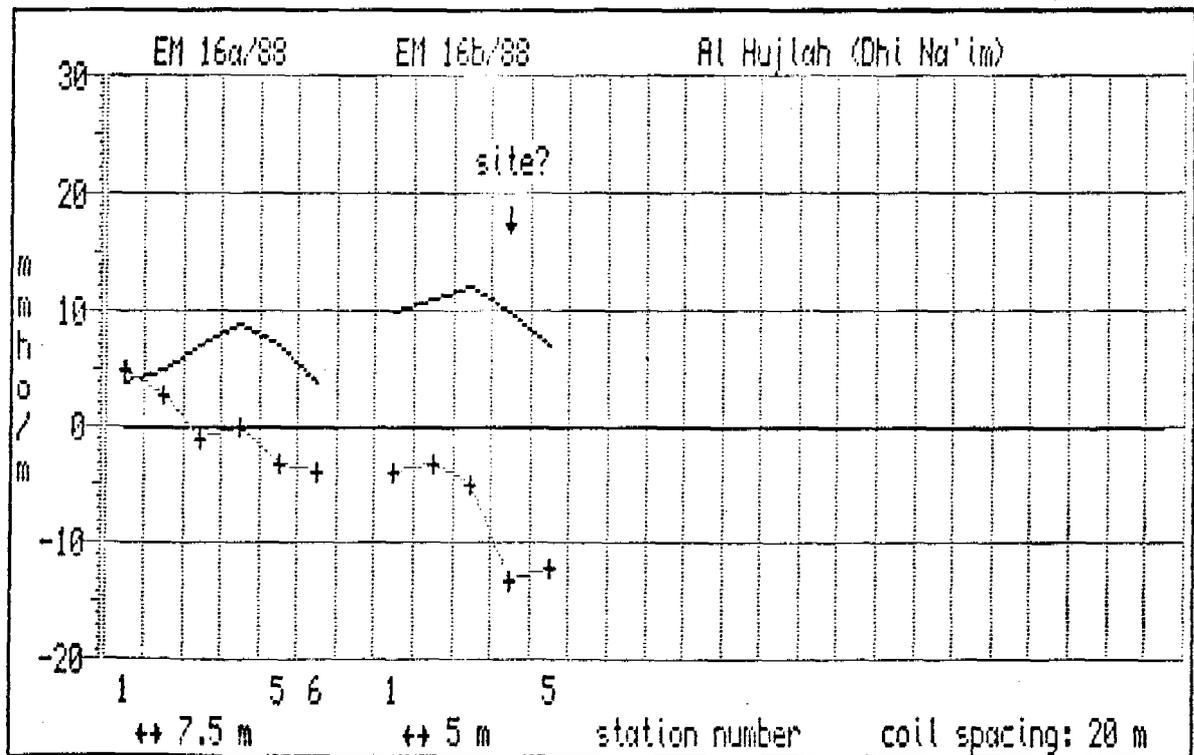
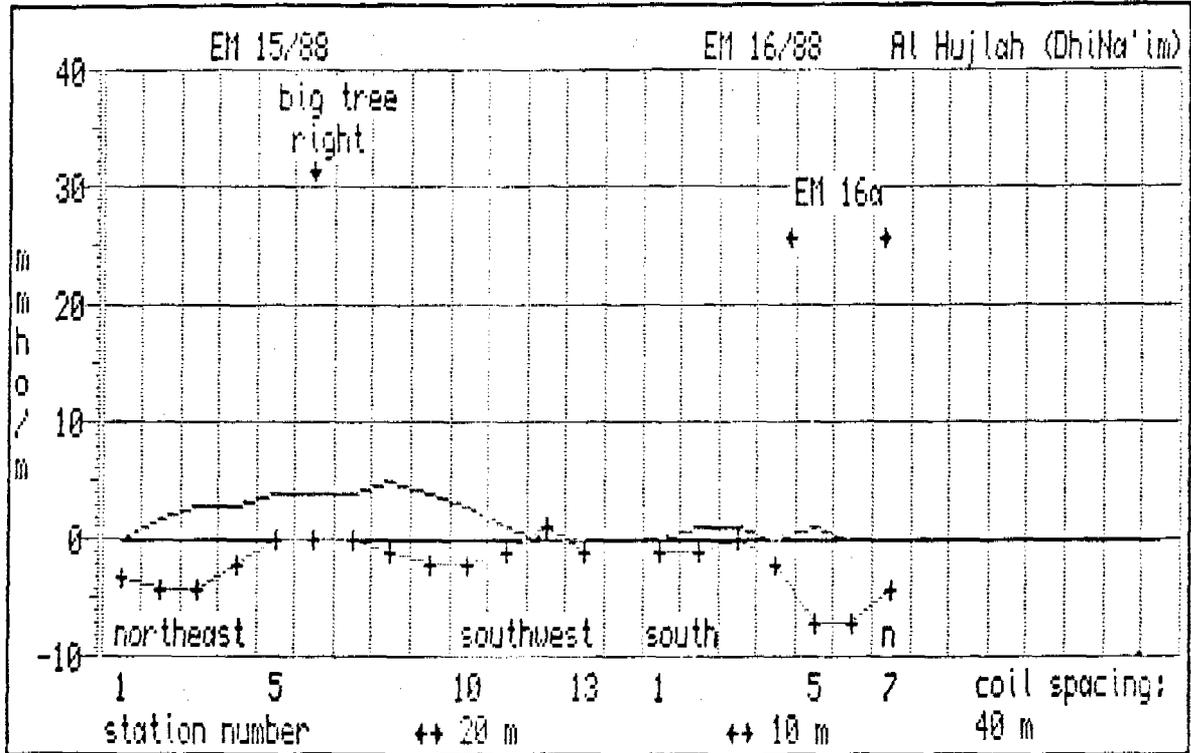


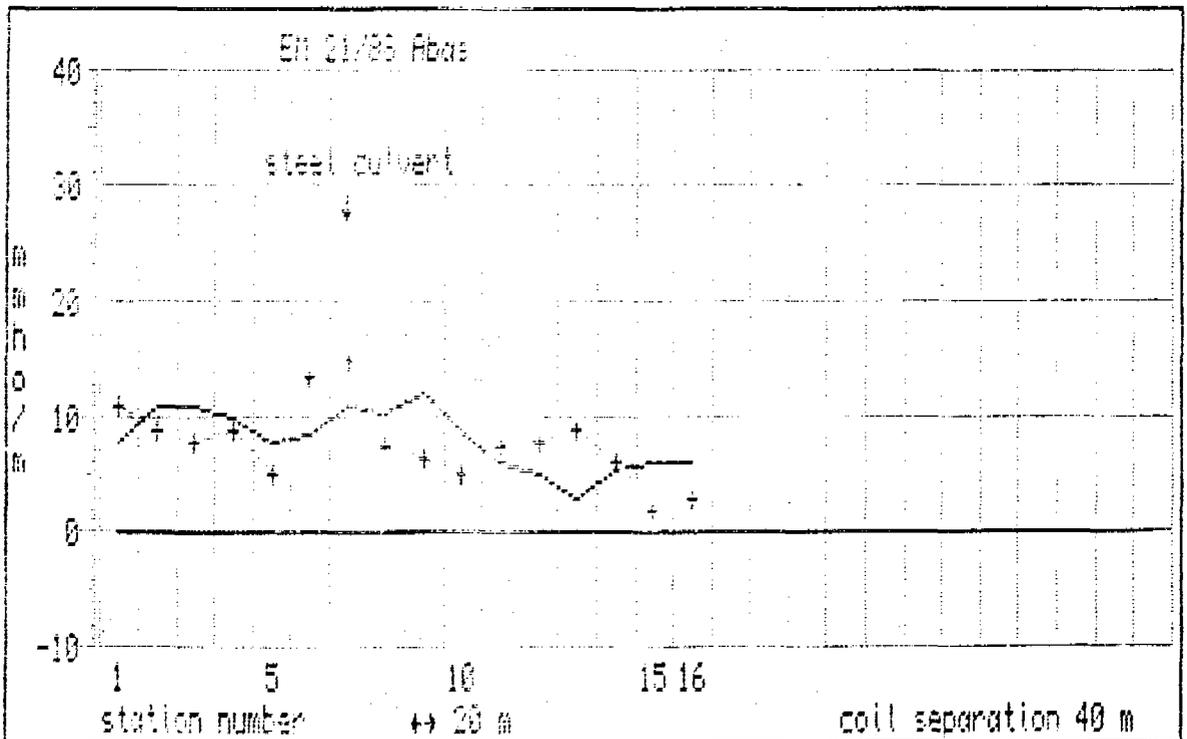
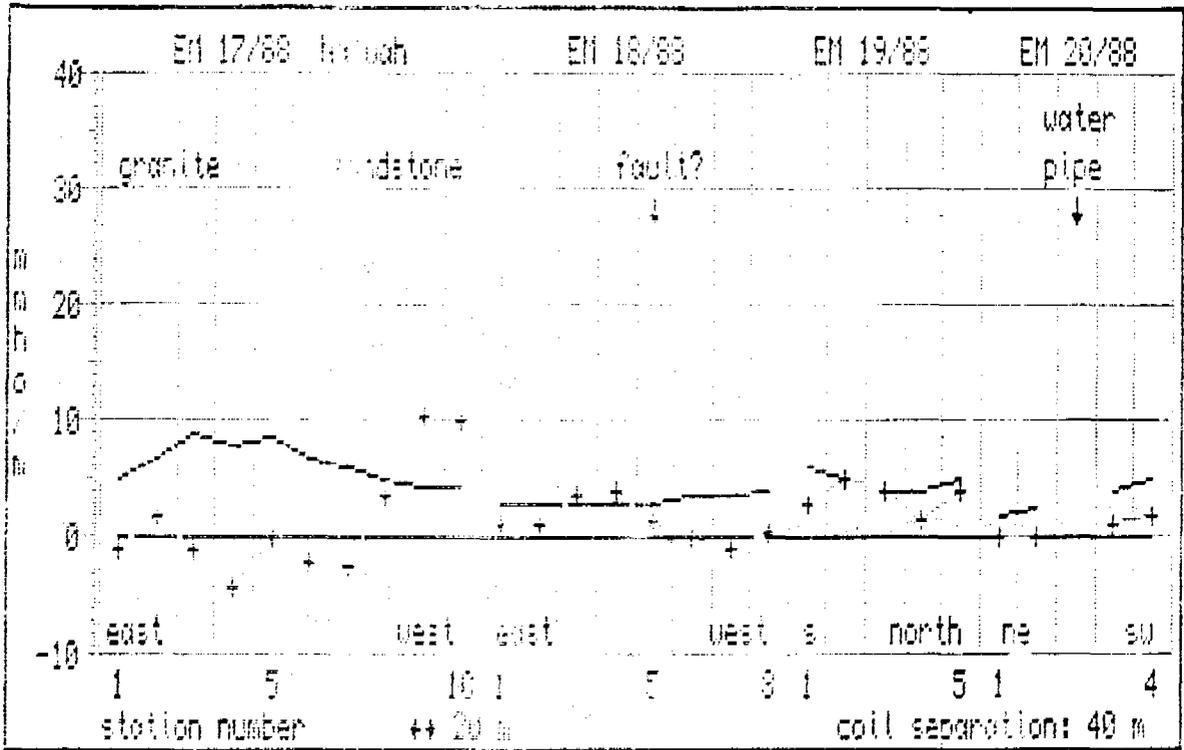


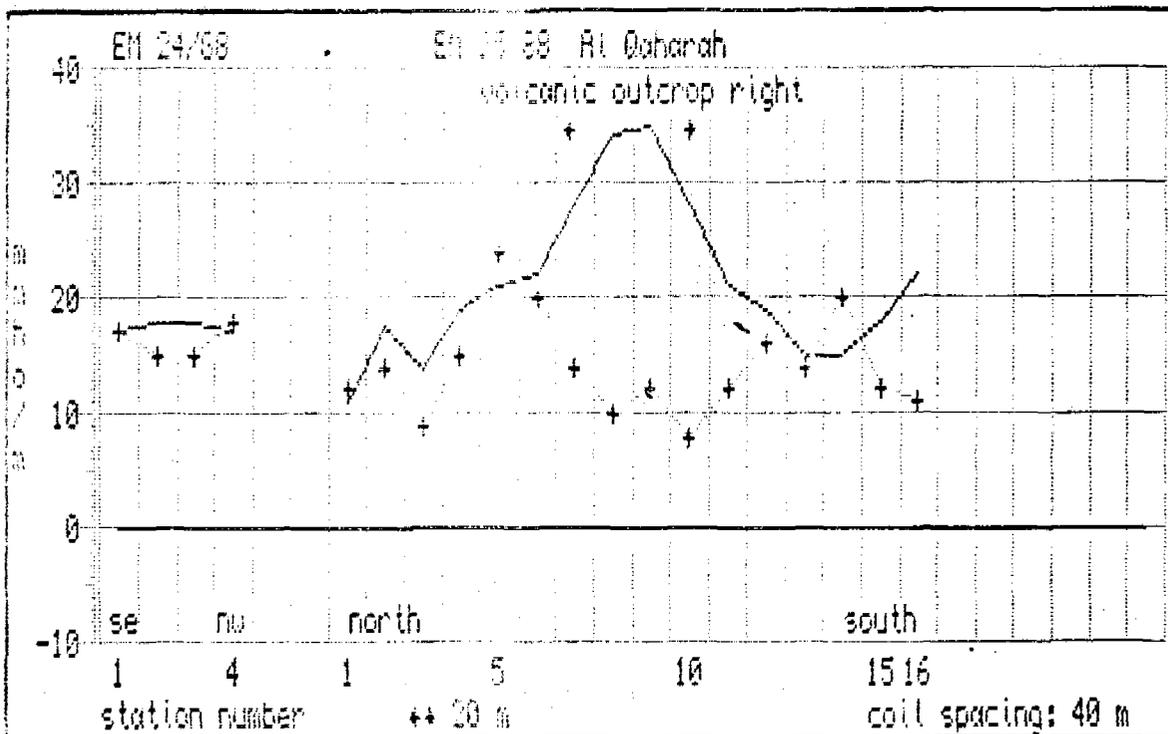
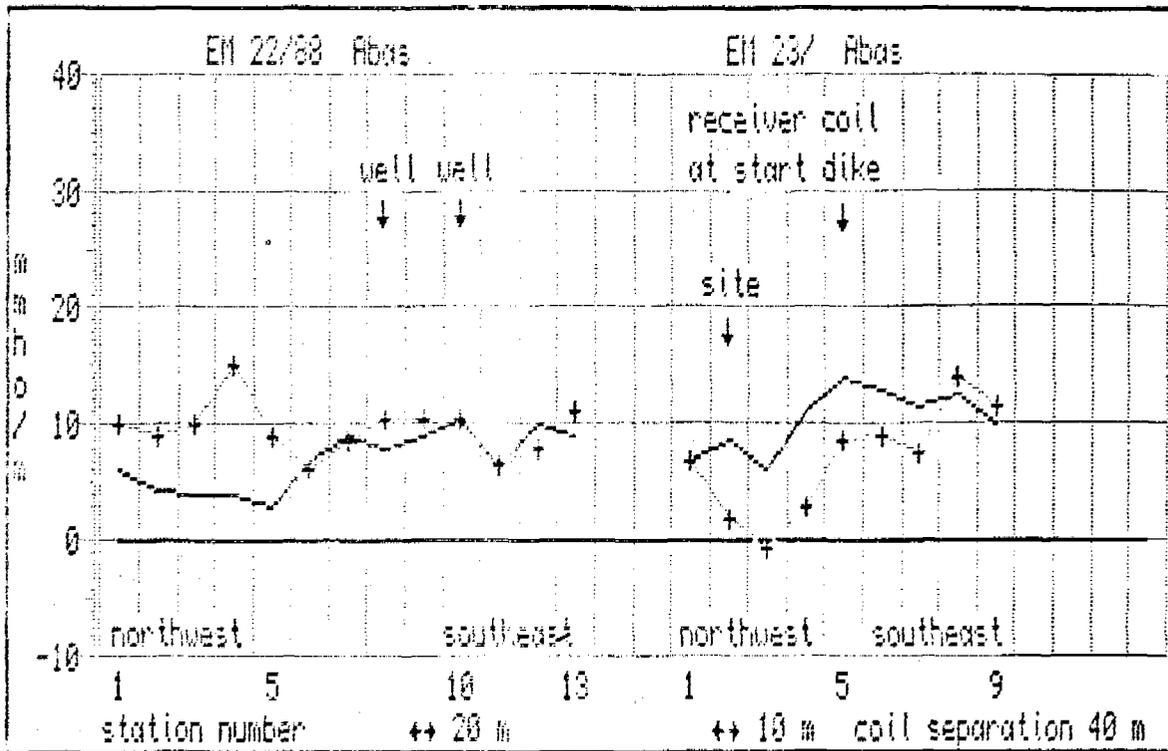












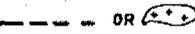


ANNEX D Legend to the Maps

TOPOGRAPHY

-  VILLAGE
-  VOLCANO
-  MOUNTAIN TOP
-  MAIN ROAD
-  TRACK
-  EPHEMERAL STREAM
-  SPRING
-  No. OF AERIAL PHOTOGRAPH
-  MAIN WATERSHED
-  WATERSHED

G E O L O G Y

-  LOAM AND SAND - ALLUVIUM
-  REMNANTS OF ALLUVIAL FANS
-  LAVA - HOLOCENE
-  VOLCANIC ROCK - TERTIARY
-  VOLCANIC ROCK - UPPER PLEISTOCENE
-  SANDSTONE - CRETACEOUS
-  SCHIST/GNEIS/GRANITE - PRECAMBRIUM
-  VOLCANIC CENTRE
-  FAULT
-  OR  INTRUSIVE DIKE
-  DIP SLOPE
-  ELECTRO-MAGNETIC SOUNDING
-     DRY BOREHOLE, PRODUCTIVE BOREHOLE  
DRY SHALLOW WELL, PRODUCTIVE SHALLOW WELL
-  CENTRE AND DIRECTION OF GEO-ELECTRICAL SOUNDING
-  STEEP SLOPE / ESCARPMENT